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Impacts of Technology on U.S. Cropland and Rangeland Productivity

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Foreword

This Nation's impressive agricultural success is the product of many factors: abundant resources of land and water, a favorable climate, and a history of resourceful farmers and technological innovation. We meet not only our own needs but supply a substantial portion of the agricultural products used elsewhere in the world. As demand increases, so must agricultural productivity. Part of the necessary growth may come from farming additional acreage. But most of the increase will depend on intensifying production with improved agricultural technologies. The question is, however, whether farmland and rangeland resources can sustain such intensive use.

Land is a renewable resource, though one that is highly susceptible to degradation by erosion, salinization, compaction, ground water depletion, and other processes. When such processes are not adequately managed, land productivity can be mined like a nonrenewable resource. But this need not occur. For most agricultural land, various conservation options are available. Traditionally, however, farmers and ranchers have viewed many of the conservation technologies as uneconomical. Must conservation and production always be opposed, or can technology be used to help meet both goals?

This report describes the major processes degrading land productivity, assesses whether productivity is sustainable using current agricultural technologies, reviews a range of new technologies with potentials to maintain productivity and profitability simultaneously, and presents a series of options for congressional consideration. The study was requested by the Senate Committee on Environment and Public Works and endorsed by the House Agriculture Committee, the Senate Appropriations Committee, and the Subcommittee on Parks, Recreation, and Natural Resources of the Senate Committee on Energy and Natural Resources.

The Office of Technology Assessment greatly appreciates the contributions of the advisory panel assembled for this study, the authors of the technical papers, and the many other advisors and reviewers who assisted us, including farmers, ranchers, agricultural scientists in industries and universities, and experts in other Government agencies. Their guidance and comments helped develop a comprehensive report. As with all OTA studies, however, the content of the report is the sole responsibility of the Office.

John H. Gibbons

JOHN H. GIBBONS
Director

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Chapter I

Summary

LAND PRODUCTIVITY

Every year, the Nation's cropland erodes at an average rate of 7 tons per acre. Yet soil is thought to form at a rate of only 0.5 ton per acre a year or less. Thus, even though knowledge of soil formation is grossly inadequate, it appears that America's agricultural soil is being eroded more than 10 times faster than it is being formed.

Erosion is not the only process that can damage the productivity of the Nation's croplands and rangelands, though it is the most pervasive. Compaction and inadequate drainage can reduce crop yields. Salinization (salt build-up in soils) can force lands out of production. Mismanagement and overgrazing can degrade rangeland productivity. Withdrawing too much ground water can deplete underground supplies and limit future agriculture. Land subsidence, whether related to ground water withdrawal or other factors, can remove lands from production with little hope for restoration.

Inherent land productivity, as used in this report, means the ability of land resources to sustain long-term production of crops, forage, and a broad range of other benefits such as water quality, genetic resources, and wildlife habitat. Land is broadly defined to include not only soil but water and all the physical, chemical, and biological components of cropland and rangeland ecosystems.

Land productivity varies from site to site and changes over time. It interacts with the other components of agricultural productivity, which are the productivity of capital, the productivity of labor, and the state of the art of technology. Because of these interactions, land productivity is exceedingly difficult to measure. Nevertheless, it is a distinct concept that farmers and ranchers understand to profoundly influence the productivity of their capital and labor resources.

This study assesses how agricultural technologies affect the inherent productivity of U.S. croplands and rangelands. It examines processes that affect the quality of croplands and rangelands and addresses the question of whether land productivity is sustainable under various modern agricultural technologies.

The report finds that certain productivity-degrading processes, especially erosion, are widespread and serious. Yet for most agricultural land, technologies exist that could achieve high production while maintaining land quality. There are, however, some particularly fragile lands where no currently available ways exist to sustain high levels of production. These lands are used because it is profitable, under the present system of agricultural technologies, markets, and policies, to "mine" the inherent productivity of the fragile cropland and rangeland sites as if they were nonrenewable resources. In doing so, long-term productivity is sacrificed for shorter term profits.

This assessment was requested by the Senate Committee on Environment and Public Works and endorsed by the House Committee on Agriculture, the Senate Committee on Appropriations, and the Subcommittee on Parks, Recreation, and Renewable Resources of the Senate Committee on Energy and Natural Resources. The assessment was designed to exclude detailed study of: 1) problems that tangentially affect agricultural lands but are not caused by agricultural technologies (e.g., air pollution); 2) impacts of agricultural technologies on lands other than croplands and rangelands (e.g., the effects of chemical runoff on estuaries); 3) technologies and impacts covered by other OTA assessments (e.g., Integrated Pest Management, 1979; Biomass Fuels, 1980; and Applied Genetics, 1980).

INTRODUCTION: TECHNOLOGY AND AMERICAN AGRICULTURE

This Nation's agricultural successes are the product of many factors: abundant resources of land and water, favorable climate, and also a history of hard work, skill, and innovation. Recent generations in particular have benefited from technological developments. U.S. agriculturalists and scientists have created a production system that not only meets our own needs but also provides a growing portion (about one-tenth in 1979) of the agricultural products used by the rest of the world.

The technologies that made this extraordinary production possible were developed primarily during the 1950's and 1960's, when fuel and capital costs were low and labor was comparatively expensive. These technologies made farmers extremely successful at replacing labor with cheap energy inputs. The principal problem policymakers faced was keeping abundant supplies of food and fiber from driving prices (and profits) so low that farmers would be forced out of business. As a result, price supports and a variety of land retirement programs were adopted.

Agricultural policymakers now face problems quite different from those of the past. The 1970's brought profound changes in the economic and resource environments. Foreign demand for U.S. agricultural products grew rapidly. Energy and fertilizer prices skyrocketed. Stockpiles of surplus commodities dwindled. Development of the interstate highway system and related changing settlement patterns took large areas of prime farmland out of production. At the same time, areas of marginal cropland began coming back into production because stronger commodity markets made price supports and the concomitant land set-aside programs less attractive.

By the end of the 1970's, the United States was exporting 30 percent of its agricultural production and expecting even higher exports in the future. With virtually all the land previously idled by Government programs already returned to crops, exports are projected to be met in part by cultivating more land, including much which is fragile and basically unsuited to long-term production under conventional technologies.

Conservation and Production

Neither empirical evidence nor compelling logic show that agricultural production must be harmful to the quality of the land resource. On the contrary, production and conservation can be mutually reinforcing, even on marginal lands, if appropriate production technologies are developed and used.

But present agricultural practices in the United States are degrading the inherent productivity of large amounts of cropland and rangeland. Much agricultural land suffers from accelerated erosion, soil compaction, water quality and quantity problems, or other adverse physical, chemical, and biological changes in soil ecology.

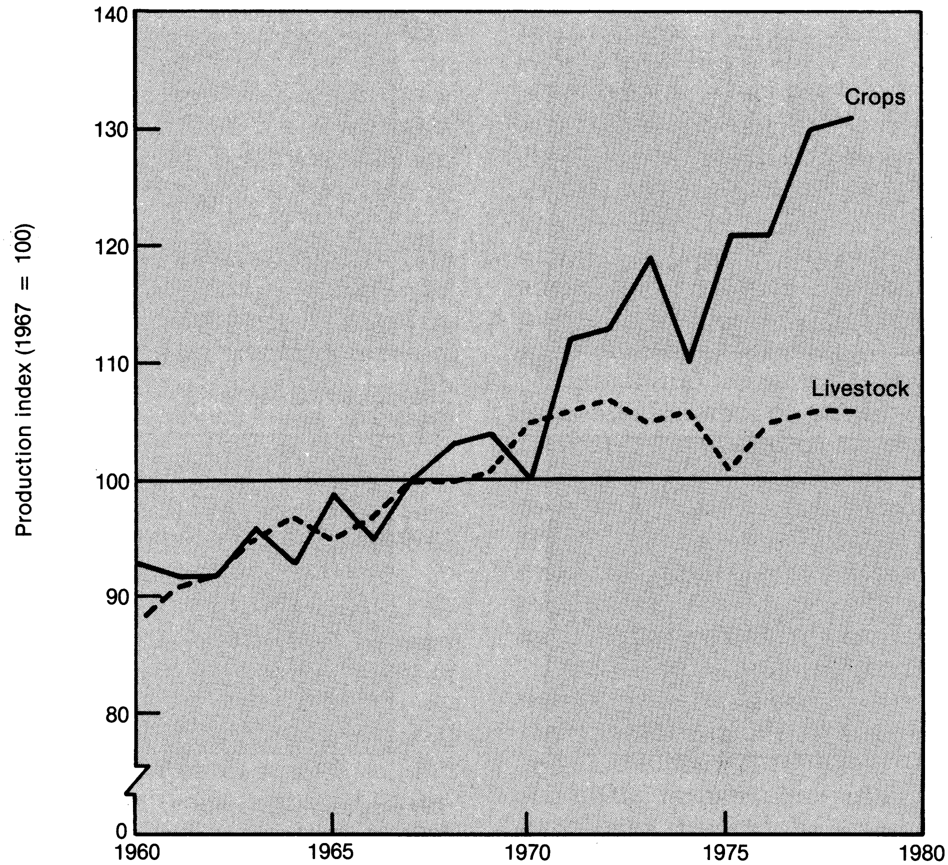
To date, losses in inherent productivity have been masked by gradual increases in capital inputs such as fertilizers, pesticides, and improved crop varieties. But productivity degradation is an accelerating and self-reinforcing process; this year's losses contribute to increasing losses in the years to follow. As capital costs rise, and losses in inherent productivity become increasingly severe, it will become more difficult to sustain production on depleted agricultural land.

Nationally, soil erosion is the most important process degrading inherent productivity. It is an acute problem on a relatively small part of the Nation's cropland, and a chronic problem on a much larger acreage.

No one can estimate the precise amounts of fuel, fertilizer, and other nonsoil resources that are required to compensate for the erosion-caused losses in soil fertility, tilth,* and water-holding capacity. The future availability and affordability of these nonsoil resources are also

*Tilth refers to the physical condition, texture, and aggregation of soil.

Agricultural Production, 1960-78



SOURCES: 1960-1963: *Agricultural Statistics 1975,* U.S. Department of Agriculture (Washington, D.C., U.S. Government Printing Office, 1975), table 618, p. 440.
1964-1978: *Agricultural Statistics 1979,* U.S. Department of Agriculture (Washington, D.C., U.S. Government Printing Office, 1979), table 633, p. 440.
Data for 1978 are preliminary.
CEQ *Environ. Trands,* 1981.

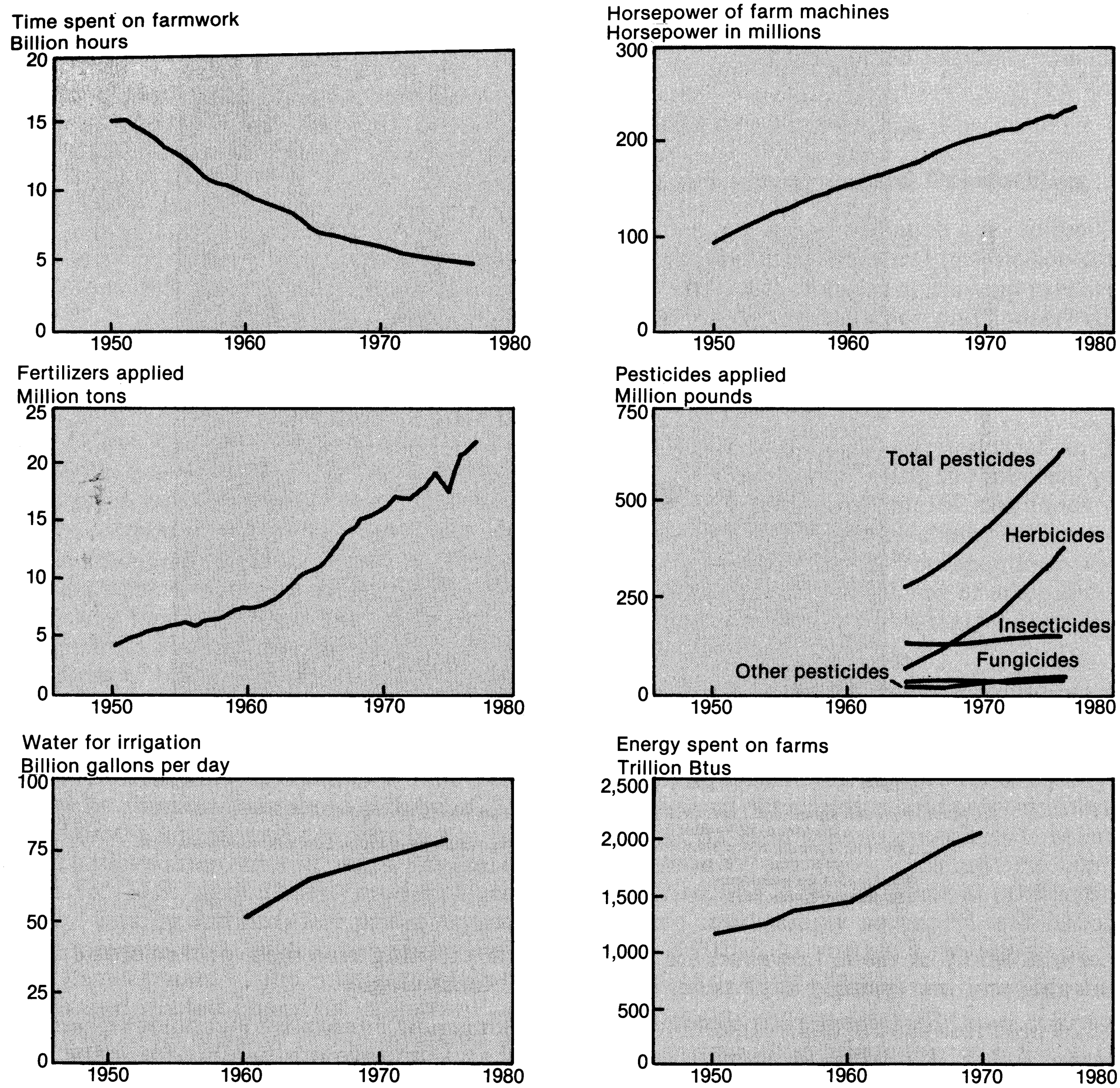
uncertain. Many of them, however, are nonrenewable and increasingly expensive.

Many practices used to maintain or improve inherent soil productivity can reduce current farm profits. For example, planting erosive fields into hay or pasture slows soil erosion, but is less profitable than planting corn or soybeans. Terraces break long slopes and retain eroding soil, but in many cases farmers cannot recoup high construction costs, even when they are shared by the Government. Contour farming reduces soil erosion and can increase yields, but it also increases labor and machinery costs. Because erosion may not noticeably affect crop yields for many years, economic considerations discourage farmers from adopting even these proven erosion control technologies.

Some new, innovative technologies can save soil and improve profitability for many farm operations. The use of some of these technologies—for example, conservation tillage*—is increasing, and they will play an important role in maintaining inherent land productivity in the future. However, there are substantial impediments to their widespread adoption. Many

*Conservation tillage refers to various ways of reducing the frequency and degree of tilling the soil. Conservation tillage methods generally share three characteristics: 1) they use implements other than the moldboard plow, 2) they leave crop residues on the soil to mitigate erosion and help retain moisture, and 3) they depend on chemical rather than mechanical weed control. (See ch. IV for a complete discussion.)

Agricultural Inputs, 1950-78



SOURCES: Time spent on farmwork: *Changes in Farm Production and Efficiency, 1977,* USDA Economics, Statistics, and Cooperatives Service (Washington, D.C.: U.S. Government Printing Office, 1978), statistical bulletin 612, p. 32.
Horsepower of farm machines: *Changes in Farm Production and Efficiency, 1977,* p. 31.
Fertilizers applied: *Changes in Farm Production and Efficiency, 1977,* p. 27.
Pesticides applied, 1964: *Quantities of Pesticides Used by Farmers in 1964,* USDA Economics, Statistics, and Cooperatives Service (Washington, D.C.: U.S. Government Printing Office, 1968), agr. econ. rep. 131, pp. 9, 13, 19, 26. 1966: *Farmers Use of Pesticides in 1971—Quantities,* USDA Economics, Statistics, and Cooperatives Service (Washington, D.C.: U.S. Government Printing Office, 1974), agr. econ. rep. 252, pp. 8, 11, 15, 18. 1971 and 1976: *Farmers' Use of Pesticides in 1976,* USDA Economics, Statistics, and Cooperatives Service (Washington, D.C.: U.S. Government Printing Office, 1978), agr. econ. rep. 418, pp. 6, 9, 15, 20.
Water for irrigation: *Estimated Use of Water in the United States in 1975,* U.S. Geological Survey (Washington, D.C.: U.S. Government Printing Office, 1977), circ. 765, p. 38 and previous quinquennial surveys.
Energy spent on farms: *The U.S. Food and Fiber Sector: Energy Use and Outlook,* USDA Economic Research Service (Washington, D.C.: U.S. Government Printing Office, 1974), p. 2.
Btu converted from kilocalories (kcal), as published in "Energy Use in the Food System," J. S. and C. E. Steinhart, *Science* 184:309 (1974). (1 kcal = 3:968 Btu, 1 Btu = 0.252 kcal.)

Time spent on farmwork includes crops, livestock, and overhead. After 1964, time used for horses, mules, and farm gardens was excluded.
Horsepower includes tractors only (exclusive of steam and garden).
Fertilizers include nitrogen, phosphate, and potash nutrients used.
Pesticides include amounts used on corps only; excludes pesticide use for livestock and other purposes.
Water used for irrigation refers to water consumed, not water withdrawn.
Energy spent on farms includes fuel, electricity, fertilizer, agricultural steel, farm machinery, tractors, and irrigation.
Cited in CEQ, 1981 *Environ. Trends.*

farmers and ranchers resist abandoning conventional practices because the innovative technologies often require more management expertise. Furthermore, farmers often are unconvinced that the new practices can be profitable for their particular farming conditions. Capital requirements for specialized mechanical equipment also impede the adoption of new technologies.

Innovative farming and grazing methods are being adopted, but not necessarily in the places where they are most needed. Farmers adopt innovative technologies first on lands where the new methods will be most profitable—often these are the highly resilient lands with low potential for productivity degradation. At the same time, large parts of the Nation's most erosive and otherwise fragile cropland, pastureland, and rangeland are not being treated with conservation practices.

The scientific community is showing renewed interest in the determinants of inherent land productivity. A new U.S. Department of Agriculture (USDA) research program* is expected to study the relationships among soil erosion, substitution of other resources, and crop yields. But much work is needed to discover how inherent land productivity is affected by management of such factors as organic matter, soil biology, irrigation water, soil compaction, and soil chemistry. Furthermore, while Federal research efforts do develop needed improvements in existing technologies, improved mechanisms are needed for developing and implementing innovative technologies.

Federal programs designed to affect crop production and support farm incomes have had mixed effects on resource conservation. While most such programs do affect the natural resource base, they generally have not been designed to provide collateral conservation benefits. Little work, in fact, has ever been done to analyze the interrelationships between agricultural policy and conservation. Mathematical models that would permit policymakers to analyze relationships among conservation, production, and income objectives have not been adequately developed. In many cases, the basic physical and biological data necessary to build such models are lacking.

*The Soil Erosion-Soil Productivity Research Project.

Agricultural technologies have significant effects on a number of public goods other than food and fiber production—e.g., water quality, wildlife habitat, and recreational opportunities. Sustaining production of these benefits does not have to conflict with sustaining crop and forage production and could be an explicit objective in developing site-specific agricultural technologies.

On the whole, inherent land productivity is deteriorating gradually. But neither the problems nor the potential solutions can be broadly generalized. Throughout this assessment, scientists, farmers, and other agricultural experts have stressed the regional diversity and site-specific nature of both degradation problems and technologies appropriate for dealing with them.* If Federal policy is to be effective in preserving inherent land productivity, it must recognize the regional and local nature of this issue. Dealing with acute localized problems may require politically difficult decisions to reallocate Federal technical and financial assistance, research, and extension work.

*This report has highlighted Alaska as an example of a region with special agricultural potentials and problems. Most of this information is in app. B.

LAND PRODUCTIVITY PROBLEMS

Erosion

Loss of soil by wind and water erosion* is the major productivity degradation process occurring on U.S. croplands and rangelands. The national average sheet and rill (water-caused)

*Erosion rates do not represent net losses of soil because eroded soil does not simply vanish. Much of the soil moved by erosion remains in the same field, but farther downslope. Soil is eventually lost, however, as it moves downslope off fields, into waterways, or onto noncroplands. Soil quality is affected by soil movement because organics and lighter materials are moved first, leaving behind poorer soils.

erosion rate from row crop and small grain cropland is 5.4 tons per acre.* When wind erosion is included, the average erosion rate for the Nation's croplands is at least 7 tons per acre. Meanwhile, soil is thought to form at an average rate of only 0.5 ton per acre. Thus, even though knowledge of soil formation rates is grossly inadequate, it appears that soil is eroded more than 10 times faster than it is formed.

Nationally, erosion exceeded 5 tons per acre** on more than 112 million acres of cropland, including 33 percent of the corn land, 44 percent of the soybean land, 34 percent of the cotton land, and 39 percent of the sorghum land.

About 45 percent of the Nation's total sheet and rill erosion occurs on the most rapidly eroding 6.5 percent of the cropland. Since it is often unprofitable to protect highly erosive sites, much of that land is farmed without the benefit of any major erosion control technology. Aiming conservation efforts at the most rapidly eroding sites could increase the cost effectiveness of programs designed to prevent soil loss.

Soil loss rates are not the same as productivity loss rates, however. Many studies have demonstrated that soil erosion reduces yields for specific crops. But most of these studies were conducted decades ago. In the interim, crop production technologies have changed substantially and the old data on yield reductions have little relevance to modern farming. Consequently, it is impossible to accurately compare the costs of erosion control technologies with their benefits. When the cost of substituting capital inputs for eroded soil is considered, some farms with low erosion and thin soils may suffer more productivity loss than farms with high erosion but deeper soil. Also, from a national perspective, the seemingly low rate of erosion on the majority of the land may be more significant than the high loss rates occurring on a relatively small acreage, since the latter lands account for a small proportion of total national farm production.

Less is known about the rates and effects of rangeland erosion. Wind and water erosion on non-Federal rangeland averages 4.6 tons per acre. As is the case with cropland erosion, a large portion of the total tonnage eroded on rangeland comes from a relatively small area—on 91 percent of the non-Federal rangeland, wind erosion is less than 2 tons per acre. The most susceptible 3 percent of the land, however, erodes in excess of 14 tons per acre and accounts for 31 percent of the total wind erosion. Because rangeland soils form so slowly, and because they are so difficult and expensive to reclaim, even low rates of soil erosion are cause for concern. Anecdotal evidence and some data indicate that rangeland soils over wide areas, particularly in the Southwest, are so eroded that they can no longer provide adequate moisture storage to sustain a good cover of forage plants.

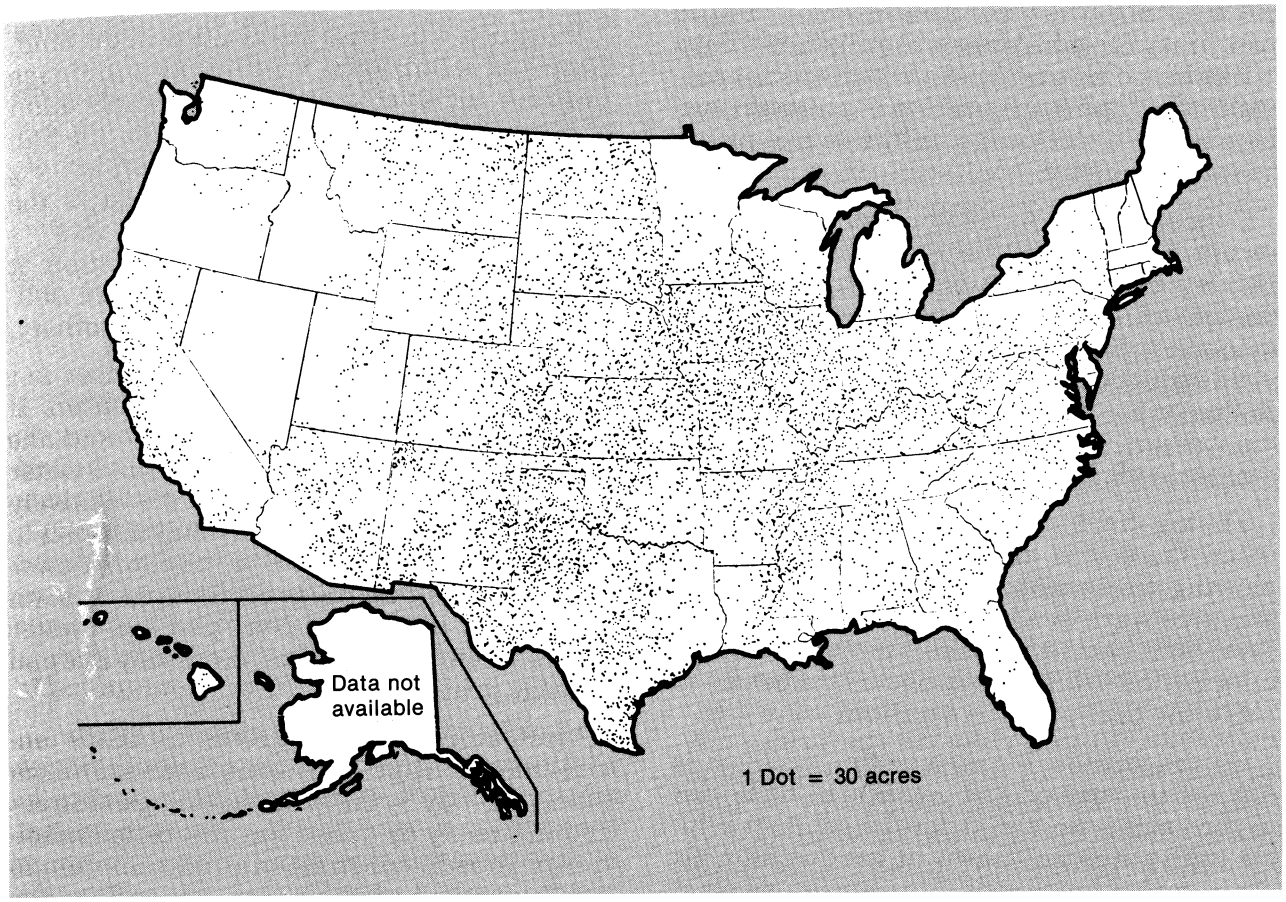
Maintenance of soil cover (by plants and crop residues) and other farm management practices (e.g., the type, frequency, and timing of tillage) are important ways to change cropland erosion rates. The most important new technologies to control erosion in the near future will be methods to minimize tillage on row crop and small grain croplands. However, none of the available erosion control technologies is likely to make row crop or small grain farming sustainable on the most fragile cropland. The most effective means of controlling erosion on such land is to cease using it for annual crops, planting it instead to permanent pasture, orchard, or wildlife habitat. For the long term, it may be possible to develop other profitable crop systems using perennial plants.

On rangelands, erosion control methods include establishing adequate plant cover, reducing or eliminating compaction on overgrazed sites and on overused animal and vehicle trails, and manipulating the soil surface to increase water infiltration.

*In this report, "tons per acre" refers to "tons per acre per year." Erosion rates are from the 1977 National Resource Inventories, USDA, as revised in 1980.

**A rate of soil loss widely used as an objective for cropland erosion control programs is 5 tons per acre. This number, called the "T value," was selected by the founder of the Soil Conservation Service, Hugh H. Bennett, and has since been reaffirmed by committees of Soil Conservation Service experts. However, there is essentially no research to scientifically establish the 5 tons per acre T value.

Acreage Where Wind and Water Erosion Are Greater Than Five Tons per Acre per Year, 1977



SOURCE: USDA, 1978.

Drainage

About 105 million acres of U.S. cropland have wet soils. Although only some wet soils are classified as "wetlands," many of the 3.8 million acres of wet soils converted to cropland between 1967 and 1975 were indeed wetlands. Their conversion meant the loss of valuable habitats, reduced flood prevention, and the loss of natural cleansing mechanisms for watersheds.

On the other hand, drainage of wet cropland can enhance crop production significantly. Wet soils often have high potential productivity because they contain more organic matter than soils that are not so wet. In the late 1960's, concern mounted over the loss of true wetlands, investment in drainage systems dropped, and Federal cost sharing for drainage systems was terminated. As a result, investment in subsurface drainage systems for the wet soils already used as croplands has declined over the past 20 years.

Many existing drainage systems were built in the early 1900's and are outdated and need repair. While repairing or replacing tile and ditch systems appears to be cost effective for individual farmers, outlet systems commonly demand collective management. Cleaning and maintenance need local funding. Cost sharing, guaranteed loans, or developing farmers' cooperatives could aid in the rejuvenation of outlet systems.

Soil Compaction

Routine operation of tractors and other farm equipment and trampling by livestock can harm land productivity by damaging soil struc-

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ture. On susceptible cropland soils, a persistent layer of densely compacted soil, a "traffic pan," may form just below the depth of tillage operations. On rangelands, which are not normally tilled, animal trampling compresses surface soil so water cannot infiltrate and plants cannot reproduce.

Concern over compaction has increased in recent years, partly because the heavy machinery characteristic of modern farming is thought to cause more compaction than lighter machines. Soil compaction can cause crop yield reductions as great as 50 percent. Some soil types are more susceptible to compaction than others, and susceptibility generally increases with increased soil moisture.

Timing field operations to avoid periods when the soil is especially susceptible, and plowing deeper than normal ("subsoiling"), are effective ways to alleviate compaction. However, both can reduce short-term profits and information is often inadequate for farmers to make the best possible decisions.

On rangelands, the compaction problem is not well understood and practical technologies to correct it are not well developed. Both vehicle traffic and the hooves of grazing animals can compact range soils. This constrains plant growth, retards seed germination and seedling emergence, and accelerates erosion.

Techniques to control rangeland compaction include restricting vehicle traffic and intensively managing livestock to reduce their impact on wet and other susceptible soils. However, practical technologies to correct compaction are not available and, as with croplands, data are inadequate to optimize site management and policy decisions.

Expert opinion on the national significance of the compaction problem differs. Some scientists allege widespread damage to productive lands in general, while others see damage occurring only on certain susceptible land. Data have not been and are not being gathered to indicate the location or extent of soil compaction constraints on productivity, although experts indicate that national data collection is feasible.

Salinization

Irrigation can cause salinization of the land. Cropland salinization is primarily a drainage problem aggravated by incorrect application of irrigation water. On irrigated fields, the Sun and crops extract almost pure water, leaving behind salts that had been dissolved in the water. If the salt is not flushed deeper into the ground by rainfall or additional irrigation, it can concentrate in and on the surface soil, ultimately destroying the land's productivity.

But flushing salt into the ground does not necessarily solve the salinization problem. If subsurface conditions are relatively porous, the saltwater may contaminate the ground water supply. If subsurface conditions are relatively impermeable, the salty water may drain into the nearest river and flow to irrigators downriver. Saltwater may also accumulate beneath the surface so that a salty, "perched" water table accumulates. This can eventually rise and damage crop roots.

Most crops cannot survive in saline environments. High salt concentrations harm plants directly by causing physiological stress and indirectly by destroying soil biota. Salinity has already constrained production on 25 to 35 percent of the irrigated land in the Western United States, or about 5 percent of the total national cropland. This 5 percent is especially important because yields here are higher, the growing season longer, and high-value crops predominate on irrigated lands.

Salinization can have costly consequences. For example, in the San Joaquin Valley, high, salt-contaminated watertables under 400,000 acres are costing $32 million annually in reduced yields. Some 1 million to 2 million acres of prime land in that region are expected to go out of crop production during the next 100 years if salinization continues unchecked.

Salinization can be controlled with elaborate drainage and disposal systems. Smaller scale, less expensive approaches include using improved irrigation techniques and converting to crops that use less water or tolerate more salt. Although less costly, these management technologies have proven more difficult to imple-

ment than large-scale, publicly funded engineering projects because they require attitude changes and capital investments from many individual farmers. And while small-scale technologies can reduce the accumulation of saline water beneath irrigated fields, they will not eliminate the need for drainage where subsurface conditions inhibit downward percolation—e.g., most irrigated areas in the Colorado and San Joaquin basins.

Ground Water Depletion*

The next several decades will bring a marked decrease in the availability and quality of the Nation's ground water resources. This will significantly reduce the productivity of much irrigated agricultural land, especially in the Southwestern States. The most severe problems will probably be confined to the West, but some Eastern States will suffer local water shortages and water quality problems that will affect agricultural productivity.

Various technologies can alter irrigation and farming systems and prolong the productivity of ground water resources. These vary from modest changes in the way water is applied to major changes in farm management such as converting to perennial crops. Although changing the technologies used can reduce water demands, the actual reduction in ground water withdrawals that will result probably will be small and will only postpone the exhaustion of some major U.S. ground water reservoirs.

The technological change most likely to occur in Western regions during the coming decades will be the return of irrigated lands to dryland farming or grazing. Such conversion will cause sharp decreases in production. Also, as wind erosion and other problems associated with dryland farming develop, a continuing, gradual decrease in land productivity can be expected.

Although some schemes for recharging overdrawn aquifers** have been proposed, the lack of local water to replenish supplies and the high energy costs involved in transporting water from distant sources may preclude such remedies. On a national scale, schemes for long-distance water transport will have to be compared with the alternatives of bringing marginal agricultural lands into production in the more water-abundant East or intensifying production on prime agricultural lands.

The current lack of effective State and Federal policies to discourage wasteful water use works against widespread adoption of water-conserving technologies. Ground water is a common property resource, so individuals have few economic incentives to practice conservation as long as others continue rapidly depleting the resource.

Land Subsidence

Subsidence—the sinking or collapse of land surfaces—is likely to become more common in the United States as the use of ground water and subsurface mineral resources intensifies. Subsidence can occur in various circumstances: when cities, industries, and irrigated agriculture withdraw large amounts of ground water; when coal and other mineral resources are mined; when there is solution mining of salt or other subsurface mineral deposits; or when large amounts of petroleum are extracted. All of these activities can result in slow subsidence or the unexpected collapse of the land surface. If agriculture overlies these areas, it can suffer slow or immediate consequences.

The effect of subsidence on agriculture has been most extensive in areas where ground water mining for irrigation is common. For example, on 5,400 square miles of San Jacinta Valley cropland in California, where irrigation wells pump as much as 1,500 acre-ft of water annually, land has subsided nearly 28 ft since 1935. Subsidence damages irrigation systems, wells, buildings, drainage and flood control structures, and other improvements. Data on this problem seem to be adequate for agricultural planning purposes. Subsidence effects are permanent and there are no attractive technological solutions.

*OTA is conducting a more detailed study of this topic in a separate assessment, *Water-Related Technologies for Sustaining Agriculture in U.S. Arid and Semiarid Lands.*

**An aquifer is a water-bearing underground layer of permeable rock, sand, or gravel.

Soil Organic Matter

Soil organic matter is important to soil productivity because it:

- contributes to the development of soil aggregates, which enhance root development and reduce the energy needed to work the soil;
- increases the air- and water-holding capacity of the soil, which is necessary for plant growth, and helps to reduce erosion;
- releases essential plant nutrients as it decays;
- holds nutrients from fertilizer in storage until the plants need them; and
- enhances the abundance and distribution of vital soil biota.

The importance of these functions varies greatly from one soil type to another.

Soil scientists generally emphasize the positive influence organic matter has on land productivity, but it can affect productivity adversely in some cases. For example, because organic matter holds soil moisture, it sometimes acts indirectly to shorten the growing season by delaying planting where moist soils warm slowly in the spring.

Although modern farming practices can affect organic matter content, this study found no data to indicate whether organic matter levels have increased or decreased in the years since widespread use of fertilizers replaced the use of crop rotations. Recent research has focused on the production-enhancing effects of off-farm inputs, and as a result soil scientists have not studied the management of organic matter to optimize land productivity under various modern farming systems.

Soil Organisms

Soil micro-organisms and larger soil invertebrates, such as earthworms and insects, perform functions essential for plant growth. Before the widespread availability of commercial fertilizers, nutrients recycled by the biota were recognized as a major component of land productivity and thus soil ecology ranked high among the agricultural sciences. In recent decades, however, this aspect of soil science has been largely neglected.

Agricultural scientists generally are not alarmed about pesticides harming soil ecology in the near term. Current insecticides and herbicides are tested for their impact on soil biota. They inhibit some biological processes and suppress particular types of biota, but generally the gross effect of each pesticide application seems neither great nor long-lived.

Frequent applications of toxic chemicals probably change the composition of soil biota communities, favoring species that can adapt to the new chemical environment. The impact of these changes on long-term land productivity is not known. Because methods are not well-enough developed to make practical differentiation among microbe species in the field, and soil invertebrates are seldom studied, the cumulative effect of agricultural technologies on productivity cannot be fully measured.

Soil Chemistry

The *chemical composition* of the soil also affects land productivity. The nutrients that cropland and rangeland plants extract from the soil come naturally from decomposing organic matter, from the weathering of soil minerals, and in the case of nitrogen and sulfur, from the atmosphere. Nutrients are removed from the land by harvesting crops, livestock, and dairy products, and by erosion, leaching, and (in the case of nitrogen) loss to the atmosphere. In addition, nutrients can be changed chemically or be bound to soil particles, thus becoming unavailable to plants.

To replace depleted nutrients, farmers used to apply manure and grow "soil-building" crops such as clover in rotation with "soil-depleting" crops such as corn. While manure is still returned to the land where it is available, it is almost always supplemented with various commercial fertilizers. Moreover, in recent years many farmers have shifted to cash-grain operations, eliminating most or all of their livestock. Thus, modern farming depends heavily

on nutrients provided by fertilizers from off-farm sources.

On rangelands, erosion commonly removes more nutrients than are naturally replaced. Unlike crop farmers, however, rangeland managers generally do not try to replace deficient nutrients. Rather, they try to reduce erosion rates to conserve the natural supply.

Wherever most of a farm's production leaves the farm, or accelerated erosion occurs, nutrients are removed faster than nature can replace them. Short-term nutrient supplies can be maintained with commercial fertilizers, but the profitability of fertilizer use may decline in future years because the manufacture of fertilizer depends on increasingly expensive fossil fuel and other nonrenewable mineral resources.

Technologies to deal with the long-term deficit in nutrient supplies include erosion control, developing cropping systems that use the nutrient reservoir more slowly and efficiently, and using special crop varieties and soil biota to improve the availability of stored nutrients.

Benefits Other Than Crops and Forage

Agricultural lands are managed to produce crops and forage, but other, less quantifiable services from the land are also vitally important to the Nation's well-being. These benefits are often taken for granted or assumed to come solely from nonagricultural land. The quality of air, water, ground water, fish and wildlife habitats, and esthetic and recreational areas is directly related to croplands, pasturelands, and rangelands.

Furthermore, an agroecosystem does not end at the edge of a field or pasture, but includes the boundaries—fences, hedgerows, windbreaks, nearby fallow fields, riparian habitats, and adjacent undeveloped areas. As the quality and quantity of these areas is changed by agricultural activities, the utilities obtained from the land also change.

Land resources help maintain water and air quality by cleansing water as it infiltrates into ground water reservoirs, discharging relatively clean water to streams and wetlands, cleansing air of pollutants, and reducing the dust content of air. To a large extent, conditions that enhance long-term productivity for crops and forage also enhance air and watershed quality. For example, fertilizers increase plant growth, thus increasing ground cover and reducing erosion. But there are tradeoffs. Chemical applications appropriate for sustaining production can pollute streams, wetlands, aquifers, or the atmosphere. Generally, existing data bases are inadequate for determining the best solutions to these dilemmas. Other significant utilities that society obtains from agricultural lands, such as recreational, scenic, and archeological resources, are even more difficult to measure but are affected by changes in land use and land quality.

SUSTAINING RANGELAND PRODUCTIVITY

There are approximately 853 million acres of rangeland in the United States. Excluding Alaska's 231 million acres, over half the Nation's rangelands are seriously degraded and suffer from reduced productivity caused by overgrazing, mismanagement, and erosion. Only 15 percent of the ranges in the contiguous States are rated in good condition.

Current range problems have their roots in early U.S. history. Throughout most of the arid and semiarid regions in the West, overgrazing damaged productivity within a few decades of initial use. Because overgrazing effects are most severe in dry areas where the land is least resilient, range conditions now are worst in the Southwestern States. Data are inadequate to assess broad trends in range conditions. The available erosion data, the findings of environmental impact statements, and the testimony of experts suggest that productivity is still being degraded and that present range management practices may not sustain productivity.

Overall, Federal ranges are in worse condition than private and State ranges because the Federal Government owns more land that is inherently less resilient and more arid. Generally, the Federal ranges are in static condition or are continuing to deteriorate, while range condition is improving on better situated non-Federal lands.

Demands for rangeland products and services are expected to increase sharply in the next two decades, and these demands can only be met through improved range management. A variety of management technologies has been developed to improve and maintain deteriorated rangeland. Broadly categorized, these include:

- adjusting livestock numbers,
- controlling animal use with grazing systems,
- promoting desired plant species, and
- controlling noxious plant and animal species.

Used in integrated systems with improved fencing and water development methods, these range management technologies could improve and help sustain the Nation's range resources.

Managing rangeland productivity for multiple uses is the stated goal of Federal range efforts. In practice, however, livestock production is usually the dominant objective on both Federal and non-Federal ranges. Translating general multiple-use, sustained-yield objectives from laws into achievable field objectives is extremely difficult, especially when two or more legitimate uses of the land are in conflict. However, there are some technologies available that focus on other than livestock production. These include fish and game management techniques, erosion control to decrease sedimentation of streams and reservoirs, and vegetation manipulation to increase watershed yields. Little information, however, is available on the opportunities and problems offered by such technologies.

SUSTAINING CROPLAND PRODUCTIVITY

The United States has about 413 million acres of cropland, including about 230 million acres of prime farmland. Productivity on these lands can be damaged by a variety of processes including compaction, salinization, inadequate drainage, subsidence, changes in the chemical composition of the soil, and erosion. These problems can be caused or aggravated when crop production is increased.

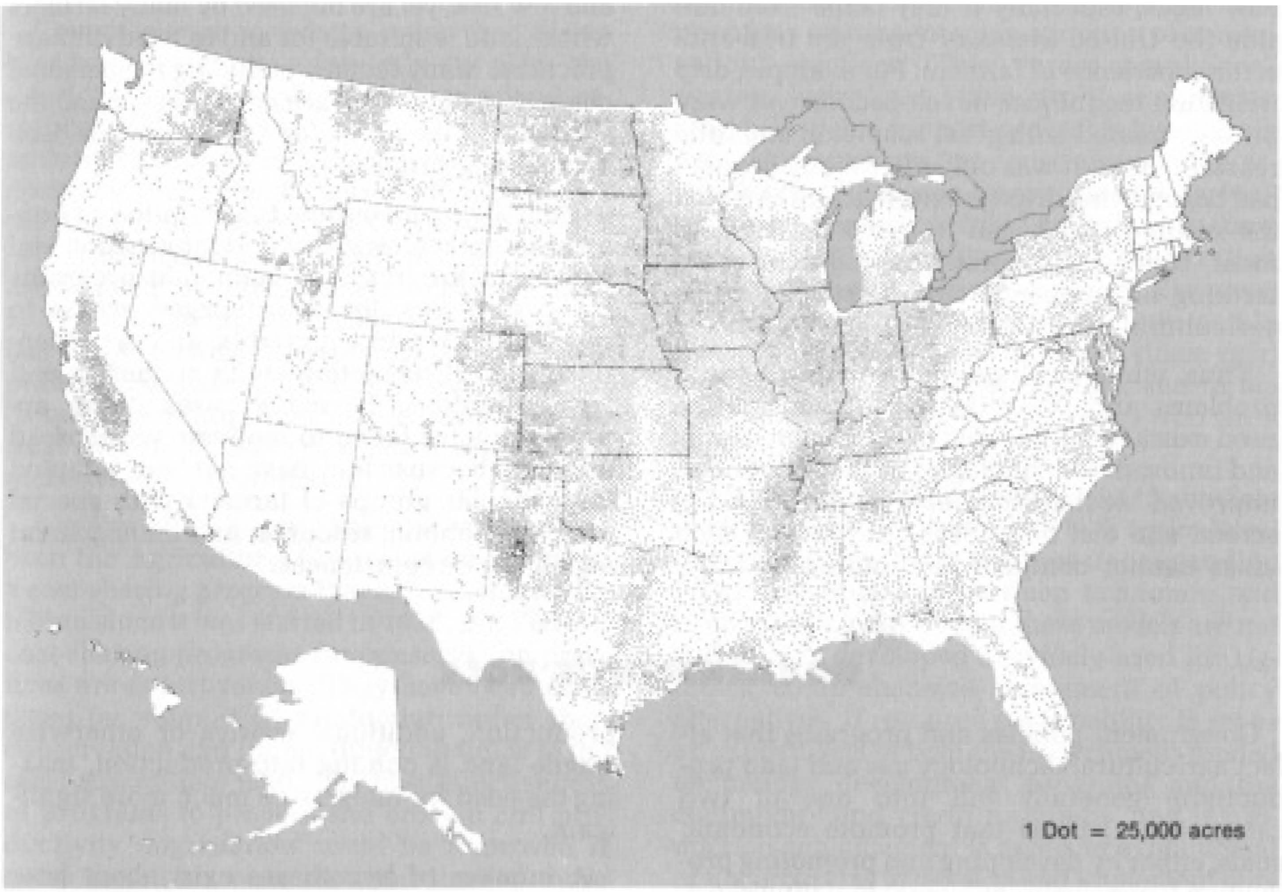
But agricultural production does not have to be harmful to the quality of the land resource. On the contrary, production and conservation can be mutually reinforcing if appropriate technologies are developed and used. For many sites, innovative farming techniques are available that maintain or even enhance inherent land productivity without sacrificing short-term profits.

These innovations are in various stages of development. Conservation tillage, the most promising of the new technologies, is being adopted rapidly in certain parts of the country. Multiple cropping is already used to expand production in many regions. Organic agriculture, drawing on both old and new knowledge, offers alternative farming systems with important conservation potentials. Computer technologies and other developments in communications, education, and farm planning are rapidly gaining importance. Cropping perennial grains, on the other hand, is unlikely to be practical before the 21st century. Similarly, breeding crops for salt and other stress tolerance is primarily a laboratory technology at present. Eventually other new productivity-conserving crops might come into use as methods and markets develop.

Although various innovative approaches to conserving land productivity will become increasingly important in the future, existing conservation technologies will continue to play a key role in good land stewardship. Contour

farming, stripcropping, shelter belts, crop residue management, tillage management, terraces, and other traditional approaches to conservation have had and can continue to have a widespread beneficial influence on many acres of farmland.

Cropland Acreage



SOURCE: USDA, 1978.

TECHNOLOGY ADOPTION

Developing and diffusing new agricultural systems is a slow process. Advances in science can accelerate the development of a new technique, but it still must be tested and adapted to site-specific conditions before it can be recommended to farmers. This need for extensive testing and evaluation partly explains why proponents of new technologies often consider agriculture overly conservative. The conservatism is also explained by chronic shortages of research funds, facilities, and personnel.* Although agricultural scientists are besieged with new and different ideas, practicality forces them to concentrate their limited resources on promising avenues of research,

*Chronic funding shortages, research priorities, and other research management issues are analyzed in a recent OTA assessment, *An Assessment of the United States Food and Agricultural Research System*, OTA-F-155 (Washington, D.C.: U.S. Government Printing Office, December 1981).

which generally means on marginal improvements in conventional technologies.

Unfortunately, this approach can limit innovation. Scientists are protective of existing projects and funding and seem reluctant to test new ideas, especially if they come from outside the United States or from the trial-and-error experience of farmers. For example, drip irrigation techniques developed abroad were initially treated with great suspicion and little research here. It was only after many farmers had begun using drip systems that USDA tested the method and began to assist its development. Similarly, rigorous testing of organic farming techniques is still resisted by some agricultural scientists.

Thus, while work on mainstream research problems and priorities should continue, a need exists for more rapid development of new and innovative technologies. If this is to occur, improved mechanisms must be developed to screen and test new ideas. At present, such ideas cannot compete for funding with the major existing crops and systems that have powerful constituencies among the electorate and scientists.

Some conservation practices, such as conservation tillage, have proven profitable, low cost, and low risk, yet are not used by many farmers whose land is suitable for and in need of these practices. Many factors, including the personal characteristics of the farmer or rancher and the attributes of the technology, influence this decisionmaking process.

Methods to encourage the adoption of conservation practices include: 1) information and education programs; 2) economic programs using subsidies, loans, privileged access to resources, investment credits, and tax incentives; and 3) regulations with economic and legal sanctions. In many cases, these approaches have failed to motivate widespread adoption because they have not been adapted to particular groups of farmers with special social, economic, resource, and management capability circumstances.

GOVERNMENT'S ROLE

Government policies and programs that affect agricultural technology use and land productivity generally fall into one of two categories: 1) those that promote economic goals, either by developing and promoting production technologies or by manipulating short-term economic factors; or 2) those that promote conservation of natural resource productivity, either by developing and promoting conservation technologies or by subsidizing investment in conservation. The two types of Government activities often operate simultaneously. Both influence farmers' decisions about technology use and about resource conservation, but the two influences are not always compatible.

Historically, economic programs supported prices primarily by keeping land out of crop production; hence no major effort was required to integrate production and conservation policies. Now, with economic goals shifting to full production, additional erosive or otherwise fragile land is coming into production, making the need for integration much more significant.

A number of hypotheses exist about how commodity price supports, credit and insurance programs, and tax policies interact with technology decisions and with the long-term trends in land use that affect conservation. For example, agricultural support programs are said to be a cause of land price inflation. This leads to increased debt, which reduces the economic flexibility that farmers and ranchers need to invest in conservation technologies. Some experts believe that commodity price supports and disaster insurance programs have promoted unsustainable uses of fragile land. It also appears that some tax and credit policies make agriculture an attractive tax shelter for nonfarmer investors, encouraging absentee ownership and tenant

farming. Although these kinds of relationships between policy and productivity are often discussed, policy analysts and program administrators have few analytical tools to predict how specific economic programs will influence land productivity in the future.

Congressional mandates exist that direct long-term resource appraisals to plan the development of cropland and rangeland resources. These processes are important for formulating the policies that influence land productivity. Both the Resources Planning Act (RPA) and the Resources Conservation Act (RCA) processes are gradually becoming more useful for these purposes. Political controversy over the findings has been a constraint, as has the sometimes narrow scope of the appraisals. For example, the RPA report scarcely mentions rangeland soil erosion and the RCA process failed to evaluate major Federal conservation programs.

A major effort supporting conservation has been the Agricultural Conservation Program, a cost-sharing program that has distributed $8 billion since it was started in 1936. But Federal cost-sharing programs for conservation practices are controversial. They have been criticized for supporting production rather than conservation and for not directing funds to the most susceptible land. The cost effectiveness of programs to prevent soil erosion and productivity degradation could be improved if more resources were directed toward those lands that have the highest risk. However, such redirections would be very imprecise until scientists learned to assess more accurately the relative effects of various productivity-degrading processes.

One widely discussed proposal for integrating conservation policies with policies designed to manipulate production is to make participation in the subsidy, insurance, and tax programs contingent upon adoption of conservation practices. This "cross-compliance" strategy loses force when strong export markets make price support programs less significant. However, greater constraints on the accessibility of disaster insurance and agricultural credit programs could contribute to some conservation objectives. Any conservation strategy that uses incentives or penalties must be responsive to changing economic conditions, to the need for continuous (v. single-year) conservation management inputs, and to the special circumstances of the farmers who work fragile lands.

Some mathematical models exist to simulate the interrelated aspects of the U.S. agricultural system, and these can improve understanding of the relationships between economic and conservation policies. But these models are not sufficiently developed or widely used for rigorous, comprehensive assessment of policy alternatives. If resource sustainability is set as an explicit goal of both the Government-funded technology development programs and the commodity and credit programs, and if production enhancement is made an explicit goal of the programs to develop and implement conservation technologies, it should become possible to improve agricultural production and inherent land productivity simultaneously.

- *Conservation and production need not conflict. Profitable technologies exist that maintain high levels of production while conserving long-term productivity of the land. More such technologies could be developed.*
- *Federal conservation programs have been poorly coordinated with other Federal programs that manipulate the economics of agriculture.*
- *Data and analysis on how erosion and other processes enhance or degrade the productivity of land under various management systems are inadequate for making the best possible decisions on national agricultural policies.*

ISSUES AND OPTIONS

Congress has two main channels to affect how technologies are developed and used to sustain inherent land productivity: 1) through legislation, including budget appropriations, to establish new programs or to change existing ones; and 2) through committee oversight of how existing laws and programs are administered. This assessment found that existing agricultural legislation does provide a sound base for the Government activities that are needed to accelerate the development and promotion of productivity-sustaining technologies. Consequently, many of the options for congressional activity are related to congressional guidance and oversight functions rather than new legislation.

Opportunities for congressional action can be categorized under five policy issues.

Integrating Conservation Policy With Economic Policy

Because agricultural production and conservation of inherent productivity are not mutually exclusive, it should be possible to establish farm economic policies that include conservation goals and to analyze the interactions of current and proposed conservation and economic programs. Options for accomplishing these ends include: 1) accelerating the development of analytical policy models that could be used in the existing RCA and RPA programs to evaluate policy alternatives, and 2) establishing a policy analysis office within USDA that would develop a systematic process to assess how agricultural policies affect inherent land productivity.

Improving the Effectiveness of Federal Conservation Programs

The Government's conservation investments could be more effective if they were concentrated on land where productivity degradation is greatest and on the most effective technologies. However, there is political resistance to redistributing program efforts and funds, and substantial debate is likely to continue. The redistribution of Federal conservation efforts now occurring is expected to concentrate efforts on those sites where soil loss is highest. Improved analysis of the site-specific relationships among erosion, other productivity-degrading processes, yield, and associated variables eventually should enhance the cost effectiveness of the program redistribution.

Conservation practices and production technologies with proven effectiveness for sustaining productivity are not being used on many sites where they are needed. Farmers and ranchers often are not convinced that available conservation practices or productivity-sustaining approaches are profitable or technically feasible for their particular situations. The problem is one of demonstration and education; therefore, Congress could improve program effectiveness by mandating in-service training and other programs that would enhance the capabilities of Federal, State, and private sector agents to transfer technologies.

Enhancing Federal Capabilities To Develop Innovative Technologies

Farmers and ranchers correctly perceive that there are many sites that simply cannot sustain profitable use with the conservation technologies now available. Hence, there is a great need for technology innovation and Congress could act to accelerate the development of productivity-sustaining technologies. Congress' options include: 1) encouraging the federally sponsored research network to make resource sustainability an explicit goal for their research programs and projects, and 2) directing particular USDA agencies and programs to evaluate and test innovative technologies that may be outside the scope of mainstream research efforts.

Reducing Pressure on Fragile Lands

Some land now in row crops and small grains, and some overgrazed rangelands, will

not be able to sustain their current uses but could be converted to uses more compatible with the land's inherent capability. However, short-term profits from the sustainable uses are often so low that farmers cannot afford the conversion. Thus, Congress has the option to establish a limited set-aside program to compensate farmers for such conversions. The program could pay farmers the difference between what the land would earn from its most profitable, productivity-sustaining use and what it now earns from the resource-consumptive use. In the long run, as new technologies are developed, the need for such a subsidy could decline. Another long-term option that could reduce pressures on fragile lands would be to encourage agricultural development of resilient potential croplands and grazinglands that are in other uses now or are virgin.

Encouraging State Initiatives

Since soil erosion was recognized as a critical issue in the 1930's, most efforts in soil conservation have been organized at the Federal level. Recently, however, several States have taken important initiatives and have developed effective programs in cost sharing and other conservation approaches. The Federal Government is cooperating in these efforts, but there are other opportunities to enhance existing State programs and to encourage similar developments in other States. The options range from low-cost efforts that would facilitate communication among States to funding arrangements that would reimburse States for part of the cost-sharing expenses.

Chapter II

Land Productivity Problems

"Shoestring" erosion on very poor condition rangeland

Photo credits: USDA—Soil Conservation Service

Row erosion in cornfield caused by heavy rains

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Chapter II

Land Productivity Problems

A variety of processes can damage the productivity of the Nation's croplands and rangelands. The greatest threat to land productivity is erosion, but other influences can also be important. Compaction and inadequate drainage can reduce crop yields. Salinization can force lands out of production. Withdrawing too much water from ground water supplies can limit future agriculture. Land subsidence, whether related to ground water withdrawal or other factors, can harm productivity with no hope for restoration.

SOIL EROSION

Congress first appropriated funds to study soil erosion in 1928. Research stations were established and both the process of erosion and its effects on crop yields were studied extensively. By the early 1950's, many studies indicated how much yields would be reduced with each inch of topsoil lost. U.S. Department of Agriculture (USDA) officials, judging the data to be adequate on that aspect of the problem, closed out most of the research on how erosion affects yields. But because there has since been a revolution in agricultural methods, the old data on yield reductions are inadequate for decisionmaking by Government or individual farmers.

Research on the causes and rates of erosion and on techniques for controlling erosion did continue after the closing of the erosion research stations, as much because of concern about erosion-caused water pollution as because of concern about agricultural productivity. Thus, much is known about methods and direct costs of controlling erosion, but very little about the benefits of such investments or, conversely, about the short- and long-term costs of allowing erosion to continue at its present accelerated rates.

The Mechanics of Soil Erosion

Water and wind cause soil erosion. The force of raindrops striking exposed earth detaches soil particles, which are then carried away if the water runs off the surface rather than soaking into the soil. Even without the force of raindrop splashes, runoff water can detach and carry away soil. Thus, the exposure of bare soil and the rates and volumes of overland waterflow are the critical factors in water-caused erosion.

There are four major categories of water-caused erosion: 1) sheet erosion is the removal of a soil layer of fairly uniform thickness by runoff water; 2) rill erosion occurs as small channels form on the soil surface; 3) gully erosion is an advanced state of rill erosion, where the channels become deeper than 1 ft; and 4) streambank erosion is the process of stream widening. Of these types, sheet and rill erosion cause the most damage.

Most serious erosion by water occurs where land has one or more of the following characteristics, and erosion control generally involves modifying these:

- steep slopes or long slopes that allow runoff water to gain momentum;
- exposure of tilled, bare soil without protection by cover crops or organic residue. This often occurs between the harvesting of one crop and the establishment of the next crop's leaf canopy;
- row crops alined up and down steep or moderate slopes;
- runoff from upslope pastures flowing across cropland;

- poor water absorption and poor drainage that result in less water entering the soil and more water running off;
- poor stands of low-quality vegetation; and
- lack of vegetation along streams.

Wind causes erosion when it blows across poorly protected soil with enough force to lift and move soil particles. Drier and more finely granulated soil is more susceptible to wind erosion. Since soil is driest and vegetation poorest during droughts, which are characteristic of the Great Plains and Western States, this is where the highest wind erosion rates occur. As recently as 1977 several drought-stricken regions experienced severe duststorms. Soil surfaces stripped of vegetation for dryland farming and overgrazed rangeland provided much of the soil for these recent storms (Wilshire, et al., 1980) as they did for the infamous dust bowl storms during the prolonged drought of the 1930's.

Although eroded soil is commonly described as "lost," it does not in fact vanish. Much of the soil moved by water remains in the same field, but farther down the slope. The portion of the soil that is actually lost from cropland or forage-producing land varies from one site to the next, depending on the shape of the slopes and other factors. On the average, about one-fourth of the cropland soil moved by water erosion each year becomes sediment in streams and about 8 percent reaches the ocean (Miller, 1981). The fate of wind-carried soil is less well-known, but the reported wind erosion rates do not always represent net losses from the affected region.

With both wind and water erosion, the material that is most likely to be lost is the best part of the soil: water soluble plant nutrients, lightweight organic matter, and tiny clay particles, which have the highest ability to store fertilizers and naturally occurring nutrients. These are moved first and farthest by both wind and water erosion.

The soil that moves downslope in the field is less fertile and more subject to drought than it was before it was moved. How croplands and rangelands are generally affected by deposits of such soil is not well understood. Nutrients transported with the eroded soil may benefit the site where the soil is deposited, but, conversely, superior soils may be buried by inferior material. Further, drainage can be impeded by deposited soil and soil particles carried by the wind can severely damage vegetation and cause partial or complete loss of crops.

Erosion is a self-reinforcing process. It lowers the fertility and water-holding capacity of the soil by removing nutrients and organic matter. As a consequence, plant growth is less and the soil is less protected. So the erosion accelerates more and more, unless the cycle is broken by a change in farming practices or a change in land use.

Estimating Soil Erosion Rates

The universal soil loss equation (USLE) relates measurements of five variables to estimate water-caused sheet and rill erosion. The variables are: precipitation; erosion potential of the soil type (which depends on texture, structure, and organic matter content); length and steepness of slope; type of plant cover and management conditions (tillage); and supporting practices for erosion control (e.g., terraces, contour farming, and stripcropping).

Research on USLE began in the 1940's, and by 1965 Soil Conservation Service (SCS) personnel were able to use it to estimate sheet and rill erosion rates accurately on most unirrigated croplands and to predict how erosion would be affected by changes in management or by specific conservation measures. Since 1965, more sophisticated computer models have been developed for more precise estimates, but USLE remains the most important technique because it is based on a pragmatic set of measurements and the calculations can be done on site. USLE has been adapted for erosion estimates on other land uses, but still needs refinement for conditions such as irrigated land and for atypical sites where soils are highly weathered (e.g., the Caribbean islands), poorly drained with long slopes (e.g., the Mississippi Delta), or where precipitation is atypical (as in parts of the Western States

where most erosion is caused by snowmelt runoff). Recently, USDA increased the research budget for the soils laboratory at Purdue University to further refine USLE.

A similar equation to estimate wind erosion (WEQ) uses measurements of five variables: soil erodability, soil ridge roughness, climate, width of field, and vegetative cover. Estimates from WEQ are not considered to be as accurate as the USLE estimates and fewer SCS personnel are expert in its use. Consequently, wind erosion data are lacking for much of the United States.

USLE and WEQ have vastly improved the reliability of erosion data for every level of conservation decisionmaking. Conservation plans for specific farms rely heavily on erosion rate predictions to indicate the appropriate level of management conservation structure investment. At the regional and national level, the equations are now used in the National Resource Inventory (NRI) conducted periodically by SCS to collect information for Government policymaking.

The accuracy of the NRI data depends not only on the USLE and WEQ equations but also on the design of the sample survey that determines what fields are measured for the inventory. The first year that the equations were providing accurate estimates for the national survey was 1967, but the sampling procedure was flawed and the 1967 data are not considered to be reliable for comparison to more recent data. The 1977 NRI was the first national survey to use a valid sampling procedure and the modern equations. The next NRI is under way in 1982. Until the 1982 data are available, the only reliable set of data on erosion rates at the national scale are from the 1977 NRI.

The 1977 NRI data are considered accurate estimates of sheet and rill erosion on croplands and pasturelands for most States, rough estimates of sheet and rill erosion on rangelands in the Western States, and fair estimates of wind erosion in the 10 Great Plains States. Wind erosion in the other States and gully and streambank erosion in general are not well covered by that NRI. The 1982 NRI will improve on those weaknesses, and the data for sheet and rill erosion are expected to be comparable for the two surveys. Unless otherwise indicated, erosion rates cited in this report refer to the NRI estimated amount of soil eroded (in tons per acre) in 1977.

Magnitude of Soil Erosion

Water-caused erosion on non-Federal land totals about 5 billion tons per year. Of that, 5 percent is from roads and construction sites, 6 percent from gullies, 11 percent from streambanks, 3 percent is sheet and rill from pastureland, 8 percent is sheet and rill erosion from rangelands, 38 percent is sheet and rill erosion from croplands, and the remaining 29 percent is sheet and rill erosion from forests and other land. Thus, the greatest sheet and rill erosion occurs on the 413 million acres of cropland.

No similar national data exist on wind-caused erosion. For the 10 Great Plains States where the wind erosion is greatest, an estimated 1.5 billion tons of soil are moved by the wind each year (fig. 1). Of that, 45 percent is from the 10 States' rangelands, and 55 percent is from the croplands (table 1).

Cropland

Erosion occurs on nearly all the Nation's 413 million acres of cropland, but a high proportion of both water- and wind-caused erosion is concentrated on a relatively small proportion of the land. The national average sheet and rill erosion rate on cropland is 4.7 tons per acre (USDA, NRI, 1980), but much of the land is eroding more slowly than this. Half the cropland has sheet and rill erosion rates of 2 tons per acre or less. At the same time, the most rapidly eroding 2 percent of the land has erosion rates over 30 tons per acre and accounts for 25 percent of all the sheet and rill erosion from cropland (see table 2).

The distribution of wind erosion over the landscape is similarly uneven. In the Great Plains States, wind erosion on croplands averages 5.3 tons per acre, but some 53 percent of

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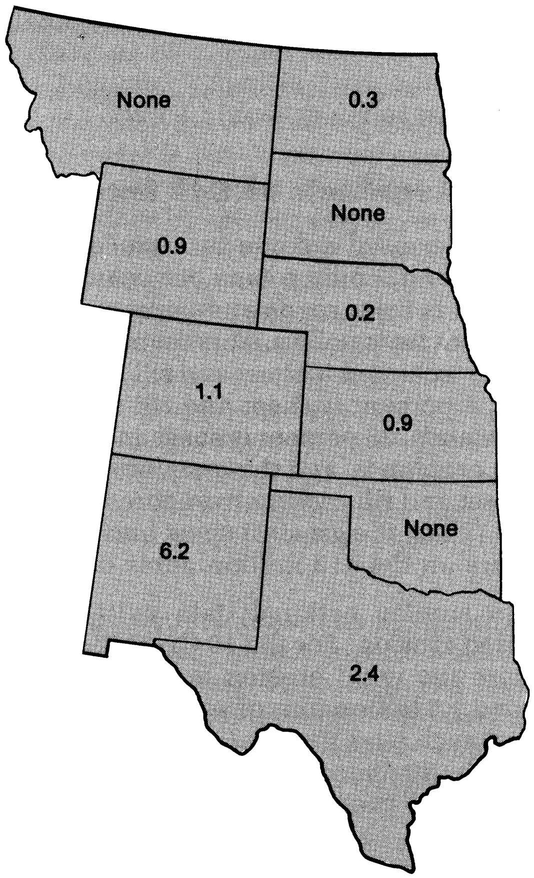
Figure 1.—Average Annual Wind Erosion (tons per acre) on Non-Federal Rangeland in the Great Plains States



NOTE: The average is 1.8 tons per acre.

SOURCE: 1977 National Resource Inventories.

the erosion occurs on 9 percent of the land. This highly fragile cropland erodes at rates over 14 tons per acre.

Pastureland

Pasture is land where planted grasses, legumes, or other herbs are managed to produce forage. It is seldom tilled, so it has a perennial vegetative cover. Because the land must be relatively well watered to repay the investment in management, the vegetative cover is typically abundant enough to protect the land from accelerated erosion. Thus, the national average erosion rate on pastureland is 2.6 tons per acre. Higher rates of pastureland erosion that do occur are concentrated on a relatively small part of the land, where poor management, steep slope, low moisture-holding capacity or drought are typical. Most of the pastureland has sheet and rill erosion rates below 2 tons, while the 11 percent of the land with rates over 5 tons accounts for half of the total sheet and rill erosion on pastureland. Wind erosion on pastureland is generally insignificant, but damage is reported occasionally, especially where overgrazing or drought destroys the plant cover (table 3).

Approximately half the grazing capacity of private lands in the United States is on pasture. Erosion threatens relatively little of this land, but improved management—more fertilizing, liming, reseeding, and better livestock management—could increase forage production by as

Table 1.—Wind Erosion on Cropland and Rangeland[a] in the Great Plains States, 1977

	Cropland				Rangeland[a]				
	Erosion, tons per acre per year				Erosion, tons per acre per year				
State	2	2-4.9	5-14	14	2	2-4.9	5-14	14	Total
			(1,000 acres)						
Colorado	4,849	1,788	2,037	2,419	23,258	55	82	406	34,894
Kansas	19,816	3,946	3,786	1,258	15,765	112	112	287	45,082
Montana	8,177	3,747	2,657	774	38,834	—	—	—	54,189
Nebraska	17,698	1,625	1,016	360	21,626	234	46	95	42,700
New Mexico	720	346	659	557	27,316	4,841	5,282	4,657	44,378
North Dakota	18,719	5,598	2,486	110	10,393	48	58	65	37,477
Oklahoma	8,233	1,379	1,543	628	14,537	15	14	—	26,349
South Dakota	9,873	5,620	2,356	343	22,191	7	—	—	40,354
Texas	12,982	1,962	6,249	9,246	85,749	2,539	2,784	4,329	125,840
Wyoming	2,112	271	527	60	24,947	403	281	538	29,139
Grand total	103,179	26,282	23,316	15,755	284,616	8,254	8,659	10,377	480,402

[a]Non-Federal rangeland only.

SOURCE: 1977 National Resource Inventories.

Table 2.—Annual Sheet and Rill Erosion on Cropland and the Amount of Erosion in Excess of 5 Tons per Acre, by Erosion Interval, 1977

Erosion interval (tons per acre)	Total acres (millions)	Cumulative percentage of acreage	Total sheet and rill erosion (millions of tons)	Cumulative percentage of erosion	Total erosion in excess of 5 tons per acre (millions of tons)	Cumulative percentage of erosion in excess of 5 tons per acre
0-1	131.6	31.8	49.2	2.6	0.0	0.0
1-2	74.6	49.8	110.6	8.3	0.0	0.0
2-3	51.5	62.3	127.5	14.9	0.0	0.0
3-4	35.9	71.0	125.0	21.4	0.0	0.0
4-5	26.0	77.3	116.3	27.4	0.0	0.0
5-6	17.6	81.6	96.2	32.4	8.2	0.9
6-7	12.6	84.6	81.8	36.6	18.6	2.9
7-8	9.3	86.9	69.4	40.2	23.0	5.4
8-9	7.3	88.7	62.0	43.4	25.4	8.1
9-10	5.8	90.1	54.6	46.2	25.8	10.9
10-11	4.8	91.3	50.2	48.8	26.3	13.7
11-12	3.7	92.2	43.1	51.0	24.4	16.3
12-13	3.0	92.9	36.9	52.9	22.1	18.7
13-14	2.8	93.6	37.1	54.8	23.3	21.2
14-15	2.4	94.2	34.6	56.6	22.7	23.6
15-20	7.8	96.1	134.8	63.6	95.8	33.9
20-25	4.4	97.1	98.0	68.7	76.0	42.1
25-30	2.9	97.8	80.6	72.9	65.8	49.2
30-50	5.5	99.1	209.9	83.8	182.4	68.8
50-75	2.3	99.6	133.8	90.7	122.5	82.0
75-100	0.8	99.9	64.4	94.0	60.6	88.5
100+	0.7	100.0	109.8	100.0	106.3	100.0
Total	413.3		1,925.8		929.2	

SOURCE: 1977 National Resource Inventories.

much as 50 percent (USDA, 1981) while reducing erosion. Unfortunately, a more likely scenario is that a significant part of the land used for pasture in 1977 will be converted to use for row crops and small grains, and that this shift will cause a significant increase in erosion on that land (Miller, 1981).

Rangeland

Rangeland is land where the natural plant cover of grass, forbs, or shrubs produces forage for livestock and wildlife, but where management is typically limited to manipulations of livestock grazing patterns. Reseeding, fertilization, tillage, and other inputs are uncommon. Erosion is the major force degrading the inherent productivity here, too.

Because rangeland is located in the arid and semiarid Western States and in Alaska, climatic limitations on plant growth make the land highly susceptible to any misuse that leaves the soil exposed to wind, rain, and snowmelt runoff. Overgrazing is the most common misuse of rangelands. It causes partial or complete destruction of the grass cover. The overall condition of U.S. rangeland is discussed in chapter III.

Sheet and rill erosion on the 414 million acres of non-Federal rangeland averages 2.8 tons per acre (see table 4 and fig. 2). As on croplands and pastureland, much of the erosion is concentrated on a relatively small part of the land. The sheet and rill erosion rate is over 5 tons on the most rapidly eroding 12 percent of the land. That 12 percent accounts for 57 percent of total sheet and rill erosion on non-Federal rangelands.

Neither is wind erosion evenly distributed on rangelands. Most non-Federal rangeland has wind erosion rates of less than 2 tons per acre, but the most susceptible 3 percent of the land, eroding at 14 tons and more per year, accounts for 31 percent of the total wind erosion.

Table 3.—Sheet and Rill Erosion on Pastureland, by State (excluding Alaska)

State	USLE, tons per acre per year			
	<2	2-4.9	5-13.9	14+
	1,000 acres			
Alabama	3,681	321	120	—
Arizona	11	—	—	—
Arkansas	3,765	838	599	426
California	1,028	57	38	4
Colorado	1,317	128	107	46
Connecticut	103	6	3	—
Delaware	21	1	1	—
Florida	5,399	89	55	—
Georgia	2,960	221	40	13
Hawaii	596	201	113	82
Idaho	1,058	—	6	45
Illinois	2,013	412	350	295
Indiana	1,480	258	239	170
Iowa	3,101	678	573	178
Kansas	2,071	413	144	73
Kentucky	3,624	835	686	590
Louisiana	2,759	107	59	20
Maine	246	—	3	—
Maryland	388	60	25	13
Massachusetts	85	3	3	—
Michigan	1,116	76	24	14
Minnesota	2,752	77	44	16
Mississippi	2,994	589	279	179
Missouri	8,352	1,881	1,747	843
Montana	2,528	80	4	35
Nebraska	2,120	422	227	130
Nevada	260	—	38	—
New Hampshire	95	—	—	—
New Jersey	139	1	—	4
New Mexico	341	1	—	40
New York	2,050	130	75	31
North Carolina	1,607	252	163	8
North Dakota	1,514	30	—	—
Ohio	1,749	377	311	178
Oklahoma	7,064	1,132	440	77
Oregon	1,678	84	5	—
Pennsylvania	1,386	206	118	87
Rhode Island	16	2	—	—
South Carolina	1,185	28	24	5
South Dakota	2,384	21	8	—
Tennessee	3,920	964	405	185
Texas	15,942	1,780	857	189
Utah	580	46	—	—
Vermont	456	34	3	12
Virginia	2,114	475	434	251
Washington	1,215	21	16	—
West Virginia	835	351	486	365
Wisconsin	2,173	313	202	50
Wyoming	701	25	10	—
Total United States	104,972	14,026	9,084	4,654
Caribbean	289	107	173	294
Grand total	105,261	14,133	9,257	4,948

SOURCE: 1977 National Resource Inventories.

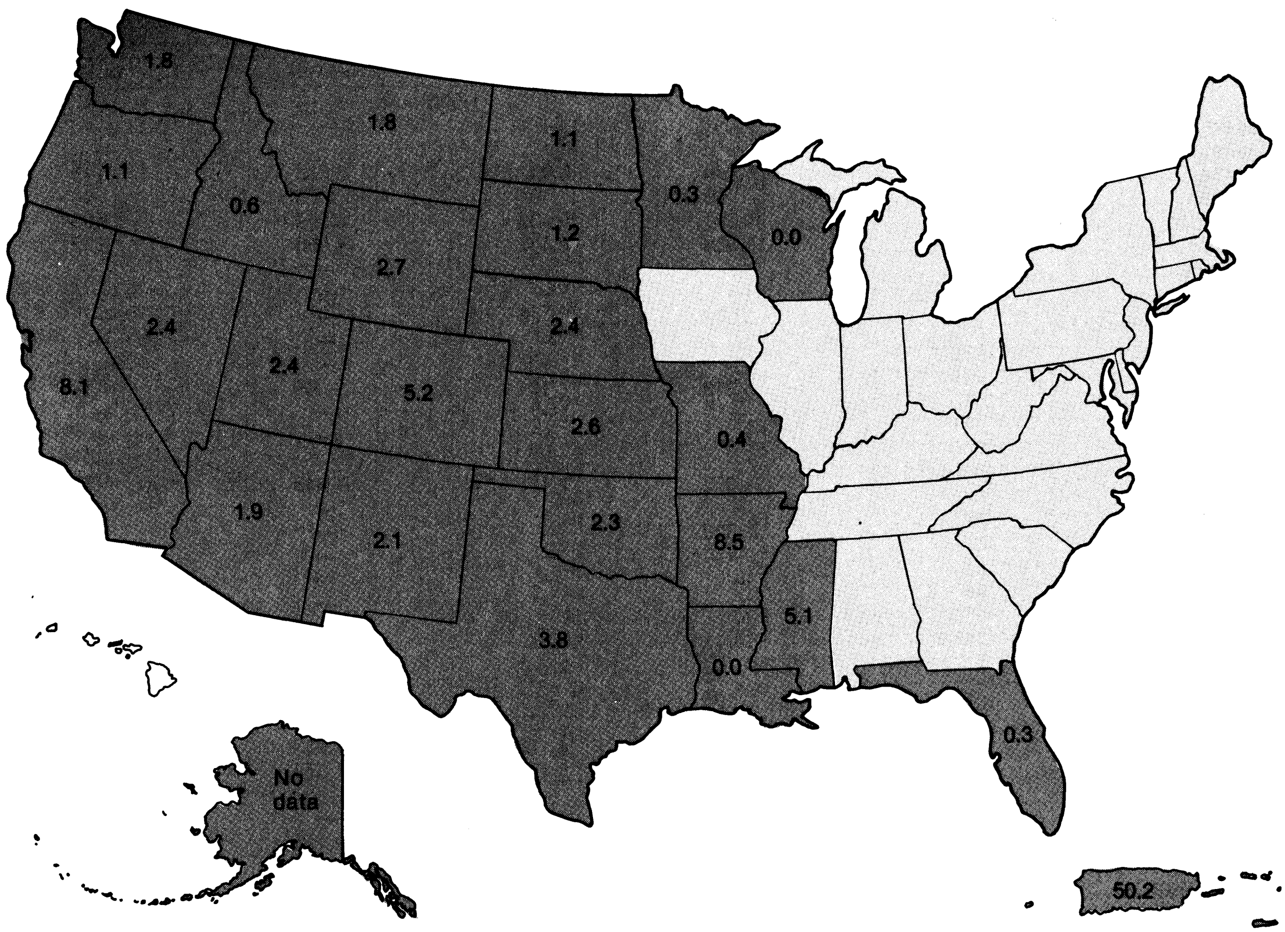
Table 4.—Sheet and Rill Erosion on Rangeland,[a] by State, 1977

State	Rangeland			
	Erosion, tons per acre per year			
	<2	2-4.9	5-13.9	14+
	1,000 acres			
Alabama	—	—	—	—
Alaska	—	—	—	—
Arizona	25,544	5,417	3,981	149
Arkansas	90	61	53	44
California	9,607	2,439	3,049	2,459
Colorado	15,659	3,867	2,586	1,689
Connecticut	—	—	—	—
Delaware	—	—	—	—
Florida	3,002	15	—	—
Georgia	—	—	—	—
Hawaii	—	—	—	—
Idaho	6,315	171	89	14
Illinois	—	—	—	—
Indiana	—	—	—	—
Iowa	—	—	—	—
Kansas	11,692	2,470	1,643	471
Kentucky	—	—	—	—
Louisiana	326	—	—	—
Maine	—	—	—	—
Maryland	—	—	—	—
Massachusetts	—	—	—	—
Michigan	—	—	—	—
Minnesota	110	—	—	—
Mississippi	15	10	—	5
Missouri	35	—	—	—
Montana	32,088	3,609	2,110	1,027
Nebraska	15,378	4,129	1,953	541
Nevada	4,970	1,199	1,074	108
New Hampshire	—	—	—	—
New Jersey	—	—	—	—
New Mexico	33,896	5,190	2,195	815
New York	—	—	—	—
North Carolina	—	—	—	—
North Dakota	9,736	394	229	205
Ohio	—	—	—	—
Oklahoma	10,954	2,095	1,095	422
Oregon	8,615	1,195	285	15
Pennsylvania	—	—	—	—
Rhode Island	—	—	—	—
South Carolina	—	—	—	—
South Dakota	19,496	1,489	947	266
Tennessee	—	—	—	—
Texas	74,009	10,427	6,158	4,807
Utah	7,271	1,090	646	378
Vermont	—	—	—	—
Virginia	—	—	—	—
Washington	4,580	926	444	91
West Virginia	—	—	—	—
Wisconsin	4	—	—	—
Wyoming	19,547	2,670	2,779	1,173
Total United States	312,939	48,863	31,316	14,679
Caribbean	1	11	8	44
Grand total	312,940	48,874	31,324	14,723

[a]Non-Federal rangeland only.

SOURCE: 1977 National Resource Inventories.

Figure 2.—Average Annual Sheet and Rill Erosion on Non-Federal Rangeland, by State (tons per acre)



NOTE: The national average is 2.8 tons per acre.
SOURCE: 1977 National Resource Inventories.

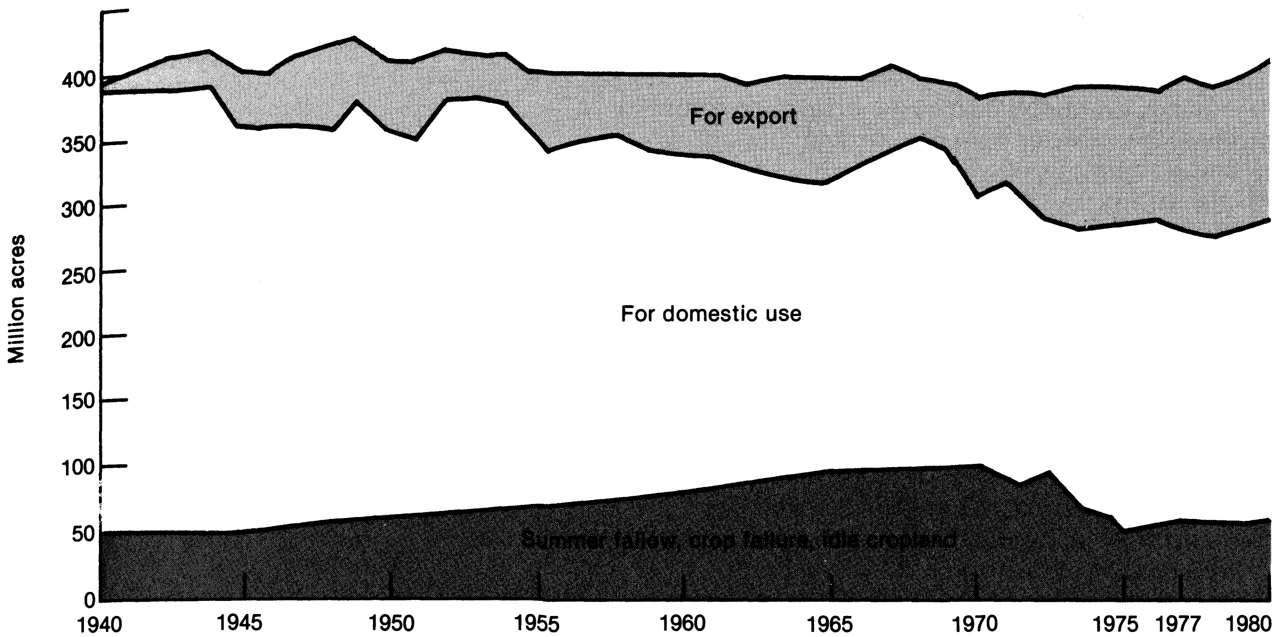
Potential Croplands

As export demand for U.S. crops continues to grow, the Nation will see changes in cropping patterns and gradual increases in the acreage farmed (CEQ-NALS, 1981). Between 1969 and 1980, for example, increased demand caused a 22-percent increase in the acreage planted to crops in this country. Land in row crops increased by nearly 50 million acres, while wheat alone increased by 27 million acres. The amount of cropland planted to row crops grew from 40 to 53 percent (fig. 3).

Generally, the best croplands are already in use, so the land available for conversion to cropland is inherently less suitable for farming. Thus, increased erosion can be expected as these more susceptible lands are brought into use. In one study designed to examine this issue, Miller (1981) used the 1977 NRI data to project sheet and rill erosion rates that would occur on potential cropland should these lands be cultivated for row crops and small grain crops.

First, the study looked at the 69 million acres of land classified as cropland that was actually being used for rotation hay, pasture, or other uses. If this land was converted to row crops and small grains and cultivated with conserva-

Figure 3.—Acreage for Domestic Use and Export, 1940-80



SOURCE: "Changes in Farm Production and Efficiency," USDA. Preliminary '78-80 data —Economics and Statistics Service.

tion tillage, it was projected to erode an average of 9.9 tons per acre. This is 83 percent higher erosion than current rates for row crop and small grain cropland.

Next the study examined acreage with high, medium, and low potential for conversion to cropland (table 5). "High potential" land is land with favorable physical characteristics where there is evidence of similar land nearby having been converted to cropland. There were 39 million acres of such land in 1977, most of it in use as pasture. If conservation tillage were used to bring high potential land into row crop and small grain production, the expected average erosion rate would be 6.5 tons per acre, 20 percent above the current average erosion rates for row crop and small grain cropland.

Table 5.—Potential for Cropland use According to the 1977 National Resource Inventories (SCS) (millions of acres)

	High	Medium	Low	Zero
Pastureland........	18	33	47	35
Rangeland.........	9	30	98	271
Forestland.........	7	24	109	230
Other..............	2	4	15	51
Total............	36	91	269	587

SOURCE: National Agricultural Land Study (1981).

If conservation tillage were used to bring the 87 million acres described as having "medium potential" for conversion to croplands into production, the expected average erosion would be 9.6 tons per acre, 77 percent more than the current average erosion.

The actual amount of land that will be converted to crops in the future depends both on demand and on how successful improved management and technologies are in increasing yields from the cropland already in use. An estimated 36 million to 143 million acres of additional cropland may come into production by 2000 (Cook, 1981). Ideally, the first land converted would be that with the lowest erosion potential. But analysis indicates that on the average the lands that are available for conversion are substantially more susceptible to erosion than the lands already in use, so erosion will increase. The newly cropped land will contribute greatly to the Nation's production of wheat, corn, and soybeans, but the cost in

terms of soil losses and water pollution may be substantial.

Areas With High Erosion Rates

Every year, the Nation's row crop and small grain cropland erodes at an average rate of 5.4 tons per acre. Yet topsoil is thought to form at a rate of only 0.5 ton per acre or less. Thus, even though knowledge of soil formation rates is grossly inadequate, it appears that soil is lost at least 10 times faster than it is formed (Larson, 1981). Agricultural areas experiencing high erosion have been identified in most parts of the United States (fig. 4). Some of the important high erosion areas include:

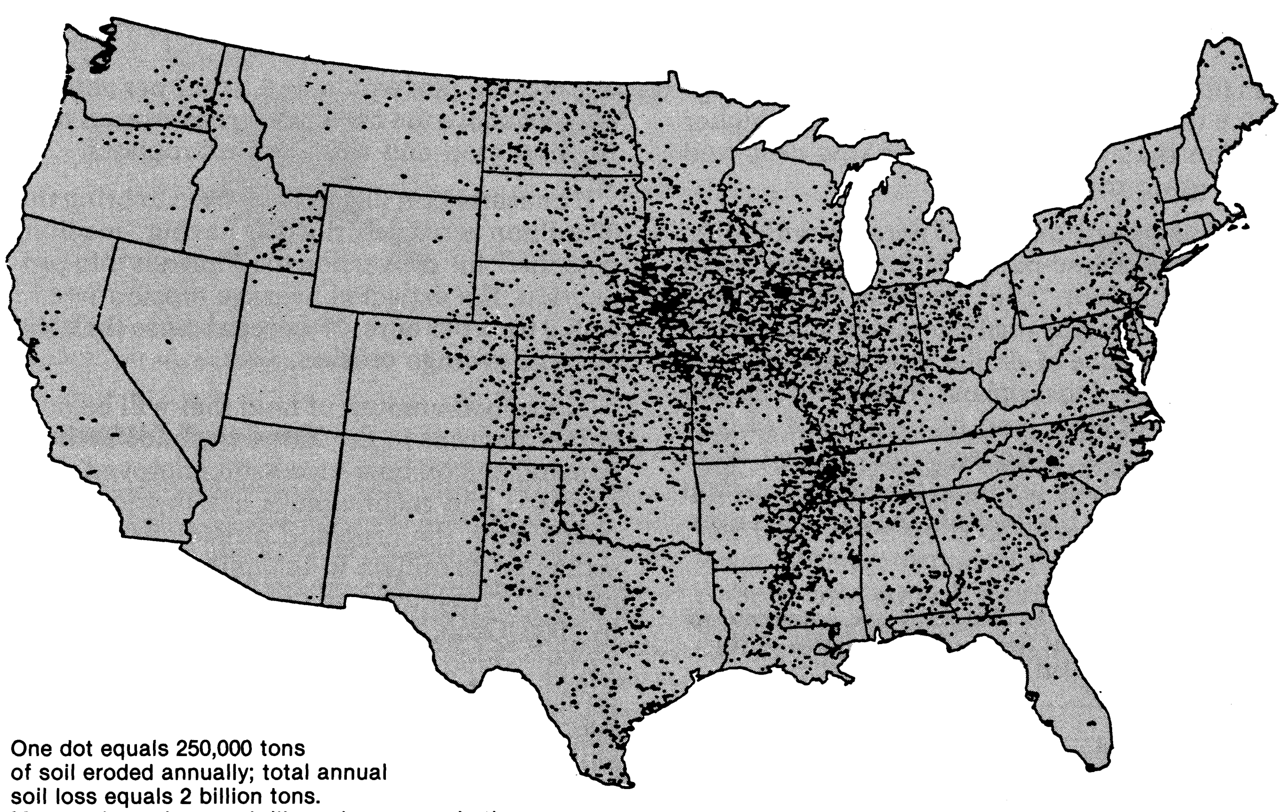
Hawaii.—After native vegetation has been stripped from semitropical soils for cultivation, the soils are susceptible to sheet and rill erosion under heavy rains, especially on sloping land. In 1977, Hawaii cropland eroded at an average annual rate of 14.2 tons per acre.

Southern High Plains.—Dryland and irrigated cotton farming dominates this region of western Texas and eastern New Mexico. The loamy soils are susceptible to wind erosion, especially during winter and early spring windstorms when the fields are bare. Annual wind erosion here averages 20 to 50 tons per acre.

The Palouse Basin.—This region covers parts of eastern Washington and adjacent Idaho along the western border of the Idaho panhandle, and is dryfarmed for wheat, barley, peas, and lentils. Most of the cropland is hilly and possesses erosive loess* soil with slopes

*Loess is a fine-grained, wind-deposited sediment of glacial origin that was formed some 10,000 years ago, whose composition and texture is reasonably homogenous.

Figure 4.—Cropland Sheet and Rill Erosion, 1977



One dot equals 250,000 tons of soil eroded annually; total annual soil loss equals 2 billion tons.
Most serious sheet and rill erosion occurs in the Corn Belt and Delta States and west Tennessee.

SOURCE: 1977 National Resource Inventories.

Photo credit: USDA—Soil Conservation Service

Critical erosion on summer fallowed land in the Palouse Basin near W. Colfax, Wash.

from 15 to 25 percent. Runoff from melting snow and heavy rains causes erosion of 50 to 100 tons per acre.

Texas Blackland Prairie.—This region comprises an important farming area in east-central Texas. Two-thirds of it is cropped mainly in cotton and grain sorghum. Rainfall averages 30 to 50 inches and the terrain is gently rolling. Many of the region's soils are highly erodible; sheet and rill erosion averages 10 to 20 tons per acre per year.

The Corn Belt States.—Iowa cropland eroded (sheet and rill) at an average rate of 10 tons per acre in 1977, Illinois cropland at 6.8 tons per acre, and Missouri cropland at 12 tons per acre.

Southern Mississippi Valley.—The soils of this area are deep, fertile, and erodible. Much of the cropland is sloping, some steeply, and row crops are grown without adequate conservation practices. In 1977, Tennessee cropland experienced average sheet and rill erosion of 17 tons per acre, and Mississippi cropland 11 tons per acre.

Aroostook County, Maine.—Potatoes are grown here on lands with slopes up to nearly 25 percent. Since cultivation began, the upper 2 ft of soil have been lost to erosion. Some sloping fields are losing as much as an inch of soil per year.

The Caribbean.—Agricultural soils in Puerto Rico and the Virgin Islands are eroding at extremely high rates. The 1977 NRI indicates that cropland here experienced average sheet and rill erosion of 49 tons per acre, and rangelands 50 tons per acre.

Effects of Erosion on Crop Production

Soil erosion reduces inherent land productivity in a variety of ways:

- loss of soil organic matter and of fine clays, and, thus, loss of plant nutrients and nutrient-retention capacity;
- loss of a soil's water retention capacity as organic matter is removed and soil structure deteriorates; and
- loss of rooting depth as soil becomes thin.

In the absence of fertilization (whether by commercial products or by animal or green manure) or the application of other capital inputs, crop production suffers as erosion progresses. Numerous studies have documented this phenomenon, but few of them have been conducted since the 1940's.

As the National Soil Erosion-Soil Productivity Research Planning Committee of USDA has explained (Williams, et al., 1981), there are two reasons for the lack of research on the effects of erosion on crop production: 1) such experiments are costly and time-consuming and years of data are needed to evaluate the effects of the generally slow process; and 2) crop production has been adequate in the past, resulting in little incentive for investment in this type of research. A few recent field experiments demonstrate that erosion can drastically reduce crop yields. However, climatic characteristics vary widely throughout the United States and have important effects on both soil erosion and crop production. Therefore, research conducted in one physiographic land area often cannot be generalized.

Some studies have examined the relationship between soil erosion and crop yields. But this is not necessarily the same as the relationship between soil erosion and productivity because technology can mask the impacts of erosion. Excessive erosion may or may not change crop yields but it invariably requires farmers to apply more inputs (including fertilizers, seeds, pesticides, irrigation, etc.). Substituting technology for soil entails a real cost because of the value of the resources, such as energy, used. Such substitutions could become more difficult if escalating energy prices make fertilizer, irrigation, and other inputs even less affordable to farmers. Thus, there are hidden and very poorly quantified costs associated with erosion, and these costs are not reflected by crop yields alone.

The studies that document the relationship between erosion and yields can provide a rough indication of the effect of current farming practices on inherent land productivity. Hagan and Dyke (1980) compared estimated yields on eroded and noneroded sloping soils using data from SCS soil surveys. For the Corn Belt, they estimated that for each inch of "A" horizon (topsoil) lost through erosion, corn yields were reduced by 3 bushels per acre. Other evidence shows that as soil erodes and changes from the slightly eroded to the severely eroded class, yields are reduced 23 bushels per acre for oats, and 1.1 tons per acre for hay (McCormack and Larson, 1980).

In western Tennessee, crop yields from severely eroded Memphis loam formed on thick loess were 14 percent less than yields from the same noneroded soil. Yields from severely eroded Granada soil were 26 percent below those from its noneroded equivalent and the yields from the severely eroded Brandon soils were 50 percent less (table 6). Table 7 shows the direct relationship between topsoil losses and decreased corn yields.

Note, however, that studies conducted in the North-Central United States, in areas where soils are formed in thick loess, show that erosion has little or no effect on productivity. A study of three experimental sites near Council Bluffs, Iowa, indicates that whereas corn yields were lower on the more eroded sites at the beginning of the study, the yield differences largely disappeared after a few years (Spomer, et al., 1973). A similar study, also in western Iowa, showed that even after some 7 ft of loess soil had been removed, crop yields were about the same as on the original soil surface (Moldenhauer and Onstad, 1975). Erosion of thick loess soils does little damage to crop yields in the short term because the underlying material is similar to that which has been eroded. Where

Table 6.—Summary of Buntley-Bell Erosion Study (1976)

Degree of erosion	Crop yields				
	Corn bu/acre	Soybeans bu/acre	Wheat bu/acre	Cotton lb/acre	Fescue tons/acre
Memphis silt loam: 2 to 5 percent slope					
Noneroded	110	40	54	1,060	4.2
Eroded	105	36	52	1,030	4.2
Severely eroded	95	32	48	940	4.0
Grenada silt loam: 0 to 5 percent slope					
Noneroded	95	40	53	940	4.0
Eroded	85	30	46	875	3.7
Severely eroded	70	24	40	750	3.2
Brandon silt loam: 2 to 12 percent slope					
Noneroded	80	30	49	815	4.0
Eroded	70	20	47	750	3.3
Severely eroded	45	16	38	535	2.7

SOURCE: Buntley and Bell, 1976.

Table 7.—Effect of Topsoil Loss on Corn Yield

Original topsoil thickness 10 to 12 inches	Percent decrease in corn yield
2 inches eroded (8 to 10 inches remaining)	7
4 inches eroded (6 to 8 inches remaining)	14
6 inches eroded (4 to 6 inches remaining)	25
8 inches eroded (2 to 4 inches remaining)	37
10 inches eroded (2 inches or less remaining)	52

SOURCE: Pimentel, et al., 1976.

the loess is thin and the underlying material is dissimilar to the eroded loess, crop yields show dramatic decreases (Buntley and Bell, 1976).

Scientists do not fully understand the mechanisms that cause yield reductions from erosion. Certainly a major factor is the reduced water retention capacity of soils from which organic matter has been eroded. In addition, loss of organic matter reduces the capacity of soils to store plant nutrients such as nitrogen, calcium, potassium, and, to a lesser degree, phosphorus.

When reduced productivity results solely from loss of nutrients, it can often be restored by applying fertilizers. Studies have shown, for example, that some eroded Corn Belt soils recover most or all of their lost productivity with adequate application of chemical fertilizers. Soils of the Southeastern United States behave differently, however, because these are deeply weathered and lack the type of soil clay minerals that can hold fertilizer nutrients for plants. These soils rely heavily on organic matter for nutrient storage, so yields on eroded soils are measurably lower, even after nutrients are supplied by fertilizers.

It is not clear whether the continued application of chemical fertilizers to maintain productivity will be economical over the long run as soils erode. Of growing concern are the rising amounts and costs of nitrogen and phosphate fertilizers required to maintain yields as less fertile subsoils are exposed and cultivated. And where the productivity of eroded soil declines for reasons other than nutrient loss (e.g., loss of moisture retention capacity), it is sometimes difficult for farmers to identify the cause of the decline or its remedy.

Overall, adequate knowledge about how various soil types are affected by long-term erosion is lacking. As long as only sparse data exist, there is the risk that the productive capacity of the land will be impaired permanently.

The recent formation of the National Soil Erosion-Soil Productivity Research Planning Committee within USDA is an encouraging development. The committee was given three objectives:

1. to determine what is known about the problem of the effects of soil erosion on

soil productivity by: a) defining it, b) identifying research accomplishments, and c) identifying current research efforts;
2. to determine what additional knowledge is needed; and
3. to develop a research approach for addressing the problem.

With adequate funding and followup, this effort could be a significant step toward answering the soil erosion/soil productivity question.

Tolerable Level of Soil Loss

"It is not possible to prevent erosion," notes a recent text on soil conservation, "but it is both possible and necessary to reduce erosion losses to tolerable rates. Tolerable soil loss is the maximum rate of soil erosion that will permit the indefinite maintenance of soil productivity" (Troeh, et al., 1980).

Soil loss tolerances (T-values) are set by SCS and profess to consider the depth of soil, the type of parent material, the relative productivity of topsoil and subsoil, and the amount of previous erosion.

The maximum tolerance loss, 5 tons per acre per year, is for deep, permeable, well-drained, productive soils. The minimum loss rate, 1 ton per acre per year, is for shallow soils having unfavorable subsoils and parent materials that severely restrict root penetration and development (Troeh, et al., 1980). Soils that have experienced severe erosion receive a lower T-value than comparable noneroded soils.

The USDA Soil Erosion-Soil Productivity Research Planning Committee (Williams, et al., 1981) has noted:

> SCS periodically reviews the soil loss tolerance limits (T-values) for all major soils .... *There is essentially no research base to support T-values;* they were established and are revised on the basis of collective judgments by soil scientists (emphasis added).

The most important reason for setting the maximum T-value at 5 tons per acre per year is that this fits the rough estimate of the yearly rate of "A" horizon formation on well-managed, permeable, medium-textured cropland soils. At this rate, an inch of subsoil becomes topsoil every 30 years. However, soil horizon formation rates vary greatly, and are likely to be much slower in soils of finer (i.e., higher clay content) texture.

It has been stated that the "fallacy" of this criterion is that it does not consider that the root zone becomes more shallow as erosion occurs. Thus, the weathering of parent rock or deeper soil horizons is a distinctly different phenomenon from the formation of the "A" horizon. In most soils it proceeds much more slowly. Understanding root zone formation is vital to predicting the long-term effects of erosion, but data on these rates are very scarce. Renewal at 0.5 ton per acre per year is thought to be a useful estimate for most unconsolidated materials. For most consolidated material (rock), rates are much slower (McCormack and Larson, 1980).

In practice, however, it would be extremely difficult—if not impossible—to limit erosion on most cropland to 0.5 ton per acre per year without either major reductions in production or fundamental changes in the methods of agriculture. The T-value that USDA has designated for most soils (almost 60 percent of the soil types) is 5 tons per acre per year. Because of data inadequacies, this value may be too high for some soils and too low for others.

USDA's T-values provide farmers with a realistic target at which to aim as they work to reduce their soil erosion rates, but the values do not provide scientifically grounded criteria for determining whether the long-term productivity of the land is being sustained under today's agricultural practices.

Other Costs Associated With Erosion

Although they are difficult to quantify, there are costs other than decreased crop yields associated with soil erosion. One cost is the fertilizer value of eroded topsoil. If the losses of the major plant nutrients—nitrogen, available phosphorus, and available potassium—in the 2 billion tons of soil removed by sheet and rill

erosion each year are calculated at current prices, they would have an annual value of roughly $8 billion (CAST, 1982). Some of these nutrients are deposited on lower slopes; however, as much as half are lost from cropland areas. They contribute to water pollution or are deposited on flood plains not used for cropland.

If 25 percent of eroded soil is lost as sediment (Miller, 1981), a conservative estimate is that the costs associated with the replenishment of fertilizer nutrients lost to erosion range from $1 billion to $4 billion each year. Dredging costs attributable to erosion have been estimated at $60 million (McCormack and Larson, 1980).

Flood plain overwash and sedimentation of reservoirs caused by eroded soil are other results of erosion, but estimates of their costs vary enormously, from $50 million (CAST, 1975) to $1 billion (McCormack and Larson, 1980). CAST estimated the cost of water treatment necessitated by erosion at $25 million for 1975.

The state of the art for estimating these types of costs is poorly developed. A team of agricultural economists and agronomists recently examined the relationship between increased crop acreage and nonpoint source pollution in Georgia. They concluded that the impacts of erosion on sediment, water quality, and the health of humans and wildlife were hard to measure in dollar terms:

> Because of limited resources, the work was based on secondary data. Deficiencies in such data became clear during the research. Data on land use changes, input use, and chemical loadings were unavailable, which forced us to simplify assumptions. While a similar study in the future could collect primary data on these factors, developing nonpoint-source pollution policy from the data currently available could be difficult and/or lead to considerable error.
>
> More research and analytical data are clearly needed in the area of nutrient and pesticide loadings. The state of knowledge in this area was so deficient that weak assumptions were made to calculate nutrient loadings, and calculation of pesticide loadings proved impossible.
>
> A major commitment to an agricultural information system and more research is unquestionably necessary to support a nonpoint-source pollution policy (White, 1981).

Conclusions

Erosion's effects are not new. At its peak, Mesopotamia supported a population of 25 million; by the 1930's, Iraq, which now makes up a major proportion of the territory controlled by that ancient civilization, supported only 4 million. Much evidence points to soil erosion as a significant factor in the deterioration of the culture (Troeh, et al., 1980). Elsewhere in the Mediterranean Basin are other examples of lands that were once grain-rich and grass-rich that are now impoverished: North Africa (Tunisia, Algeria, Morocco), the southern Italian peninsula and Sicily, and Asia Minor.

Erosion is a self-reinforcing process. Erosion causes a loss of soil fertility and as a result plant growth diminishes. This in turn results in less plant cover to protect the soil and less plant residue to enrich it. Consequently, more erosion occurs, the land becomes progressively less fertile, and the loop continues. Thus, erosion is an important problem for this Nation to combat.

The fact that most of the country's erosion occurs on a relatively small amount of land has only recently been widely recognized by national policymakers. However, even the relatively lower erosion rates that occur on most cropland may be causing significant degradation of land productivity because these lands account for most of the Nation's agricultural production.

A conservative estimate of total cropland erosion assumes that wind erosion is significant only in the 10 Great Plains States and that gully and streambank erosion do not affect cropland significantly. Thus, cropland erosion is estimated to be the sum of sheet and rill erosion plus Great Plains wind erosion, or 2.8 billion tons a year. This is an average of 7 tons an acre each year for the Nation's total 413 million cropland acres. This soil erosion rate is much

greater than the most optimistic estimates of soil formation rates.

Because much of the research on the effects of erosion on yields has been conducted in the thickly loess-covered areas of the North-Central United States, it is likely that the magnitude of the adverse effects of erosion on crop yields is underestimated for other important U.S. croplands where the soils are thinner. Increased research is needed to determine the effects of water and wind erosion on crop yields in these other areas.

Information on the rates of soil formation for important agricultural soils under specific climatic and technological conditions also is needed. In addition, existing methods for estimating soil erosion need to be improved. But conservation efforts cannot be deferred until this information becomes available. Research results should be used as they become available to improve existing conservation programs and technologies.

There are indications that some arid and semiarid areas that have been converted to irrigation, especially center-pivot irrigation, may be returned to dryland farming or grazing or may be abandoned because of rising pumping costs and declining ground water levels. If this becomes widespread, significant increases in wind erosion can be expected.

The extent to which cultivated land has been affected adversely by erosion and has consequently reverted to pasture or rangeland, woodland, or brush is not known. The productive capacities of most soils in the United States are reduced to some degree by erosion. An active research program into the damage suffered and the causes of the damage to a wide range of cropland and rangeland soils is needed as a basis for formulating rational conservation programs.

The land that is most likely to be brought into row-crop and small-grain production in the years ahead will erode at higher rates, on the average, than the land now used, even if conservation tillage practices are used. With Federal conservation funds constant, or even lowered as was predicted at the end of 1981, and with large amounts of land being brought into more erosive agricultural use, the capacity of existing programs to check or reduce soil erosion on U.S. farmlands will be greatly stressed. This will accentuate the need to find more cost-effective means of reducing erosion, and the need to take steps to discourage production of row crops and small grains on land where cost-effective measures will not result in acceptable erosion rates.

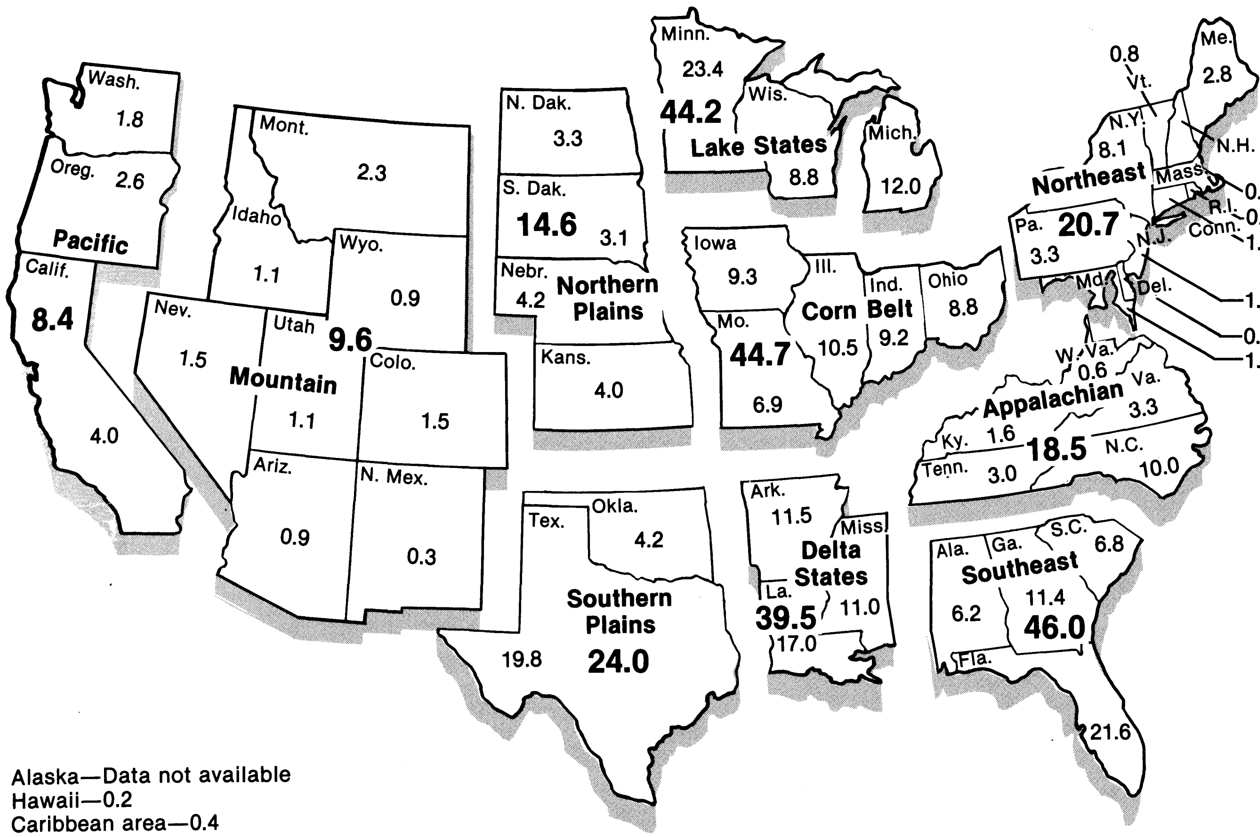
DRAINAGE

Farmland drainage has been the primary agricultural water management and farm reclamation activity in this country. There are about 270 million acres of wet soils in the United States, including about 105 million acres of cropland where wetness is the dominant constraint on production (USDA, NRI, 1980). Wet soils can be extremely fertile and productive because they commonly contain more organic matter than soils that are not as wet. The Southeast has the largest acreage of wet soils, followed closely by the Corn Belt, the Great Lakes, and the Southern Delta States (fig. 5).

Although only certain wet soils are classified as "wetlands," much of 3.8 million acres of wet soils converted to cropland between 1967 and 1975 were indeed wetlands (USDA-RCA, 1980). Their conversion meant the loss of valuable wildlife habitat, reduced flood prevention, loss of the natural cleansing capacity of watersheds, and other services. On the other hand, drainage of wet cropland enhances crop production significantly.

Drainage provides benefits in six major areas:

Figure 5.—Wet Soils by State and Farm Production Region (millions of acres)



Alaska—Data not available
Hawaii—0.2
Caribbean area—0.4
Total—271.1

SOURCE: 1977 National Resource Inventories. 1967 Conservation Needs Inventory.

1. improves the root zone environment for optimum plant growth,
2. increases efficiency of farm machine use,
3. lengthens growing season,
4. increases water absorption capacity,
5. increases control of health hazards associated with excess water, and
6. facilitates onland disposal of organic waste material.

Surface drainage can channel water through shallow-grassed ditches and into outlets, reducing erosion on sloping soils and surface ponding on flat soils. Up to 40 percent of the precipitation in an area can be removed by proper drainage (Schwab, 1975). Surface drains do not lower the water table directly. To accomplish this, subsurface drains must also be used.

Subsurface conduits, or tiles, are laid by opening a trench in the field to a depth dependent on the soil, crop, and hydrologic conditions of the site. Porous pipes are laid at intervals to channel water into ditches at the edges of the field, and from there into outlet channels. Subsurface drains have a number of advantages over surface drains, including fewer weeds, less wasted land, improved machinery use, less maintenance, and better soil drainage.

Removing excess water prevents seed rot and fosters higher soil temperatures, thus promoting rapid and even germination. Productive soil requires an adequate supply of oxygen for plant roots; poor drainage can reduce oxygen levels, inhibiting root transpiration and the ability of roots to absorb nutrients. Because

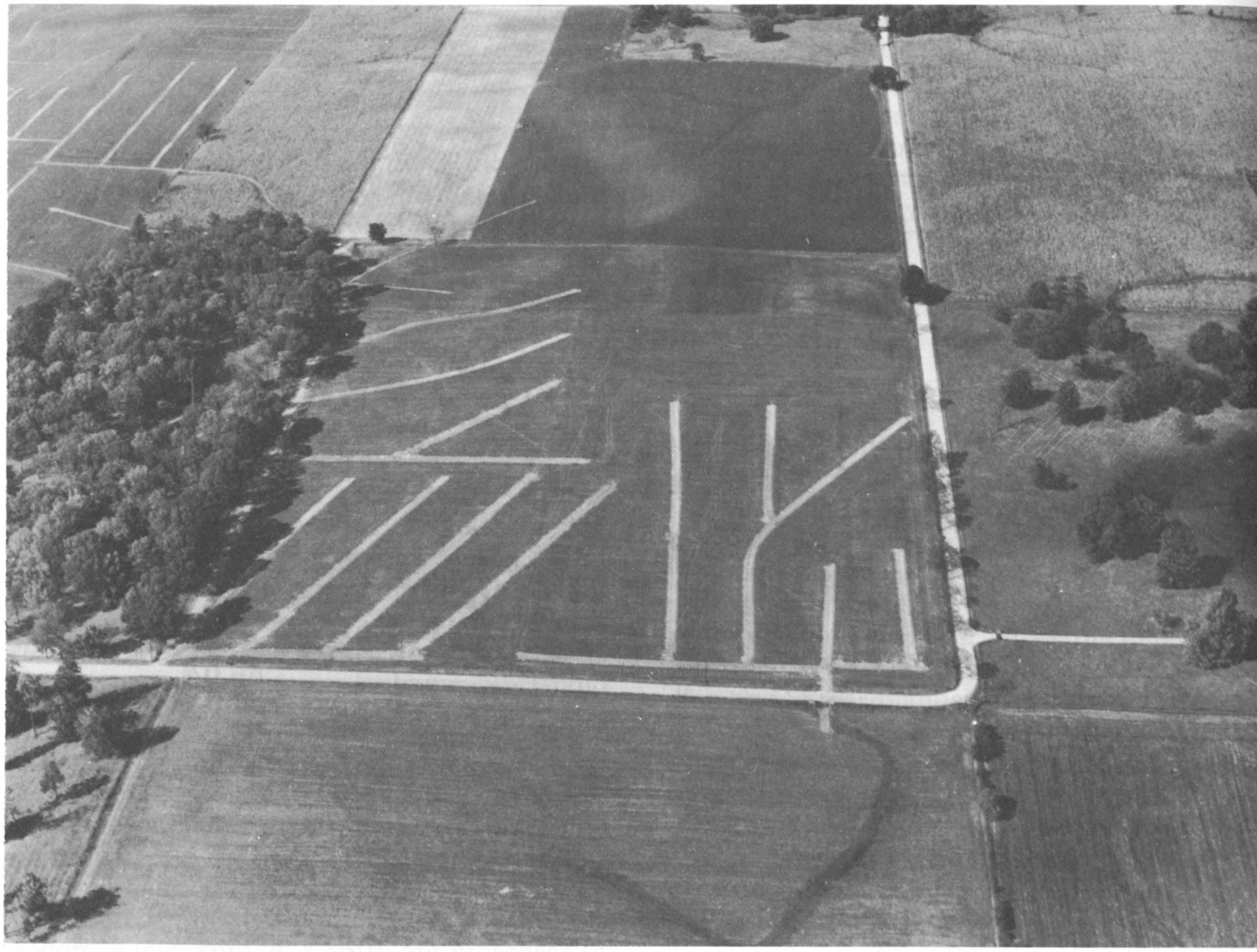


Photo credit: USDA—Soil Conservation Service

Till drainage system on Crosby silt loam, 0 to 3 percent slope, 100 ft spacing

the roots of most cultivated crops will not penetrate saturated soil, poor drainage can also result in a shallower root spread and a commensurate reduction in plant size, stability, and yield. Deeper root growth helps crops withstand drought, and lower water tables provide a greater volume of soil from which plants may obtain nutrients and moisture. Soil structure is damaged when tillage or harvesting operations are done while the soil is too wet. Excess water also increases the likelihood of compaction and obstructs the loosening activities of soil biota.

Drained fields can be planted earlier because of earlier accessibility of machinery to fields and higher soil temperatures. Improved drainage will usually advance the potential planting or seeding date by 1 or 2 weeks (Irwin, 1981). From May 1 to 15, each day of delay reduces corn yields by 1 bushel per acre, and in the latter half of May, each day of delay reduces yields by 2 bushels per acre (USDA-SCS, 1975). Furthermore, earlier planting broadens the selection of crop varieties available for the farmer to grow, advances the maturity date, and produces higher final yields. Drainage also

offsets uneven field ripening of grain crops, allows more flexibility in harvest time, and increases the potential for double cropping.

Water-saturated lands promote surface runoff of rainwater, inducing erosion and increasing the problem of flooding on downslope land. A well-drained soil reduces erosion because surface runoff is substantially reduced when more water can infiltrate into the soil. The top layer of soil is richest in organic matter and applied chemicals, so using drainage to reduce runoff can reduce losses of sediment and some nutrients. This also reduces the contamination of runoff waters and enhances the distribution of fertilizer nutrients through the upper soil layers. In areas of high salinity, drainage will promote leaching and removal of salts.

Drainage of waterlogged lands can also help control health hazards to man and livestock, such as mosquito- and fly-borne diseases, certain worms, and liver flukes. Removal of excess water removes the breeding ground or favorite habitat of these carriers and thus reduces their populations.

Good drainage makes the onland disposal of organic waste material, increasingly under consideration as an alternative to ocean disposal, environmentally safer. Adequate aeration and warm soil temperatures are necesary for the efficient decomposition of wastes into usable plant nutrients.

Investment in farmland drainage systems occurred throughout the last century, peaking in the mid-1930's. Research to improve these systems was performed extensively by USDA agricultural research stations and land-grant colleges until the late 1960's. During the 1960's, however, growing concern over the loss or degradation of actual wetlands (v. wet soils) discouraged investment in drainage systems. As a result, drainage has been specifically exempted from USDA cost-sharing programs in most instances, and SCS technical assistance on drainage has been limited by personnel reductions and the pressure of higher priority demands for the expert's time (Ochs, 1981).

Technologies developed in the mid-1960's for more efficient and cost-effective installation of drainage tiles represent the latest advances in the field. Corrugated plastic drainage tubing was developed to replace the heavier and shorter-lived clay tiles, with significant cost savings to farmers. This tubing can be installed more quickly and effectively using laser beam grade control. In addition, trenchless machinery was developed to install tiles faster than earlier deep-trench operations. Two new technologies under study are well-point drainage for vertical, rather than horizontal, movement of excess water, and reversible drainage, which introduces as well as removes water through porous tubes. The latter technique would be especially applicable to the climatically variable Southeastern United States.

The dearth of drainage research during the 1970's has resulted in a lack of data in many important areas. Few analyses are available on design procedures, system maintenance, and integration of drainage with modern cropping systems to maximize production. Such basic information as the lifetime of drainage systems is not available. Furthermore, while information on the costs and benefits of farmland drainage is available, it is frequently site specific and therefore is of little value to individual farmers. Compounding this problem is a lack of synthesis of the research completed in the 1960's and before, and of the data available from other nations.

The need for such information is growing. There are indications that the drainage systems constructed in the early 1900's, particularly in the Midwest, are now out of date and in need of repair. Drainage systems can often repay the farmer's investment within 2 to 4 years (Ochs, 1981), so farmers with adequate information and capital would probably not allow subsurface drainage systems to decay seriously. The outlets, however, are frequently municipal waterways or other such systems demanding collective management. These canals and ditches require occasional clearing of weeds and accumulated sediments, as well as other

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maintenance. Nondestructive and efficient techniques and machinery recently have been developed in Germany, but costs are high. Such operations must be done locally. Cost-sharing programs with local municipalities, revolving loan funds, and greater development of farmers' cooperatives could aid in rejuvenating the outlet system. Federally guaranteed loans could speed the repair of both the drainage and outlet systems to the benefit of farmers, consumers and society.

SOIL COMPACTION

Routine operation of farm machinery ("traffic") and trampling by livestock can harm land productivity by compacting the soil. In croplands, compaction can damage the structure of the soil near the surface and can create a "traffic pan," which is a persistent layer of densely compacted soil just below the depth to which the soil is tilled. On rangelands, which are not normally tilled, compaction compresses surface soil causing an effect called "shingling" where wide areas have a surface so dense that water cannot infiltrate and plants cannot reproduce. Animal traffic and off-road vehicle traffic can form compacted pathways on rangelands where plants cannot grow and gully erosion may begin. The severity of both cropland and rangeland compaction varies with the nature of the site's soil.

Concern over compaction has increased in recent years, partly because the large, heavy machinery characteristic of modern farming is thought to cause more compaction than lighter machines. In general, the role of technology in causing and treating cropland compaction is relatively well known; however, the extent to which compaction is a constraint on U.S. cropland productivity is not so well known. On rangelands, the problem is not well understood and practical technologies to correct it are not well developed.

Process and Effects

Because the potential for compaction varies greatly among different types and conditions of soils, and because compaction affects different plants in different ways, generalizations must be made with caution. The basic physical effect of soil compaction is collapse of the large pores between soil particles. In most agricultural soils, it is desirable to maintain the larger pores because they allow ready movement of air and water. One of the chief functions of tillage is to increase or restore these large pores in the soil.

Thus, water infiltration and percolation are impeded by surface and subsurface compaction. The consequences include poor drainage or standing water in a field, increased water runoff and soil erosion, and slower rates of crop residue decomposition. A compacted wet soil may remain colder for a longer time during the spring, delaying planting or slowing seed germination. Compaction-caused drainage problems also encourage higher rates of soil nitrogen loss through anaerobic microbial denitrification. The presence of a traffic pan can impede root penetration and the proper development of root crops such as potatoes and sugar beets. Surface compaction reduces the nitrogen-fixing nodule mass on soybean roots (Voorhees, 1977b) and alters the geometry of root growth, keeping roots out of the uppermost part of the soil profile where applied fertilizers are most available (Trouse, 1981). Traffic pans may keep roots from growing below the upper tilled layer and so deny access to moisture during drought or to nutrients available below the tilled layer.

Under certain conditions, a moderate amount of cropland compaction has been shown to be beneficial. Soybean yields on moderately compacted Minnesota soils have been 25 percent greater than on noncompacted soil in dry years. In some soils, the wicking effect of smaller, compacted capillary pores has

the advantage of bringing water and dissolved nutrients to germinating seeds, and it may also explain the higher toxicity of herbicides on compacted soils. Compacted soils, if dry, can warm more rapidly in the spring, and the presence of a subsurface pan can help to retain water that might otherwise percolate away from roots. Corn grown on compacted soil has been shown to mature earlier and to have a lower ear moisture content. Traction is sometimes better on a compacted soil, but the greater energy required to till such soil probably outweighs the traction benefits (Voorhees, 1977a, 1977c).

More typically, compaction reduces crop yields.* Yields of corn grown on clay soil are decreased with increased machine contact pressure and number of field passes, sometimes by as much as 50 percent (Raghaven, et al., 1978). Deeper than normal tillage, called subsoiling, is sometimes used to reduce compaction in dry years and can increase corn yields by as much as 100 bushels per acre in the Southeastern Coastal Plain (Cassel, 1979). In one study, yields for corn and cotton in Alabama rose 83 percent with subsoiling under crop rows and controlled traffic (Trouse, 1981). The effects of compaction on overall productivity sometimes may not be evident because they can be masked by use of other inputs such as irrigation and fertilization. In crop rotations that do not foster significant buildup of organic carbon, wheel-traffic-induced soil compaction may increase soil aggregate size and stability slightly, resulting in improved production even though organic matter content is decreasing. Thus, by substituting for the aggregating effects of organic matter, compaction may mask soil deterioration (Voorhees, 1979).

Technological Causes and Remedies

Factors that determine the degree of compaction occurring on a cropland site include: the pressure (pounds per square inch) exerted by machinery tires; the proportion of the field that gets pressed by the tires; the number of times per year the area is pressed; the type and frequency of tillage that loosens the compacted soil; various features of the soil type (including texture and percent organic matter); and especially the moisture content at the time it is pressed by machinery tires. The interaction of these factors is site specific and usually difficult to determine.

Certain soil types are more susceptible to compaction than others. The sandy loam of California, the Mississippi Delta, and the Southeastern Coastal Plain are especially susceptible to formation of traffic pans. Moisture is the most critical variable for any specific site, as compaction effects increase sharply when moisture content is above an optimal level. In certain soils, compaction can also increase because of too little moisture

Average tractor weight has more than doubled in the past three decades as a cause and a consequence of the increasing size and efficiency of U.S. farms. Modern four-wheel-drive tractors now weigh as much as 33,000 lb (Voorhees, 1978). The pressure exerted by the tires, however, has not doubled because the tires are now wider and better designed. However, the pressure per square inch is generally less important than the proportion of the field that is compacted. The wider tires press more soil on each pass, but make fewer passes to do the same job, and the larger machinery can allow field operations to be timed to drier conditions when compaction potential is relatively low. Yet there is little evidence to indicate whether farmers consider compaction prevention in their use of machinery. More farmers may be using larger equipment—four-wheel-drive, dual-wheel tractors* in particular—to get into fields under wet conditions (Robertson, 1981).

A trend that more surely indicates increased compaction is the increasing proportion of cropland used for row crops that require more tillage than close-grown crops such as hay or oats. Fortunately, the compaction associated

*During 1981, OTA conducted extensive research on the CAP and Agricola searches of 1980.

*Voorhees (1977c) states that "dual wheels do not prevent compaction, they just change its distribution. Compaction from duals may not be quite as deep, but it can be more than twice as wide."

Photo credit: OTA staff

Modern farm equipment has grown larger and heavier, raising concern that compaction may harm productivity on susceptible soils

with this trend may be offset to some extent by increased use of conservation tillage and the no-till method. However, reduced tillage will generally not counteract subsurface compaction that already exists and even no-till does not completely eliminate traffic and consequent compaction effects.

Some compaction is unavoidable in most cropping systems, but farmers can modify their operations to limit compaction. The least costly adjustments include timing operations to drier soil conditions, limiting the number of field trips (the first pass over any spot accounts for 80 percent of total compaction), and confining wheel traffic to the same paths each pass. However, sometimes it is not economically feasible to rotate crops with meadow or to delay planting or harvest until soil moisture is suitable because of the income and yield reductions associated with these practices.

The practice of subsoiling—plowing deeper than the conventional 7 to 8 inches to break up compacted soil layers—is becoming more widespread in the Midwest as it has shown its effectiveness in counteracting compaction in the Coastal Plains States, California, and elsewhere. Subsoiling reduces soil density and hardness and increases the volume of macropores to promote aeration, internal drainage, and more rapid infiltration of water (Cassel, 1979). The practice takes significantly more tractor power, however, so the value of yield gains must be compared to the increased fuel cost. These tradeoffs change as compaction effects accumulate and as relative prices change.

The most radical technological proposal for dealing with cropland compaction is development of "wide span" equipment that would confine wheel traffic to a small part of a field by spanning many rows with an arching,

bridge-like tractor. Prototypes of the machine are being developed (Trouse, 1981).

Research Needs

Compaction on Croplands

While considerable research has been conducted in several regions of the United States concerning the causes, effects, and cures of traffic pans (and, to a lesser extent, of the more subtle soil structure changes in the plow layer), no nationwide research effort has been mounted. Compaction is generally seen as a regional problem. Thus, there is no data base to determine the extent to which compaction is limiting U.S. soil productivity. Experts disagree: Voorhees (1979) reports that: "except for root crops, crop yields probably are not being suppressed yet as a result of normal soil compaction in the northern Corn Belt . . . . Regardless, the relatively good soil tilth enjoyed by farmers in the region should not be taken for granted. Once soil is compacted, it may be more difficult to restore than previously." In contrast, Trouse (1981) states that: "every acre that is plowed suffers some compaction," and "we have compaction even in our best fields, and it is hurting us."

More information is needed before these questions can be answered with any certainty. Data on compaction could be collected by NRI, for example, although each item added to the inventory.

Little is known about how farmers perceive the effects of compaction. In areas where traffic pans are important constraints on crop yields, some information is generally available to help farmers decide whether the yield increases from subsoiling will pay for the extra fuel used. More complex decisions regarding timing of operations, for example, are less well supported by hard data. How well farmers diagnose and monitor cropland compaction problems is another unknown.

Compaction on Rangelands

Even less is known about rangeland compaction. Overgrazing has led to dense soil surfaces over much of the Western rangelands, and this "shingling" is a severe constraint on productivity. It prohibits water infiltration, resulting in more arid conditions for the plants; it accelerates erosion; it severely constrains seed germination and the survival of seedlings when seeds do germinate. Shingling is generally believed to be caused by the trampling of animal (mainly livestock) hooves. Another phenomenon that also contributes to the shingling effect is soil capping. This is a thin crust caused by the force of raindrops striking unprotected (lacking plant cover) soil surfaces. The direct impacts of livestock trampling are most harmful in the spring when soil is moist, after the sporadic heavy rains characteristic of much of the semiarid range, and on the moist soils along streams (Gifford, et al., 1977; Cope, 1980).

The scientific literature on rangeland soil compaction and capping is scanty. Soil scientists historically have concentrated their attention on croplands where the returns on research investments are more obvious.

The usual way to improve compacted, overgrazed rangeland is to alter grazing pressure to be consistent with carrying capacity and, in cases of severe land deterioration, to reintroduce desirable plants through reseeding. One method to deal with capping or compacted crusts is to concentrate a herd of cattle on the affected area for a very short time (2 to 3 days) to churn up the soil surface. Another method is to roll a "soil imprinter," a heavy, usually water-filled drum with a textured surface, over the ground to break up the shingled surface (Dixon, 1977). However, fuel costs may make this impractical. Where compaction is deep, there may be no technological solutions except tillage, which is likely to be expensive, and excluding livestock.

Conclusions

Cropland compaction is probably a constraint on productivity in many regions, but technologies to deal with it do exist. No major

Federal policy decision to increase the effort to educate farmers about compaction, or to support their use of practices that would prevent or cure the problem, is likely as long as little is known about its significance in relation to other problems.

On rangelands, the compaction and capping of soils is a constraint on productivity. Generally, overgrazed rangeland has good regenerative capacity once proper grazing management is instituted. In some instances, however, particularly in the arid Southwest, reseeding o desirable species must precede improved grazing management in range rehabilitation. The problem of shingling and the processes of compaction and capping have not been high-priority research topics for range science. The consequences of compaction are well understood but too little is know about its causes, prevention, or economic reparation.

SALINIZATION

Salinization is primarily a drainage problem aggravated by the misapplication of irrigation water. Where water is applied to fields, the Sun and crops extract almost pure water, leaving salts behind. If that salt is not flushed deeper into the ground by rainfall or additional irrigation, it can gradually concentrate in and on the surface soil, first damaging and ultimately destroying the land's productivity.

But flushing salt into the ground does not necessarily solve salinization problems. If subsurface conditions are relatively porous, the saltwater may contaminate the ground water supply from which the irrigating water is drawn. If subsurface conditions are relatively impermeable, the salty water may drain into nearby rivers. Irrigators downstream will ultimately reuse it. The saltwater may also accumulate beneath the surface so that a salty, "perched" water table builds up. This may eventually rise near enough to the surface to contaminate the root zone.

Most crops cannot survive in saline environments. The effect of salinity is to increase the osmotic pressure in the soil water, which works against the water extraction mechanism of the plant roots.

There are no data on the overall amount of cropland in the United States that has been salinized or is undergoing salinization. An informed guess is that 25 to 35 percent of the irrigated croplands in the West have salinity constraints on productivity (van Schilifgaarde, 1981).

Some data are available on specific areas where salinization is a recognized problem. At present, it is severe on the western side of the San Joaquin Valley of California, one of the country's most fertile regions. Here, excess saline irrigation water accumulating beneath the surface is invading the root zone and is reducing crop yields on some 400,000 acres of land. The cost of the resulting crop loss is estimated at $31.2 million per year (Sheridan, 1981). If the saline subsurface water is not drained from the cropland, it is projected that 700,000 acres will have reduced output by 2000, for an annual loss of $321 million. If unresolved by 2080, an estimated 1 million to 2 million acres of cropland in the San Joaquin Valley will be salinized out of production.

Three alternative sinks for the valley's salt are the Sacramento-San Joaquin Delta, the Pacific Ocean, and local evaporation ponds. A drainage system to carry the irrigation runoff to the Delta, an estuary of the San Francisco Bay, would cost $1.26 billion for the central drains, plus the costs of underground drains to carry the water from the farmers' fields (USDA—RCA, 1980). Further, the saline water could cause serious environmental damage to the estuary itself, which is the largest wetlands area on the west coast. In addition to its importance as a wildlife and fisheries habitat, the estuary is the major source of water for municipalities, industries, and agricultural operations located nearby.

Piping the drainage water to the Pacific could cost even more because of the high ener-

gy required to pump the irrigation runoff over the intervening mountains. If farmers were required to pay the entire price of these engineering solutions to the drainage problem, the costs would be on the order of $75 per acre per year (Sheridan, 1981).

The third solution makes use of as much of the drainage water as is possible in irrigation of salt-tolerant crops. The best irrigation water would be used first on salt-sensitive crops, and the increasingly salty runoff would then be used to irrigate more salt-tolerant crops. Finally, the highly saline water would be drained into evaporation ponds, providing some wildlife habitat, or be disposed of in other ways (van Schilifgaarde, 1981). The costs of establishing this integrated irrigation system have not been estimated, but would depend partly on the profitability of farming the salt-tolerant crops (see discussion in ch. IV). This use would reduce the volume of drain water requiring disposal. Although the drainage problem is not eliminated, the reduced volume makes the options for disposal more viable. This scheme would require substantial changes in farming practices, and getting farmers to participate may be as formidable a difficulty as paying the costs of more conventional engineering solutions.

A key issue in these schemes is who pays. Costs of a drainage system would presumably be shared among the Federal Government, the State of California, and the San Joaquin farmers. If the capital cannot be raised, there is another solution to the drainage problem—to continue the present system until the soil becomes too salty, then to switch to more salt-tolerant crops, and eventually abandon 20 percent or more of this highly productive San Joaquin cropland.

Another type of salinity problem has developed in the Colorado River Basin. Here, too, the water is becoming more saline, and thus less useful for irrigation and other purposes. The source of about two-thirds of the salt in the river is natural drainage of salt-laden geological formations; the remaining third is saline runoff from irrigation (Frederick, 1980). Salt concentration is increasing because most of the water diverted from the river for use is consumed, ultimately evaporating, while that which is returned by irrigation drainage systems is highly saline.

The problem is the disposal of the salt. Potential solutions include expensive engineering approaches and less expensive but more difficult system management changes. Eventually, as Colorado River water use and reuse becomes more expensive, a combination of structural and management approaches will probably be adopted. One possible engineering approach is to build a desalinization plant near Yuma, Ariz., to remove salt from the drainage water. The river management approach, already being implemented by some farmers receiving Federal technical assistance and cost sharing from USDA programs, begins with increasing irrigation efficiency. Crop yields are maintained with less water use by improving on-farm systems with such techniques as land leveling, ditch lining, and alternative irrigation systems. If enough farmers improve irrigation efficiency, a significant improvement could be achieved. However, as nonagricultural use of the Colorado River increases, farmers may still need to shift toward more salt-tolerant crops and to the use of drain sinks other than the river, such as local evaporation ponds.

Saline seeps are a soil-and-water problem occurring in Montana, North and South Dakota, Wyoming, and Canada's prairie provinces. This problem is the combined result of regional geology and farming practices. Farmers traditionally alternate strips of wheat with strips of fallow to conserve moisture. This summer-fallow system can actually conserve too much water—in some places, the water thus saved has infiltrated through the upper layers of soil, picking up salts, and has formed a perched water table above an impermeable layer of shale. In downslope areas, the salt-laden water seeps out, creating saline seeps—unproductive swampy areas. Some saline seeps are as large as 200 acres. They affect about 400,000 acres in the Northern Plains of the United States; the total including Canada and parts of Texas and Oklahoma may reach 2 million acres.

Saline seeps may be battled by using a creative management technology called "flexible cropping" developed by USDA scientists and cooperating farmers. Under flexible cropping, water conditions are monitored carefully. Alternative crops are planted, including alfalfa, safflower, and sunflower, each of which uses more water and draws it from deeper in the soil. Continuous cropping is practiced whenever possible to avoid water accumulation in the perched water table, but the option to fallow land remains if water is limited. This approach demands more complex management than summer fallow, but participating farmers have demonstrated that it can keep significant areas in production that might otherwise be lost. (This technology is discussed in detail in app. A, "The Innovators.")

Conclusions

The U.S. agricultural sector must continue to develop innovative systems to conserve productivity on land that is threatened by salinization. The proportion of cropland involved is relatively small—30 percent of the irrigated land in the West amounts to only 5 percent of all the Nation's cropland—but the land is disproportionately productive because of long growing seasons and the high economic value of irrigated crops. (An assessment of water-related technologies to maintain agricultural production in the arid and semiarid regions of the United States was begun by OTA in July 1981.)

GROUND WATER DEPLETION

Introduction

The next several decades will bring a marked decrease in the availability and quality of the Nation's ground water. This could significantly reduce the productivity of much irrigated agricultural land, especially in the Southwestern United States. The most severe problems will probably be confined to the West, but some Eastern States will suffer local water shortages and water quality problems that will affect agricultural productivity.

Technologies that alter irrigation and farming systems to conserve water while continuing to produce crops profitably can prolong the productivity of ground water resources. These technologies vary from modest but effective changes in the way water is applied to major changes in farm management such as converting to perennial crops or drip irrigation. Although changing the technologies used may reduce ground water demands in some areas, the actual reduction in ground water withdrawals that will result from new agricultural technologies probably will be modest and will only postpone the exhaustion of some major U.S. ground water reservoirs.

The technological change most likely to occur in Western regions during the coming decades will be the return of some irrigated lands to dryland farming or grazing. This conversion will cause sharp decreases in production. Also, as wind erosion and other problems associated with dryland farming develop, a continuing, gradual decrease in land productivity can occur.

Although some schemes for recharging overdrawn aquifers* have been proposed, the lack of local water to replenish depleted supplies and the high energy costs involved in transporting water from distant sources may preclude such remedies. Schemes for long-distance water transport will have to be compared to the alternatives of farming additional, potentially erosive, croplands in the more water-abundant East or intensifying production on existing agricultural lands (Vanlier, 1980).

The data and information bases relating water and agricultural productivity are obtained largely by Federal and State agencies. At the

*An aquifer is a water-bearing underground layer of permeable rock, sand, or gravel.

local level, county agencies and quasi-governmental units collect a variety of water data specific to their management needs. The information is dispersed among a number of sources including large Federal water data banks. The data available are adequate for general planning, but considerable effort will be required to aggregate them into a format clearly adapted to policymakers' and planners' broader needs.

The Nation's ground water resources could be affected adversely by a number of changing agricultural technologies and by future land and water use policies as well as by the growing needs of water for energy development. The principal factors that will affect the availability and suitability of ground water for agricultural use are:

- ground water overdraft (mining),
- water-quality degradation,
- reduction in streamflow and discharge of springs, and
- subsidence and collapse of the land surface.

Ground Water Overdraft

Hidden beneath the land surface in almost every part of the United States is water that fills the openings in beds of rock, sand, and gravel —called ground water. Studies of the U.S. Geological Survey (USGS) indicate that more than 97 percent of U.S. freshwater resources are located underground. The Nation's ground water resource supplies about 70 percent of the irrigation water for the 17 Western States (Lehr, 1980).

In many areas, ground water is a readily available source of potable water. Half the population in this country gets its drinking water—either partly or completely—from ground water supplies (Costle, 1979). Because ground water is a high-quality, low-cost water source, its use grows at the rate of several percent each year. Ground water use has grown from 35 billion gallons a day in 1950 (Murray, 1970) to an estimated 82 billion gallons a day in 1975 (CEQ, 1980).

Withdrawing ground water from an aquifer in excess of the long-term rate of recharge is called ground water overdraft, mining, or depletion. Ground water mining is common in arid or semiarid areas of the United States where precipitation is low and recharge rates are slow (fig. 6). Water is available from these aquifers only because it has accumulated in the ground over many thousands of years.

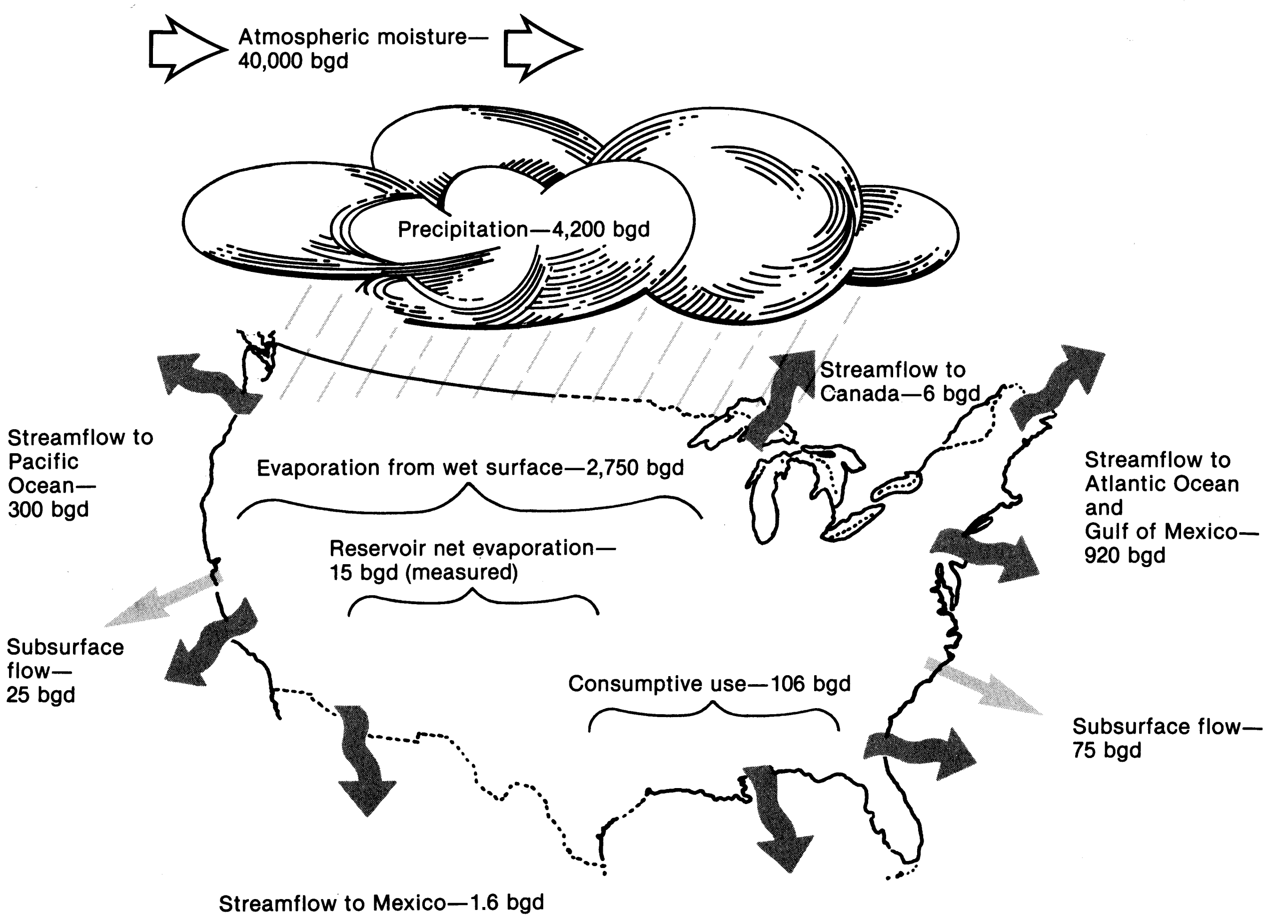
Ground water overdraft lowers ground water levels, subsequently reduces the thickness of water-saturated sediments, and in some places degrades water quality. Declining water levels reduce the total amount of water available. In order to meet demands, pumps must be set deeper and larger motors installed. In some cases, new wells are needed. These investments increase operating costs.

Over the past several decades, ground water overdrafts have reduced agricultural productivity. The greatest reductions, however, are expected to occur in the next three or four decades. Most such losses in agricultural productivity will be permanent because alternative water sources already are fully committed to other uses.

The major areas of ground water overdraft are in Texas, Nebraska, Colorado, Kansas, Oklahoma, New Mexico, Nevada, Arizona, and California. Major ground water overdraft problems also are reported in the lower White River area of Arkansas and the Souris and Red River basins in North Dakota and Minnesota (Vanlier, 1980). Shortages have raised conflicts in other regions as well.

In Iowa, proposals have been considered to prohibit ground water use for irrigation because of acute shortages. In Nebraska, the ground water situation is prompting officials to consider allocating available ground water. In the first court conflict between ground water users, the Nebraska Supreme Court held that an irrigator can be held liable for costs incurred as a result of disturbing a neighboring ground water supply (Lehr, 1980).

Figure 6.—Water Budget for the Conterminous United States



NOTE: bgd = billion gallons per day.
SOURCE: Water Resources Council, 1978.

One of the most dramatic instances of ground water depletion occurs in the Ogallala Formation, an aquifer stretching approximately 1,000 miles from Nebraska to Texas. It underlies roughly 150,000 square miles (mi^2) and varies in thickness from 1 to 1,200 ft. USGS, in an ongoing study of the Ogallala and certain associated aquifers, reports that 46 percent of the 177,000-mi^2 study area now has less than 100 ft of water-saturated sediment. Ground water pumping, which began in Texas in the 1930's, has caused the following declines in the region's watertable:

Percent of 177,000 mi^2	*Watertable drop in feet*
14	10 to 25
5	25 to 50
5	50 to 100
2	100 to 150

(Weeks, USGS, 1981.)

The USGS reports that water levels in the Ogallala Formation consistently have been declining in regions where water is pumped for irrigation (Borman, et al., 1977). Declines of 32 to 40 ft were monitored in Kit Carson County from 1964 to 1972. In other areas influenced by irrigation, declines of as much as

16 ft were noted. The USGS findings confirm an increasingly rapid water-level decline in parts of the Ogallala Formation since 1974. More than 98 percent of the pumping from the Ogallala is for irrigation agriculture.

The Ogallala aquifer is recharged by direct precipitation at a rate of only 50,000 acre-ft per year, while 7 million to 8 million acre-ft a year of ground water are withdrawn. Thus, the 93,000 wells pumping to irrigate as much as 65 percent of Texas croplands could exhaust the aquifer. Some additional recharge is supplied from the eastern slopes of the Rocky Mountains. (Details of the Ogallala water budget will be included in the OTA water assessment.)

In fact, ground water depletion in the High Plains section of west and north Texas has been so extensive and expensive that it has compelled abandonment of some once-productive farmland or the return to dryland farming (Hauschen, 1980).

Similar abandonments are occurring in other areas. In the Roswell Artesian Basin of New Mexico, where ground water withdrawal has exceeded recharge for many years, the Pecos Valley Artesian Conservancy District has been purchasing and retiring irrigated acreage. About 3,000 acres have been retired under this program. In the Estancia Basin of Santa Fe County, an estimated 5,900 acres will go out of production by 2000 (Vanlier, 1980).

Nearly all major aquifers experiencing overdraft in the arid or semiarid areas of the country ultimately will be exhausted. This does not mean there will be no more underground water in those places, but that it will be so reduced that it cannot be profitably extracted. Lower agricultural productivity and reduced economic activity can be expected in these areas.

Degradation of Ground Water Quality

In addition to declining ground water availability in many aquifers, degradation of ground water quality from increasing salinity and contamination by pesticides, herbicides, fertilizers, animal wastes, and nonagricultural sources of chemicals is on the rise. Heavy pumping of ground water can result in seawater intrusion into freshwater aquifers, and recycling irrigation water to recharge aquifers may make water substantially less suitable for irrigation or other purposes than the aquifer's original water. Because organic chemicals do not degrade efficiently in the slow-moving waters of underground aquifers, recharge water may disperse agricultural contaminants over broad areas where they may remain indefinitely.

Saltwater Contamination

Many aquifers contain both fresh and mineralized (saline) ground water. The lighter freshwater in such aquifers "floats" on the denser saline water. Saltwater/freshwater aquifer systems are best known in coastal areas where freshwater in the landward part of the aquifer is in contact with saltwater in the seaward part, but some also are present in inland areas. When freshwater is pumped from such aquifers, the saline water migrates toward the wells and eventually replaces part or all of the aquifer's freshwater. This exacerbates problems of soil salinity that plague many irrigation projects.

Saltwater intrusion into freshwater aquifers has occurred in many areas undergoing ground water irrigation. In the Roswell Artesian Basin of New Mexico, the artesian head has been declining for many years and now saline waters are encroaching in the aquifer north and east of Roswell. Extensive ground water declines in the Carrizo aquifer in Dimmit and Zwala Counties, Tex., caused reversals in the aquifer's hydraulic gradient, thus allowing poorer quality water to enter areas that previously had good quality water (U.S. Water Resources Council, 1978).

In some places, aquifers are degraded by water leakage from a saline aquifer into overlying or underlying freshwater aquifers via improperly constructed and maintained wells or abandoned wells that have been improperly plugged and sealed. For example, in Dimmit County and adjacent areas of Texas, saline water from the Bigford Formation is leaking through old well bores into the underlying Carrizo aquifer.

Aquifer water-quality degradation has a negative impact on nonirrigation water uses, too. In the High Plains region, ground water quality is declining as the Ogallala aquifer drops, and in some parts of the region the water has become unsuitable for domestic use. This may have a serious adverse impact on the economy of the area (Vanlier, 1980).

When withdrawals lower aquifer water levels, poor-quality surface waters can infiltrate. The problem of saline recharge to aquifers used for irrigation water is exacerbated locally by degradation of surface water quality. For example, in the Trans-Pecos region of Texas the ground water is becoming saline, in part from recycling irrigation waters. The U.S. Water Resources Council noted that in the San Joaquin Valley in California there is a need for a valley-wide management system that would dispose of or reclaim saline water to help prevent degradation of the San Joaquin River and ground water supplies.

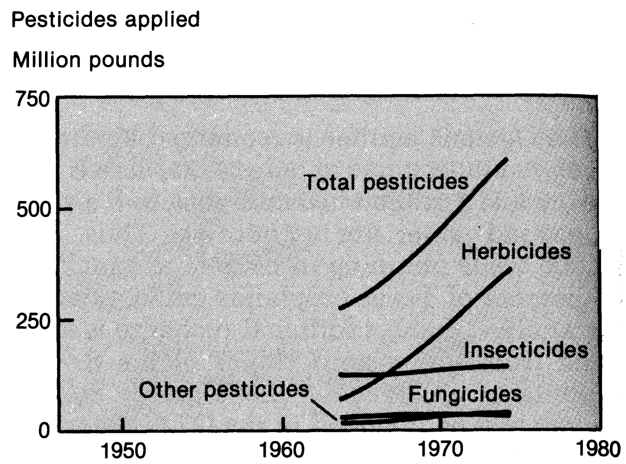
The contamination of freshwater aquifers by infiltration of saline surface waters and agricultural drainage has not received the attention given to other sources of ground water contamination, but it is a factor that must be considered in long-term planning for agricultural productivity.

Pesticide Contamination

USDA reports that more than 1,800 pesticide compounds are marketed and that an estimated 1.25 million tons will be applied on American soils by 1985 (see fig. 7). Approximately 5 percent of the pesticides will reach the Nation's waters. A 1970 report of the Working Group on Pesticides cautioned that the potential for ground water contamination must be analyzed from the perspective of the properties of the pesticide, hydrological traits of the disposal area, and the volume, state, and persistence of the pesticide. For example, greater hazard occurs when high concentrations of pesticides are deposited near shallow wells or in regions of thin and highly permeable soil.

Residues of DDT; 2,4-D; lindane; and herbicides are the focal point of ground water contamination discussion and research. Arsenate compounds used in insect control in Maine's blueberry fields have been detected in shallow ground water, and chlorinated hydrocarbons used on Massachusetts cranberry bogs were reported in a sand and gravel well. Soil samplings in the Houston black clay of three watersheds in Waco, Tex., demonstrated that DDT had penetrated the soil and percolated down into the ground water (Lehr, 1980).

Figure 7.—Pesticides Applied



SOURCE: Pesticides applied, 1964: *Quantities of Pesticides Used by Farmers in 1964,* USDA Economics, Statistics, and Cooperatives Service (Washington: U.S. Government Printing Office, 1968), agr. econ. rep. 131, pp. 9, 13, 19, 26. 1966: *Farmers' Use of Pesticides in 1971—Quantities,* USDA Economics, Statistics, and Cooperatives Service (Washington: U.S. Government Printing Office, 1974), agr. econ. rep. 252, pp. 8, 11, 15, 18. 1971 and 1976: *Farmers' Use of Pesticides in 1976,* USDA Economics, Statistics, and Cooperatives Service (Washington: U.S. Government Printing Office 1978), agr. econ. rep. 418, pp. 6, 9, 15, and 20. Cited in CEQ, 1981 *Environ. Trends.*

A field study in which toxaphene (an insecticide) and fluometuron (a herbicide) were applied to the topsoil and observed for 1 year showed that both compounds were found in underlying ground water 2 months after application (LaFleur, et al., 1973). Residues persisted throughout the 1-year observation period.

Contamination by Organic Material and Pathogens

In general, ground water does not have the natural cleansing mechanisms of surface water. Although most removal of readily degradable organic compounds occurs very near the water's point of entrance into the aquifer, some

sorption (binding of organics to mineral substrates) and biodegradation do occur within the aquifer. Sorption affects the rate of travel of organic contaminants and allows the accumulation of organic materials in or on subsurface solids. Biodegradation depends on a number of variables including pH, temperature, and having a primary source of organic material on which the bacteria can subsist. Relatively little is known about how organic materials degrade in ground water; possible interactions between primary and secondary substrates and bacteria are not known, nor are the effects of sorption on the rate of transformation. The breadth of organic compounds that may be reduced by biological activity are unknown and methods for assessing the potential of a specific aquifer for microbial activity are also lacking (McCarty, 1981).

There are conflicting reports on the levels of fertilizer pollution in ground water. According to the General Accounting Office, heavy reliance on fertilizer contributes to an estimated 1 million metric tons of dissolved nitrogen in ground and surface waters. In the Seymour water-bearing formation in Texas, jumps in nitrate levels of from less than 50 to 165 ppm can be traced to fertilizer use (Lehr, 1980). Yet, nitrates from fertilizers and from natural reservoirs of nutrients in fertile soils are indistinguishable, and some experts have claimed that, apart from occasions when a spring application of fertilizer nitrogen may be followed by very heavy rain, the problem of high nitrate levels in drainage water (which can infiltrate aquifers) is not so much one of fertilizers as of soil fertility, especially after ploughing (Armitage, 1974). Because high nitrate levels in ground water used for drinking can present a health hazard for infants up to the age of 3 months, this nutrient contaminant needs careful monitoring.

Nearly half of all documented waterborne disease outbreaks in the United States result from contaminated ground water. Certain viruses, some of which may constitute a health hazard to humans or livestock, may be absorbed onto soil organic matter and clays and move downward slowly in the ground water (Gerba, 1981), while others may remain free in infiltrating water and enter the ground water more quickly. Fecal coliform bacteria counts are commonly used to monitor for contamination by animal wastes. As livestock management is intensified, and as onland waste disposal systems develop, consideration must be given to potential infiltration of pathogens into the ground water below.

Reduced Streamflow and Spring Discharge Caused by Ground Water Pumping

Water-well pumping lowers ground water levels in the well vicinity. In part, this may reduce the natural discharge of water from the aquifer, much of which is through springs and seeps along and beneath streams. If ground water levels are lowered below the level of a stream, water can infiltrate from the stream to the aquifer, and areas along streams that under natural conditions received water from the ground now accept water from the stream. The resulting decline in the streamflow reduces the availability of surface water for other uses, including irrigation.

Sometimes the changes in the water regimen that can result from pumping ground water for irrigation can be beneficial in that some of the water tends to accumulate in the ground and can be pumped later during the irrigation season. Ground water irrigation, however, requires energy for pumping, whereas diversion of surface waters generally is accomplished through gravity flow. As energy costs increase in future decades, irrigation systems with lower energy requirements probably will take precedence.

Standardized data on ground water quality is needed for responsive policymaking. The USGS catalog of Information on Water Data might be useful as a prototype (Vanlier, 1980). In it, ground water quality is outlined in terms of four traditional categories: physical, chemical, biological, and sediment related. Identified

within each category are a number of factors (e.g., turbidity, pH, coliform bacteria content, sediment particle size) that should be measured at regular intervals. Frequent measurement of these indicators will promote the early detection of a contaminant by a monitoring system. Sufficient leadtime is important for corrective action.

Conclusions

The continuing decline of ground water quality and quantity apparently is not caused by lack of data or knowledge. The probability that agricultural productivity in the High Plains region would decline during the latter part of the 20th century, and that economic problems would consequently emerge, has been clearly recognized locally and nationally for the last several decades (Vanlier, 1980). Rather, the decline is caused by a lack of a coherent, national resource-use philosophy and water management policy. This has led to a separation of policies toward surface and ground water.

The separation of ground and surface water issues results in administrative mismanagement of both resources. These two elements are mistakenly not seen as part of the same hydrologic cycle. This insular treatment extends in many cases to the laws pertaining to their use, to the Federal agencies and institutions that regulate and control them, and to the research and development that guides their future uses.

To ignore a substantial hydrologic imbalance costs money—money in production costs, farm income, crop prices, food prices, etc. For cropland affected by ground water depletion, salinity, and subsidence problems, a total calculation of ground water-related damage has not been compiled.

Directly entwined with ground water economic impacts is the ripple effect felt by society. As ground water problems increase in severity, interactions between producers directly affected and those not affected can be expected to change land values. For example agricultural producers' net income along the Colorado River would drop because of crop yield reductions and increased production costs as salinity increases. On the other hand the lands of a producer of the same crop in an area without salinity problems would increase in relative agricultural value.

Eventually, this imbalance will spur production relocation and passing of increased costs on to consumers. The rural business community of banks and agricultural suppliers, too, is ultimately influenced through changes in service demands and the tax base. And if the irrigated dry Western States are compelled to revert to dryland farming, the ultimate effects on food prices and the entire economy would be substantial.

The national agricultural policies that have the greatest effect on ground water resources are economic. For example, the quantity of water used to irrigate rice in Arkansas doubled between 1970 and 1975 as a result of relaxation of acreage controls (Halberg, 1977). It is not known if Government acreage controls and crop price-support programs increase ground water pumping for irrigation where otherwise it would be unprofitable.

Most individual farmers understand the costs and risks of their decisions to continue to pump water from aquifers that are experiencing overdraft or declining water quality. The individual farmer, however, is left with little choice except to use the water under his own land to maximize his profits. If he does not pump the water, his neighbors will. Farmers cannot unite to save water for some future date when each has made substantial individual investments in land and equipment. The specter of low agricultural prices and high production costs in areas of major ground water overdraft undoubtedly inhibits the individual farmer's decision to invest in expensive technologies to save water.

SUBSIDENCE

Land subsidence could become more common in the United States as the use of ground water and subsurface mineral resources intensifies. Subsidence can occur in various circumstances: when cities, industries, and irrigation agriculture withdraw large amounts of ground water; when coal and other mineral resources are mined; when there is solution mining of subsurface mineral deposits, such as salt; or when large amounts of petroleum have been extracted. All of these activities can result in the slow subsidence or the unexpected collapse of the land surface. If agriculture overlies these areas, it can suffer slow or immediate consequences.

Land subsidence is often the result of the combined influence of human activities and the land's natural proclivity to such disturbances. Certain soils and terrains are much more likely to suffer subsidence than others. Clays, for example, generally compact and subside more than coarser sediments such as silts and sands. Thus, it is often difficult to isolate the specific cause or causes of land subsidence.

But how does ground water withdrawal, irrigation, or perhaps the draining and farming of organic-rich soils cause subsidence? Because water commonly fills the spaces between the rocks and particles that make up underground sediments or sedimentary rock, it contributes to the volume of land. When wells are drilled and ground water is removed faster than it is replaced naturally, the ground water level drops. The loss of the water's buoyant support of the rock and mineral grains leads to increased grain-to-grain stress in the aquifer below. If the stress is great enough to cause the individual grains to shift and move close together, land subsidence results. Subsidence can take place in small increments over decades and, therefore, may go unrecognized in its early stages.

The effects of subsidence on agriculture have been most extensive in areas where ground water withdrawal for irrigation is common. For example, water withdrawal has greatly affected agriculture in the San Joaquin Valley of California. During 40 years of irrigation pumping, some 2,500 mi^2 in three main areas have suffered subsidence. Some areas sank as much as 20 ft; in 1967, some land was sinking at rates up to 1 ft a year (Marsden and Davis, 1967). The gradual lowering of the land surface damaged expensive water-well casings, irrigation systems, buildings, drainage and flood-control structures, and other manmade structures. As the land subsided, flow directions were reversed in irrigation canals that normally had slopes of 0.3 ft per mile and major structural changes were required to maintain irrigated crop production. Such changes included raising or rebuilding bridges, pipelines, and other associated structures. Costs are high for repairing such damage. In California's Santa Clara Valley, subsidence costs are estimated at $15 million to $20 million (Lehr, 1980).

Similarly, in California's San Jacinta Valley approximately 5,400 mi^2 of cropland have subsided at the rate of 1.2 ft a year since measurements began in 1935. Subsidence has reached nearly 28 ft in areas where irrigation wells pump as much as 1,500 acre-ft of water per year (Lehr, 1980).

Withdrawal of large amounts of ground water from the gulf coast aquifer underlying the Houston-Galveston, Tex., area parallels the California experience. In this case, most ground water withdrawals have been for industrial and urban uses. Nevertheless, agricultural lands are affected adversely. Land subsidence there began as a result of ground water withdrawal starting as early as 1906. During a 26-year period, 1943-69, in the Houston area, a region some 15 miles in diameter suffered 2 ft of sub-

sidence. An area with a diameter of about 60 miles, much of it rural land, suffered at least 6 inches of subsidence during the same period. These depressed land surfaces act as catchments during heavy hurricane-associated rainfall and, thus, periodically limit the land's usefulness for crop production (Flawn, 1970).

Land subsidence can be halted, but not easily. Water can be pumped back into the aquifers to end subsidence, and a slight rebound of the land surface may occur. But in areas where water is scarce, what would be the recharge water source? Subsidence can be slowed by reducing ground water withdrawals or by pumping only from widely dispersed wells. These approaches have promise only where alternative sources of freshwater are available for irrigation agriculture. Finding alternative water sources is becoming increasingly difficult.

Introducing irrigation water into very dry areas that are covered by alluvial or mud-flow sediments with large pore spaces can cause reorientation of the sediment particles and thus cause subsidence. A 27-month irrigation test on such sediments along the western side of the San Joaquin Valley in central California caused a 10.5-ft drop in the land surface, resulting in damage to roads, pipelines, and transmission lines (Flawn, 1970).

When drained, peat and other organic-rich soils are subject to oxidation and decomposition of the exposed organic matter, thereby causing shrinkage and subsidence. Drained organic soils in the Sacramento-San Joaquin delta area of northern California subsided to 14 ft between 1850 and 1950 (Flawn, 197(A similar situation exists in the Belle Gla(area of Florida where half of a 10-ft peat dep(it has disappeared from agricultural fiel(through oxidation over a 50-year period. Und original conditions, the peat accumulated about 1 ft per 400 years (Shrader, 1980). Su sidence on organic soils in Florida's Everglad agricultural area varies from 1.5 to 3.1 cm/ye(depending on the land use (Lehr, 1980).

Conclusions

Land subsidence can affect agriculture adversely. These changes are typically permanent, and subsided land cannot be restored to its original state. In most areas of land subsidence, relevant data are collected largely by State and local agencies. In California, for example, USGS, in cooperation with the State, maintains a network of land subsidence stations and wells. The data on subsidence seem to be sufficiently accurate and adequate for most agricultural planning purposes.

Agriculture's investments in irrigation systems are expensive and normally are designed for a long useful life. But where ground water withdrawals for irrigation cause subsidence, sustainability of the agriculture system is jeopardized. Subsidence related to changes in organic soils affects land productivity, as well, because continual changes in the topography of the land may interfere with irrigation systems and other infrastructure.

UTILITIES OTHER THAN CROPS AND FORAGE

Agricultural lands are managed to produce crops and forage, but other, less quantifiable services from the land are also vitally important to the Nation's well-being. These benefits are often taken for granted or assumed to come solely from nonagricultural land. The quality of air, water, ground water, fish and wildlife habitats, and esthetic and recreational areas are all directly related to croplands, pasturelands, and rangelands.

An agroecosystem does not end at the edge of a field or pasture, but includes the boundaries—fences, hedgerows, windbreaks, nearby fallow fields, riparian habitats, and adjacent undeveloped areas. As the quality and quanti-

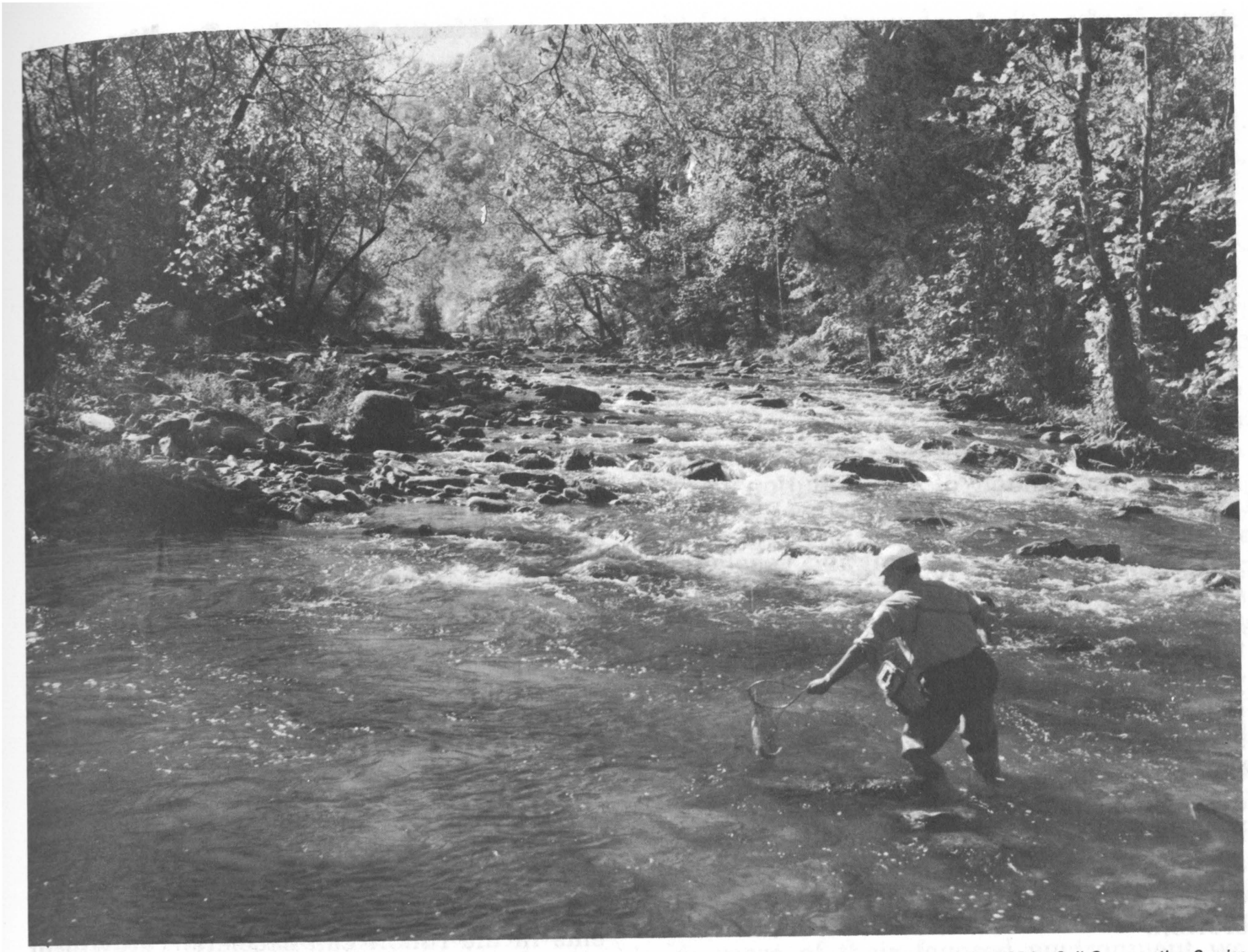


Photo credit: USDA—Soil Conservation Service

A cool, clear unpolluted stream in the Monongahela National Forest

ty of these areas is changed by agricultural activities, the utilities obtained from the land also change.

Effects on Air Quality

Vegetation and soil are major factors in the balance of gas cycles. Plants, through photosynthesis, remove carbon dioxide and are the primary source of atmospheric oxygen. Soil plays a less well-known role in the nitrogen cycle. Nitrogen oxides are an important factor in the destruction of stratospheric ozone, and agricultural activities affecting nitrous oxide (N_2O) are coming under increasing scrutiny. Soil can act both as a source and as a sink for atmospheric N_2O during periods of moderate soil-water content.

N_2O is produced during denitrification in soils when the soil nitrate content is high, the temperature is conducive to high respiratory oxygen demand by soil biota, and the water content causes restricted soil aeration. Any agricultural activities affecting nitrate content, water content, or soil temperature will affect the yearly flux of nitrogen oxides. For example, converting grassland to annual crops is likely to release N_2O to the atmosphere.

Soil micro-organisms can eliminate air pollutants, such as carbon monoxide and various gaseous hydrocarbons, in the lower portion of

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the atmosphere that comes into contact with the ground (Alexander, 1980). In addition, plants are effective in removing pollutants such as sulfur dioxides (SO_2), from air and converting them to less toxic or harmless substances. Plants absorb SO_2, which then reacts with water to form phytotoxic sulfite. This is slowly oxidized within the plant cells to relatively harmless sulfates. If too much gas is absorbed too rapidly, however, the plant suffers the consequences of retaining a dangerous level of the toxic sulfite within its cells (Daines, et al., 1966). It is difficult to measure the amount of pollution with which an ecosystem comes into contact, and more difficult still to measure how much of the pollution is removed.

Another way in which soil and vegetation help maintain air quality is by controlling wind erosion. Wind erosion introduces 30 million tons of particulates to the U.S. atmosphere each year. Soil organic matter and vegetation anchor the soil and keep it in place. Conventional tillage removes plant cover and pulverizes soil, thus impairing its binding functions. Crop residue management, stubble mulching, no-till farming technologies, irrigation, and appropriate grazing management—technologies discussed later in this report—can decrease wind erosion.

Forests, woodlands, shrubs, and the taller farm crops also filter the suspended particulate matter from moving air masses and return it to the soil, improving the layers of air immediately above the ground. When vegetation is removed, as it was for the expansion of agriculture in the 1930's, the effect on quality of air and life is dramatic:

> More than 6 million acres were put out of production by dust storms; farmsteads were partially buried and damaged or totally destroyed and abandoned; the health of people and livestock suffered; many animals died of dust suffocation; machinery was damaged or destroyed; ditches and waterways were filled; valuable topsoil was lost; and soil fertility was seriously impaired for years to come (Walker, 1967).

Effects on Water Quality

When properly managed, land acts as an e cient "living filter" in the water cycle. Pla roots absorb nutrients, microbes degrade co plex organic molecules, and the soil's organ and inorganic colloids have tremendous a sorptive capacity. Any agricultural activity th reduces any of these three mechanisms reduc the land's ability to provide clean water. Son of the major forms of water pollution asso ated with agriculture are silt from soil erosic nutrient runoff from large feedlots, and co centration of chemicals (including those fro pesticides and fertilizers) in return flows fro irrigation systems.

Increased sedimentation of streams an other bodies of water, primarily a result of ero sion, has many adverse effects. Fish feedin and breeding areas may be destroyed by sil Streams may become broader and shallowe so that water temperatures rise, affecting th composition of species the stream will suppor Riparian wildlife habitats change, generally re ducing species diversity.

Pollutants and nutrients associated wit eroded sediments can have adverse impacts on aquatic environments. Concentrations of tox ic substances may kill aquatic life, while nutri ents in the runoff can accelerate growth o aquatic flora. This can aggravate the sedimen tation problem and lead to accelerated eutro phication of the water bodies. Eutrophication is a process that usually begins with the increased production of plants. As they die and settle to the bottom, the micro-organisms that degrade them use up the dissolved oxygen. Sedimentation also contributes to exhausting the oxygen supply, especially in streams and rivers, by reducing water turbulence. Thus, the aquatic ecosystem changes dramatically.

Phosphorus and nitrogen are the major nutrients that regulate plant growth. Soil nitrogen is commonly found in water supplies. Phosphorus, on the other hand, is "fixed" in the soil, so runoff typically contains relatively small amounts. Under normal conditions, phosphorus is more likely to be the limiting factor

in aquatic plant growth. Since phosphorus (along with potassium, calcium, magnesium, sulfur, and the trace elements) is held by colloid material, it is abundant in waters receiving large amounts of eroded soil.

Natural eutrophication is generally a slow process, but "cultural" (man-caused) eutrophication can be extremely rapid and can produce nuisance blooms of algae, kill aquatic life by depleting dissolved oxygen, and render water unfit for recreation. Replenishing the oxygen supply is a costly remedy because of the energy required to mix and dissolve such a sparingly soluble gas into aqueous solutions.

The nutrients reaching water supplies from natural sources, however, vary widely depending on the land and soil type. Water from highly fertile, unfertilized agricultural lands can have a higher content of plant nutrients than water from heavily fertilized, well-managed cropland low in natural fertility. Nutrient losses from properly fertilized soils, in fact, can be less than from soils to which no amendments are added, since a vigorously growing crop will use the available nutrients (Smith, 1967).

Another aspect of water pollution from agricultural sources is the danger to human and animal health by runoff from livestock feedlots. Coliform and enterococcus bacteria living in the fecal waste of the animals can reach water supplies if the runoff from these feedlots is improperly managed. If allowed to percolate slowly through the soil, however, the coliform and enterococcus bacteria are adsorbed on colloidal material and die. This natural filtering mechanism is very efficient—more than 98 percent is removed in the first 14 inches of soil.

Effects on Ground Water Resources

Another essential service provided by a properly managed environment is that it provides clean recharge water for ground water aquifers. Most of the removal of readily degradable pollutants occurs near the water's point of entrance into ground water reservoirs, provided the environment is conducive to microbial action. Precipitation filters through the ground and recharges ground water at a rate of approximately 300 trillion gallons per year (CEQ, 1980).

Reducing the percolation and filtration capabilities of soils, contaminating surface waters, and lowering water tables all hinder aquifer recharge. Improved grazing management, technologies to reduce erosion and runoff into surface water, controlled ground water withdrawal, and artificial recharge with fresh or purified water are technologies that enhance the land's ground water recharge function.

Effects on Fish and Wildlife

Wildlife are broadly affected by agricultural activities. The most widespread problems are a result of expanding cropping and grazing into wildlife habitats, overgrazing of riparian areas, and agricultural activities that contaminate aquatic habitats.

As American settlers cleared forests and plowed prairie land for cultivation, many wildlife species vanished. Some species that were adapted to open areas continued to prosper. The cottontail, bobwhite, crow, robin, red fox, skunk, and meadow mouse benefited as forests were opened to fields. Forest edge-loving species, such as the white-tailed deer, increased as more of their favored environment was available, but later declined as forest clearing increased. Other species could not adapt to the changed environments, however.

In the West, wilderness prairie animals—bison, pronghorn antelope, mule deer, and grey wolf—began to decline almost immediately as their habitat disappeared. Large species and predators were especially affected. By the turn of the 20th century, wilderness animals had virtually vanished from the East, from much of the prairie further west, and from the more fertile valleys of the Far West.

The abandonment of farms, particularly upland farms with sloping fields, sometimes improves habitat for wildlife, though the diversity of species is still greatly reduced from the original flora and fauna. Some conversion of

farmland to protected forestlands and vacationlands also occurs.

As crop yields on sloping uplands decline with erosion and fertility loss, farmers sometimes convert upland fields to pasture and drain lowlands for crops. Wetlands drainage removes habitats for migrating and resident waterfowl, and can remove the last remaining winter cover for some species of wildlife such as pheasants. The removal of fence rows and shelter belts also reduces wildlife habitat.

Irrigation of drylands, though, actually provides new habitat into which pheasants and other wildlife can expand. Habitat also is enhanced by the more than 2 million acres of farm ponds, dugouts, and stock tanks that have been created. Especially where protected from livestock, these waters and their shoreline vegetation provide habitat diversity and niches for birds, amphibians, reptiles, fish, and other wildlife (Burger, 1978).

Mechanization also has had a dramatic impact on wildlife. For example, mechanical cornpickers leave more waste grain after corn harvests than handpicking. Canadian geese, mallard ducks, and other field-feeding waterfowl have benefited substantially from this new food source. As a consequence of this drainage of wetlands, irrigation of drylands, and creation of waterfowl refuges, the migratory paths of many wildfowl have changed.

Land-forming, chemical treatments, and other agricultural technologies often affect wildlife adversely. The replacement of contour plowing and stripcropping by leveling and filling surface irregularities in fields removes wildlife habitat on farmlands. Various agricultural chemicals have deleterious effects on wildlife. For example, bioaccumulated chlorinated insecticides produce eggshell thinning in several predaceous birds. Other insecticides that have found their way into streams can significantly reduce invertebrate populations on which many fish depend (NAS, 1974).

Adverse effects from chemical applications are not new. In Colorado, the pesticide Paris Green, used by farmers to counter a grasshopper invasion in 1931, nearly eliminated the newly introduced ring-necked pheasant. Pesticide pollution is also responsible for the emergence of pesticide-resistant populations of agricultural pests. A shortage of data exists, however, on the adaptations of these pests on a biochemical or genetic level. Thus, the long-term effects of pesticides on pest populations are unknown (Winteringham, 1979).

Cattle and sheep grazing and man's control of fires in the Western States have been responsible for changing large areas of grassland into shrubland, thereby reducing the productivity of those lands for wildlife and water resources (Littlefield, 1980). Competition between some wildlife—e.g., bighorn sheep and American elk—and livestock also can occur.

Overgrazing reduces the perennial native grasses on which cattle thrive and allows sagebrush, a less nutritious forage, to increase. Seedings of introduced grasses (e.g., crested wheatgrass) can provide good replacement forage for livestock, but wildlife generally does not prosper in such monocultures.

Overgrazing of riparian habitats is particularly detrimental, both to the wildlife that depend on streamside vegetation and to the aquatic life in streams and lakes. Riparian habitats are generally more productive of plants and animals and are more diverse than the surrounding range. Abuse or misuse of these more fragile waterside habitats thus can be especially damaging.

Generally, sheep do little damage to riparian habitats because they prefer open vegetation areas. Cattle, however, are particularly damaging to riparian habitats because they prefer the succulent growth and because they congregate in large numbers over long periods, especially during the often critical periods of spring and summer. Deer and elk rarely congregate enough to do damage (Cope, 1980)

Riparian soils generally have high infiltration capacities and release captured water slowly to streams. Cattle grazing in these areas, however, reduces riparian vegetation, compacts soils, and destroys overhanging streambanks

all of which promote erosion and increase the sediment load of the stream.

Stable streambanks hold sediment, control water velocities, give cover to aquatic life, and supply terrestrial foods to the ecosystem. When streambanks are broken down, sediments from the debilitated streambank and from runoff on nearby lands pollute the stream. Thus, eutrophication may begin along with all of the concomitant changes in the riparian and aquatic ecosystems. Fish production is suppressed by elevated water temperatures, fish foods and spawning beds are buried by sediments, and aeration is reduced. Game fish, such as trout, are reduced or eliminated, and replaced by hardy but less desirable species (e.g., chubs) that can survive in shallower streams with lower oxygen content.

Grazing also can intensify bacterial and pesticide pollution. Flushing of animal feces into aquatic systems may cause algal blooms that reduce photosynthesis by aquatic plants, make less oxygen available to aquatic life, and release toxic wastes under anaerobic conditions.

Conclusions

The food and fiber products supplied by the Nation's agricultural lands represent only a part of their value. Agroecosystems play an essential role in maintaining air and water quality, in recharging underground aquifers, and in providing fish and wildlife habitat. Although these benefits are often difficult to measure, they are an important dimension that should not be underrated by agricultural policymakers.

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Chapter III

Rangelands

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Rangelands

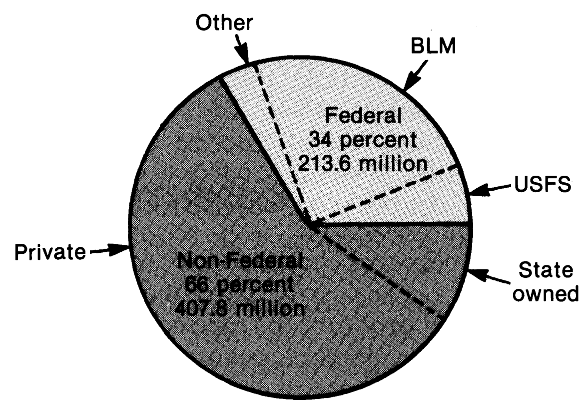
INTRODUCTION

There are about 853 million acres of rangeland in the United States. This includes natural grasslands, savannas, shrublands, most deserts, tundra, coastal marshes, and wet meadows. Typical range vegetation includes grasses, grass-like plants, forbs, and shrubs. (Pastureland, by contrast, is land improved for forage production by intensive management of the soil and vegetation.) In the contiguous United States, over half the rangelands are seriously degraded (USDA/RPA, 1980).

Excluding Alaska, 97 percent of the Nation's rangelands are located in the Great Plains and the arid and semiarid West. More than half of this land, 66 percent, is privately owned (see fig. 8). These private rangelands generally have the greatest inherent productivity and include most of the highly productive prairie and wet grassland ecosystems.

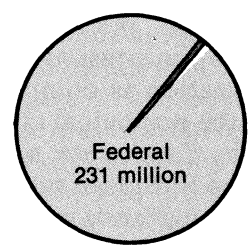
Federal rangeland areas are administered as follows: Bureau of Land Management (BLM), 24 percent; the U.S. Forest Service (USFS), 6 percent; and other Federal agencies (including the Fish and Wildlife Service and the military), 4 percent. Generally BLM lands are drier, less productive, and more fragile than private lands. They include large desert ecosystems with little or no carrying capacity for livestock and extensive shrubland of low productivity. USFS rangeland includes substantial areas of less arid, more productive mountain ecosystems.

Figure 8.—U.S. Rangelands



Rangeland, excluding Alaska

Total = 621.4 million acres



Alaskan rangeland

Total = 231 million acres

NOTES: Federal data are from the Resource Planning Act (RPA) 1979; non-Federal data are from 1977 National Resources Inventory (NRI); State land estimated by Tom Frye, USDA, Census of Agriculture; statistics on total range are imprecise. NRI indicates 621 million acres (outside Alaska) whereas RPA indicates 588 million acres.

Alaska contains 231 million acres of rangeland, much of it (79 percent) in good condition because it has not yet been used for livestock grazing. Information on which agencies administer Alaskan rangelands are imprecise because of landownership changes mandated in the 1980 Alaska lands bill. The 1980 Resource Planning Act report indicates that BLM is the major "owner," managing over half the Alaskan rangelands. When that figure was determined, USFS controlled about one-fifth of the Alaskan rangelands, other Federal agencies had about two-fifths, and only about 2 percent was in private ownership (USDA/RPA, 1980.)

Demands for rangeland products and services are expected to increase sharply in the next two decades (USDA/RPA, 1980 and USDA/RCA, 1980), but opportunities for increased production from U.S. rangelands are

great. For example, the potential production of herbage and browse from rangelands outside Alaska is estimated at over 700 million pounds per year while the present production is less than half of that (USDA/RPA, 1980). In regions of moderate to high rainfall, water yields from rangeland watersheds could be significantly increased by appropriate vegetation management (Hibbert, 1974). Recreational use, too, can be increased substantially (USDA/RPA, 1980).

In spite of these potentials, most rangel ecosystems are not resilient when misused cause they are typically arid and natural p growth is slow. The natural forces that ten degrade ecosystems—i.e., wind, rainfall, temperature extremes—are also especi powerful in dry areas.

CONDITION OF U.S. RANGELANDS

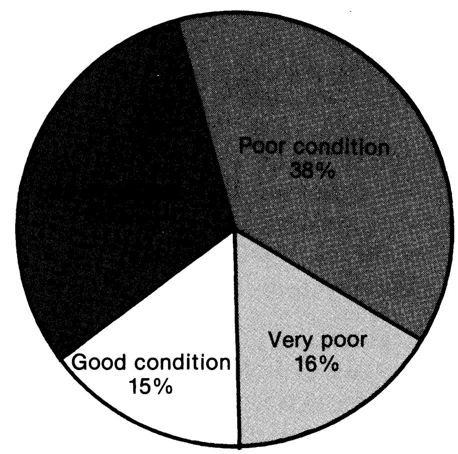
In the contiguous United States, over half the rangelands are seriously degraded and suffer from reduced productivity caused by the ill effects of mismanagement, overgrazing, and erosion. Only 15 percent of the range is rated in good condition. Ranges in fair condition constitute another 31 percent of U.S. rangelands; 38 percent are rated poor; and 16 percent are very poor (see fig. 9) (USDA/RCA, 1980).*

"Range condition" is a complex and inexact measure where the present condition of the soils and vegetation is compared to what is thought to be the ecological climax community as dictated by the climate, native vegetation, and original (pre-European settlement) soil type at the site. For rangelands where exotic vegetation has replaced the natural plant communities, as in most of California, range condition is determined by comparing the present soil and vegetation to the potential for the site without irrigation or fertilization.

Overgrazing causes great loss of productivity on U.S. rangelands. While present trends in range productivity are difficult to determine, the historical deterioration is well documented. Almost all the Western arid and semiarid ranges were severely overgrazed in the first two or three decades following settlement. For example, the first settler to the Salt Lake Valley, Utah, arrived in 1847; just 32 years later, the Utah paper, Deseret News, reported:

> The wells are nearly all dried up and have to be dug deeper. At the present time the prospect for next year is a gloomy one for the farmers, and in fact, all, for when the farmer is affected, all feel the effects. The stock raisers here are preparing to drive their stock to where there is something to eat. This country, which was one of the best ranges for stock in the Territory, is now among the poorest; the myriads of sheep that have been herded here for the past few years, have almost destroyed our range (Clegg, 1976).

Figure 9.—Rangeland Condition in the United Stat



SOURCE: USDA 1980, Resources Conservation Act.

*For this assessment, range is rated in four categories—good, fair, poor, and very poor, depending on the difference between the land's present vegetation and the ecological potential of the site. Range rated "good" has vegetation between 61 and 100 percent of potential; "fair" range is 41 to 60 percent of potential; "poor" range is 21 to 40 percent of potential; and "very poor" range is 20 percent or less of potential (USDA/RCA, 1980).

The process by which rangelands deteriorate is well understood. Cattle and sheep bite plants for food, consuming much of the aboveground part of the plant before moving to the next plant. In this they are like the enormous herds of bison and other large wild herbivores that once grazed the rangeland. But domestic livestock can cause serious harm to plants, especially grasses, whereas large wild herbivores generally did not (Littlefield, et al., 1980). The wild herbivores stayed in herds and moved to other ranges after "mowing" the forage once. Domestic livestock, on the other hand, scatter over the landscape and stay on the same general site until the rancher moves them. If a rancher overstocks a site and does not move the herd, they are likely to return to a plant again and again, never letting it regain enough green material to maintain its root system or to store energy against periods of drought stress (Savory and Parsons, 1980). When the palatable and overstressed perennial grasses die out, substantial changes in the ecology and hydrology of the land commence. Overgrazing removes the grass cover and leads to less plant litter; increased runoff; sheet, rill, gully, and streambank erosion; and less organic matter in the soil. The resulting denuded land is also more susceptible to wind erosion, especially during drought.

Moreover, the degraded land can then be invaded by less productive plants, commonly called weeds and brush. Annuals, such as Russian thistle (tumbleweed) and cheatgrass, take hold, and deep-rooted shrubs, such as mesquite, proliferate. In northern regions, sagebrush is the primary invader. Accompanying these vegetation changes are upheavals in wildlife populations. Most species decline, especially the ground-nesting birds, such as quail and grouse, and the herbivores, such as bighorn sheep, pronghorn antelope, and American elk. A few wildlife species, such as the kangaroo rat, jackrabbit, zebra-tailed lizard, and horned lark, prosper in overgrazed areas.

Livestock grazing can be particularly hard on riparian areas near streams, waterholes, and springs. Riparian plants are more appealing to grazing animals and more productive, so are eaten more often. And riparian sites suffer greatly from trampling because animals spend more time in them and because their moist soils are more susceptible to compaction.

Overgrazing also reduces the proportion of rain and snowmelt that soaks into the ground. Ungrazed rangeland on the southern Great Plains, for example, was found to have infiltration rates nearly four times the rates on grazed rangeland of similar character (Brown and Schuster, 1969). Rainwater and snowmelt rush off denuded or compacted land instead of being absorbed into the soil. This, in turn, makes streamflows more erratic, tending toward a flood and drought regime. Whole river systems can be changed. The Santa Cruz River in Arizona, for example, was a meandering perennial river that supported an abundance of fish and other wildlife until its watershed and riparian areas were overgrazed. Now it is dry most of the time (Sheridan, 1981). Grassland restoration and conservation programs can reverse these effects and improve streamflow significantly (Hibbert, et al., 1974).

The increased runoff associated with overgrazing also increases gullying, or "arroyo-cutting," as it is called in the Southwest. Combined with the increased sheet erosion caused by overgrazing, gullying carries large amounts of silt into rivers such as the Rio Grande. Indeed, it is estimated that one of the Rio Grande's most overgrazed watersheds—the Rio Puerco Basin in northwest New Mexico—produces over 50 percent of that river's total silt load while supplying only 10 percent of its water (Adams, 1979).

Historically, overgrazing effects have been most severe in arid areas where the land is least resilient. Thus, range conditions are now worst in the Southwestern States. Two-thirds of the rangelands of Texas, New Mexico, Arizona, and California have range condition degraded to 40 percent or less of the original condition. (USDA/RPA, 1980).

The loss of productivity from overgrazing in the Southwest is reinforced by climate changes. Over the past 100 years, the natural vegetation on large parts of the Southwest has undergone

changes on a scale usually associated with geologic time. Vegetation zones at different elevations have changed noticeably. At low elevations, vegetation in the desert shrub and cactus communities have become sparser, while the desert grasslands have receded greatly and have been replaced by desert shrubs, cacti, and mesquite. At higher elevations, mesquite has taken over oak woodlands, and the timberline of spruce and fir trees has moved upward (Hastings and Turner, 1972).

Scientific opinion differs on the cause of these profound changes. Some experts contend that the changes are the result of a change in the region's climate, which apparently has become more arid, with rainfall decreasing about 1 inch every 30 years. Other scientists contend that the prime cause of the vegetation changes was the huge influx of cattle and sheep that occurred in the latter part of the last century. It is likely that climate and livestock co bined forces to bring about the most drama changes. By weakening the grass cover, dom tic grazing animals have reinforced the gene tendency toward aridity by contributing to imbalance between infiltration and runoff favor of runoff (Hastings and Turner, 197

Average range condition figures for t United States as a whole are not so negati as the figures for the Southwestern States b cause the climate in other regions gives t land more resiliency. Still, the overall con tion is not good. Excluding Alaska, over ha (54 percent) of the U.S. rangelands have rang condition degraded by 60 percent or more. I Alaska, four-fifths of the rangeland still ha over 80 percent of its original productivity- most of it is still virgin. Less than 2 percent- just over 4 million acres—has been degrade to 40 percent or less of the original conditio

CURRENT TRENDS

Experts do not agree on whether the overall trend in rangeland productivity is improving, remaining static in its degraded condition, or continuing to degrade, and there are inadequate data to resolve the question. Nationwide studies of range condition were done in 1936, 1968, 1972, and 1976. Unfortunately, these do not comprise a time series that can be examined to discern the national trend. The studies from 1976 and 1972 use much of the same data as the 1968 study. Comparing the 1936 data to the 1968 data is not useful because the methods for measuring range condition have changed and because the earlier study measured conditions under an uncharacteristic drought while the later study measured conditions in a more normal period.

Trends in range condition can be estimated without time series data by using indicators such as species reproduction, plant vigor, plant litter, and surface soil condition. BLM, in the process of making environmental impact assessments for its range management plans, is now investigating range condition trend indicators rigorously. Most of their assessments indicate that stocking rates (grazing pressure) must be lowered 20 to 75 percent to avoid further deterioration (Young and Evans, 1980).

In general, range experts report that forage production on non-Federal land has gradually improved over the past 30 years, but that these lands are still degraded from their ecological potential. The Federal rangelands are apparently either static in their degraded condition or are continuing to deteriorate. There are some exceptional sites where atypical levels of management are improving Federal range condition.

Available data indicate that the area of rangelands has been declining in recent decades. By 2030, the total area of rangeland is projected to decline 7 percent. The acreage lost will come primarily from private lands as range is converted to cropland or pasture or developed for residential areas, highways, airports, and mines (USDA/RPA, 1980).

MONITORING PRODUCTIVITY

One factor that seriously complicates the evaluation of rangeland productivity trends is the highly variable weather characteristic of the Western States. Rangeland plant production can fluctuate more than 300 percent from one year to the next as a result of a variation in precipitation (Box, 1980). Ideally, a large sample of sites in each rangeland region and subregion should be monitored regularly through several drought cycles to determine trends in rangeland productivity. Eventually, the Resource Planning Act and Resource Conservation Act processes of planning and assessment might include such a monitoring program.

Meanwhile, however, improved monitoring is needed to help manage local sites. Estimates of factors such as species composition, forage output, degree of ground cover, and symptoms of erosion—on which rangeland trend assessments have traditionally been based—would be more useful if they were augmented by systematic monitoring of the rangeland's other vital signs, including:

- the reproduction rate of various species in order to determine whether the plant community succession is advancing or regressing;
- the rate of soil loss by water and wind erosion;
- the soil's water infiltration rate, organic content, and degree of compaction and capping;*
- the water quantity and quality of aquifers and their hydrologic interaction with streams; and
- the population dynamics of native animals (including fish) which depend on the rangeland habitat for food, water, and cover.

*"Capping" refers to the formation of a thin crust on the soil surface. It occurs in the more arid types of rangelands, caused mainly by the action of raindrops striking the soil surface and by the chemical-physical dynamics of soil drying. It leads to increased runoff and decreased infiltration of rain and snowmelt.

PRODUCTIVITY-SUSTAINING TECHNOLOGIES FOR RANGELANDS

A variety of management technologies has been developed to improve deteriorated rangeland. These may be broadly categorized as:

- adjusting livestock numbers;
- controlling animal use with grazing systems;
- promoting desired plant species;
- controlling noxious plant species; and
- controlling noxious animal species.

Congress has legislated objectives for use of Federal rangelands. These are stated in the Classification and Multiple Use Act of 1964, the Forest and Rangeland Renewable Resources Planning Act of 1974, the Federal Land Policy and Management Act (FLPMA) of 1976, and the Public Rangeland Improvement Act of 1978. Generally, these laws state that multiple resource values are the management objectives for public land. The laws establish resource-inventory and land-use planning mechanisms for "the harmonious and coordinated management of the various resources without permanent impairment of the productivity of the land . . . ." (FLPMA, sec. 103 (c)). Translating general multiple-use, sustained-yield objectives from laws into achievable management objectives is extremely difficult, especially when two or more legitimate uses of the land are in conflict. FLPMA specifically states that multiple-use management should consider the relative values of the resources and not necessarily the combination of uses that will give the greatest economic return or the greatest unit output.

In theory, rangeland management strategies should include explicit statements of achiev-

able objectives, management programs to apply technologies, monitoring programs to measure progress toward the objectives, analysis methods to indicate how the management could be changed to enhance progress, and a mechanism to implement the changes indicated by the analyses. In practice, however, there are often no statements of achievable objectives, no rigorous monitoring programs, no replicable analysis methods, and no feedback mechanisms to facilitate adjustment of the technologies.

Most range management technologies are designed to foster livestock production. However, some technologies exist that have other utilities as their major objective. These include game and fish management techniques, erosion control to decrease sedimentation of streams and reservoirs, and vegetation manipulation to increase watershed yields. These technologies are not well developed, however. Scientists and resource managers working with rangelands seem most concerned with livestock production technologies. Because livestock management considerations dominate rangeland use, managers seeking to enhance wildlife or other values would probably be most effective if they focused on influencing the choice of livestock production techniques. This traditional focus on livestock and the paucity of technologies directed at other values may explain in part why livestock considerations continue to dominate Federal rangeland management decisions, even on ranges where livestock is not the dominant objective (e.g., on wildlife refuges) (Littlefield, et al., 1980).

This discussion begins with an overview of technologies appropriate for sustaining range resources and concludes with more detailed descriptions of three promising new approaches: integrated brush management systems, short duration grazing, and grazing potentials in eastern woodlands.

• *Adjusting livestock numbers* is the most widely used range management technique. First, the carrying capacity of the range site is estimated to determine the numbers and types of grazing animals and the seasons they are to graze. Then grazing occurs with the indicated livestock in the indicated seasons. After one or more years of grazing, the range condition need to be carefully reassessed. If the range shows indications of overgrazing or undergrazing, the intensity and timing of grazing are adjusted accordingly. The process can be repeated to fine-tune the carrying capacity estimate.

Adjusting stock rates to the land's carrying capacity sounds relatively simple, but in practice there are severe difficulties. First, the initial carrying capacity can only be estimated. In theory, the range manager calculates carrying capacity by measuring the site's total annual forage production. Then he subtracts the forage that must remain ungrazed to protect the health of plants and soil quality. The remainder is available for grazing, but the range manager must also consider that some forage is likely to be eaten by wild herbivores. (In some cases this sharing of the forage between wild and domestic animals is adjusted by reducing the wild animal numbers to decrease their share, or by manipulating the number or timing of domestic animals' grazing to increase the forage for wildlife.) When the total pounds of forage available for livestock are known, that weight is divided by the ration needed per animal per time unit. (Rations per animal can vary with the character of the site.)

The estimation of carrying capacity is complicated by the vagaries of precipitation in the arid and semiarid West. Since range managers cannot foretell precipitation rates when planning stocking rates, they need to determine if the year that produced the forage crop measured was typical and then discount that to allow for drier years. At this stage, the carrying capacity estimate changes from science to art, and the value of estimates of factors such as the wildlife share of the forage becomes doubtful.

Rather than do such precise analyses, managers commonly measure total forage production and estimate that 50 percent of it is available for livestock grazing (Menke, 1981). Although the continuous reevaluation of range

condition, trend, stocking records, and the adjustment of animal numbers and timing are critically important, this reevaluation and readjustment is often not practiced. As a result, the rangeland is overgrazed, especially during drought, and sometimes undergrazed during wetter periods (Box, 1980).

Another difficulty with adjusting animal numbers is that ranching operations often are not flexible and cannot accommodate changes in animal numbers or adjust seasonal grazing. If reduced grazing pressure is necessary at a time when livestock prices are low, the rancher might incur a substantial loss. To avoid this loss, some ranchers choose to overgraze the range, hoping the drought will pass quickly. This is possible if the rancher controls range use by right of ownership or tenure, or if his lease is based on a carrying capacity estimate that did not foresee the drought. Obviously, this method can damage the long-term productivity of the range. Other ranchers may stockpile or purchase alternative sources of forage to feed livestock through drought. Losses incurred by selling part of the herd in stressful times can be minimized if the age and sex ratio of the herd are designed for economic flexibility (Scifres, 1980).

Yet another problem in range management is related to the issue of animal types. The carrying capacity of most range ecosystems can be greater for a variety than for any one type of animal (Box, 1980). If a single species such as cattle is stocked, the overall productivity of the rangeland can be less and overgrazing more likely than if a variety, such as cattle with bison, sheep, or goats, could be used. It is also possible to achieve higher productivity by using a combination of domestic and wild animals with different food preferences. In prac-

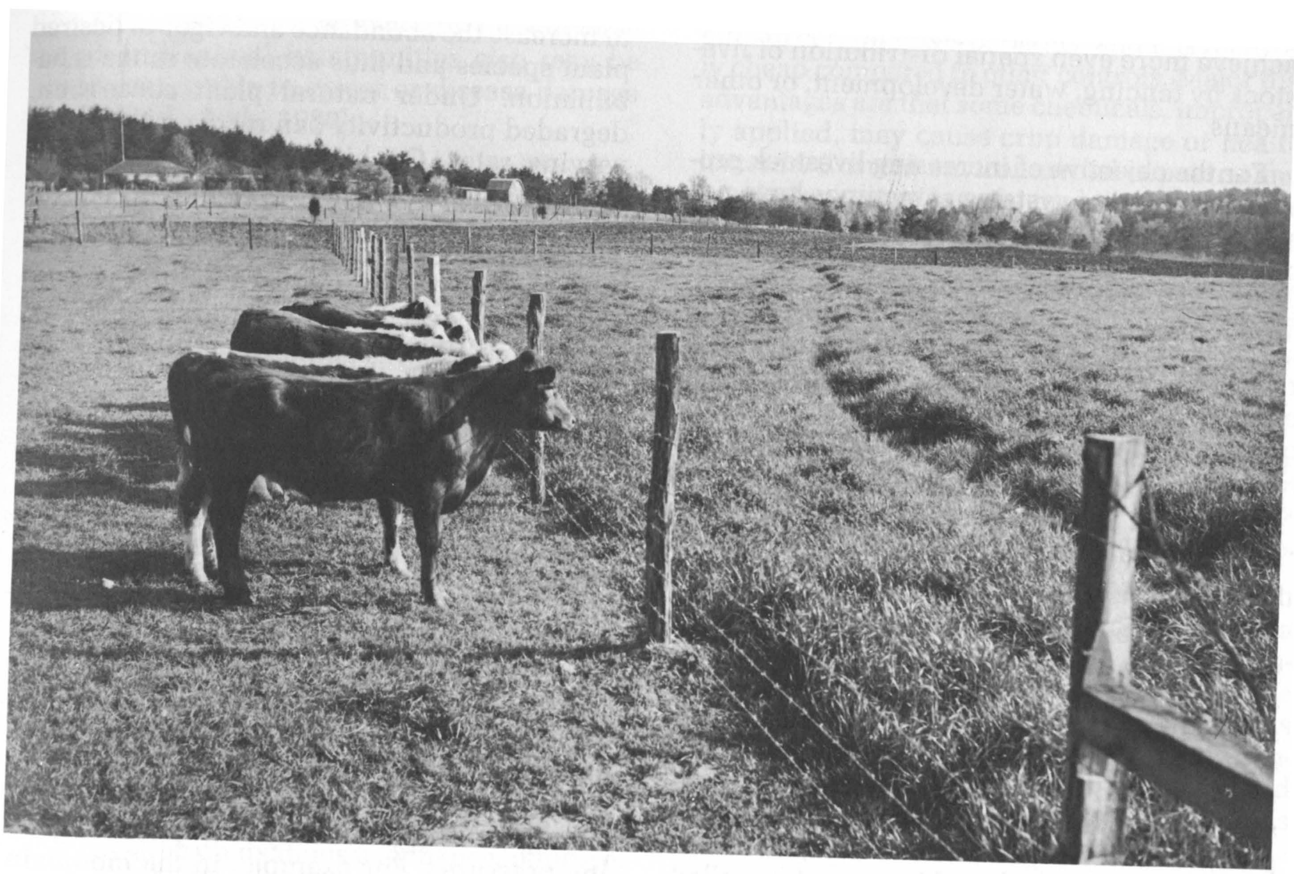


Photo credit: U.S. Department of Agriculture

The grass is always greener on the other side. These young heifers look longingly at a fenced-off fescue seed patch that was set aside for recovery

tice, however, most range sites are managed for single species, usually cattle or sheep.

There are several reasons for the lack of multiple-species management. One is a lack of information on techniques and economics, but this lack of information is probably the result of a more powerful constraint—the conservative attitudes of the ranchers, and of the institutions that support them, toward untried techniques that may affect their profits.

• *Grazing systems* are technologies based on intensely managing how animals use range sites. The aim is to schedule systematically recurring periods of grazing and nongrazing for subunits of the site on the premise that periodically removing the animals from the range gives the palatable plants a chance to recover before being bitten again (Scifres, 1980). Some grazing systems strive to distribute livestock by season of use whereas others work to achieve more even spatial distribution of livestock by fencing, water development, or other means.

For the objective of increasing livestock production, grazing systems sometimes have not proven superior to continuous, year-long grazing at moderate stocking rates (Scifres, 1980; Box, 1980). However, even when livestock production is not increased in the short term, the range is often improved so that, in the long term, increased livestock production, as well as increased overall productivity, can result (Scifres, 1980). While grazing systems offer opportunities for improving rangelands, they are site specific and no one system should be considered a panacea for the problems of range degradation.

One of the more simple systems is rotation grazing. This involves subdividing the range and grazing one unit, then another, in regular succession. Another type of grazing system is called deferred grazing. This means delaying grazing in an area for a particular purpose, such as allowing old plants to gain vigor or new plants to become established. These two concepts have been combined into a system called deferred-rotation grazing. In this system, different parts of the range are deferred in rotation so that in the series all units will benefit from the deferment.

BLM reportedly is relying heavily on variations of the rotation systems and considerable controversy has been generated. Critics say that if stock reductions do not accompany rotation grazing, harmful impacts on riparian area and regional hydrology will be amplified by periodically concentrating animals on particular sites. Fences to restrict livestock access to riparian lands can be part of the grazing system, but some critics object to the increased physical injuries that fences can inflict on wildlife (Littlefield, et al. 1980). Others who are concerned about the profitability of ranching object to the high cost of fences and to livestock being excluded from highly productive riparian sites.

• *Rangeland vegetation can be manipulated* to increase the abundance and vigor of desired plant species and thus accelerate range rehabilitation. Under natural plant succession, degraded productivity can recover, though at varying rates. On high mountain sites with deep soil that receive 40 to 50 inches of rainfall a year, recovery may occur in a few years. But on lands that receive only 20 or less inches of rain, it may take plant communities centuries to recover from the severely degraded conditions (Box, 1980). Rehabilitation techniques to speed up the recovery process range from "interseeding"—introducing desired plant species without removing the existing plant community—to intensive site preparation, reseeding, and sometimes temporary inputs of water or fertilizers to help desired plants become established. (If the intensive vegetation management is a continuing process, the site is no longer rangeland, but pasture.)

Reseeding and interseeding are widespread practices on private rangeland. Usually the objective of seeding is to increase forage during a season when native ranges do not provide enough or are particularly susceptible to grazing pressures. For example, in the mountain and intermountain regions, there is usually a shortage of early spring forage. Native bunch-

grass should not be grazed because that will stunt future growth, so extensive areas are seeded with introduced species such as crested wheatgrass, which produces heavily during the spring season and is more tolerant of spring grazing (Box, 1980).

There are drawbacks to this "monoculture" technique. The introduced grass can so dominate the ecosystem that other species, productive at other seasons, are crowded out. Crested wheatgrass, for example, has low nutritional value for fall or winter grazing livestock or wildlife. To compensate, other species that can compete with wheatgrass can be introduced—e.g., four-wing saltbush and other forage shrubs. These provide the protein and carotene that the grasses lack in the fall grazing season (McKell, 1980). Another disadvantage of reseeding programs where one or a few species are introduced is that the resulting ecosystem has fewer niches for animal life. Less diverse plant and animal communities also may be more susceptible to insect or disease damage (Littlefield, et al., 1980).

Inadequate nitrogen is often a limiting factor on rangeland productivity, so interseeding legume species may be beneficial. In the United States, alfalfa has been used this way; in Australia and parts of Asia, interseeding with the legume Townsville Stilo is reported to be very successful. Legume shrubs and trees are important sources of nitrogen for rangelands in Africa (Felker, 1981). There is little information available on the positive or negative impacts of legume interseeding on U.S. rangelands, but it is known that forage can be significantly increased (Lewis and Engle, 1980).

For sites where multiple-use management is the objective, and if economics allow, reseeding or interseeding can introduce mixtures of grasses, herbs, and browse plants and can rely more on native species so that the resulting ecosystem is more complex. Presumably this would be the method used on Federal rangelands. In recent years there has been considerable research on methods to enhance, improve, and reseed or interseed vegetation for wild animal use (Box, 1980). However, for several reasons, such technology is as yet underused on the Federal rangelands. One problem is a lack of reasonably priced seed, but this constraint might be resolved by willing entrepreneurs. A more intractable reason for underuse of seeding to accelerate recovery of diverse native communities is the chronic lack of funding for Federal rangeland improvements. Congress recognized the need for accelerated rehabilitation of range condition when it passed the Rangelands Improvement Act of 1978. However, the act remains unfunded.

• *Controlling noxious plants:* excessive cover of woody plants, the "brush" characteristic of degraded ranges, is one of the primary deterrents to increased forage production. There are three major approaches to brush control: chemical, mechanical, and fire. *Chemical control* has certain advantages: it is effective, various chemicals may be selected that are specific to certain types of plants, and it is relatively cheap compared to other controls. Major disadvantages are that some chemicals, improperly applied, may cause crop damage or health hazards. Current environmental concerns and regulations have largely prohibited chemical use on Western Federal rangelands.

Mechanical control methods vary from hand-clearing or chopping individual plants to using big machines that plow or drag plants from the ground. These methods are advantageous in that the plants are removed immediately while the residue remains on the ground as organic matter. The disadvantages are that costs are generally high and considerable soil disturbance occurs with most mechanical methods.

Fire is a natural factor on all of Western rangelands and it is gaining acceptance as a major brush control technique. To its advantage, it is fairly inexpensive and can be quite effective against nonsprouting species. It has disadvantages, however. Brush areas often cannot support a fire, and since the burned land is denuded for a short period of time, there is an increase in the erosion potential.

Conventional vegetation control techniques have been criticized for being used without

regard to their effect on values other than forage production for livestock. The effect of brush control on wildlife depends on the technique used. When large areas of brush are removed, the effect on the wildlife species adapted to brush is detrimental. But when alternate cleared and uncleared strips are left, populations of wildlife species, such as deer, increase (Littlefield, et al., 1980). In general, burning seems to find most favor with the champions of wildlife. A newer approach, integrated brush management, offers improved opportunities for enhancement of broad-scale productivity. That approach is described later in this chapter.

• *Programs to control noxious animals* are used to achieve three range management objectives: 1) to protect livestock, 2) to reduce the numbers of herbivores that compete with livestock for available forage, and 3) to protect the range from overgrazing and subsequent damage to productivity. The techniques used sometimes serve one objective while detracting from another.

Predators, particularly high populations of coyotes, can decrease range productivity by killing sheep or other livestock (Box, 1980; Young and Evans, 1980). On the other hand, when predator numbers are too low, they may kill too few rodents and other wild herbivores, so that grazing pressures increase and range conditions deteriorate (Dwyer, 1980; Box, 1980). Thus, the purpose of modern predator control programs is to optimize, rather than minimize, predator populations.

In the past two decades, Government agencies responsible for predator control have been studying new techniques for estimating predator populations, judging what constitutes optimum predator population levels for particular sites, manipulating the populations or, in some cases, the behavior of the animals, and monitoring the effects of the actions. The overall state of the art for these techniques is primitive and their development is not well supported (Lewis and Engle, 1980). The integrated pest management approach, assessed in another OTA report (U.S. Congress, 1979), seems to be one way to resolve conflicts among the objectives of noxious animal control programs in rangeland ecosystems.

Wild horses and burros represent a particular nuisance and controversy on Federal range lands. Without effective predators, they are capable of rapid increases in population and can inflict heavy damage on range ecosystems. Capturing and moving these animals is only a temporary control measure, since the population will quickly rebuild. Treating them with fertility-controlling drugs seems to be effective but very expensive. Selective killing of the animals is simple and effective, but some stockmen and others killed horses and burros with unnecessary cruelty before the animals were protected on public lands by the Wild Horse and Burro Act of 1974. As a consequence there are now strong social and political constraints to killing large numbers of these animals. A report from the National Academy of Sciences will review the state of the art in managing these animals and will indicate what further research is needed. It will not defuse the political controversy, however (Dwyer, 1980; Box, 1980; Meiners, 1981).

With the correct application of management technologies, there is a great potential to improve productivity on many of the severely degraded rangelands. Rangeland management techniques, however, are very site specific and there is a potential for long-lasting harm to productivity when technologies are misapplied. With degraded plant cover and compacted soils, overgrazed rangelands are exposed to powerful erosion and further degradation. Thus, careful monitoring of the soil and vegetation is necessary so that management technologies can be adjusted when needed. Congress, as the manager of policy for the Federal rangelands, recognized the need for information on soil and vegetation changes with the Resource Planning Act and other legislation. The data available are still inadequate, however, to determine whether present policies will suffice to achieve the multiple-use objectives that Congress has mandated for Federal rangelands.

In theory, the primary objective of multiple-use management is to sustain or enhance the overall productivity of the resource base. Production of livestock and other specific benefits are secondary objectives. The rationale of such an approach is that managing for productivity will, in the long run, give the greatest production of all the multiple-use values. In practice, livestock production is usually the dominant objective for management plans on both Federal and non-Federal rangelands. The plans to produce livestock are then adjusted to provide for maintenance or enhancement of some nonlivestock values such as wildlife, fisheries, or water quality.

Integrated Brush Management Systems

Introduction

Excessive cover of woody plants, commonly referred to as brush,* can constrain forage production on rangelands. The concepts underpinning brush management have changed drastically during the past 30 to 35 years. Initially, the goal of most brush management was to eradicate undesirable species. But as it became obvious that eradication was not possible, the emphasis shifted to "brush control."

Various brush control methods have been developed that can be effective in specific situations or for particular purposes, but each also has characteristic drawbacks. Brush can be physically removed, for example, but that is labor and energy intensive and thus expensive. Chemical treatments, too, are increasingly expensive and sometimes restricted.

Looking for the most effective controls, ranchers began using certain of these treatments in combination—e.g., spraying and then physically removing (chaining) unwanted species. During the past 5 years, researchers have begun studying the most effective overall management schemes to combat brush problems and have developed a new approach called integrated brush management systems (IBMS).

Basic IBMS principles include:

- reducing dependence on any one method, such as repeated herbicide treatments, in favor of coordinating techniques;
- using available techniques in a complementary sequence to take advantage of synergistic effects;
- patterning the application of selected treatment sequences to enhance livestock production and habitat diversity for wildlife simultaneously;
- developing treatment sequence alternatives to make systems flexible for adaptation to particular site circumstances and the producer's operating constraints;
- integrating actions with other management strategies, such as grazing systems, for maximum utility; and
- enhancing economic returns from brush management investments by increasing effective treatment life and optimizing output of products.

IBMS incorporate existing and new technologies to take advantage of the unique strengths of each method while minimizing the inherent drawbacks. The systems are designed to consider multiple uses of the resource (e.g., forage production, wildlife, watershed, etc.) so that overall production is optimized rather than maximizing returns from one use to the detriment of others (Scifres, 1980).

IBMS can be applied most effectively when they are orchestrated with other key practices, particularly grazing management. Brush management is futile when the range is overgrazed. In fact, brush management without grazing management may be more detrimental than beneficial in the long run by opening up more land to repeated overuse (Welch and Scifres, 1980).

A planned, orderly sequence of treatments is important in IBMS results. For example, suppose a range livestock producer using a four-

*Brush is a growth of shrubs or small trees usually of a type undesirable to livestock or timber management, but which are sometimes useful or can be managed for wildlife—e.g., mesquite, pinyon, juniper, chaparral, sagebrush, etc.

pasture, three-herd grazing system* has determined certain brush species are limiting production. The chosen control procedures and rationale might include (Scifres, 1980):

1. An aerial spray, used to reduce the competitive advantage of a weed species, considering:
   - Herbicides should be applied in the fall when potential for spray drift damage to susceptible nontarget species is minimized.
   - The pastures should be treated in turn as they are scheduled for deferment from grazing in the fall, thus spreading the investment over 4 years and taking advantage of regularly scheduled deferments to maximize forage response. This also allows the producer to increase his livestock herd gradually in response to the rate of improvement.
   - The herbicide should be applied in patterns to retain some brush for white-tailed deer habitat and reduce total land area sprayed.
2. The area should be burned 18 to 24 months after spraying to remove standing woody debris, reinstate valuable broadleaves damaged or removed by the spray, improve botanical composition of the forage stand by favoring the more productive grasses, suppress brush regrowth that survived the spray, and improve the browse value of large, decadent, unsprayed brush.
3. Repeat burning at 2- to 3-year intervals, depending on weather, unless brush regrowth becomes excessive, in which case individual plant treatments with herbicides or treatment of local areas may be advisable.

Potential Scale of Application

IBMS should be applicable on almost any site now treated by single methods. It has been estimated that an average of 1.5 million acres Texas rangeland were treated for brush co trol annually from 1956 through 1977 (Scifre et al., 1980). Junipers, mesquite, and sagebrus alone infest some 242 million acres of U.S rangeland* (Klingman, 1962).

To be successful, IBMS require relativel long planning horizons. For example, wherea the expected treatment life of a given herbicid spray for mesquite control may be 7 years o less, brush management systems are designe to span 15 or 20 years (Scifres, 1980). For th next 10 years, IBMS are expected to receiv most attention in States such as Oklahoma Texas, and New Mexico where the brush problem is a priority concern among both Government land managers and private ranchers.

Much of the impetus for developing IBMS lies in recent Federal scrutiny of herbicides and the rising costs of conventional range improvement methods. If these factors continue to be important, the rate of adoption of IBMS will probably increase rapidly during the next decade.

Potential Impacts

The primary goal of IBMS technology is to optimize range products on a sustained basis. By expanding forage opportunities, IBMS may have the potential to double livestock carrying capacities of many range sites (Thomas, 1970). For example, combining use of a pelleted herbicide with prescribed burning for whitebrush-infested rangeland in Texas increased the livestock carrying capacity from 1 animal unit (AU)** per 35 to 40 acres to 1 AU per 12 to 15 acres in three growing seasons (Scifres, 1980). Other, similar increases have been reported. These levels of productivity, discounting weather fluctuations, are expected to hold as long as the systems are operative and livestock management is maintained at a high level.

*Although a four-pasture, three-herd grazing system was used to relate IBMS procedures, other grazing management systems can be used effectively. Short duration grazing (SDG) appears to be especially amenable to IBMS. However, there is no available research or field experience to support a discussion of the integration of IBMS into SDG.

*Another OTA assessment, "Water-Related Technologies for Sustaining Agriculture in U.S. Arid and Semiarid Lands," is exploring potential innovative uses for these and other range species.

**An animal unit is the forage required to support a cow and a calf for 1 year.

The primary biological processes affected by IBMS relate to vegetational change. Wildlife habitat quality is improved by developing a mosaic of vegetation types rather than total supression of brush. Increasing the ground area covered by perennial native grasses decreases sheet erosion during wet periods and the mulch cover increases water infiltration. This increases the amount of forage produced per increment of precipitation received (Scifres, et al., 1977a).

The impacts of the herbicides used in IBMS are uncertain. Residual patterns of newer herbicides, such as tebuthiuron, have not been established over a wide range of conditions, and additional research is needed. At application rates used in IBMS, herbicides such as 2,4,5-T (2,4,5-trichlorophenozy acetic acid) are dissipated in the growing season of application, and picloram (4-amino-3,5,6-trichloropicolinic acid) should not be expected to carry over into the second growing season (Scifres, et al., 1977b). However, just what happens to the dissipated chemicals is not clear.

The effects of fire on rangeland soils are as follows:

1. *Erosion potential:* The greatest erosion occurs on steep slopes when a high intensity storm follows a burn. This is of special concern with soils that seal readily and promote overland flow. However, erosion can be reduced by limiting burning to gentle slopes (no greater than 5 percent) and to late winter or early spring to promote early regrowth and rapid development of cover.
2. *Water relationships:* The greatest difference in water dynamics of burned v. unburned rangeland is that lush new growth consumes more water. This extra demand typically exists only through the first growing season after burning.
3. *Nutrient status:* Minor amounts of nitrogen, sulfur, and phosphorus are volatilized by range fires, organic matter may be decreased somewhat depending on conditions of the burn, and soluble salts (calcium, potassium, etc.) are returned to the soil in the ash.

The net impacts of IBMS burns on rangeland soil have not proven detrimental, perhaps because prescribed burns are generally less intense than wildfires.

Conclusions

The costs of IBMS are the sum of the costs of each step in the treatment sequence and are therefore highly variable. Indirect costs, too, should be considered. For example, risks of herbicide drift and the possibility of a prescribed burn getting out of control are indirect costs. There are also indirect benefits. Improving vegetation of one management unit within the ranch should relieve stress on adjacent units and encourage their improvement. Other potential effects, such as increasing or reinstating streamflow, benefit users removed from the actual site of brush management.

The primary constraints to implementation of IBMS are economic, environmental, and technical. The major economic constraint is the capital required to initiate the first (and usually most costly) step in the sequence. Federal cost sharing through agencies such as the Agricultural Stabilization and Conservation Service (ASCS) is of increasing importance, especially for smaller ranches (Whitson and Scifres, 1980).

Technical constraints to wider use of IBMS technology are significant because research is still in the formative stage and the rate of testing treatment-sequence variations cannot exceed the pace of natural seasons. For example, prescribed burning must be explored in more depth to capitalize on its full potential. Herbicide use must be refined through new application techniques for registered compounds and development of improved compounds. Low-energy mechanical methods for brush management should be developed and refined. The economic factors that affect IBMS adop-

tion must be identified and various tradeoffs analyzed to determine optimum system designs for various types of ecosystems and management objectives.

Short Duration Grazing

Considerable interest exists among both livestock producers and range scientists in short duration grazing (SDG) systems. Such grazing systems may as much as double the carrying capacity of certain ranges (Scifres, 1980).

SDG systems concentrate a relatively large number of animals on a given area, but for much shorter times than in more conventional deferred grazing systems. SDG also has shorter rest periods and other differences from traditional grazing management.

Rangelands and their management needs vary widely, not only in a geographic sense from the arid and semiarid West to humid Southeast, and from the cool North to the mild South, but also among specific sites within geographical regions. Any discussion of range management, including SDG, must recognize the site-specific nature of range improvements.

Most modern grazing management espouses the idea that periods of rest (removal of all grazing animals) are necessary to prevent overuse and allow plants to recover vigor. The typical SDG system rotates herds through a series of pastures several times (six or more) per year. Grazing periods are short (7 days or less), and rest periods generally are not longer than 60 days. This concentration of relatively large numbers of animals on a given area for a short time followed by long rest periods is designed to simulate the grazing activities of the wild herbivores under which the range ecosystem evolved. Consequently, SDG is sometimes considered to be the most "natural" grazing method available.

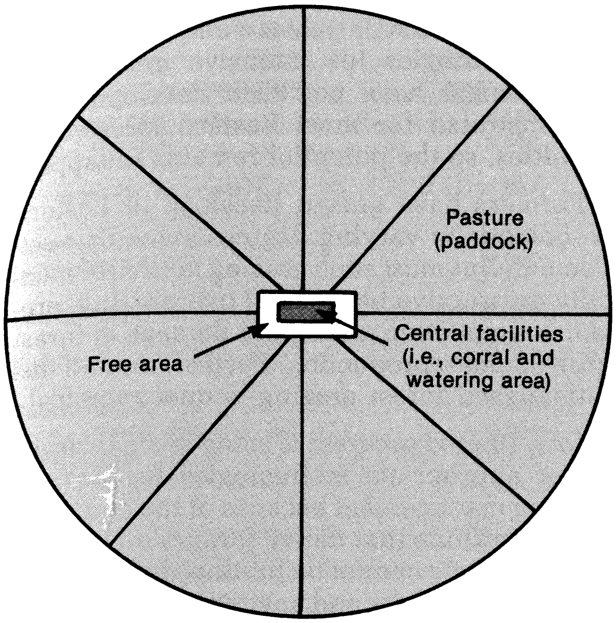
Because SDG entails frequent movement of stock and high stocking rates, ranchers must take precautions to minimize animal stress. Livestock under stress can suffer low conception rates, nutritional difficulties with weaning, and poor summer weight gains. One to reduce stress is to reward the livestock moving between sites. In a Pavlovian proach, the cattle can be trained to associ extra food with some stimuli, such as a h or call, that occurs before changing cells. Ev tually the livestock will lose their apprehens and will move without the extra reward.

The SDG systems might be most attracti to larger ranches with the reserve capi necessary to invest in adequate fencing a facilities. Larger operations, too, would be ab to absorb the short-term reductions in sales th might come with the transition to higher stock ing rates. This transition period can tak several years, depending on the size of th system and characteristics of the ranch.

Proponents of the technology claim that th increase in livestock carrying capacity ca occur without harming the range ecosystems, either plantlife or wildlife. Unfortunately, there is a paucity of research data to allow an objective assessment of these management strategies. There is some concern that high stocking rates could damage certain soils during wet periods. If excessive compaction does occur in those situations, this negative impact should be weighed against the previously mentioned claims of beneficial impacts from trampling.

In terms of technology diffusion, SDG is in the early stage of adoption in this country. One type of SDG, the Savory grazing method (SGM), for example, was only introduced to the United States 3 years ago, although it has been used abroad for a decade. SGM, sometimes called the "cell system," arranges pastures in a cartwheel design, with watering and handling facilities in the hub (see fig. 10). Livestock are herded through the various cells according to a management plan that accommodates site variables in each cell. In preparing a SGM plan, the rancher notes his particular needs (e.g., pastures for breeding, birthing, weaning, etc.) and notes which cells will be unavailable at any time for any reason. For instance, the rancher may want to avoid having his heifers in close proximity to a neighbor's bull or too near recently planted crops. Or he may wish to keep

Figure 10.—Cartwheel Pasture Arrangement Used in the Savory Grazing Method



SOURCE: Office of Technology Assessment.

livestock out of certain cells when they are expected to harbor poisonous plants or during breeding season for ground-nesting birds.

The SGM system purports not only to protect the land but actually to enhance it. According to proponents, the physical impact of livestock hooves has two interrelated beneficial effects, if properly managed. First, livestock hooves churning the soil surface can break up any crust formed by the impact of raindrops and runoff. This reduces erosion. Also, as more rainfall penetrates the soil, more moisture is available for plant roots and for replenishing ground water supplies.

This method, developed in East Africa, is beginning to receive relatively rapid acceptance among U.S. ranchers. However, American range scientists are only just beginning to investigate the system's constraints and potentials. Thus, many questions about the method's impacts, both good and bad, remain to be answered. The following discussion answers some of these questions from the view of the developer of SGM (Savory, 1981).

1. **Who can use SGM?** Theoretically, any rancher could apply this method on his own without assistance. But in practice, SGM differs greatly from conventional range management and is also, because of its flexibility, quite complex. Accordingly, many who have tried it without prior training have had considerable difficulty. Under the guidance of private range consultants, increasing numbers of U.S. ranchers are succeeding with the methods. The agricultural educational community could be trained to provide this instruction. In fact, together with inadequate data on its effective use, the lack of a trained cadre of instructors is the major barrier to the system's adoption.
2. **Are some soils unsuited to SGM?** Certain soils may be particularly susceptible to compaction when wet. Other than this possible limitation, SGM has been used on many soil types without ill effects. To avoid compaction, ranchers must plan, insofar as possible, to use pastures only when they are relatively dry.

   Some desert margin soils may also have problems under SGM. Even brief periods of livestock trampling seem to promote the growth of undesirable runner grass communities in small areas—typically 20 to 30 yards in diameter—where the soil is most disturbed.
3. **Can SGM be used on steep terrain?** Adapting SGM to steep terrain may call for special layouts and fence arrangements. The usual rule of thumb, however, is that if other range management methods can be used on the mountainous land in question, so can SGM.
4. **What are typical installation costs for an SGM grazing system?** It is impossible to generalize because construction costs are site specific. As an example, the cost of a grazing cell system, installed as part of a whole ranch development near Midland, Tex., was $4.80 an acre, including expenses for water, fencing, and labor. In the 2 years since the system began operating, its stocking rate has more than doubled and survived the 1980 drought at that increased rate.
5. **Does SGM require a great deal of paperwork?** These systems require more advance

planning and recordkeeping, but the paperwork burden is reduced as the ranchers become practiced in the use of the special recordkeeping systems.

6. **When a grazing system has only one watering point and that point is a natural stream, pond, river, or lake, is there danger of serious riparian damage?** Although more work needs to be done on this question, proponents of SGM maintain that riparian damage can be avoided by designing the system so that cattle use only part of the watering source at a time, and then for just a limited period.
7. **Is the fencing necessitated by a full-blown application of SGM detrimental to wildlife?** Fencing in any range management scheme can be detrimental to wildlife, but these effects can usually be limited by using simple three-strand fences that allow most wild species to jump over or crawl under them without injury. In addition, game gates sited on SGM fence lines may be left open when domestic stock are not in the paddocks served by the gates. This facilitates wildlife movements. These systems count good wildlife management as an asset to the rancher because it can have economic as well as esthetic benefits.

Grazing Potential for Eastern Woodlands*

Introduction

If properly managed, Eastern forests could provide substantial increases in economically and environmentally sound livestock grazing. The 310 million acres of forests in the East could support as much as 20 million AUs of forage (an AU is the forage required to support a cow and a calf for 1 year) if the land were intensively* managed for multiple purposes (Byington, 1980). Under less rigorous, extensive** management, potential forage is only about 1 million AUs (tables 8 and 9). However, the technologies for intensive multiple-use management have not been developed and demonstrated for most Eastern forest communities, so the potential remains untapped.

Farmers have grazed livestock in Eastern woodlands to varying degrees since first settlement. But most such grazing is environmentally destructive because of overgrazing, erosion, compaction, and other damage to forest growth and reproduction. Further, most of this unmanaged forest grazing is uneconomical.

Only limited progress is being made in developing appropriate technologies for Eastern grazing management because of the commonly held attitude that native forages on Eastern forests simply cannot be produced and grazed in an economically and environmentally sound way.

Current Use

The Eastern United States is blessed with abundant rainfall, adequate growing seasons, and good soils needed to produce abundant vegetation. Most forage in the East comes from intensive crop and pasture management on cleared land, either from growing forage crops as part of a crop rotation or from allowing livestock to graze on residues and stubble left after harvest. Native grazing lands, those forests and grasslands with naturally occurring vegetation suitable for livestock grazing, are of secondary importance.

It is difficult to judge the current extent of grazing in Eastern forests because of problems

*The Eastern United States is defined here as that area east of the 97th meridian. This basically excludes the Great Plains States but includes the forests in Oklahoma and Texas.

*"Intensive management" makes investments in technologies and practices to maximize production, quality, and use of native forages while maintaining the forest for wood products, wildlife, and recreation.

**"Extensive management" controls livestock numbers with little effort to achieve planned distribution of livestock or to increase carrying capacity through alterations of the forest canopy. Management investments are made only to protect the land from damage.

Table 8.—Estimated Potential of Major Forest Communities to Produce Livestock Forage Under Extensive and Intensive Management—Northern Region

Potential natural community	Total grazable acres (000's)	Average potential production (total AU): Extensive management	Average potential production (total AU): Intensive management	States in which community is primarily located
Great Lake spruce-fir	5,503	7,673	91,581	Minnesota, Wisconsin
Great Lake pine	5,660	13,217	112,426	Michigan, Minnesota, Wisconsin
Northeastern spruce-fir	11,934	31,838	646,478	Maine, New Hampshire, New York, Vermont
Northern floodplain	2,518	32,029	158,547	Minnesota
Maple-basswood	1,690	0	122,693	Illinois, Iowa, Minnesota, Wisconsin
Oak-hickory	14,310	146,536	890,662	Iowa, Illinois, Indiana, Michigan, Montana, Ohio
Elm-ash	18,556	0	1,650,284	Indiana, New York, Ohio, Pennsylvania
Beech-maple	1,448	1,206	125,452	Michigan, Ohio
Mixed mesophytic	5,039	0	132,520	Ohio, West Virginia
Appalachian oak	15,309	0	424,419	Connecticut, Massachusetts, Maryland, New Jersey, New York, Ohio, Pennsylvania, Rhode Island, West Virginia
Northern hardwoods	38,665	34,921	2,596,887	Massachusetts, Maine, Michigan, New Hampshire, New York, Pennsylvania, Vermont, Wisconsin, West Virginia
Northern hardwoods-fir	7,891	0	511,218	Michigan, Wisconsin
Northern hardwoods-spruce	10,421	43,370	334,452	Maine, New Hampshire, New York, Vermont
Northeastern oak-pine	1,471	31,209	88,817	Massachusetts, New Jersey, New York
Oak-hickory-pine	3,587	8,528	305,214	Delaware, Maryland, Montana, West Virginia

SOURCE: Evert K. Byington, "Livestock Grazing on the Forested Lands of the Eastern United States," OTA background paper, 1980.

Table 9.—Estimated Potential of Major Forest Communities to Produce Livestock Forage Under Extensive and Intensive Management—Southern Region

Potential natural community	Total grazable acres (000's)	Average potential production (total AU): Extensive management	Average potential production (total AU): Intensive management	States in which community is primarily located
Oak-hickory	32,113	294,369	1,846,497	Alabama, Arkansas, Kentucky, Mississippi, Oklahoma, Tennessee, Texas
Mixed mesophytic	5,203	0	169,097	Alabama, Kentucky, Tennessee
Appalachian oak	20,788	0	415,760	Georgia, North Carolina, South Carolina, Tennessee, Virginia
Oak-hickory-pine	71,069	59,224	6,573,882	Alabama, Arkansas, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia
Southern mixed	24,801[a]	413,350	1,972,360	Alabama, Florida, Georgia, Louisiana, Mississippi, Texas
Southern floodplain	25,607	21,339	832,227	Arkansas, Louisiana, Mississippi, Tennessee

[a]About 2 million acres of total are not suitable for intensive management.

SOURCE: Evert K. Byington, "Livestock Grazing on the Forested Lands of the Eastern United States," OTA background paper, 1980.

of definition and classification of land use and land type among the three primary agencies that collect such information. The Forest Service, Soil Conservation Service, and Department of Commerce conduct some inventories of livestock grazing in Eastern forests, but the information is limited and inconsistent. Estimates vary from the Forest Service's high figure of 100 million acres of grazed Eastern forest to Census of Agriculture statistics that indicate only 26 million grazed forest acres. The inconsistency is partly because the latter estimate considers only a certain class of forest owners.

Ownership is an important factor in the use of forests for livestock grazing. Generally, four classes of ownership are considered: public, forest industry, farmer, and other. Farmers throughout the East graze livestock in a higher percentage of their forests than other classes of owners (Byington, 1980).

Overall, forest grazing has declined in recent years. The Soil Conservation Service's conservation needs inventory of 1967 estimated that over 80 million acres of forest in the East were being grazed. The 1977 National Resource Inventories by the same agency estimated that only 36 million acres were then being grazed. The decline, however, is not because of any increasing unwillingness among farmers to graze their woodlands; it is, in large part, caused by the changing pattern of landownership. During the past 25 years, the area of forests owned by farmers dropped 35 percent, though the tot area of forest in the East remained relativel stable (table 10). Nearly 55 million acres forests passed from farmers' hands, much it into other private holdings less amenable t grazing (Byington, 1980).

History

Throughout the East, native grazing lands played an important role in settlement. The forests and prairies provided inexpensive forage to support livestock used for food, transportation, and animal power for tillage. However, there are major ecological and cultural differences between the northern and southern halves of the Eastern United States that have affected the acceptance of woodland grazing.

During the late 1800's and early 1900's, timber industries denuded large acreages in the East and conflicts between cattle and lumber interests increased. By the 1920's and early 1930's, the Federal Government became increasingly concerned with land use, particularly on the cutover lands in the South. The National Forest System in the South was established, and research began on the interactions between forestry and livestock.

In the Southern pines region, cattle were seen as an opportunity to bring clearcut forestland back into production. But in the Northern hardwoods, grazing was observed to damage

Table 10.—Area, Including Change Over Time, of Commercial Timberland in the Eastern United States, by Ownership, Region, and Section, and for the years 1952 and 1977

	1952		1977		Percent change in forest area, 1952-77	
Region and section	All ownerships (000's of acres)	Farm ownerships (000's of acres)	All ownerships (000's of acres)	Farm ownerships (000's of acres)	All ownerships	Farm ownerships
Northern region	167,768	64,567	169,353	44,431	1.0	−31
New England	30,936	7,842	31,015	2,391	0.3	−70
Middle Atlantic	42,099	15,114	48,215	10,013	15.0	−34
Lake States	51,838	14,227	49,356	11,345	−5.0	−20
Central States	42,895	27,384	40,767	20,682	−5.0	−24
Southern Region	192,083	91,311	188,433	57,217	−2.0	−37
South Atlantic	46,963	31,937	47,677	19,016	1.5	−40
East Gulf	42,104	23,134	40,142	11,006	−5.0	−52
Central Gulf	49,497	21,198	51,045	18,016	3.0	−15
West Gulf	53,519	15,042	49,569	9,179	−7.0	−39
Total	359,851	155,878	357,786	101,648	−0.6	−35

SOURCE: Adapted from table 2, "Forest Statistics of the U.S., 1977," Forest Service, USDA, 1978.

the forest, so research was oriented toward documenting livestock impacts. The results of various experiments and observations led to a near-universal conclusion that grazing was necessarily detrimental to Northern forests and was not economically worthwhile. This split in research approach is still visible.

Conservation in Grazed Forests

Table 11 is a summary of non-Federal acres of forest being grazed and thought to require conservation treatment in 1967 and 1977. Two types of conservation treatments are recommended: 1) to reduce or eliminate livestock grazing, and 2) to maintain grazing but improve forage production. Reducing or eliminating grazing is the most recommended practice in the Northern region, while increasing forage production is more often recommended in the South.

Most of the recommended conservation treatments are directed at reducing erosion by maintaining adequate ground cover. Table 12 contains summaries of erosion by land capability class and land use and by the area being grazed. This indicates that a considerable amount of erosion is caused by livestock grazing in woodlands, particularly on land classes V-VIII.

Technologies for Multiple-Use Management of Forest Grazing

Multiple-use management offers the best opportunity for expanding the production of both wood and forage in Eastern forests. The most basic technology used for grazing lands is the management of grazing animals. The technologies needed to develop the forage/livestock systems in forests include:

- Technologies to manage livestock use of native forages that ensure: 1) livestock health and productivity is adequate, 2) the vigor of the plants is maintained, and 3) other resources are not damaged. These technologies include grazing systems, controlling season of use, managing stocking rates, selection and mix of grazing animals, use of feed supplements, and construction of physical structures (fencing, water development, etc.).
- Technologies to improve forage productivity and quality and to increase output per acre to get adequate economic returns or to restore vegetation on damaged land. Technologies include seeding with improved plant species; fertilization; water development; use of mixtures of cool- and warm-season plant species, as well as shade-tolerant species in forests; and the

Table 11.—Area of Forestland in the Eastern United States Being Grazed by Livestock, Including Area Requiring Conservation Treatments

		1977 NRI		
		Acres of grazed forest requiring conservation treatment		
Region and section	Acres of forest grazed (000's)	Reduce or eliminate grazing (000's)	Improve forage (000's)	Percent of grazed forestland requiring conservation treatment
Northern region	13,130	8,236	3,533	90
New England	231	81	59	61
Middle Atlantic	1,870	1,418	210	87
Lake States	3,264	2,051	753	86
Central	7,765	4,686	2,511	93
Southern Region	22,967	6,081	10,239	71
South Atlantic	2,318	962	553	65
East Gulf	4,346	824	2,209	70
Central Gulf	5,549	2,283	1,400	66
West Gulf	10,754	2,012	6,077	75

SOURCE: Derived from "Basic Statistics: 1977 National Resource Inventories (NRI) revised 1980."

Table 12.—Average Sheet and Rill Erosion Rates in Crop Production Regions[a] of the Eastern United States in 1977 (non-Federal land only)

Region and capability groupings	Erosion by land use (ton per acre)					
	Ungrazed forest	Grazed forest	Cultivated	Hay	Pasture	Range
Northeast						
Classes I-IV......	0.27	1.42	6.33	0.79	0.96	—
Classes V-VIII....	0.54	4.60	11.75	1.27	3.79	—
Lake States						
Classes I-IV......	0.06	1.14	2.81	0.54	0.82	0.05
Classes V-VIII....	0.39	12.42	6.94	2.65	2.74	0.44
Corn Belt						
Classes I-IV......	0.66	5.47	7.56	1.72	2.43	0.37
Classes V-VIII....	1.94	11.42	29.60	4.20	9.18	—
Appalachian						
Classes I-IV......	0.26	2.52	9.12	1.56	1.65	—
Classes V-VIII....	1.90	7.26	46.13	8.06	10.65	—
Southeast						
Classes I-IV......	0.16	0.53	6.95	0.38	0.47	0.27
Classes V-VIII....	0.63	1.41	16.42	0.86	1.30	0.36
Delta						
Classes I-IV......	0.18	1.56	6.86	0.78	1.33	1.90
Classes V-VIII....	0.99	8.54	28.35	5.09	9.20	4.51
Southern Plains						
Classes I-IV......	0.10	0.45	3.41	0.76	0.97	1.00
Classes V-VIII....	0.71	1.62	4.58	0.44	2.15	5.22

[a]Geographic regions and land capability groupings are as defined by the Soil Conservation Service.

SOURCE: USDA 1980. "Table 172" in Basic Statistics, 1977 National Resource Inventories, revised 1980.

use of livestock, chemicals, fire, and machines to control unwanted plant species.

- Technologies to manage the interactions of forage plants and livestock with other land uses so as to reduce conflicts and maximize overall output of goods and services. Such technologies often involve tradeoffs between uses and depend on the judgment of the land manager. For example, the tree canopy limits light and water flow to the soil, and thus forage production. Opening up the tree canopy will increase forage production but may reduce overall production of wood. Success in selecting a technology to manage such interactions depends on the availability of knowledge about how each resource will respond, so that tradeoffs can be estimated and evaluated.

Conclusions

The grazing potential of the Eastern forest is a resource that has not been considered of sufficient value to develop and manage with appropriate technologies. Forest production in the East is based primarily on a philosophy of single dominant use, and although farmers use their woodlands for grazing, it is at a low level of management which typically is neither economically nor environmentally sound. Because few techniques for intensive management have been developed except in the Southern pine forest, the forest owner has little choice except to manage for wood products, sell the land, or clear the forest to establish pasture.

Over 50 million acres of forested land have passed from farm ownership in the last 30 years. With increasing land values and higher taxes, farmers have often found that they cannot afford to keep forests for either woodland grazing or production of wood products. The future of these lands will depend on how the mix of economic and social factors changes the value that is placed on the various resources these forests can supply. Intensive management of forest lands to produce both wood products and livestock forage may make it profitable for farmers to retain their farm forests.

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Chapter IV

Croplands

Photo credit: U.S. Department of Energy

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Chapter IV

Croplands

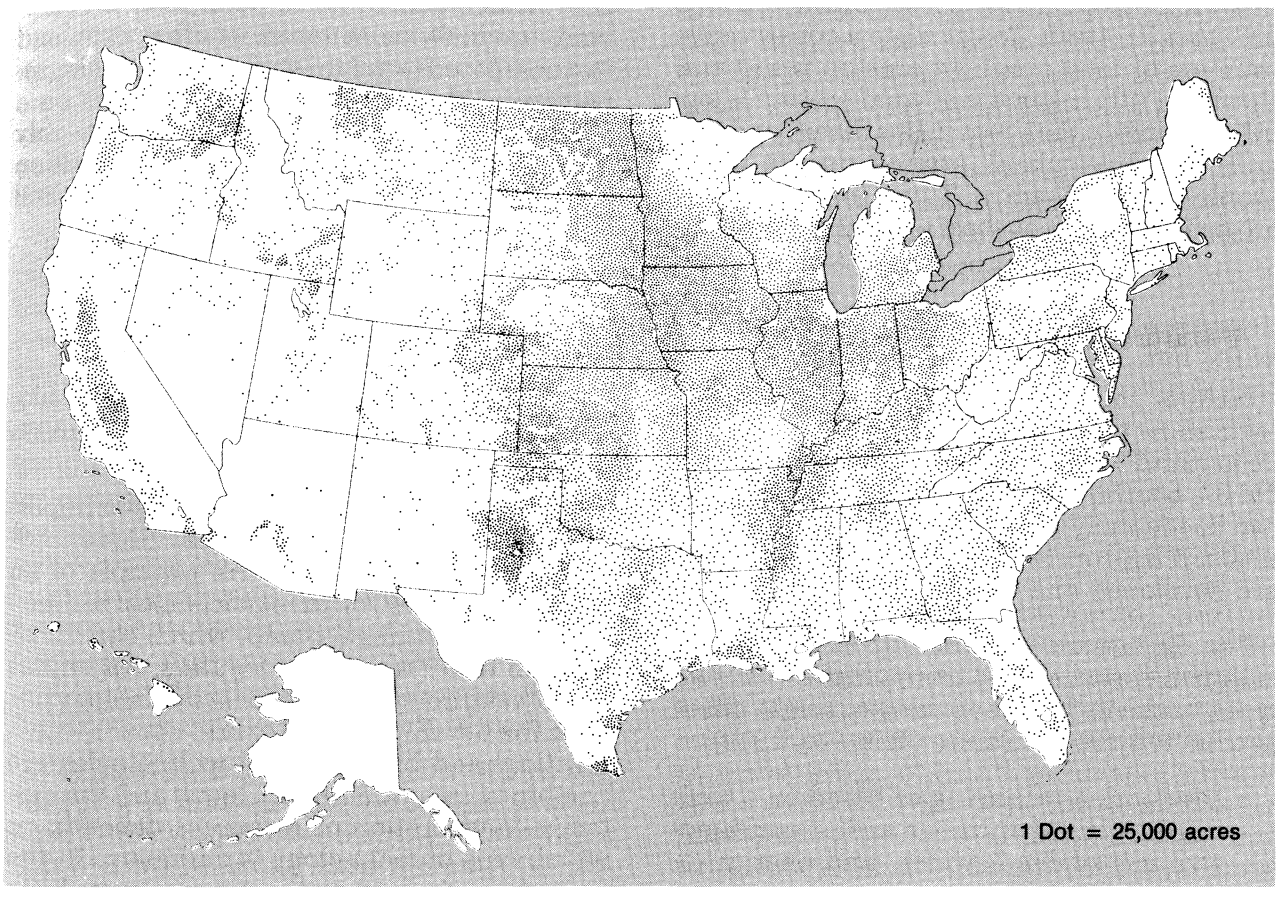
INTRODUCTION

There are about 413 million acres of cropland in the United States (excluding Alaska), including about 230 million acres of prime farmland (see fig. 11). Generally, prime lands are those with extremely desirable characteristics for growing crops, including good soil, moisture, climate, drainage, and slope. These attributes make prime land the most efficient and environmentally stable lands for food production.

Another 115 million acres of cropland classified as prime were not used for crops when the National Resource Inventories (NRI) data were collected in 1977. Forty-two million acres of this were forest, 23 million were rangeland, and 40 million were pasture (CEQ-NALS, 1981). The 1982 NRI are expected to show that some of this land has since been put into crops.

Soil Conservation Service (SCS) experts estimated that 127 million acres of noncropland in the United States had high or medium potential to be converted to cropland as of 1977. As discussed previously, this land is generally more susceptible to erosion than croplands

Figure 11.—Cropland Acreage



SOURCE: U.S. Department of Agriculture.

already in use. Some of this land is productive forage and timberland, so conversion to agriculture would mean the loss of those products. On the other hand, about 23 million acres of agricultural land were converted to nonagricultural uses between 1967 and 1974—a rate of nearly 3 million acres a year. Of the 3 million acres taken out of crops each year, about 675,000 acres were prime farmland (CEQ-NALS, 1981).

Technologies discussed in this chapter are designed to sustain or enhance production while reducing erosion, the greatest threat to the Nation's land resource. Sheet and rill erosion totaled about 2 billion tons of soil in 1977, the only year for which accurate data are available. Data on wind erosion are available only for the 10 Great Plains States, where this problem is most severe. Wind erosion in those States, which comprise 40 percent of the Nation's total cropland area, was 892 million tons (USDA-NRI, 1980). To calculate a conservative estimate of total cropland erosion (wind and sheet and rill), assume that wind erosion is significant *only* in the Great Plains States, and that gully and streambank erosion do not affect cropland significantly. Thus, total cropland erosion is the sum of sheet and rill erosion plus Great Plains wind erosion, or 2.8 billion a year. This is an average of 7 tons per each year for the Nation's total 413 mi cropland acres.

Information about soil formation rates un cropland conditions is inadequate, but highest likely rate on unconsolidated par materials is probably 0.5 ton per acre. The r is much slower for consolidated mater (rock). Thus, average soil erosion is more th 10 times greater than average soil format on U.S. croplands (Hall, et al., 1982; McC mack, et al., 1982).

Although erosion occurs to some extent all cropland, it is much worse in some are than in others. The severity of erosion vari depending on the type of crop grown, the ma agement system used, terrain, climate, a other factors. Row crop and small-grain cro land, which constitute 75 percent of all cro land, erode twice as much as other croplan (5.4 compared to 2.5 tons). Further, a high pr portion of the Nation's soil loss occurs on relatively small portion of the cropland—on 6 percent of the Nation's cropland (24 millic acres) accounted for 43 percent of all sheet ar rill erosion.

PRODUCTIVITY-SUSTAINING TECHNOLOGIES FOR CROPLANDS

Neither empirical evidence nor compelling logic show that agricultural production has to be harmful to the quality of the land resource. On the contrary, production and conservation can be mutually reinforcing, even on marginal lands, if appropriate production technologies are developed and used.

For discussion purposes, it is possible to categorize agricultural technologies into two types to clarify how technologies might affect productivity in the future (Wittwer, 1980):

- production technologies based on a high degree of mechanization and on consumptive use of land, water, and energy resources; and
- production technologies based on bio logical approaches that use land, water and energy resources efficiently.

Both types of technologies have been impor tant in the revolution that has made U.S agriculture so productive. An example of an important breakthrough in mechanical technology is the centrifugal pump, which can lift irrigation water from deep aquifers. An important breakthrough in biological technology has been the development of hybrid corn. Mechanization- and biology-based technologies are combined in agronomy systems, and the system's consumption of resources depends on which type of technology is dominant. In the United States, land and water resources have

been abundant and energy resources cheap, so development has been dominated by resource consumptive technologies. In regions with fewer natural resources, such as Japan and parts of Europe, agronomic systems are dominated by land- and water-sparing biological technologies.

Wittwer foresees a shift in American agronomy to the resource-sparing biological technologies. This shift implies changed objectives in technology development and promotion. Now that land, water, and energy are no longer so abundant or so cheap, changes have begun to occur. Rapidly increasing prices for fuel and agricultural chemicals have stimulated development of new machinery, chemicals, and cropping systems to make the capital inputs more efficient. Using newly designed machines, farmers can till less frequently, and so use less fuel, while maintaining production. They must use more herbicides, but other new machines enable them to use the chemicals more efficiently. New biological technologies are developing more slowly, but in the long run, these are expected to be the basis of important improvements in agronomic systems (OTA, 1979).

To develop resource-sparing systems, agricultural scientists will have to rely heavily on the potential inherent in the world's genetic resources. Genetic selection to produce high yields continues to be important, but much more attention will have to be given to how genetic types vary in their ability to use the fertility of soils efficiently. Improved strains of the major crops will probably dominate the genetic work for decades, but these are unlikely to suffice for sustaining productivity on the driest, most steeply sloping, and otherwise most fragile croplands. Development of currently underexploited crops, new crop systems, and improved symbiosis with soil microbes will be necessary to sustain productivity of such sites.

This chapter describes a number of new and emerging technologies for agricultural production. These are resource-sparing technologies that are designed and used not only for production but also to maintain inherent land productivity. **But no technology is a panacea; all are site specific in their design and application. The new technologies generally require more sophisticated management than the resource-consuming technologies they would replace. And they will take time to implement.**

The technologies described here are in various stages of development, ranging from the early research stage (e.g., polyculture of perennial plants) to the rapid adoption stage (no-till farming). A brief review of common, current conservation technologies is also included. All these approaches have drawbacks, though these often are inadequately documented. For example, no-till agriculture relies heavily on pesticides, and possible negative impacts on soil biota and water quality may offset some of the technology's erosion control benefits. Other problems can result if a new technology is misapplied. This can prematurely discourage other farmers and ranchers from trying the technique. Such misapplication can happen when a complex technology is adopted by farmers or ranchers more rapidly than it is learned by the extension agents, university faculties, Government scientists, or private consultants from whom the innovative farmers and ranchers seek advice.

The new resource-conserving technologies, however, are not being developed and implemented rapidly enough to prevent lasting damage to inherent productivity of the Nation's croplands and rangelands. Such damage has occurred already and is continuing where processes such as accelerated erosion and ground water overdraft are mining resources. Thus, the pertinent question is: Will such technologies be developed, improved, and implemented in time to preserve enough of the land's inherent productivity to assure adequate sustained production to satisfy consumer needs? The answer depends on who the consumers are (e.g., only U.S. residents v. anyone in the world who can pay), how needs are defined (e.g., what level of pollution is acceptable), the extent of application of conventional conservation technologies, and other factors.

From the more narrow point of view of this technology assessment, whether new technologies will be implemented soon enough depends largely on the institutions responsible for developing and promoting agricultural technologies. Will they invest in screening, testing, and developing production technologies that have resource conservation as a primary objective? The institutions (e.g., agricultural experiment stations, agriculture schools in universities, the Federal Agricultural Research Service) seem to be conservative regarding investment in new technologies. There is a rationale for that conservatism: It is based mostly on the fact that agricultural research and development funds are severely limited. If funds remain limited, some institutional changes may be needed to ensure adequate development of new resource-sparing technologies and farming systems.

This report could include only some of the promising technologies for preserving inherent land productivity. Those selected hold great promise, but there are others available that might achieve the same ends. For example, drip irrigation is a proven technology for reducing irrigation water consumption, but other technologies may be more cost effectiv more conserving of water and other resou depending on specific local farming co tions. The following discussion is not inten to recommend any particular technol Rather, it is to illustrate some of the tech ogies that are designed to enhance produc and conservation at the same time.

Conservation Tillage

Spraying More, Tilling Less

Prior to the development of chemical h bicides in the 1940's, farmers relied on a vari of tillage practices to control unwanted pla (weeds) in their fields. It was not uncomm for Midwestern corn farmers to make as ma as 10 trips across their fields before harve most of them to control weeds (Triplett a Van Doren, 1977).

Today, most producers of the major fiel crops have substituted herbicides for some their tillage practices. Table 13 illustrates th magnitude of increase in herbicide use b tween 1966 and 1976 for the crops grown o most of the total U.S. cropland base. In eve

Table 13.—Percentage of Crop Area Treated With Pesticides (active ingredients) and Percentage of Pesticides Used on Crops in the United States, 1976

Crop	Herbicides		Insecticides		Fungicides		All pesticides[a]		
	Percent area treated	Percent of total herbicides used	Percent area treated	Percent of total insecticides used	Percent area treated	Percent of total fungicides used	Percent area treated	Percent of total pesticides used	Area planted million acres
Major crops									
Corn	90	53	38	20	1	NA	92	37	84.1
Cotton	84	5	60	40	9	NA	95	14.5	11.7
Soybeans	88	20	7	5	3	<0.5	90	14	50.3
Peanuts	93	1	55	1	76	16	99	2	1.5
Sorghum	51	4	27	3	—	NA	58	3	18.7
Tobacco	55	<0.5	76	2	30	<0.5	97	3.6	1.0
Rice	83	2	11	<0.5	—	NA	83	1	2.5
Wheat	38	6	14	4	1	2	48	4.6	80.2
Other grain[b]	35	1	5	1	2	NA	41	1	29.8
Alfalfa and other hay	2	<0.5	7	4	—	NA	8	1	61.0
Pasture and rangeland	1	2	<0.5	<0.5	—	NA	2	1	488.2
Other crops[c]	67	5	79	20	44	81	NA	16	10.9
All crops	23	100	9	100	1	100	NA	100	839.9
Total usage, million lb		394.3		162.1		43.2		649.8	

— None reported.
NA Not Available.
[a]Includes miticides, fumigants, defoliants and dessicants, and plant growth regulators.
[b]Includes oats, rye, and barley.
[c]Includes potatoes, other vegetables, fruits, and other minor crops.

SOURCE: USDA, *Farmers' Use of Pesticides in 1966, 1971, and 1976,* Agricultural Economic Report Nos. 179, 252, and 418, Economics, Statistics, and Cooperatives Service, USDA, Washington, D.C., 1970, 1974, 1978.

case, the total quantity of herbicides used, the amount of land on which they were used, and the amount of herbicide (active ingredient) applied per treated acre have increased markedly. For example, the amount of herbicide applied per acre of treated corn increased by 125 percent between 1966 and 1976. Over this same period the herbicide application rates for cotton went up 58 percent; for wheat, 40 percent; for soybeans, 80 percent; and for all other crops, 75 percent (Eichers, 1981). And this herbicide was being applied to many more acres. In 1978, 90 percent of the corn acreage was treated with herbicides, as was 84 percent of the cotton acreage, 88 percent of the soybean acreage, and 38 percent of the land in wheat (Harkin, et al., 1980).

Reliable national data do not exist on the number of acres tilled by various methods nor on the average number of tillage passes made with the wide variety of equipment available. But there is general agreement among experts that the types of tillage equipment employed, and the extent to which tillage is used, have been undergoing considerable change.

This makes it difficult to characterize a particular tillage system as "conventional." The conventional is continually changing. In the scientific literature, conventional tillage most commonly means plowing (in fall or spring) with a traditional moldboard plow, then using a disk, harrow, or other implements to break up soil clods, smooth the seedbed, and destroy weeds. But a 1978 survey in Illinois shows that approximately 56 percent of the corn and soybean acreage is no longer moldboard-plowed; most of this acreage is chisel-plowed or disked (Larson, 1981).

The chisel plow is the primary tool of conservation tillage. It is a series of curved, sprung, steel shanks that have points or "sweeps" spaced 18 to 30 inches apart. The chisel plow disturbs less surface soil and leaves a great deal more crop residue on the surface than does a moldboard plow (which cuts to the same depth but turns over all of the soil in its path). Table 14 illustrates the effect of implements on the quantity of surface residues—residues which help retain moisture, reduce runoff and erosion and provide a barrier to the erosive effects of wind.

Conservation Tillage and No-Till: Descriptions

A bewildering variety of definitions, descriptions, and synonyms exists for conservation tillage. For example, the term "reduced tillage" is sometimes used interchangeably with conservation tillage. But reduced tillage may mean merely that a farmer who previously made 10 to 12 passes over his field in the course of a season now, perhaps in response to higher fuel costs, makes only 8 to 10. The farmer may still be using the moldboard plow, may be plowing under or removing his crop residue, and may therefore not be mitigating erosion on his land.

There are three characteristics that distinguish conservation tillage:

Table 14.—Effect of Tillage Operations and Time on the Quantity of Surface Residues, Flanagan Silt Loam, Fall 1971-Spring 1972

	Corn residues on soil surface (t/a)[a]					
Tillage system	Nov. 3	Nov. 11	April 19	May 3	June 12	June 16
1. Fall chop & moldboard plow	2.76	0.00	0.00	0.00	0.00	0.00
2. Fall disk & twisted chisels	2.76	2.28	2.18	1.31	1.51	1.43
3. Fall coulter & twisted chisels	2.76	2.19	1.43	1.09	1.67	2.08
4. Fall chop & straight chisel	2.76	0.78	0.49	0.86	0.96	0.79
5. Spring chop and moldboard plow	2.76	2.76	2.73	0.00	0.00	0.00
6. Spring chop & disk	2.76	2.76	2.73	0.98	1.63	1.68
Effect due to	Initial stalk cover	Fall tillage. Wind action	Decomposition over winter	Spring tillage and planting	Application of NH_3	Cultivation

[a]Tons per acre.

SOURCE: Unpublished data, Departments of Agricultural Engineering and Agronomy, University of Illinois.

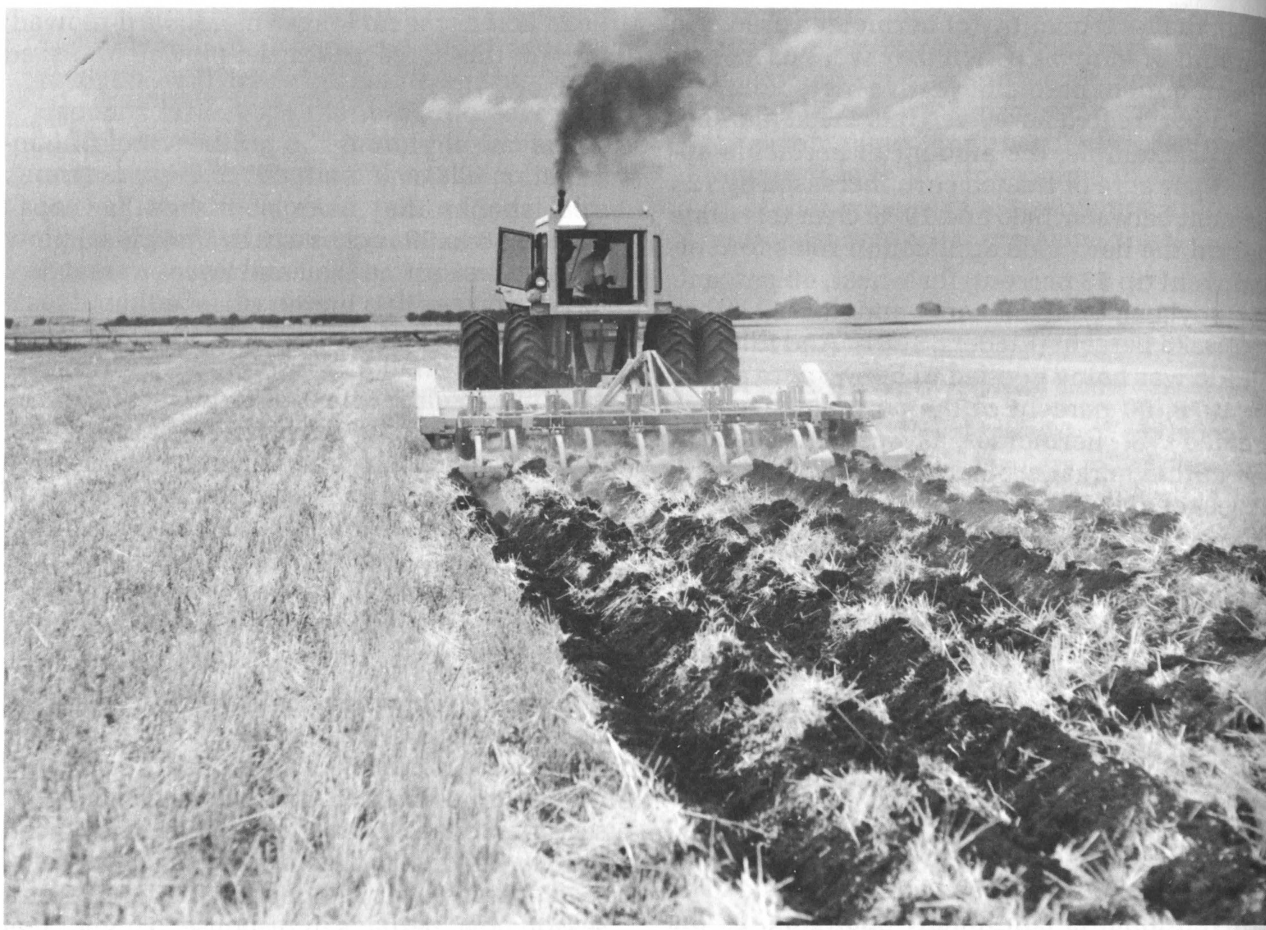


Photo credit: USDA—Soil Conservation Service

A chisel plow and stalk chopper on a Minnesota farm keep old crop residue on or near the surface. This helps keep soil from washing or blowing away

1. *Conservation tillage uses implements other than the moldboard plow.*
2. *Conservation tillage leaves residues on the soil surface to mitigate erosion and to help retain moisture.* The amount of residue retained depends on the type of tillage implement, its manner of use, and the crop. Different crops naturally have different amounts of residue available for postharvest retention.
3. *Conservation tillage depends primarily on herbicides for weed control.*

Together, these concepts provide a useful description of conservation tillage. But it still includes a broad array of tillage implements including chisel plows, subsoilers (V-sweeps, sweeps, rodweeders), one-way disks, field cultivators, mulch treaders, strip rotary tillers, different types of no-till planters (sometimes called "zero" or "slot" till planters), and special modified planters that accommodate the more rigorous conditions often encountered under conservation tillage.

These and other conservation tillage implements vary considerably with respect to the amount of residue they leave on the soil surface (from 5 percent for rotary rodweeders to 100 percent for no-till planters) (Fenster, 1973), and, therefore, their capacity to conserve soil and water varies, as well. In addition, certain

systems are preferred in different regions. For instance, subsoilers are widely used on the southern coastal plain and no-till planters are used mainly in eastern Nebraska, eastern South Dakota, and western Iowa. The goal of these implements is to conserve fuel, labor, soil, and water. Their capacity to achieve these savings is highly variable. Systems or even specific tools that perform well in one region often are impractical in others. Because the concept of conservation tillage embraces so many different techniques, it is difficult to make a general assessment of its impact on current yields, farm profits, or long-term land productivity. This is particularly true because reliable data on the acreage do not exist, even for the more widely used of these techniques.

Major conservation tillage methods include:

- *Strip tillage.*—Seedbed preparation is limited to a strip one-third or less of the distance between rows. A protective cover of crop residue remains on the balance. Tillage and planting are completed in the same operation.
- *Till plant.*—Seedbeds are prepared with plowing and planting in one operation. Crop residues are mixed into the soil surface between rows.
- *Chisel planting.*—Seedbeds are prepared by chisel plowing. Some crop residue is left on the soil surface; some residues are mixed in the top few inches of soil. Seedbed preparation and planting may, but need not, be accomplished in the same operation.
- *Disk planting.*—Seedbeds are prepared by disking the soil, leaving a protective cover of crop residue on the surface and some residue mixed in the top few inches of soil. Seedbed preparation and planting may, but need not, be accomplished in the same operation.
- *Zero tillage, slot planting, or no-till.*—Planting disturbs only the immediate area of the row. Crop residue is left on the surface for erosion control.

In this report, no-till is considered separately from conservation tillage whenever possible. No-till is an extreme form of conservation tillage where the new crop is seeded directly into existing crop residue. A special planter is used that slices a minimal trench or slot through the residue into which seeds are dropped. No other soil manipulation is necessary. Weeds are controlled with herbicides, crop rotations, and plant competition (Giere, et al., 1980). Again, the lack of a precise and commonly accepted definition, along with a paucity of data on the extent of no-till use, hampers evaluations of its current and potential effects on inherent land productivity.

Adoption of No-Till and Conservation Tillage

RATES OF ADOPTION

Two sets of national time series data exist on conservation tillage, one from SCS, the other from surveys of State agronomists or other officials conducted by the private sector journal *No-Till Farmer.* The former has been collected since 1963, the latter since 1973. Table 15 shows how divergent the two sets are. Both are based on surveys of experts, rather than on physical measurements, so the estimates are rough at best. For discussing past trends and for projection of future conservation tillage adoption, this report uses SCS data because it has been collected longer and, when aggregated from the county level where it was col·

Table 15.—Estimates of Conservation Tillage in the United States (millions of acres)[a]

Year	USDA	No-Till Farmer[b]
1973	29.5	44.0
1975	35.8	56.2
1976	39.2	59.6
1977	47.5	70.0
1978	51.7	74.8
1979[b]	55.0	79.2

[a]This table is taken from Crosson (1981).
[b]Preliminary.

SOURCES: *USDA data:* Gerald Darby, Soil Conservation Service. Based on reports from SCS field offices at county level. SCS data were collected for "minimum tillage," as defined in the text, but the agency now refers to this series as "conservation tillage." It includes no-till. Since 1977 data have not been collected by SCS on specific conservation practices, including conservation tillage. Thus, the numbers for 1978 and subsequent years are "extrapolations."
No-Till Farmer Magazine data: These data include no-till, as defined by the magazine, and "limited tillage," where the total field surface is worked by tillage equipment other than the moldboard plow.

lected, may be more reliable than the State-level data gathered by *No-Till Farmer.*

No-Till Farmer defines no-till broadly to include many forms of conservation tillage and mulch tillage—no-till, till-plant, chisel plant, rotary strip tillage, etc. Under this definition, up to 25 percent of the surface can be worked and still qualify as no-till. Thus, the *No-Till Farmer* estimates are considerably higher than they would be under a more strict definition.

Table 15 shows that conservation tillage is becoming more widespread. The estimates for 1978 and 1979 are based on 1977 data and project growth at 5 percent. The actual growth in 1978 and 1979, however, was slower—2 percent per year.

Table 16 shows that after a jump in the early 1970's, no-till use reached a plateau around 7 million acres. It is not possible to determine whether no-till use will remain at this level. These data, too, may not be entirely accurate because they were gathered from surveys of State conservationists rather than from field censuses. No-till methods apparently encountered obstacles in the 1970's that slowed their spread, and it is not clear whether they have been overcome even though anecdotal reports indicate that no-till increased substantially in 1981 (Triplett, 1981).

In a preliminary assessment of the potential offered by "minimum tillage," the U.S. Department of Agriculture (USDA) projected the maximum adoption of the technology (USDA, 1975). OTA repeated this exercise, but where the USDA projection assumed an upper li for minimum tillage of 100 percent of cropla planted, OTA's assessment uses a 75-perc upper limit for conservation tillage adopti (This figure is a compromise between Cr son's estimated maximum of 50 to 60 perc adoption, and 84 percent estimated by t Resources Conservation Act (RCA)). The resu ing projection is shown in figure 12 as an adc tion curve. The earlier USDA projection is i cluded in the figure for comparison. At prese conservation tillage is on the very steep pa of the adoption curve. Because of the d ference in assumed upper limits, by the yea 2000 the gap between the two curves is ove 10 percent of planted cropland—or anywher from 35 million to 40 million acres.

Table 16.—Total No-Till Acres and Percent of Acres Planted

Year	No-till (million acres)	Acres planted principal crops (million acres)	Percent no-till
1973	4.9	318.7	1.54
1974	5.4	326.5	1.65
1975	6.5	332.4	1.96
1976	7.5	336.3	2.23
1977	7.3	344.0	2.12
1978	7.1	334.5	2.12
1979	6.7	347.0	1.93
1980	7.1	357.0	1.98

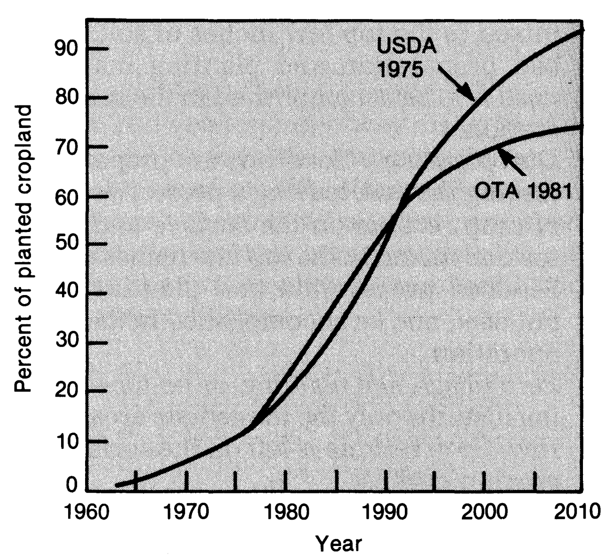
SOURCE: *No-Till Farmer* magazine, Annual Survey, 1981.

ECONOMIC INCENTIVES FOR ADOPTION

Most studies of conservation tillage and no till technologies indicate that farmers are adopting them primarily to improve the prof itability of their overall farming operations. Im portant economic incentives include:

- *Reduced labor requirement.*—Labor re quirements for conservation tillage are generally reported much lower than for conventional tillage. The reason is simple

Figure 12.—Projected Adoption of Conservation Tillage



SOURCE: Office of Technology Assessment and Congressional Research Service

Photo credit: USDA—Soil Conservation Service

No-till of a cornfield in Belknap, Ill. Rapid growth is shown where corn is planted in wheat stubble and competing weeds were chemically killed at planting time

fewer trips are required across the field. Adoption of no-tillage methods can increase the productivity of farmworkers as much as threefold (Triplett and Van Doren, 1977).

Most of the labor savings come at spring or fall planting time, when labor is extremely valuable to farmers. The time saved may enable a farmer to plant more land; to plant his land closer to the optimum time for tillage, seed germination, and weed control; or to plant a second (or, in the Southeast, a third) crop on the same land in the same season. The ability to get into fields earlier in the spring, when the heavier equipment used for conventional tillage cannot, is frequently mentioned as a benefit of no-till, although moist soils under no-till sometimes remain cold and delay planting.

- *Reduced preharvest fuel requirement.*—Fewer trips across the field also conserves fuel in preharvest operations. Lighter machinery can also save fuel.

Compared with conventional tillage, no-till requires 3 to 4 fewer gallons per acre of diesel fuel equivalent. For other kinds of conservation tillage the saving is on the

order of 1 to 3 gallons (Crosson, 1981). It should be noted that these are savings in the preharvest, on-farm fuel use. Total farm energy use may remain essentially unchanged, for fuel savings may be offset somewhat by the increased use of petroleum-derived herbicides.

- *Reduced machinery costs.*—Conservation tillage and no-till often require smaller, less powerful, and (when total equipment is considered) less expensive equipment than does conventional tillage. Maintenance costs for no-till equipment also may be lower. Machinery costs would be higher, however, for farmers who want to maintain on-farm capability for both conventional tillage and conservation tillage (Trouse, 1981).
- *Potential for multiple cropping.*—The time and soil moisture saved under no-till and conservation tillage systems make multiple cropping possible on some sites where climate previously prohibited it. This benefit may prove to be the most attractive economic feature of these tillage systems (Phillips, et al., 1980; USDA, 1975).

  Common double-cropping combinations under conservation tillage or no-till include wheat or other small grain (for grain, silage, hay, or grazing) followed by corn, soybeans, sorghum, or millet (Hayes, 1973). Possible triple-cropping combinations in the Southeast include: barley-corn-soybeans; barley-corn-snapbeans; barley-sweet corn-soybeans. The *No-Till Farmer* (March 1981) estimated that about 75 percent of the no-till soybeans in 1980 were double cropped (approximately 1.96 million acres out of 2.61 million).
- *Expansion of row crops to sloping land.*—Triplett and Van Doren (1977) have observed:

  > Since erosion can be reduced a hundredfold or more with no-tillage planting, the production of row crops on rolling terrain becomes practical. Although highly productive soils are found in many hilly areas, the practice has been to devote them to forage crops as a conservation measure. With no-tillage methods a higher proportion of thi land can be planted to more profitabl crops.

The long-term implications of this poten for row crop production on rolling terr could be profound. The present classificati of land capabilities, used for planning by S and other Government agencies, assumes lower capability class for sloping land becau of its susceptibility to erosion. With no- techniques, more sloping land could be us for production without increasing erosion

BARRIERS TO ADOPTION

Weed, Insect, and Disease Problems.—Th future expansion of conservation tillage an no-till depends on developing improved tec niques for controlling weeds, particularly pe ennials (Crosson, 1981; Worsham, 1980; Ower and Patterson, 1973). In fact, a 1979 survey almost 1,000 farmers in the Lake Erie regic showed weed control problems to be the nu ber one barrier to adopting conservation tilla and no-till (Forster, 1979).

Continued use of conservation tillage, and of no-till in particular, seems to create an environment favorable to perennial weeds because herbicides do not attack the root system of these weeds as tillage does. Thus, the perennial weeds have a competitive advantage over annual weeds. Also, certain weeds such as johnsongrass and bermudagrass cannot be controlled with available herbicides.

Most experts agree that any shift away from conventional tillage requires increased herbicide use, both type and amount. First, more herbicides are needed for what is called the "substitution effect:" herbicides are simply substituted for tillage. Second is the "efficiency effect." More herbicide is required because some of that applied is intercepted by surface crop residues before reaching target weeds. The third reason is termed the "environmental effect," wherein weeds are said to thrive under conservation tillage conditions because greater soil moisture fosters weed germination and growth. One or more of these effects can increase weed problems on no-till and conser-

vation tillage acreage. The answer, however, is not necessarily greater amounts of herbicides. New types and application methods are also needed.

One of the reasons for increased pest problems under no-till is that the crop residue left on the fields provides a habitat conducive to the growth of pests. Surface residue can also increase disease problems. For example, the incidence of southern corn leaf blight can increase because surface residues provide an inoculum for bacteria (Boosalis and Cook, 1973). However, the greater disease hazard for crops under conservation tillage may not imply greater fungicide expenses. Instead, resistant plant varieties can be used. Disease problems could be a barrier to the spread of conservation tillage if the development of resistant varieties is too slow or if seed for these types is comparatively expensive.

Unfavorable Soil Conditions.—The capacity of surface residues to conserve soil moisture actually can be a disadvantage when conservation tillage or no-till is used on soils that are poorly drained. Thus, it is generally held that these technologies are best suited to well-drained soils. Cosper (1979) has estimated the amount of land suitable to conservation tillage for four States on the basis of soil characteristics—most importantly, soil drainage. He estimates that 47 percent of the "tillable acres" (for practical purposes, the sum of cropland and pasture) in Ohio is suited to conservation tillage; 53 percent in Indiana; 66 percent in Illinois; and 76 percent in Iowa. Data on conservation tillage from *No-Till Farmer* illustrate that the proportion of land actually in some form of conservation tillage increases from east to west through these States, as does the drainage of the soils. Thus, drainage is already having an effect on the distribution of the technology (Crosson, 1981).

Moist soils also tend to remain cool for a longer period in the spring. This limits conservation tillage in Northern States where delayed planting combines with a relatively shorter growing season. It is conceivable that with an active sod crop in a no-till system, such soil moisture could be removed by evapotranspiration in the early spring. Indeed, in some drier regions, no-till is not feasible because an overwintering cover crop removes necessary soil moisture.

Diffusion of Information.—Several studies indicate that one barrier to the adoption of conservation tillage and no-till is inadequate information on the technologies: farmers either do not understand the advantages of the various systems, or they harbor misconceptions about them. (The general process of technology adoption is considered in ch. V.)

One recent study of Iowa farmers (Nowak, 1980) dramatically illustrates the misperception problem. Farmers who had and had not adopted "minimum tillage" methods were surveyed to find out their attitudes regarding the technologies, and important differences were observed.

Table 17 shows the responses of users and nonusers of minimum tillage to questions about the cost, profitability, and other aspects of the technology. Users of minimum tillage considered the practice to have either no additional cost or moderate additional cost, whereas one-quarter of the nonusers thought additional costs for minimum-tillage were "very high." Almost 60 percent of the minimum, till practitioners thought that returns exceeded costs for the technology, compared with 31 percent of the nonusers.

Although experts estimate time and labor to be lower for conservation tillage, and three-quarters of the users felt less time and labor were required for the technology, only about half of the nonusers felt this way. Users and nonusers also felt differently about ease of use; 75 percent of the users thought it very easy, compared with 50 percent of nonusers. Eighty percent of the users found minimum tillage compatible with their farm operation, while only 43 percent of the nonusers thought it would be.

Finally, 80 percent of the users thought minimum tillage was improving their soil savings. Only half of the nonusers held this view of

Table 17.—Perceived Characteristics of Minimum Tillage

Characteristic	Minimum Tillage (N=154) Users	(N=35) Non-users
Cost for using		
No cost	49.3%	38.2%
Moderate cost	47.4%	35.3%
Very high cost	3.3%	26.5%
	100.0%	100.0%
Profitability		
Costs exceed returns	7.8%	21.9%
Costs equal returns	32.5%	46.9%
Returns exceed costs	59.7%	31.2%
	100.0%	100.0%
Time/labor requirements		
More time/labor	7.8%	20.0%
No change	17.5%	28.6%
Less time/labor	74.7%	51.4%
	100.0%	100.0%
Ease of use		
Very difficult	2.6%	20.6%
Moderate	22.2%	29.4%
Very easy	75.2%	50.0%
	100.0%	100.0%
Compatibility		
Not compatible	3.9%	28.6%
Moderately compatible	15.6%	28.5%
Very compatible	80.5%	42.9%
	100.0%	100.0%
Influence on soil erosion		
Worsened	1.4%	0.0%
No change	16.8%	50.0%
Improved	81.8%	50.0%
	100.0%	100.0%

SOURCE: Nowak, 1980.

Table 18.—Reasons Given by Lake Erie Basin Survey Respondents for Adopting and Failing to Adopt Reduced Tillage Systems, 1979

Reasons	Number of responses	Mean sco
Reasons for adopting reduced tillage		
1. Reduced fuel costs	464	4.37
2. Conserve soil productivity	439	4.18
3. Reduced labor cost	455	4.00
4. Reduced equipment costs	437	3.87
5. Increased yields	427	3.79
6. Reduced water pollution	435	3.61
Reasons for failing to adopt reduced tillage		
1. Weed control problems	392	4.14
2. Soil not conducive	375	3.89
3. Poor stands	342	3.86
4. Increased equipment costs	355	3.68
5. Pest control problems	334	3.34
6. Increased fuel costs	326	3.27
7. Increased labor costs	321	2.93

[a]Scale: 1 to 5 where 1 is completely unimportant and 5 is very important.
SOURCE: Forster, 1979.

minimum tillage; the other half thought the technology would have no effect on erosion. Given the wide play in farm magazines and Government-sponsored education efforts on the conservation benefits of minimum tillage, this gap between users and nonusers is especially surprising.

Similar confusion seems to exist among farmers in the Lake Erie Basin. Farmers who had adopted "reduced tillage" (meaning either no-till or tillage without the moldboard plow) cited as reasons reduced fuel cost, reduced labor cost, and reduced equipment cost. Farmers who had not adopted reduced tillage listed increased fuel cost, increased labor cost, and increased equipment cost as reasons (see table 18).

It is obvious that in these two surveys nonusers of conservation tillage hold views of the technology that differ markedly from the views of users, and in most cases the views of nonusers are at odds with well-established conclusions in the scientific literature. It is possible to make any number of speculations as to why this may be so: simple lack of information, observed failures of the technology on nearby farms, the "trashy" look of conservation tilled fields.

Management Requirements.—Although conservation tillage requires less labor, these systems do require better managers. Farmers using these systems cannot fall back on additional tillage operations to correct mistakes in weed control or planting. In addition, they need to be more familiar with complex weed and insect problems and with different types of machinery.

But this need for good management need not be a major obstacle to the spread of conservation tillage and no-till. The cost of acquiring no-till and conservation tillage skills is not prohibitive. Indeed, experts and users of no-till technology (the most demanding in the conservation tillage spectrum from a management point of view), while acknowledging that a different set of skills may be required (i.e., more

knowledge of spray equipment), feel that these skills are not necessarily more difficult to acquire than those for conventional farming.

It is probably fair to say that nonusers are always skeptical of new technologies. Skepticism about no-till is probably related to the fact that the technology is still evolving and that early mistakes—poor stands, poor weed control, use of no-till on poorly drained sôil, and overall low yields—remain fresh in the minds of farmers and, to some degree, agricultural extension personnel, soil conservation technicians, and farm implement and chemical dealers. The only thing that will break this barrier will be good performance of no-till in more experimental settings and on more farms. As this begins to happen, no-till farming will move into the rapid-increase part of the adoption curve, as conservation tillage has already done.

Environmental Effects (Soil Erosion).—Conservation tillage has proven to be very effective in the control of wind and water erosion. A variety of field and experimental studies show that conservation tillage can reduce erosion by 50 to 90 percent compared to conventional tillage (Crosson, 1981; Phillips, et al., 1980). The presence of crop residues on the soil surface presents a barrier to wind and retards water runoff. The formation of larger soil clods that occurs with most conservation tillage systems also serves as a further barrier to wind and water movement. No-till systems also offer the additional protection of a nearly continuous soil cover, particularly during spring and fall when erosion potential is greatest.

This capacity to reduce erosion is one of the most important features of conservation tillage technologies. The scientific literature more than adequately establishes the superiority of these technologies over many conventional systems for erosion control, particularly from an economic point of view.

However, available data on conservation tillage and no-till agriculture as practiced today make it difficult to estimate whether the promise of experimental findings is being achieved. For example, the rather loose definition of minimum tillage and conservation tillage used by SCS admits a broad array of technologies, the erosion control effectiveness of which vary markedly. Furthermore, it seems that much of the land in conservation tillage did not have severe erosion problems prior to the adoption of the technology—i.e., motives other than erosion control have influenced farmers to adopt conservation tillage.

Eventually, use of no-till is likely to make it possible to cultivate slopes now in pasture or hay crops. This expansion of row-crop and small-grain acreage is not without risk, however. These sloping lands may be exposed to erosion hazards every 4 to 5 years if periodic moldboard plowing is deemed necessary to combat weeds, insects, or disease. Further, by specializing in row crops, farmers may open themselves to greater economic risk by losing farm diversity. Mixed crop and livestock operations, while perhaps less profitable in years of high crop prices, provided more stable income in the long term by virtue of diversity.

Finally, as more hilly land is brought into row-crop production with conservation tillage, it could leave less pasture and hay acreage, thus increasing grazing pressures on both Western rangelands and Eastern forests.

Nutrient and Pesticide Pollution.—Water runoff from agricultural lands has been identified as a major cause of pollution in freshwater streams and lakes. Conservation tillage and no-till have proven very effective in reducing one component of pollution in agricultural runoff—i.e., sediment, which constitutes (by weight) most of the pollution of freshwater bodies. However, a more complicated relationship exists between tillage systems and pollution from pesticides and nutrients.

Nutrients.—Additions of even small amounts of nutrients, particularly nitrogen (N) and phosphorus (P), accelerate plant growth in aquatic systems, which in turn reduces oxygen concentrations when the plants are decomposed by aquatic micro-organisms. The change in oxygen levels can dramatically alter conditions of survival for fish. Although "eutrophication" is a natural process, it can be greatly accelerated by human activities.

Nutrients in agricultural runoff are divided into two forms: a portion adsorbed chemically onto soil particles and a portion dissolved in the water. By reducing soil loss, conservation tillage and no-till reduce sediment-associated nutrient pollution. However, there can be an increase in the concentration of dissolved nutrients in runoff from fields where conservation tillage or no-till were in use.

For instance, if crop residues are not incorporated into the soil, they are a source of additional dissolved N and P in runoff. Similarly, applying surface fertilizers can increase nutrient levels in runoff. And because nitrate N is relatively mobile in the soil, tillage practices that increase infiltration and subsurface flow may lead to increased N losses, thus reducing crop production and increasing ground water N levels (Wauchope, et al., 1981).

The net result of conservation tillage and no-till on nutrient pollution of surface and ground water will vary under different conditions. For example, Wauchope, et al. (1981) have noted that losses for either system can be quite high if rainfall occurs shortly after fertilizers are applied. The same is true of pesticide pollution. There appears to be little basis for generalizing about the differences between conservation tillage and conventional tillage with respect to delivery of nutrients to surface water bodies.

Pesticides.—Some contamination of surface waters is inevitable as long as pesticides are used in agriculture, and they are widely used today. The extent of contamination depends on the amount and type of pesticide applied, the area to which it is applied, and the timing of rainfall.

The overall impact of pesticide runoff on surface waters is difficult to determine given the available data. Too little is known about dynamics of dilution, sediment exchange (the movement of pesticide molecules from soil particles), and pesticide effects on aquatic life. Although accurate estimates of the actual field inputs into waterways are available, knowledge of the impacts of those inputs is greatly lacking (Wauchope, 1978).

Some pesticides either are not very solu or they adhere tightly to soil particles. In th cases erosion reduction prevents or greatly duces the pesticide's entry into surface wate Thus, conservation tillage and no-till act lessen the impact of such pesticides, which i clude trifluralin, endrin, toxaphene, and par quat. Several researchers have reported th pesticide losses are virtually eliminated und no-till, although less drastic reductions i tillage have lesser effects.

A problem can arise, however, where som soils are not able to capture the herbicides. Fo example, soil clays in wet tropical regions, suc as Puerto Rico, do not bind the herbicides t their surfaces. In such environments, a larg portion of the herbicide can be carried int water bodies regardless of the timing of appli cation.

There is also the problem of persistent tox icity of some of the herbicides and othe pesticides. Whether the herbicide binding t clays is permanent is unknown. It may be tha the chemical can be released in some change form by microbial activity, with unknown con sequences for soil microbiology. Although mos of the insecticides degrade rapidly, the toxici ty of the compounds produced by the degrada tion process is unknown.

Conservation tillage and no-till reduce wate runoff, but do not eliminate it. Thus, the sam question can be posed for pesticides as wa posed for nutrient losses: Do higher concen trations of pesticides in runoff offset reduction in the sediment-associated pesticides unde these systems? Several studies suggest that con centrations of specific pesticides are greater i lower runoff volumes, as happens under con servation tillage and no-till, possibly becaus pesticides on crop residues are easily washe off. In other instances pesticides seem to b filtered out as runoff passes over untreated so and vegetation.

Because conservation tillage has such an in creased reliance on pesticides, particularly her- bicides, it is a greater threat to the environment than conventional tillage as far as pesticide damage is concerned (Crosson, 1981). Although

many herbicides have low toxicity to human beings, they or their metabolites may have carcinogenic, mutagenic, or teratogenic effects. Greater use of pesticides also implies greater potential for it to drift in the wind to unintended sites.

Available data suggest that agricultural chemicals do not damage the ability of the croplands to produce crops in perpetuity; however, data are sparse and little analysis on herbicide impacts on soil ecology exists. The water pollution effect of the increased use of chemicals is another unknown. Quantitative information is inadequate on the amount of toxic chemical applied with each of the many variations of conservation tillage and no-till, and scientists have not estimated the overall increase in use of herbicides or pesticides that is associated with these technologies. Even if such data were available, an accurate environmental benefit/cost analysis could not be done because too little is known about the impacts of the chemicals.

A rigorous assessment of conservation tillage and no-till that makes some conclusion regarding the tradeoff between the reduction of erosion and the proliferation of toxic chemicals will not be possible until: 1) more adequate mathematical models of agricultural systems are constructed to use the data that are available, and 2) much better data are collected on the dynamics of soil chemistry and biology, especially research on the effects of pesticides on so-called "nontarget" organisms, including wildlife, aquatic plants and animals, humans, and soil flora and fauna. Meanwhile, most analyses of these technologies imply that the recognized erosion prevention potential outweighs the plausible but unknown chemical hazards.

FEDERAL ROLE

A limited amount of cost sharing for conservation tillage has been provided through the Agricultural Conservation Program (ACP) administered by the Agricultural Stabilization and Conservation Service (ASCS). For these lands, the average annual erosion rate before assistance was 9.7 tons per acre, but conservation tillage reduced it 3.8 tons per acre annually—a notable achievement. Morever, the average cost of erosion reduction with conservation tillage was $0.98 per ton, well below the average cost of $2.22 per ton for all practices. An even greater soil savings and a lower cost per ton might have been achieved if more of the practices had occurred on more highly erosive land.

Under ACP, participating farmers have received an average of $10 per acre to defray roughly half the cost of equipment and chemicals for conservation tillage. The remaining half of the cost, it was assumed, would be made up by expected savings in labor and fuel. Either the Extension Service or SCS would recommend which equipment or chemicals to use. Cost sharing was extended to farmers for 2 years only. ASCS analysts feel conservation tillage has been and continues to be a cost-effective practice and it has ranked high among the practices identified by ASCS for cost sharing within States and counties. But the willingness of farmers to continue using conservation tillage beyond the support period depends to a great extent on their success in these first 2 years (Nebeker, 1981).

Another scheme, adopted by numerous conservation districts around the country in conjunction with private companies or the Environmental Protection Agency, has been to buy a no-till planter (or other conservation tillage device) and make it available free to district farmers, with or without technical assistance. Anecdotal reports in farm magazines and from conservationists suggest this type of approach does work for spreading no-till.

Clearly, basic data regarding the use of conservation tillage and no-till by American farmers are lacking, notably the extent and quality of the acreage on which these technologies are being used. Considering the degree to which the conservation professionals are relying on these technologies to protect land productivity in the future, it is remarkable that there are not more reliable data on the amount of acreage in no-till. These data would not be particularly expensive to obtain. By one estimate, the acreage in no-till could be assessed by in-

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cluding a few questions on the spring planting survey conducted by the USDA Statistical Reporting Service (SRS) at a cost of $100,000 or less. Information on conservation tillage will be provided by the 1981-82 National Resource Inventories, but no-till practices will not be separated from conservation tillage in general. A special inventory of no-till has been considered within SCS, but as yet has not been performed.

CONCLUSIONS

Conservation tillage and no-till have a variety of effects on land productivity. By making possible more double or multiple cropping, both conservation tillage and no-till can help increase production of major field crops without increasing the acreage cropped, even though more fertilizer, tractor fuel, herbicides, and so forth may be needed. In addition, conservation tillage and no-till enhance inherent cropland productivity by reducing and, in some cases, virtually eliminating soil erosion.

But *how much* soil will be saved depends on: the type of technology used, the way farmers use it, and the quality of the land on which it is applied. The many different types of equipment that can be used in conservation tillage and no-till vary greatly in the amount of surface soil they disturb and in the amount of crop residue they leave on the surface. With two different types of equipment—e.g., a chisel plow and a till planter—farmers on virtually identical land may experience considerably different erosion rates, yet both may call their practice "conservation tillage."

Another important consideration is the way farmers use the technologies. For example, the soil savings possible with a no-till system are enormously diminished if at harvest the farmer does not return crop residues to his land. Farmers in the basin of the main Patuxent River in Howard County, Md., for example, commonly use minimum or no-till technologies to produce continuous corn on their moderately sloping land. Those who retain surface residues can expect an erosion rate of approximately 5 tons per acre. But if they use these technologies without retaining the residues, the predicted erosion rate jumps to 21 tons per a per year, or about the rate that would occ with moldboard plowing and two passes w a disk (Helm, 1980). Thus, farmers can obta the labor and fuel saving benefits of conser tion tillage and no-till without necessarily s ing much soil in the process.

The acreage of cropland treated with thes conservation technologies probably will co tinue to increase. OTA projections show tha 75 percent of U.S. cropland may have som form of conservation tillage by 2010. Yet th land most severely affected by erosion may stil be missed, just as it has been missed by mor traditional conservation measures. Table 1 shows that in 1977, conservation tillage wa used on less erosive land. This poses severa policy questions. First, it is commonly said tha the benefits of reduced soil erosion with con servation tillage and no-till outweigh the risk posed by greater herbicide use. But this trade off is less justifiable if these technologies d not find their way to land with acute erosion problems where potential soil savings are great

Numerous studies on the costs and benefits of various erosion control technologies indicate that conservation tillage and no-till are the most effective and economically attractive methods of erosion control for many farmers. Current national policy proposals (such as RCA) have included heavy reliance on these technologies to reach future soil and water quality and conservation goals.

Table 19.—Acreage Treated With Minimum Tillage and Crop Residue Practices in 1977
(sheet and rill erosion only)

Expected erosion with conventional tillage	Acreage treated with minimum tillage and crop residue	
(tons per acre per year)	Million acres	Percent
Less than 5	20.0	74.9
5 to 10	3.7	13.9
10 to 15	1.1	4.1
15 to 25	0.9	3.4
Over 25	1.0	3.7
Total acreage treated with minimum tillage and crop residue	26.7	

SOURCE: Miller, 1978.

The greater use of agricultural chemicals, herbicides in particular, is not now known to be a major threat to environmental quality. However, there is a potential for greater pesticide runoff from farmland where conservation tillage technologies are used, and even though the pesticides involved are relatively more benign than their precursors, many of their effects are not fully understood and deserve further study.

Neither conservation tillage nor no-till are panaceas to America's erosion problem. On very fragile lands, these technologies need to be used in conjunction with terraces, contour farming, and other traditional conservation measures. In some cases, even the combination might not suffice. Probably the most important point to remember about these technologies is that their suitability is site specific, as are the soil and water savings they will achieve. But efforts to bring conservation tillage and no-till to critically eroding areas could, if well designed and adequately funded, significantly reduce the Nation's overall erosion problem and protect some of its most fragile lands.

Organic Agriculture

Introduction

Although there is a paucity of good data on organic agriculture, recent studies suggest that many organic farming practices are both economically viable under current market conditions and effective in reducing soil erosion and nonpoint pollution (e.g., fertilizer and pesticide runoff). Even though per-acre yields tend to be lower for organic agriculture than for conventional farming, operating expenses on organic farms also tend to be substantially lower. One study found that net per-acre returns to organic farmers over a 5-year period were virtually identical to those of their conventionally farming counterparts (Kohl, et al., 1981).

As defined by USDA, organic farming is a production system that avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators, and livestock feed additives. To the maximum extent feasible, organic farming systems rely on crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, mechanical cultivation, mineral-bearing rocks, and biological pest control to maintain soil productivity and tilth, to supply plant nutrients, and to control insects, weeds, and other pests (USDA, 1980; Oelhaf, 1978).

Organic agriculture encompasses a wide spectrum of practices, attitudes, and philosophies. Some producers avoid manufactured chemical inputs without exception; others try to minimize chemical application but selectively use chemical inputs to deal with specific problems and conditions. Some reflect "counter-cultural" opposition to traditional agriculture. However, most organic producers employ practices and enjoy a profitability that differs less from conventional farmers (except for chemical use) than is generally presumed. An in-depth survey of organic farming in the Corn Belt found that over 80 percent of the operators had previously farmed with conventional methods (Kohl, et al., 1981). Further, organic farmers tend to be experienced farm operators. Eighty percent of a USDA sample of organic farmers had at least 8 years of farming experience and 44 percent had 30 or more years of experience. The same study found organic farmers were evenly distributed in all age categories and were generally well educated, with about 50 percent having attended college (USDA, 1980).

Organic agriculture is not limited by scale. While some organic farmers are small-scale operators with substantial off-farm income, and small-scale organic farms (10 to 50 acres) do predominate in the Northeast, there are a significant number of large-scale (100 to 1,500 acres) operations in the West and Midwest (USDA, 1980).

Organic agriculture reflects an attitude shared by an increasing number of people, both urban and rural, which holds that sustainable agriculture can best be attained through the use of technologies that are less demanding of nonrenewable resources and less exploitive of soils (USDA, 1980). Organic farmers share an increasing concern about the adverse effects of intensive production of cash grain crops and about the extensive, and sometimes excessive,

use of chemical fertilizers and pesticides. Even though data to substantiate their views in some cases are not available, some of the specific concerns most often voiced by organic practitioners include:

- increased costs and uncertain availability of energy and chemicals;
- increased resistance of weeds and insects to pesticides;
- decline in soil productivity from erosion and accompanying loss of organic matter and plant nutrients;
- pollution of surface waters with agricultural chemicals and sediment;
- destruction of wildlife, bees, and beneficial insects by pesticides;
- possible hazards to human and animal health from pesticides and feed additives;
- perceived detrimental effects of agricultural chemicals on food quality;
- gradual depletion of finite reserves of concentrated plant nutrients—e.g., phosphate rock; and
- decrease in number of farms, particularly family-type farms, and disappearance of localized and direct marketing systems (USDA, 1980).

Organic agriculture is not, as is commonly assumed, simply a throwback to the past. Although it is true that some past techniques remain important to modern organic farming, most of today's organic producers use modern farm machinery, currently recommended crop varieties, certified seed, sound livestock management, recommended soil and water conservation practices, innovative methods of organic waste and residue management, and many of the other techniques of modern agriculture.

The technologies that make organic agriculture different from conventional agriculture are primarily management technologies. The clearest distinction shows in the respective sources of major nutrients used for crop growth—nitrogen, phosphorus, and potassium. Conventional farmers generally meet their nitrogen needs through the input of commercially produced fertilizers. These manufactured inputs allow farmers to plant more or all of their land to the most profitable crops (CAST 1980). Most organic farmers use crop residues animal manure, and crop rotations that include legumes and cover crops, to provide adequate nitrogen for moderate-to-high crop yields. In fact, legume crops commonly covered 30 to 50 percent of the cultivated acreage on the organic farms surveyed by USDA. Organic farms appeared to use little of other organic inputs such as sewage sludge or processing wastes (USDA 1980).

Crop rotations used on nonirrigated organic farms are similar to those used on farms 30 to 40 years ago. Typically, farmers plant a heavy green manure crop followed by a nitrogen demanding crop such as corn, sorghum, or wheat. For example, in a corn-soybean area such as the Midwest, a rotation might include oats/3 years of alfalfa/corn (or wheat)/soybeans/corn/soybeans. On more productive soils, there might be an additional corn or wheat crop after the alfalfa (USDA, 1980).

Large-scale organic farms are usually mixed crop and livestock operations, since the forage produced through crop rotation can most economically be used by the producer's own livestock. Farmers then return the manure to the land as fertilizer. Ninety percent of the organic farmers surveyed in the Corn Belt had substantial livestock holdings (Kohl, et al., 1981). Organic livestock operations do not use hormones, growth stimulants, or antibiotics in their feed formulations (except as needed to treat sick animals). Because such chemicals are not used the livestock sometimes command premium prices from certain consumer groups. However, the declining profitability of livestock farming in general could affect the profitability of diversified farms, including organic farms.

Organic farmers tend to pay less attention to the phosphorus (P) and potassium (K) components of the soil's nutrient budget. Some organic farms are actually "mining" P and K from either soil minerals or residual fertilizers applied when the land was farmed chemically (USDA, 1980; Lockeretz, et al., 1976). While these sources of P and K may sustain high crop

yields for some time (depending on soil, climate, and cropping conditions), it is likely that some organic farmers eventually will have to apply supplemental amounts of these two nutrients. Rock phosphate and greensand (unprocessed glauconite) are acceptable sources of P and K, respectively, for organic farmers. But few organic farmers actually apply any mineral sources of phosphate and very few apply any form of mineral potassium (USDA, 1980).

Another major difference between conventional and organic farmers is in their approach to pest control. Conventional farming relies on a variety of pesticides, herbicides, insecticides, and the like to combat destructive pests, sometimes in combination with biological and cultural controls. Organic farmers avoid such chemicals and instead use more intensive managerial, biological, and cultural methods to avoid or control pest outbreaks. Some organic farmers use insecticides to fight epidemic outbreaks or to control specific insects. Insects are particularly difficult to control in vegetable and orchard crops, especially given existing consumer quality preferences. Producers of such crops use organic (nonmanufactured) insecticides and biological methods of pest control.

Organic producers emphasize preventive methods for controlling weeds. The USDA study noted surprising success with timely tillage and cultivation, delayed planting, and crop rotations. Some farmers contend that weed problems were most serious during the early stages of transition and that they subsided once the rotational cycle was established. Rotations also help counter insect infestations with relatively good results (USDA, 1980).

Comparisons of conventional and organic agriculture also focus on differences in economics, energy use, crop yields, and labor. One problem that clouds the analysis, however, is that accurate information about these topics is sparse or contradictory. On the average, organic farms are somewhat more labor intensive but use less energy than conventional farms (USDA, 1980). On the other hand, economic returns above variable costs can be greater for conventional farms (for corn and soybeans) than for several crop rotations grown on organic farms because of the large portion of land necessarily devoted to legume crops at any one time (USDA, 1980).

One study of economic performance and energy use on organic farms showed that organic producers had an average overall production level 10 percent below that of comparable conventional operations (in terms of market value of output per acre). However, because operating costs also were lower for organic farms, returns to crop production were virtually equal for the two groups. The conventional group was 2.3 times more energy intensive, primarily because of the energy needed to produce conventional fertilizers. The organic group required 12 percent more labor per unit of market value of crops produced (Lockeretz, et al., 1976). Other studies confirm this general pattern of reduced energy use and slightly reduced yields for organic farms (CAST, 1980). Continuing escalations in energy prices may have already enhanced the relative profitability of organic farming methods. However, data on yields and net per-acre returns to organic farms for 1979 and later are not available.

Modest additions of nitrogen to organically managed corn fields might reduce their yield disadvantage relative to conventional fields, while preserving most of the lower production costs and reduced energy consumption characterizing these methods. Thus, cultivation systems that draw on the management practices of organic farming, while using small additions of manufactured fertilizer, may have substantial potential for maintaining high yields and reducing costs.

Organic farming may also have advantages for sustaining inherent land productivity that could in the long run compensate for short-term yield reductions. Careful land management, crop rotations, use of cover crops and other conservation methods, and reduced nonpoint pollution (e.g., nitrogen and pesticide runoff) cause organic farming to have fewer apparent adverse effects on environmental

quality than many conventional farming methods (USDA, 1980). Preliminary estimates suggest that organic techniques can reduce erosion by one-third or more in some areas (Kohl, et al., 1981). If the additional costs of the detrimental effects of production (e.g., erosion and sedimentation) are considered, cost differences between organic and conventional systems may decrease in areas where these problems occur (USDA, 1980). If, on the other hand, yield reductions or other factors associated with a shift to organic farming caused farmers to bring new, less suitable agricultural lands into production, erosion problems could be aggravated rather than alleviated.

Future of Organic Farming in the United States

The future extent of the role of organic farming in American agriculture is uncertain. Much depends on the availability and price of fertilizer (especially nitrogen), farm labor, producer-price relationships, domestic and world demands for food, concern for soil and water conservation, concern for health and environment, and U.S. policies toward the development and promotion of organic practices.

Many of agriculture's current trends—for example, increased energy and input costs, or increased concern for long-term soil productivity—could prove strong incentives for a shift toward organic agriculture. But a major shift from conventional to organic farming would be limited by the availability of resources. Certain parts of the United States simply do not have an adequate and economic supply of organic wastes and residues or the soils and climate to support profitable organic agriculture (USDA, 1980).

USDA projections show that small farms, many of the remaining mixed-crop/livestock farms, and farms with access to ample quantities of organic wastes could be shifted to organic methods without major effect on total agricultural production. All farms with sales less than $2,500 (more than 35 percent of the total number of farms in 1977) could be farmed organically with little total economic impact on U.S. agriculture. On the other hand, if significant numbers of the conventional farms currently producing more than $20,000 per year in continuous corn, soybeans, or other crops converted to organic methods, the resulting changes in cropping patterns could have substantial economic impacts, particularly if such changes occurred rapidly (USDA, 1980). Such a shift would reduce U.S. exports, since corn and soybeans are important export crops. The likelihood of such a shift, however, does not seem great.

Throughout the sometimes heated debate surrounding organic agriculture, one fact has gained prominence: many questions remain unanswered. Again and again, sections of USDA's comprehensive overview of organic farming concluded saying, "there is a need for research to determine . . . ."

The USDA study strongly recommended that research and educational programs be developed and implemented to address the needs and problems of organic farmers and to enhance the success of conventional farmers who may want to shift toward organic farming, adopt some organic methods, or reduce their dependency on agricultural chemicals. The study advocated a holistic research effort to investigate the organic system of farming, its mechanisms, interactions, principles, and potential benefits to agriculture, especially considering that there is a severe lack of well-designed, replicative research on this set of technologies (USDA, 1980).

Often this view is countered by saying that many pieces of current agricultural research are already applicable to organic producers' needs. Work on biological nitrogen fixation, sewage sludge, soil fertility, and mechanical means of weed control are cited as examples. But considering the promise offered by organic methods and variations thereof, efforts to develop a more comprehensive research foundation for organic agriculture could provide valuable paybacks. Further, many of the "unknowns" highlighted by the organic agriculture study are fundamental to agriculture in general, not just to organic approaches.

Conclusions

- Organic farming can, given suitable climatic conditions, markets, and required inputs, be a productive and efficient farming option in parts of the United States.
- Organic farming techniques can reduce soil erosion and nonpoint pollution because such methods increase the use of cover crops and rotations and decrease chemical inputs.
- Rising costs of chemical inputs are likely to cause more conventional farmers to adopt techniques being used by organic farmers. If research supports the development and improvement of such techniques, and if resource sustainability is an explict goal of that development, the shift toward organic farming may help to sustain crop yields and to reduce energy use and attendant costs while preserving land productivity.

Alternative Cropping Systems

Changes in cropping systems have had major, though not well understood, impacts on the inherent productivity of U.S. croplands. The overall trend has been to greater production of fewer crops, fewer crop rotations, and less crop variety. Some of the impacts on long-term productivity have been beneficial, such as the reduced need for production from some fragile lands, while some have been harmful, such as the increased erosiveness of row crops.

Cropping systems will continue to change as the social, economic, and environmental milieu of agriculture changes. This section examines some cropping system changes that could work to sustain inherent land productivity on U.S. croplands. Multiple cropping is already practiced and is growing in popularity, partly as a result of the increased use of no-till techniques. New crops are receiving increased attention, though for the most part they receive little attention from the Federal Government, agricultural experiment stations, or agricultural faculties of universities. Finally, an approach that would integrate these two kinds of technologies, polyculture of perennial plants, is described. This technology is unlikely to be ready for implementation before the 21st century.

Multiple Cropping

Multiple cropping is an intensive form of agriculture where two or more crops are grown sharing land and resources. Such systems can enhance both land-use efficiency and long-term productivity. Multiple cropping is not a new technology but rather is an ancient technique that has been most developed in areas of high rainfall in the tropics, where temperature and moisture are favorable for year-round crop growth (American Society of Agronomy, 1976). High cropland costs and other economic pressures have stimulated new interest in temperate multiple cropping systems.

Today's multiple cropping systems vary greatly depending on the nature of the site being farmed. Traditional tropical multiple cropping systems differ from most U.S. systems because of differences in climate and farming scale, though both are based on the same principles. In general, multiple cropping systems are managed to maximize total yearly crop production from a unit of land. This can be achieved by sequential cropping, which is growing two or more crops in sequence on the same land area, and by intercropping, which refers to various ways of growing two or more crops simultaneously on the land.

Generally, productivity in well-developed multiple cropping systems can be more stable and constant in the long run than in monocultures.* Although individual crops in the mixture or sequence may yield slightly less than in monoculture, combined production per unit area can be greater with multiple cropped fields. The overall increased yields result because the component crops differ enough in their growth requirements so that overlapping demands—whether for sunlight, water, or nutrients—are not critical constraints. Multiple cropping, in effect, broadens the land's productive capacity by more fully exploiting the dimensions of time and space (Gliessman, 1980).

*The cultivation of a single crop to the exclusion of other uses of land.

Only certain crop mixtures will produce better yields under multiple cropping. Crop combinations and sequences that make successful, efficient overall use of available resources are considered complementary. One of the main ways to achieve such complementarity is by using sequential planting. For instance, in double cropping, the second crop is planted soon after the first crop is harvested.

Double cropping soybeans after wheat or barley is a widely practiced multiple cropping system for grain production in the longer growing seasons of the Southeastern United States. Recent advances in herbicides, short-season cultivars (particularly soybeans), and no-till planting have led to increased double cropping in Delaware, Maryland, and the southern part of the Corn Belt, including Kentucky, Illinois, Indiana, and Ohio (American Society of Agronomy, 1976).

Double cropping requires careful management—timely harvesting, the use of proper, short-season varieties, alteration of standard planting distances, and special selection of herbicides to avoid residual toxic effects. In general, climate and precipitation in the Western United States are not suitable for most present systems of sequential cropping. North of latitude 37 °N or above 600 m elevation, the short growing season limits the time available for sequential cropping, and rainfall is usually inadequate to permit good growth in a second crop. Further research with innovative crops, however, may change this picture.

The western regions of Washington, Oregon, and northwestern California are exceptions. In those regions, with their humid, cool summers and mild winters, multiple cropping is an established practice. The main combination used is intercropping oats with red clover. In fruit and nut orchards, small grains or annual forage crops are grown between rows of newly established trees. Double cropping is also practiced with vegetable crops, bush beans, or sweet corn following early maturing annual crops.

Another way to grow complementary crops is through relay intercropping. To make more efficient use of the growing season and avi able water, and to avoid direct competition, second crop is planted after the first crop ha completed the major part of its developmen but before it is harvested. Relay intercroppin of soybeans into no-till wheat is being practice as far north as Wooster, Ohio (Triplett, 1981 The success of this intercropping depends o the correct combination of timing and othe variables to avoid shading, nutrient competi tion, or inhibition brought about by toxicit produced by the decomposition of previou crop residues.

Farmers also can get complementarity in systems where two or more compatible crops are grown simultaneously, either in rows, strips, or mixed fields. For instance, traditional corn, bean, and squash systems grown in Mexico show how three species can benefit from multiple cropping. All three crops are planted simultaneously, but each matures at a different rate. The beans, which begin to mature first, are followed by the corn and they use the young corn stalks for support. The squash matures last. As the corn matures, it grows to occupy the upper canopy. The beans occupy the middle space and the squash covers the ground Research shows that the system achieves improved weed and insect control. And while the beans and squash suffer a distinct yield reduction, corn yields are higher than in comparable monocultures. It is still uncertain whether the higher yields are the result of more efficien resource use or if some mutually beneficial interaction is occurring between the crop components (Gliessman, 1980).

ADVANTAGES

The key to multiple cropping's benefits is the intensity of the cropping pattern—i.e., drawing as much as possible from the land resource. Such systems need not abuse the land. With proper design and operation, multiple-cropping management can sustain soil fertility. Depending on the multiple-cropping system used, ***potential advantages*** can include:

- more efficient use of time and vertical space, imitating natural ecological patterns, and permitting a more efficient cap-

ture of solar energy and nutrients;
- more organic matter available to return to the soil system;
- improved circulation of nutrients, including "pumping" them from deeper soil profiles when deep-rooted species are used;
- reduced wind and water erosion because of increased surface protection;
- potential production from fragile lands when systems are designed to accommodate variable soil types, topography, and steeper slopes;
- reduced susceptiblity to climatic variation, especially precipitation, wind, and temperature;
- reduced evaporation from soil surface;
- increased microbial activity in the soil;
- more efficient fertilizer use through the more diverse and deeper root structure in the system;
- improved soil structure, less likelihood to form hardpan, and better aeration and infiltration;
- reduced fertilizer needs because legume components fix atmospheric nitrogen;
- improved weed control because of heavier crop and mulch cover; and
- improved opportunities for biological control of insects and diseases because of component plant diversity.

DISADVANTAGES

Multiple cropping technologies can harm inherent land productivity if misapplied. Sequential cropping, for instance, of two or three crops can mine the land of nutrients if fertilizer applications, legume rotations, green manures, animal manures, or other fertility-building activities are neglected. Other ***potential disadvantages*** in multiple cropping in the United States might include:

- competition for light, soil nutrients, or water;
- difficulties in mechanizing various operations (tillage, planting, harvesting, etc.);
- the potential to harm one crop component when harvesting other components;
- difficulty building a fallow period into multiple cropping systems, especially when long-lived tree species are included;
- increases in water loss caused by greater root leaf surface areas;
- the possibility of unforeseen problems with one crop's plant-produced toxins harming other crops (allelopathy);
- damage to shorter plants from leaf, branch, fruit, or water drop from taller plants;
- higher relative humidity in the air than can favor disease outbreak, especially of fungi; and
- possible proliferation of harmful animals (especially rodents and insects) or plant pathogens in certain types of systems.

The most common objection to multiple cropping is that it does not fit into this Nation's highly mechanized methods of agriculture. However, as seen by the frequency of double cropping in parts of the country, sometimes this is not true. Mechanization is easiest when farming operations can be performed uniformly over the entire field. Most types of sequential cropping require few modifications of normal equipment. Machinery for producing two crops that are planted and harvested simultaneously and with the same implements, as is done with mixtures of forage crops, also requires little modification. But when two or more nonforage crops are grown on the same land at the same time, mechanization becomes difficult because the operations done for one crop must not damage the other crop(s) (American Society of Agronomy, 1976.)

Although it seems that the biological and physical advantages of multiple cropping often outweigh the disadvantages, a range of social and economic factors also influences the acceptance of multiple cropping technologies. In terms of social stability, multiple cropping seems advantageous because it leads to a diverse agricultural system. Such a system is less susceptible to climatic fluctuation, environmental stress, and pest outbreaks. It also might be less vulnerable to swings in crop prices and markets. Multiple cropping also

demands more constant use of local labor and provides a more constant output of harvested goods over the course of the year.

Reported lower yields, complexity of activities and management, higher labor demands, and difficulty in mechanizing operations are factors that discourage modern farmers from some types of multiple cropping. Although these tangible disadvantages exist, most of the problems involved in multiple cropping are derived from lack of experience and knowledge of the workings of complicated agroecosystems. Additional research and development could bring multiple cropping into wider acceptance among U.S. farmers.

Potential New Crops

At present, less than 20 crops provide almost 90 percent of the world's food supply. Yet this planet is believed to host 90,000 edible species. That means we rely on 0.025 percent of the available edible plants for our food (Myers, 1979). The number of species used to produce fiber is correspondingly small when compared with the number of plants available. Thus, current food and fiber production for the world rests on a narrow genetic base. An epidemic in any of the food and fiber species could cause severe dislocations in local, national, and global economies, and could restrict the amount of food and fiber available on the world market. Developing some new crops could help avoid such catastrophies.

Beyond broadening the food crop's genetic base, new crops hold potential to expand our food supplies as world population continues to grow. The ability to achieve such an increase in a world with a paucity of new prime agricultural lands, increasingly expensive energy, and impending water shortages may well depend on technological advances in new-crop production. New crops could help establish high levels of sustainable production from nonprime lands, drylands, and energy-constrained farming operations.

NEWLY DOMESTICATED CROPS

Several ways exist to broaden the plant r source base. First and most obvious, ne species could be domesticated. This presen both the greatest challenges and also the grea est potential rewards.

All of today's economically important crop were originally selected by pretechnologica peoples. The traits for which they were se lected, while refined in modern times, hav shaped and dominated agricultural practice Traits such as concentrated seed productio short ripening period, easy hulling, an palatability were selected because they mad the plant more useful to humans. Some trait necessary to the plant's survival, such as protective hull, were rejected in the process, however, and the plants became dependent on humans for survival.

In developing new cultivars, different traits reflecting the needs of a technological and land-limited society may need to be selected. For example, the retention of naturally occurring pest repellents may make economic sense to a society capable of removing them during processing, or the retention of perennial characteristics may make more sense to a society with permanent agriculture than to a pretechnological slash and burn culture. Moreover, by starting with plants that have never been domesticated, the entire germ plasm base of the species is available for manipulation. Geneticists will not be faced with the problem of trying to find and restore useful genes that were selected against by their ancestors and lost to the current gene pool.

Some plants that appear to have potential for domestication include the herbaceous perennials of the high prairies, the salt-tolerant halophytes of the Southwest, and certain leguminous trees and shrubs adapted to environmental extremes.

OLD CROPS REVISITED

The second way to expand the agricultural plant resource base is to revive cultivars that had previously been cropped but which were neglected or abandoned for reasons not related to their value as food, fiber, or fuel. The prime example of the economic potential inherent in neglected "old" crops is the soybean. It was spurned in the United States from the time of its introduction by Benjamin Franklin until University of Illinois scientists established two comprehensive soybean research programs in the 1920's. It is now the world's premier protein crop.

Traditionally grown crops can be lost to political and social pressures. Amaranth was outlawed by the explorer/conqueror Cortez in his efforts to subdue a culture. Winged bean has long been neglected because many consider it a "poor man's crop." Many times these traditional crops are better adapted to the local soil and climatic conditions than introduced species. Indigenous plants commonly are more resilient to stress, as well. They have evolved defenses for local disease and pest organisms and are efficient users of available resources, whether water, soil nitrogen, or other nutrients.

In the Southwestern United States, which is faced with declining water tables and increasingly salinized soils, it seems appropriate to exploit such native resources as tepary bean, buffalo gourd, and jojoba whenever possible. In order to do this, germ plasm from promising plants would have to be gathered and assessed, and the most promising strains identified. Then selective breeding and genetic manipulation could be used to develop economically viable strains that could be propagated rapidly through the use of cell culture or other modern techniques.

MANIPULATING EXISTING PLANTS

A third way to expand the plant resource base is to manipulate current cultivars so that they are better adapted to environmental stresses. Here again, modern genetic techniques will play a major role: either the plant itself can be manipulated for desired characteristics, or the natural symbiotes of plants—i.e., the bacteria and fungi of the soil—can be altered. In the former case, such characteristics as perennialism, salt tolerance, and cold tolerance may be added to a cultivar's genetic inheritance. In the latter case, a number of possibilities exist, including: 1) breeding symbiotes for leguminous plants to maximize their nitrogen-fixing capacity; 2) breeding free-living nitrogen-fixing organisms adapted to specific soil types and plants to maximize nitrogen availability; and 3) breeding those fungi, such as mycorrhiza, that symbiotically inhabit root hairs and not only prevent the intrusion of harmful organisms but also make available otherwise insoluble nutrients.

Polyculture of Perennial Plants

Throughout the history of agriculture, with few exceptions, tillage has rarely been practiced productively on the same site for more than a few centuries. This occurs because tillage opens the land to erosion (slow, if carefully practiced, and rapid, if poorly practiced).

A new technology being investigated in the hope of developing a sustainable form of agriculture is based on the polyculture of herbaceous perennial plants (Jackson and Bender, 1980). Polyculture is the growing of two or more intermingled crops simultaneously. Of course, polyculture of perennials has long been used for forage. But current research focuses on grain production using plants not now regarded as food crops but which, through genetic selection and perhaps genetic engineering, may become productive cultivars. Such cultivars are being sought because: 1) the search for genes to alter current high-yield grain crops into perennial plants has been unsuccessful and may be impossible because little of the original genetic diversity of those plants has been preserved; and 2) current grains are adapted to grow in monocultures.

Herbaceous perennials are nonwoody plants, such as grasses, that live for 3 or more years, regrowing each spring from existing roots or rhizomes. That means the seed can be harvested without interfering with the next year's

growth potential. Several economically important cultivars, such as cotton and sorghum, are in fact tropical herbaceous perennials that are grown in the United States as annuals. Perennials should not be confused with biennials which develop a rosette the first year and one or more reproductive stalks the second.

Except for sorghum, which is grown as an annual, there has been little genetic selection to improve seed yield of herbaceous perennials. Research on these plants has been done mainly by range agronomists who seek *forage* yield increases. Thus, the perennials for which seed yield data exist are those grasses that have been selected and managed to put their energy into leaf production for forage rather than into seed production. Perennial grasses that have relatively poor forage output but good seed yields (1,000 lb/acre) generally have not been studied or selected for. Thus, herbaceous perennials for which seed yields have been measured produce only one-third to two-thirds as much as annual cultivars such as winter wheat. However, the ability to improve these yields seems great with available plant breeding technologies.

While yields are lower, the protein content per seed of many herbaceous perennials is much higher than for corn or wheat and may approach the protein level of soybeans. This high protein content in the seed should be maintained during breeding programs so the plants would be valuable for both animal and human nutrition.

It is encouraging to note that perennials cross more freely with close relatives than do annuals and their hybrids are more likely to be fertile. In addition, chromosomal sterility is rare in perennials—i.e., gene elimination, addition, or transfer is relatively easy. The incidence of polyploidy (having a chromosome number that is a multiple greater than two) is high in perennials, and in the grass family, in particular, there is a correlation between efficient vegetative reproduction and high percentage of polyploidy.

The most serious drawback to seed yield improvement in perennials may be the energy cost to maintain their roots over the winter and to rejuvenate the following spring. However, if breeding strategies are successful in increasing the overall biomass of the perennial, a larger part of the photosynthate could be allocated to seed production.

The anticipated (albeit mostly hypothetical) benefits of a successful perennial polyculture include:

1. Because tillage essentially would be eliminated, perennial agriculture would reduce soil erosion risks and might actually foster the accumulation of soil.
2. The efficiency of water use and water conservation by the perennial ecosystem would be near maximum. Irrigation could decline, thereby helping to avert water shortage problems in ground water overdraft areas.
3. The application of manufactured fertilizers would be reduced because of the use of legumes in the polyculture, the decrease in the denitrification which occurs when a climax grass cover is in place, and the decreased loss of nutrients through soil erosion.
4. The use of manufactured pesticides could be reduced where polycultures replace monocultures because the latter are more susceptible to damage. The new cultivars could be bred to retain naturally occurring pest and disease resistance and the permanent crop cover might eventually suppress growth of weeds.
5. Fuel consumption would be reduced because of the elimination of frequent tillage.
6. Substantial areas of land not used for crops because of serious erosion potential could be brought into production.

Conclusions

Changes in cropping systems can have major impacts on land productivity. Multiple cropping is one way, when practiced carefully, to expand the land's potential. Another option is to increase the size of the productive crop base—that is, to bring different types of crops into wider use. Either option, in the proper circumstances, could be used to enhance land

productivity, but further research and development efforts may be needed to fully exploit the system's potentials.

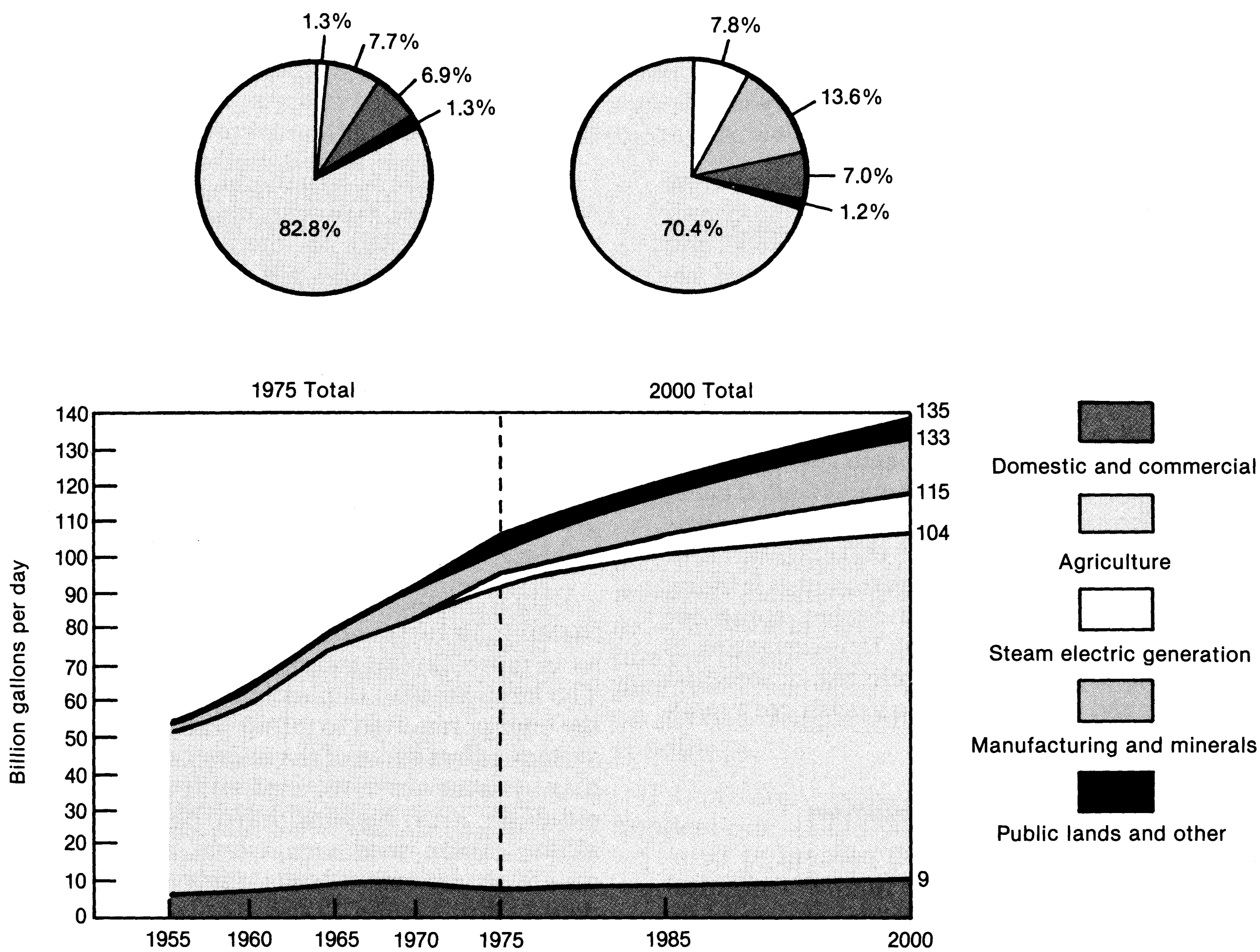
Drip Irrigation

Irrigation is an important tool for improving land productivity. The United States has more than 45 million acres of irrigated farmland. Irrigated agriculture uses more than 150 billion gallons of water a day, accounting for nearly 80 percent of the Nation's total water use (U.S. Water Resources Council, 1978). Because irrigated crops tend to be high-value products, irrigated lands account for a disproportionate share of the value of the crops produced in the United States.

The importance of adequate water supplies for agriculture will be highlighted in the upcoming decades as industry, urbanization, and recreation compete with agriculture for finite water supplies (see fig. 13). And as water conflicts become apparent, more attention will focus on various new water-conserving technologies for irrigated agriculture.

One such technology is drip (sometimes called trickle) irrigation. Drip irrigation is the frequent, slow application of moisture to the soil near the roots of a plant or tree in amounts

Figure 13.—Water Consumption by Functional Use



SOURCE: U.S. Water Resources Council, 1978.

just sufficient to meet its needs (University of California, 1979). Systems vary in design, but generally consist of a head or control station and main and lateral lines with openings at intervals along the length of the hosing or pipes.

Typically, these openings are fitted with emitters, nozzle-like devices that regulate water flow from lateral lines into the soil. The system also includes provisions for filtration with or without chlorination, since clean water is essential to maintain open drip lines. In addition, a liquid fertilizer injector pump, a fertilizer holding tank, and hardware to regulate water pressure are usually necessary.

Some growers have equipment that permits automated operation of the watering system, and some use the technology in conjunction with plastic mulch to limit evaporation. Indeed, were it not for the development of suitable plastic components for the technology as a whole, drip irrigation would probably still be in its infancy.

Drip irrigation is, however, not really a new technology. It was developed in Germany and elsewhere in Europe beginning about 1860, and by the 1950's and 1960's was in widespread use in greenhouses in several countries. Commercial outdoor applications were first achieved in Israel during the 1960's. In 1969, drip irrigation was introduced to the United States on a 5-acre avocado orchard in northern San Diego County (University of California, 1979; Gustafson, 1980). By 1980, an estimated 494,000 acres of U.S. farmland were irrigated by drip systems (Howell, 1981). Although 305,000 of these acres were in California, drip irrigation also is being used in more than 30 other States, some not arid or semiarid (Hall, 1980). Drip irrigation is being used to reduce economic risk of seasonal or prolonged drought and to assure crop quality.

Advantages of Drip Irrigation

- Water savings of 15 to 30 percent as compared with sprinkler or furrow irrigation because of reduced runoff and evaporation.
- Lower seedling mortality and greater uniformity of plants, bushes, or trees.
- Yield increases (generally).
- Fewer weeds because of less wetted area and therefore less need to weed and use herbicides.
- Fuel savings.
- Reduced fertilizer inputs.
- More efficient use of rainfall because drip irrigation does not saturate the soil to the point where it cannot absorb more.
- Can be used on steep terrain when other forms of irrigation cannot—a particular bonus where industrialization and urbanization are encroaching on acreage formerly devoted to farming.
- Furnishes erosion control and offers shelter to livestock when used to establish windbreaks in pastures and around homesteads, feedlots, and farms.

Conclusions

Drip irrigation is, in general, a versatile technology. Growers, however, must adopt systems particularly suited to their circumstances. Systems choice varies not only with the crop in question but also with the location and type of soil, the local climate, the water source and its distance from the field, and whether what is to be grown is an annual or a perennial. For example, sandy soils require more frequent irrigation than clay-rich soils because the latter have less capacity to hold water. Shallow, gravelly soils are not suited to trickle technology.

Drip irrigation is initially more expensive to install than furrow or sprinkler irrigation and so is more capital-intensive (Schuhart, 1977). The large amount of plastic pipe required, and the energy required to pump water through the system, offset some of the energy savings when drip systems are compared with others. Thus, although drip systems have been used for alfalfa, cotton, feed corn, wheat, and sorghum on a demonstration basis, their major use to date in the United States has been for high-value crops.*

*A partial list of crops grown with drip irrigation includes: avocados, apples, table and wine grapes, strawberries, grapefruit,

Once installed, drip systems must be maintained in good condition for efficient performance. This often entails flushing the lines and, where emitters are used, requires keeping them clean. Emitter clogging caused by chemical buildup from water contaminants or fertilizers, dirt, rock, silt, sludge, algae, slime, salt, or roots is, in fact, one of the big problems associated with this technology.

Drip irrigation is somewhat labor-intensive because the emitters must be inspected frequently and because breakdowns in the system, not being readily visible, easily can be overlooked. Furthermore, drip may be inappropriate where water has a high iron or sulfur content because the buildup of these elements in the lines fosters the growth of slime-producing bacteria that can clog emitters.

Drip systems also can have problems with salinity buildup and damage to the water lines from wildlife, insects, or soil-dwelling animals. Salinity problems vary greatly depending on the soil type and precipitation. Animal damage, too, varies by site. In some areas of Florida, for example, wire worms are such a threat to the lines that drip irrigation can be impractical. Similarly, in some areas gophers, mice, rabbits, coyotes, and other creatures enjoy either playing with the pastic lines and pipes, coiling themselves under them, chewing on them, or drinking from them.

Some plastic materials are less attractive than others to animals, and putting as much as possible of the equipment underground tends to discourage land-roving animals. But these and other measures, such as setting out water pans in the fields for visiting wildlife and spraying repellents on the lines, are only partial remedies. No pesticides registered by the Environmental Protection Agency exist that can be injected into the lines.

The strengths and weaknesses inherent in drip irrigation are not, however, the only factors affecting its use. Institutional arrangements also act as either incentives or constraints. For example, the availability of expertise from agricultural extension services, both Federal and State, can help to build a clientele for new technology. Subsidies encourage dissemination, too. In some areas, USDA has offered 50- to 75-percent cost sharing for the installation of trickle systems for certain purposes such as windbreaks (Conrad, 1981).

Irrigation is an important tool in maintaining and enhancing the productivity of U.S. croplands. But water use efficiency varies greatly with the system used and how it is managed onsite. Because drip irrigation supplies water directly to the plant root zone, it can provide increased water and energy efficiency as well as reduced erosion.

Breeding Salt-Tolerant Plants

Most commercial crops cannot survive in salty soils. Until recently, little scientific attention was paid to this problem because freshwater and land seemed limitless. But now scientists have begun investigating salt-tolerant plants. Their efforts involve both identifying the most salt-tolerant strains among conventional crop species and studying the genetics of wild species that live and reproduce in oceans, seashores, estuaries, deltas, salt marshes, and saline desert soils. Studying these halophytes and how they have adapted to saline environments may help scientists develop plant varieties, either through cross-breeding or genetic engineering, to survive in salty conditions.

If salt-tolerant crops could be developed, the implications would be far-reaching:

- currently productive, irrigated land such as that found along the lower Colorado River—e.g., the Imperial and Coachella Valleys—could remain in crop production

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lemons, limes, oranges, tangelos, macadamia nuts, papaya, peaches, pears, persimmons, walnuts, almonds, boysenberries, tomatoes, cucumbers, celery, potatoes, peppers, melons, sweet corn, asparagus, eggplant, peas, lettuce, ornamental trees and shrubs, bedding plants, cacti and succulents, bulbs, carnations, gladioli, poinsettias, chrysanthemums, radishes, apricots, pistachios, plums, cherries, pecans, sugarcane, pineapple, bananas, mangoes, olives, figs, passion fruit, Christmas trees, etc. Street medians and turf—both for homes and golf courses— have also been successfully managed in this way.

even though its source of irrigation water was becoming increasingly saline;

- saline water drained from underneath irrigated fields in drainage-problem areas such as the San Joaquin Valley and the lower Gila River Valley, Ariz., could be reused or recycled, thereby reducing costs of saline-water disposal; and
- coastal areas where ground water overdraft has caused saltwater intrusion into aquifers—e.g., along the Gulf of Mexico—could continue to be agriculturally productive, as could arid inland areas where the ground water is naturally saline—e.g., the Pecos River Valley, Tex., or the Arkansas River Valley, Colo..

Photo credit: U.S. Department of Agri

Plant Propagation: Transferring strawberry shoots t a culture jar containing fresh shoot-inducing mediu

Salt-tolerant cultivars would not solve salinity problems, but they could provide an opportunity for enhancing the productivity of some lands. Research on salt tolerance is increasing, though not substantially. Epstein, et al. (1980), conducted research on barley, wheat, and tomatoes to determine their tolerance to saline water. The findings on these three crops are promising.

Ongoing Research

Barley has long been known as a salt-tolerant grain. With only undiluted seawater for irrigation, but supplemented with nitrogen and phosphorus, the most salt-tolerant barley had an average yield of 962 lb/acre, 23 percent more than several standard cultivars tested. Normal annual barley yields are under 1,780 lb/acre.

Wheat does not have as high a salt tolerance as barley. Nevertheless, Epstein's tests found that 34 lines of spring wheat were able to produce grain when using water having 50 percent salinity, a level lethal to commercial wheat. Other researchers feel that they can improve these results.

While commercial tomatoes showed little salt tolerance, a wild variety, *Lycopersicon cheesmanii,* from the high-tide level on the Galapagos Islands, shows promise. The small, economically useless tomato differs markedly from the commercial cultivar by having uniq ways of transporting ions and different wa of accumulating and excluding salt. When t two cultivars were crossed, they produced plant that could survive, flower, and set fr the size of a small cherry tomato when irrigate with 70 percent seawater (Epstein, 1980). Th experiment is important because it indicat that salt tolerance can be transferred from wi species to those of commercial value.

Other research shows that tissue and cel culture techniques may speed up the proces of identifying and selecting salt-tolerant plant cells. Through these techniques, individua plant cells can be introduced into a culture medium that is designed to support the growt of cells having a desired trait, such as resistance to high salt levels. Those cells that survive are regenerated into whole plants, a possible, though sometimes difficult task. Adult plants then can be used to propagate additional plants—all with the ability to withstand the desired stress selected for—namely, salt tolerance.

Some evidence suggests that some salt-tolerant crops may be enhanced by inoculating their roots with certain mycorrhizal fungi (Menge, 1980). Such fungi are known to help plants obtain soil nutrients and survive during

drought stress. In addition, some legumes can fix nitrogen from the air through a symbiotic relationship with rhizobial bacteria strains that live in nodules on the plant's roots. The appropriate selection of rhizobium may enhance the salt tolerance of these plants (Epstein, et al., 1980).

Researchers know little about how salt-tolerant plants survive. The growing interest in genetic engineering should provide some answers, but for now the search for wild, salt-tolerant relatives of modern crops will be important in selection and breeding activities. To date, screening existing varieties has only limited potential because these plants have been bred for certain desirable traits such as disease resistance and yield, and in the process have lost much of their original, natural variability. A worldwide search for halophytes such as the tomato in the Galapagos Islands could increase chances of developing other crops with built-in salt tolerance. However, native vegetation in saline wetland and desert ecosystems is under heavy pressure in the United States, and most lesser developed countries, the part of the world having the greatest variety of plant species. Destroying wild wetland and desert vegetation narrows the chances for finding the genetic variability needed for salt-tolerance research.

Impacts

If new varieties of crops that are substantially more tolerant to salinity can be developed, they could be used most effectively on lands that are already nonproductive because of soil salinization or on lands that have no major, readily available freshwater resources. These areas are mostly in the West, where the increasing competition over water for agriculture, energy, mining, and growing urban populations makes it unlikely that large quantities of freshwater will be available to reclaim salinized soils or to supply new agricultural areas.

Widespread use of salt-tolerant plants could lead locally to increased soil salinization and the increased salinity of ground water and raises the chances of increasing the salinity of surface water regionally. If production occurs close to freshwater resources, there is the risk that the freshwater would be polluted with salt. This might lead to an expanded salinization problem, resulting in some negative economic, social, and environmental impacts.

Conclusions

- Salt-tolerant crops probably do not perform as well as plants not under salt stress. Therefore, it is important to prevent salinization of soils and not merely to rely on the possibility of switching to salt-tolerant plants as soils are ruined.
- Salt-tolerant plants could help free high-quality freshwater for conventional irrigated crops or for human consumption.
- The search for wild, salt-tolerant relatives of modern crops will be important in the selection and breeding activities for developing the desired traits in plants. The tropics have the greatest variety of plant species but native vegetation in these countries is being destroyed rapidly. This is narrowing the chances of finding the genetic variability needed for salt-tolerance research and agricultural research generally.
- Locally, use of salt-tolerant crops probably would lead to increased soil salinization, increased salinity of the ground water, and increased salinity of surface water regionally.

Computers in Agriculture

Computers can affect land productivity by enhancing a producer's ability to make sound management decisions. New applications for computers are emerging rapidly. However, three areas that relate directly to land productivity are visible today: 1) storing and making available vast amounts of agricultural information, 2) assisting in farm management decisions, and 3) continuing education.

Computer-based information systems potentially can offer farmers and ranchers quick access to the thousands of bulletins, pamphlets, books, and periodicals generated annually for

the agricultural community. Because computer systems are updated easily and have thorough indexing and search functions, they make it possible for users to select relevant information from the vast amounts available. Most of the agricultural information systems now functioning are geared to specialists and researchers rather than to farm operators. Farm-oriented systems, however, are being developed. An experimental system in Kentucky, "Green Thumb," is designed to disseminate weather, market, and other production and management information directly to farmers through devices that print the information on home television screens. A private firm, Control Data Corp., has included interactive information services—in which the computer responds to a farmer's specific questions—as part of its prototype "agricultural business center" in Princeton, Minn.

Computer programs to assist farmers in managing farm production have been developed at several universities. Notable examples are Michigan State University's Today's Electronic Planning (TELEPLAN), the University of Nebraska's Agricultural Computer Network (AGNET), Virginia Tech's Computerized Management Network (CMN), and the Fast Agricultural Communications Terminal Systems (FACTS) in Indiana. Similarly, some commercial firms are developing computer-based management aids for their clientele. Programs for determining optimum livestock feeding rates, irrigation timing, fertilizer applications, and pest management strategies are available, as well as programs to help farmers compute profit potentials for full season and double cropping, and judge the economic feasibility of land and equipment purchases. The Control Data prototype offers 10 computer-based management systems that can assist farmers in keeping financial or production records and marketing and loan applications, among other services.

The computer's ability to allow direct dialog between student and teacher, at any time and location, and at the student's chosen pace, gives it great potential as an educational medium. Educational programs can be stored conveniently on disks or cassettes and u wherever appropriate facilities exist. F educational programs tailored for farm a ranch use have been developed, howev though computer question-and-answer cour on a wide variety of topics have been includ in Control Data's agricultural business cent

If region-specific models are developed help farmers calculate complex tradeoffs b tween short-term benefits and long-term cost or vice versa, it is likely that agricultural use will be better matched to the capability of th land. However, the economics of making in teractive computer programs or models tha are site specific enough for such purposes hav yet to be determined. If the models must b made so specific that they cover a region wit too few customers to pay for the developmer costs, Government subsidies may be necessar As the work of risk-taking entrepreneurs pr gresses, the economics of computers bein used to enhance long-term land productivi will become more clear.

Soil Amendments

Soil amendments—also known as soil conditioners and soil additives—are materials other than conventional fertilizers or organic matter that are added to soils to change them physically, chemically, or biologically to improve productivity. These products have proliferated as manufactured fertilizers have become more expensive, but the efficacy of mos of them is doubtful. To some extent, they ar associated with organic farming, though only some organic farmers use them and traditional farmers use them as well.

With rare exceptions, university agronomists who have tested these products have found that yield increases, if any, do not justify the increased production costs. This does not mean that all unconventional soil amendments are without promise. Some biological soil amendments, such as inoculation with nitrogen-fixing bacteria suited for a particular legume, or inoculation with mycorrhiza after a soil has been fumigated, have proven to be cost-effective alternatives to manufactured fertilizers (Halliday,

1981; Menge, 1980). Some chemical amendments, such as water-holding starch copolymers ("super-slurper") have shown great promise in preliminary tests in soils where tree seedlings are planted. Certain zeolite minerals have been proven to improve soil water-holding capacity and to enhance fertility by increasing the soil's ion exchange capacity. These naturally occurring fine-grained minerals have been the subject of intensive agricultural research in Japan, Bulgaria, and Russia, but have yet to attract much attention from agriculturalists in the United States.

But many of the soil amendments available have been called "snake oil"—that is, their value is very doubtful. The situation with soil amendments resembles that of pharmaceuticals before 1962, when the Federal Food and Drug Act was amended to require scientifically acceptable evidence for efficacy of pharmaceutical products before they could be offered in interstate commerce. Some States have moved or are moving toward a similar philosophy to govern intrastate commerce in soil amendments. Oklahoma, for example, now requires proof of effectiveness before an agricultural product of this kind may be registered for sale in the State. In Wisconsin, labeling claims cannot be made without research data to back them up. Nebraska recently amended its law encompassing soil amendments to require manufacturers to list every ingredient on the label.

CURRENT CROPLAND EROSION CONTROL TECHNOLOGIES

In the coming years, various innovative approaches to conserving land productivity will become increasingly important. But existing conservation technologies will continue to play a key role in good land stewardship. Many of these technologies were developed in response to the 1930's Dust Bowl. Planting belts of sheltering trees to break the winds, learning to terrace sloping fields to control runoff and erosion, improving on farm management to keep protective cover on the land—these are conservation techniques with long useful histories. Although they sometimes are not enough to protect the most fragile and erosive lands, such traditional conservation technologies have been widespread, important influences on many acres of American farmland.

Water Erosion Control

Practices for controlling sheet and rill erosion fall in two broad categories: 1) engineering practices, including the construction of such structures as terraces, dams, diversions, or grade stablization structures; and 2) management practices, including crop residue management, seeding methods, soil treatment, tillage methods, the timing of field operations, and vegetative controls such as winter cover crops, sod-based rotations, contour farming, and permanent vegetative cover. This section briefly describes these practices and comments on their potential.

Engineering Practices

TERRACES

Terraces are earth embankments, channels, or combinations of embankments and channels built across the slope of the land at suitable spacings and with acceptable grades. They reduce soil erosion, provide maximum retention of moisture for crop use, remove surface runoff at a nonerosive velocity, reduce sediment content in runoff water, and/or reduce peak runoff rates.

Terraces are the best mechanical erosion control practice available that allows continuous row-crop production. They may trap up to 85 percent of the sediment eroded from the field, although they cannot stop erosion between terraces. Analysis of the 1977 NRI data on terraced cropland shows that terracing was responsible for reducing erosion an average of 71 percent compared with similar untreated

land (Miller, 1981). The NRI data also indicate that 27.5 million acres of cropland had terraces in 1977.

However, several problems associated with the terracing have not been overcome. Terrace construction may cause extreme surface compaction and remove topsoil from large areas of the field. Uneven drying, ponding, and severe erosion in different parts of the same terrace channel are also common, especially for the first 3 to 5 years after construction. In addition, problems with terrace alinement resulting in point rows and poor maneuverability of machinery, and maintaining grass waterways, have reduced terrace use.

The design and construction of a terrace system are expensive and require skilled professionals. Installation costs of $400 per acre are not uncommon for uniformly spaced cut-and-fill terraces with necessary drains (Shrader, 1980). Further costs include loss of land to terrace backslopes, loss of crops during construction year, higher labor and energy costs to work terraced fields, and costs of controlling insect pests that may be harbored in backslope grass strips. In addition, maintenance is mandatory to retain an adequate terrace cross section for proper functioning of the system.

DIVERSIONS

Diversions differ from terraces in that they consist of individually designed channels across a hillside. They are used to protect bottomland from hillside runoff, to divert runoff away from active gullies, to reduce the number of waterways, and to reduce slope length so that contour strips can control erosion. The 1977 NRI show that approximately 2.4 million acres of cropland contain diversions.

Management Practices

CONTOUR FARMING

The practice of planting on a line perpendicular to the slope of the land is termed contour farming. This practice can be used at relatively low cost. Contour tillage can reduce average soil loss by 50 percent on moderately sloping fields (2 to 8 percent slope) not more than 300 ft long. Extrapolations from the 1977 NRI data show erosion rates on land treated with contour farming average 61 percent less than the corresponding untreated land (Miller, 1981). The effectiveness of contouring, however, declines as the inherent potential for erosion increases. In certain cases, climatic, soil, or topographic conditions limit the application of contour farming.

CONTOUR STRIPCROPPING

In contour stripcropping ordinary farm crops are produced in relatively narrow strips of variable or even width that alternate with close-growing meadow crops. The strips are oriented approximately on the contour and perpendicular to the slope. Contour stripcropping reduces erosion about 50 percent more than contour farming. The slowing and filtering action of the sod strips reduces runoff water velocity and soil loss. The exact width of strips needed for adequate erosion control depends on soil types, percent slope, length of slope, and the crop rotation. The practice is commonly used in combination with diversions on long slopes of 400 ft or more. Contour strips are relatively inexpensive to install, but require farmers to keep headlands, waterways, and turn strips in grass, thus reducing crop acreage.

GRASS WATERWAYS

Grass waterways are one of the most common conservation practices. They are simply grass-covered strips of land running at intervals the length of the fields. They provide a path for surface runoff from fields, alone or in combination with diversions or terrace systems. Maintaining grass cover is a major problem in row-cropped fields because the extensive use of herbicides and their transport in surface runoff often kills the grass.

COVER CROPS

Cover crops are crops planted between regular cropping periods to protect the soil from water and wind erosion. Fields planted in tobacco, potatoes, vegetables, and silage corn can benefit from planting cover crops once the major crop is removed.

Photo credit: USDA—Soil Conservation Service

Contour stripcropping on Class II Kenyon and Ostrander silt loam

The crop selected should be adapted to the soil, climate, and the quantity of organic material produced, and easily worked into the soil at the time of seeding. Cereal grains (rye, oats, and winter wheat) are popular cover crops.

CROP ROTATIONS

Sod-based crop rotations, growing dense, ground-cover crops in rotation with other crops, are used to minimize wind and water erosion. They also can be used to provide some nitrogen for later crops. Total soil loss is greatly reduced, although soil losses are not equally distributed over the rotation. On many soils, crop rotations favor higher yields and improved crop quality.

The use of sod-based rotations can be traced to such notables as Thomas Jefferson. However, sod-based rotations have decreased significantly in popularity under modern agricultural conditions, in part because severe reductions in the number of farmers engaged in livestock-based agriculture have reduced the need for forage crops normally planted in such rotations.

MANAGEMENT OF SOIL FERTILITY

High soil fertility allows greater numbers of plants, and larger plants, at all stages of growth. The resulting increase in plant cover provides additional soil protection, particularly during the critical early period when soil is most exposed (Troech, et al., 1980).

Fertility management in modern agriculture often depends on precise soil testing and tailoring practices to specific fields, soils, and crops. But estimates of fertilizer needs based on general knowledge of crop requirements, soil type, and a field's erosion, crop, and fertilization history are likely to be imprecise. This can lead to underfertilization or overfertilization, which may be extremely costly and result in suboptimum yields, increased erosion, and increased water pollution. Major techniques to enhance fertility include the use of manufactured or nonmanufactured fertilizers, the use of additives such as lime or gypsum to control soil pH, technologies for controlling soil moisture, crop rotation, and the use of adapted crop varieties.

Wind Erosion Control

A number of practices are used to control wind erosion, many of which parallel or are similar to practices for controlling water erosion. Establishing and maintaining cover is the "cardinal" rule of wind erosion control.

Stubble Mulch and Minimum Tillage

Stubble mulch and other variations of minimum tillage are used to maintain as much crop residue on the land surface in a standing or near-erect condition as is compatible with planting procedures for the next crop. The residues slow the wind at ground level, reducing its power to detach and carry soil particles. This technology has been known for decades, but is becoming more feasible with the development of improved herbicides and new conservation tillage machinery (see previous discussion of conservation tillage and no-till).

The acceptance of stubble mulch and minimum tillage continues to grow each year as the methods' advantages for both controlling wind erosion and conserving soil moisture beco more apparent. Extrapolations from 1977 N data show erosion rates on erosive lar treated with minimum tillage alone average percent less than the corresponding rates untreated cultivated land (Miller, 1981).

Cover Crops

Cover can also be maintained by plantin cover crops when land is bare between regul crops. Cover crops hold soil in place and th reduce erosion. Cover crops are well suited t humid areas and may also be used on irrigate land where irrigation water can give quick ge mination and growth. They are less practica in drier areas where wind erosion can be severe because they compete for limited sup plies of soil moisture. However, one practica method to avoid the moisture depletion prob lem is to plant crops that grow before winte kill, leaving plant residues for protection with no additional water requirements. Similar re sults also can be obtained by using a herbicid to kill a crop after it has provided some protective growth.

Mulches and Nonvegetative Cover

Mulches, nonvegetative, and processed covers can protect areas of severe wind erosion or areas with high economic return potential. Costs prohibit widespread application of this method of wind erosion control. However, it is applicable for dune stabilization, providing erosion control on vegetable and speciality crop lands, and to "blow out" or "hot spot" erosion problems in the large dryland agricultural areas.

Reduction of Field Lengths

Another fundamental way to reduce wind erosion is to reduce field lengths along the prevailing wind direction.

Stripcropping

Wind erosion can also be reduced with stripcropping, where strips of erosion-resistant crops are alternated with strips of erosion-susceptible crops. Stripcrops run at right

angles to the prevailing winds. The actual width of strips needed to control wind erosion varies with topographic features such as the length, degree, and exposure of slope in relation to prevailing winds, and with factors affecting field erodibility—e.g., soil texture, cloddiness, roughness, and wind velocity and direction. Stripcropping has disadvantages, however, as less acreage is available for the highest profit crops and insect problems may increase. Incompatibility with modern, large farm machinery also has made stripcropping objectionable to some farmers.

Windbreaks and Shelterbelts

Windbreaks and shelterbelts which reduce field lengths and lower windspeeds also help control wind erosion. The effectiveness of any barrier depends on the wind velocity and direction and on the shape, width, height, and porosity of the barriers. Nearly any plant that reaches substantial height and retains its lower leaves can be used as a barrier. Tree windbreaks have most application on sandy soils and in areas where there is substantial rainfall. Narrow rows of tall-growing field crops, perennial grass barriers, snow fences, solid wooden and rock walls, and earthen banks have also been used for windbreaks.

The use of windbreaks to control wind erosion is declining, in part because windbreaks interfere with the large machinery and center-pivot irrigation systems. Plants used for windbreaks also can compete for water and commonly produce no increases in crop yield. For these reasons, many shelterbelts planted in the 1930's have been torn out and few new shelterbelts are being planted.

PRODUCE SOIL CLODS OR AGGREGATES AND ROUGHEN THE LAND

Rougher, more aggregated soils are less likely to suffer wind erosion. During regular tillage and planting operations, the soil will be rougher if minimum or stubble mulch tillage practices are used. Special planters such as the fill planter for row crops and the deep furrow or hoe drill for small grains also produce effectively rough soils. Emergency or "last resort" tillage can produce roughness and cloddiness on both cropped and fallow land. It can be accomplished with a number of common tillage implements, including chisel plows and field cultivators.

LEVEL OR BENCH LAND

Land is often leveled or benched for purposes of water erosion control, irrigation, and moisture conservation. These land modifications also provide substantial wind erosion control because field lengths are shortened and erosion forces may be reduced on slopes and hilltops.

INVESTMENT IN EROSION CONTROL: CURRENT STATUS AND EFFECTIVENESS

Studies investigating the effectiveness, profitability, and investment trends in conservation practices show a marked decline in the use of "permanent" conservation structures and a tendency for such practices to be uneconomical for many farmers under a wide variety of conditions. At the same time, the use of these conservation practices which are an integral part of crop production systems has increased rapidly and has been shown to be profitable under a broad range of earning conditions.

Data from USDA on natural resource investments in agriculture show that "soil and water conservation improvements on U.S. farms, which experienced rapid expansion from 1935 to 1955, are now deteriorating in overall value and probably also in effectiveness." Net investment in permanent conservation measures on farms, accounting for estimated depreciation, declined from $9.9 billion in 1955 to $7.9 billion in 1975 (both figures are 1972 dollars.) (There is some disagreement over these figures; the

rate of disinvestment depends on assumed depreciation rates.) Total private or non-Federal investment in permanent conservation measures *on all lands* declined from $4.95 billion in 1955 to $4.3 billion in 1975 (USDA/ESCS, 1979).

These figures reflect a tendency for farmers to remove, or not maintain, permanent measures such as terraces, diversions, windbreaks, and permanent vegetative covers, as well as decisions not to expand such methods to unimproved land. The high costs of such methods, their incompatibility with large machines, and the lack of demonstrable yield improvements associated with the practices act against their use. Although Federal cost sharing has been and continues to be available to implement such practices, long-term projections indicate that in many cases farm incomes can decline because of installation of the permanent soil conservation structures.

Recent studies of the economic feasibility of installing terraces, in particular, document losses to farmers who use them. One study of Illinois farmland found that over the expected 20-year life of a terracing system, construction on gentle slopes incurred a net cost because the erosion prevented was not great enough to significantly alter crop yields. On steep slopes, initial building costs were so high that losses in yield could not offset the costs, even though severe erosion was occurring (Mitchell, et al., 1980).

While the public benefits of installing terraces and other structural or permanent practices may justify their costs, current incentives for their use do not appear to be sufficient to motivate private producers.

Land management that integrates conservation practices into normal cropping activities, on the other hand, appears to be capable of maintaining (and, in some cases, increasing) farm income while providing conservation benefits. Such practices may include conservation cropping systems, use of cover and green manure crops, subsoiling, crop residue manipulation, conservation tillage, intensive grazing management, and range seeding.

Such management practices have spread idly throughout the U.S. agricultural sec They tend to require smaller initial investm than permanent erosion control methods, w much of the investment made in special equ ment required to implement the practice. (Co sequently, such investments do not show as conservation investments in the Economi Statistics, and Cooperatives Service figur quoted above.) Some management practice such as contour plowing, involve higher ope ating costs than conventional practices an may not produce sufficient gains in land pr ductivity to maintain profits on a short-ter basis (USDA Land and Water Task Forc 1979).

Because costs for conversion to productivity conserving systems—e.g., equipment pur chases and higher current operating costs— are incurred over an indefinite period of time cost sharing to promote them is difficult. Loa programs or tax credits to promote equipmen purchases might prove to be more effective in centive mechanisms. However, the major con straints to installing these practices do not appear to be up-front costs but rather the lack of documented evidence that the benefits of the practices exceed their costs, and the high levels of management (and education) required for carrying out the practices successfully (USDA Land and Water Task Force, 1979).

One study found that the use of chisel plowing in all areas of the Corn Belt where it would be profitable—77 million acres of farmland—would reduce average soil losses by 43 percent, from 5.17 to 2.96 tons per acre per year (Taylor, et al., 1978). Conservation tillage practices have, in general, been shown to reduce production costs, particularly those associated with labor and fuel.

Integrated erosion control practices also appear to have greater potential for reducing aggregate amounts of erosion than permanent control measures. An analysis of the 1977 NRI data, based on the universal soil loss equation, demonstrates that without existing "supporting practices" (contour farming, stripcropping, and terraces), erosion would have been only

5 percent higher than it was in 1977. But without the use of "cover and management practices," which provide greater conservation benefits than conventional methods, erosion could have been 13 percent higher than it was in 1977 (Miller, 1981).

However, extrapolations from NRI data also suggest that no erosion control practice, or combination of practices, would be capable of bringing soil losses to conventionally acceptable tolerance values on the Nation's most erosive land. The NRI show 23.5 million areas of cropland to be eroding at rates of over 15 tons per acre per year—these acres account for fully 77 percent of the erosion exceeding conventional T-values of 5 tons per acre per year. The T-value represents a useful management target for soils eroding in excess of 5 tons per acre per year, but it is generally considered to be higher than actual soil formation rates. (A more extensive discussion of erosion impacts on productivity is presented in ch. II of this report.) Yet even the most effective combination of practices—e.g., a combination of contour farming, minimum tillage, and crop-residue use—would not reduce erosion rates on these soils to 5 tons per acre per year (Miller, 1981).

Producers' economic incentives to use practices that control erosion call for installing these practices on lands where the potential return is greatest. These lands are not necessarily the same as those that are most susceptible to erosion. Thus, an appreciable part of the most fragile cropland is being farmed without any major erosion control practices. Of the 146 million acres of cropland with an inherent erosion potential* of over 15 tons per acre per year, 20 million had terraces installed as of 1977, and 51.7 million were being treated with contour farming, minimum tillage, or crop-residue use, leaving 74.3 million acres, or 51 percent of the land considered fragile under this definition, without these practices (Miller, 1981).

Although 73 percent of the terraces existing as of 1977 had been installed on land with an inherent erosive potential of over 15 tons per acre per year, only 34 percent of the contouring, minimum tillage, or crop residue use occurred on these lands (Miller, 1981).

*This indicates the amount of erosion that would occur under conditions of continuous tillage, fallow fields, without any erosion control practices.

POTENTIAL FOR MODIFYING CURRENT TECHNOLOGIES AND POSSIBILITIES FOR NEW TECHNOLOGIES

Projections for technological advances in the control of erosion focus primarily on improving and refining current control methods. Improvements that enhance the feasibility and profitability of currently known practices have significant potential for influencing rates of adoption by farmers and increasing aggregate amounts of farmland protected from water and wind erosion.

The greatest potential for improving current technologies lies in improving conservation tillage systems. Increased effectiveness of chemicals for controlling weeds without damaging the following crop through residual pesticide carryover could increase the acceptance of such systems, thereby providing protection to additional thousands of acres. New design of subsurface sweep tillage to incorporate vibratory action to the blades' movement through the soil could increase weed kill and production of cloddiness on the soil surface and present erosion. Similarly, improving the design of planting equipment to provide easier, more efficient planting in heavy residues could increase acceptance of conservation tillage systems and protect more acres from erosion.

Cover crops may hold promise of providing greater erosion control if technologies for seed pelletization and encapsulation are improved to assure that seeds have water and nutrients

for quick and even germination and vigorous seeding establishment.

Basic research to determine optimum porosity of narrow windbreaks and efforts to select and develop more hardy adaptable tree and shrub species and perennial grass barriers for use in narrow windbreaks could revive farmer interest in using this method of controlling wind erosion.

The effectiveness of emergency or "last-resort" tillage could be improved by research to provide guidelines on the use of different implements. Also, development and design of new machines capable of forming clods through compaction and then stablizing them with an adhesive before spreading them back on the land surface could greatly improve erosion control.

Effectiveness of land modification techniques can be improved by additional investigation of the influence of topography on erosion and by developing better design criteria for benching or other topographical modifications.

Methods for reducing crop residue decay by exercising control over microbial activity and by treating residues with petrochemicals similar to wood preservatives could provide improved erosion control. Impacts on the microbial population would have to be assessed to avoid any adverse consequences to soil productivity from their loss.

Developing improved data on the impact of erosion on long-term soil productivity, and quantifying erosion standards for report severity of erosion, would improve eros control by providing concrete information the value of control techniques for mainta ing soil productivity.

New technology for forecasting wind eros could greatly improve our ability to cope w the problem. Using probability functions convert basic wind erosion equations to s chastic projections would be required. Remo sensing support would also be needed.

Continued efforts in weather modificati might have potential for reducing the wind e sion problem, especially those aimed directl at preventing drought by enhancing precipit tion. But weather modification is justifiabl controversial. Improved irrigation technologie to reduce seepage, evaporation, and transpira tion losses could also reduce wind erosion in directly, by conserving scarce ground water r sources, thereby reducing the need to reve to dryland farming in many areas of th country.

Improved methods for calculating optimum site-specific fertility management decisions could aid farmers in achieving maximum crop cover to minimize erosion and produce optima yields. The increasing availability of computers makes improvements in mathematical models for analyzing fertility—e.g., models that ac count for the fertility effects of soil moisture management—of significant practical value t agricultural producers.

CONCLUSIONS

Farmers and agricultural scientists have developed a range of technologies to protect the inherent productivity of the Nations's cropland. Yet several processes, erosion being foremost, continue to degrade this essential resource. Many of the conservation practices were developed decades ago, and some of the most important of these—for instance, terraces and shelterbelts—have become less common as U.S. agriculture has undergone a fundamental change, becoming more and more productive, more labor efficient, and more dependent on fossil fuels. The apparent correlation of these trends seems to suggest that production and conservation are antithetical. However, a closer look at some innovative farming tech-

niques suggests that production and long-term productivity can be maintained or enhanced simultaneously.

These productivity-sustaining technologies are generally changes in management rather than additions of engineering structures, and often their conservation significance is overlooked. Improved management of soil fertility, which leads to better crop cover and thus reduces erosion, is one example. Perhaps the most promising of the productivity-sustaining technologies for the near term is conservation tillage.

The productivity-sustaining technologies typically require new management skills and may come into use slowly for this reason. Many are still in early stages of development and require more research before they can be widely used. Whether this research will be done in time to avert further degradation of U.S. croplands depends partly on public funding. However, the development of technologies to increase production while sustaining inherent productivity may not occur until this is made an explicit, primary goal for the agricultural research system and until some mechanisms are developed for screening and testing fundamentally new technologies.

Both the new productivity-sustaining technologies and the traditional conservation practices typically are used first and most on the Nation's best croplands. This means that croplands with steep slopes, drought hazards, poor drainage, and other problems—the sites where the improved technologies are most needed—are often not benefiting from conservation technologies. Thus, the adoption of productivity-sustaining technologies by owners and operators of these lands is a critically important goal for Government policy.

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Chapter V

Technology Adoption

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Technology Adoption

INTRODUCTION

Why do some farmers adopt technologies, while their neighbors do not? What attracts some farmers to publicly subsidized conservation programs? Could these programs be modified to attract more participants or different participants? Considering that a number of the major technologies with great potential to preserve and enhance agricultural land productivity are neither new nor extremely complicated, questions such as these assume considerable importance.

Many factors affect how quickly farmers and ranchers adopt new technologies. Various characteristics, including age, education, management capacity, and the size and type of farm operation may predispose a producer's views toward a given technology. Other important factors are the cost of the technology and the rate of return on the investment, the complexity of the technology, its compatibility with current farm size and operating methods, and the accessibility of information.

In the past, conservation programs often were designed as though all farmers had similar abilities and motivations, and similar resources of capital, knowledge, and management skills. Actually, though, many farmers and ranchers lack some or all of these resources. For instance, a conservation program may use loans or cost sharing to make various conservation practices affordable or profitable for farmers. But if a farmer lacks management skills or fails to integrate the practice into the overall farming operation, his yields and profits may actually drop. As a result, even if a farmer receives cost-share funds from the Federal Agricultural Conservation Program to convert part of his cropland to no-till farming, it does not mean that he will stick with the new system. If he does not master the technology in the first 2 years, or suffers weed problems that reduce yields and profits, he may revert to conventional methods when the cost sharing is discontinued. And he may become convinced that the fault lies in the conservation practice, and so be more likely to reject future new technologies or programs. Clearly, understanding the producers' managerial capacity and other factors that influence their decisions on the adoption of productivity-sustaining technologies is an important step in influencing the management of the Nation's agricultural lands.

LAND TENURE AND OWNERSHIP

Farm ownership in the United States is concentrated. Even though more than half the acres in the country are farmland, they are owned by just 3 percent of the population (USDA, 1981). Only 25 percent of the Nation's farmland is owned by full owner-operator (those who own and operate all their own land without renting extra acres). Another 30 percent is owned by nonoperator landlords. The remaining land is owned by farmers who rent supplemental acreage or who rent out a portion of their acreage to other farmers (Lee, 1980).

As farm ownership and farm operation have become increasingly separate, questions have arisen regarding the effects of this trend on conservation. Some experts have hypothesized that larger corporate farm structures will have unfavorable consequences on land stewardship. They suggest that landlords, particularly absentee landlords, are more likely to plan for

short-term objectives and to favor maximum current income over investments in resource protection (Lee, 1980).

Some research has supported this view. One study, for example, found that a significant number of absentee landlords in the Corn Belt were unaware that conservation measures would improve farm income over time. Research in Iowa showed that owner-operators are more likely than renters to use conservation practices because owners are more likely to reap the long-term benefits. Similarly, owner-operators benefit more from institutional factors, such as economic incentives and regulations designed to improve the short-term profitability of conservation practices (Nowak, 1980).

Recent research at the national level, however, finds no significant differences in soil losses among different types of ownership groups. This work, which used the 1980 National Resource Inventories data and 1978 data from the U.S. Department of Agriculture's (USDA's) Land Ownership Survey, did find differences in average erosion by ownership in 4 of the 10 U.S. farm production regions, but attributed the differences to physical rather than management factors (Lee, 1980).

In 5 of the 10 regions studied (the Northeast, Corn Belt, Delta, Southern Plains, and Mountain regions), there was a relationship between higher incomes and lower erosion rates. In the Corn Belt, for example, full owner-operators with net incomes of $20,000 to $49,000 averaged 9.4 tons an acre less erosion than did owners with farm incomes below $3,000. The correlation seems to result from the larger operations having less erosive land as well as m conservation practices.*

Nonfamily corporations appear average their adoption of minimum tillage and resid management practices. Family corporatic and partnerships with family members gene ly had higher use of those conservation pr tices than did other owners (table 20). Becau these practices have been promoted as ener and labor saving as well as soil conservir they may not be the best indicators of an ow er's conservation ethic.

In summary, the relationship between lan tenure and conservation remains unclear. It a pears, however, that farm structure alone h little direct relationship to soil loss rates.

In light of the increasing significance absentee landownership, more information i needed on the relationship between variou leasing arrangements and the use of conserva tion practices. Tenancy arrangements deter mine the distribution of the costs and benefit of conservation investments between owner and operators, and so may encourage or dis courage conservation. The shift from crop share leasing to cash leasing, for example, ma influence conservation efforts. As cash leasin increases, it could create an incentive for th exploitation of soil resources.

Further research is necessary before policy makers can be certain about how land tenure affects land stewardship. And while a national perspective on land tenure issues relative to

*Nationally, only 40 percent of cultivated cropland owned by operators in the $20,000 to $49,000 range is classified as having an erosion hazard, while 59 percent of cultivated cropland owned by operators below $3,000 is labeled erosion-prone.

Table 20.—Adoption of Conservation Practices on Cultivated Cropland by Type of Owner and Land Quality

Type of owner	Erosion hazard land with conservation practices	Nonerosion hazard land with conservation practices
	Percent of acreage	
Sole proprietor	48.0	53.1
Husband-wife	45.0	47.3
Family partnership	51.6	58.9
Nonfamily partnership	46.4	53.2
Family corporation	56.6	55.4
Other corporation	47.0	51.3
Other	49.3	50.4

SOURCE: Linda K. Lee, "Relationships Between Land Tenure and Soil Conservation," OTA background paper, 1980.

soil conservation would be useful for policy planning, regional and local analyses are necessary for implementation of conservation strategies.

MANAGERIAL CAPACITY

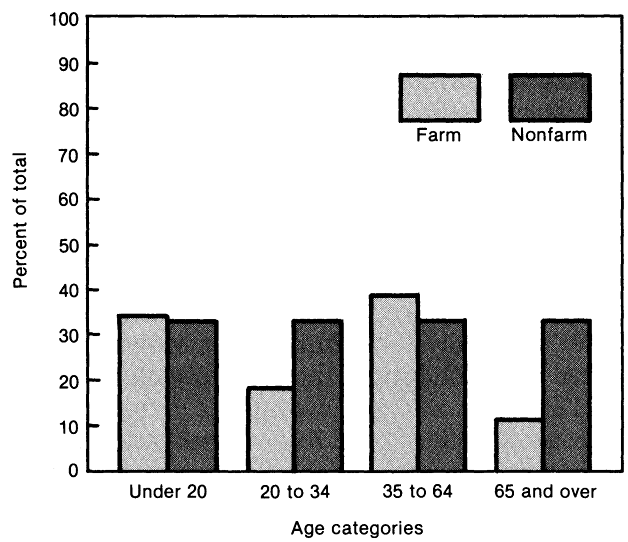
A producer makes management decisions in three major areas: production and organization, administration, and marketing. In fulfilling these management functions, the operator can supplement his own capabilities, and those of his family and employees, with professional management services and institutional resources supplied through Government programs, financial institutions, educational institutions, and farm cooperatives.

Age and education are associated with management capacity and with attitudes toward the adoption of conservation technologies. The U.S. farm population has an older age structure than the nonfarm population (fig. 14). In 1979, the median age of the farm population was about 34 years compared with about 30 years for nonfarm residents. Farm populations also had a lower proportion of young adults and a higher proportion of middle-aged persons than the nonfarm group (Nowak, 1980).

The relation between age and managerial capacity as it relates to maintaining productivity often depends on the "newness" of the technologies employed (Nowak, 1980). Government conservation strategies that involve adopting and maintaining new technologies may be less successful among older farmers. On the other hand, many conservation practices have been in existence for some time. Older farmers with experience using these practices often can integrate them successfully into their overall farming operations.

Age and education among farmers are highly correlated. In 1970, 72 percent of farmers aged 55 to 64 years had not finished high school. However, only 12 percent of young farm operators (20 to 24 years) had failed to finish high school, and more than 25 percent had some college training (USDA, 1980). In general, the amount of formal education is directly associated with managerial capacity (Nowak, 1980).

Figure 14.—Farm and Nonfarm Population by Age, 1979



SOURCE: Peter J. Nowak, "Impacts of Technology on Cropland and Rangeland Productivity: Managerial Capacity of Farmers," OTA background paper, 1980.

Farmers with more education often translate this into greater managerial skills that are reflected in larger and more prosperous farms. Importantly, there also is a direct relationship between managerial capacity and the use of productivity-enhancing soil conservation practices (Rogers, 1980).

One trend that could have great impact on sustained land productivity is the general movement among farmers and ranchers toward continuing education, or life-long learning. Today's producers are better educated and are more open to information than were earlier generations.

It cannot be assumed that information necessarily changes attitudes and behavior. But information is a first step toward action; if a farmer or rancher receives a thorough briefing on, for instance, some innovative, land-sustaining technology such as conservation till-

age, he is more likely to adopt that technology than if he does not. Many variables, including the adequacy of the information, will affect his decision.

It is difficult to measure the value of information. Some experts estimate that 25 to 60 percent of the expected returns on public investment in agricultural research would not be realized without extension involvement (Araji, et al., 1978). Both intuition and research indicate that at an individual level, the farmer or rancher who receives information will be a more capable manager than the one who does not; one simulation suggests that informat added an average of 12 percent to a farm annual profits (Debertin, et al., 1976).

Although many potentially valuable n communications technologies exist or being developed, in general they seem to of more than they deliver—i.e., designing n communications tools seems easier than p ting them to use. This seems especially true efforts to bring some of the new electro media into rural areas, and illustrates tha is important to address both technological a sociological questions simultaneously.

INFORMATION DIFFUSION

Diffusion of agricultural technology to the U.S. producer is accomplished mainly through three broad channels: the private sector, public institutions, and peer groups. Private technology suppliers tend to develop and support only those technologies that can make substantial profits. On the other hand, public research and information is more generally disseminated for those technologies being developed and supported by public institutions.

The third channel, peer group action, is particularly important because even the most independent farmer is subject to peer approval or disapproval. Changes in conservation behavior that are not supported or reinforced by the farmer's neighbors or community opinion-leaders are unlikely to occur or be maintained (Nowak, 1980).

The dominant system in the United States to diffuse agricultural technology is the USDA's Federal Extension Service, in coordination with the 50 State agricultural extension services. This is the world's largest public investment in a diffusion system and is guided by three basic principles (Rogers, 1980):

- the innovation to be diffused is fully developed prior to its diffusion;
- information diffuses from a center of expertise out to its ultimate users; and
- diffusion is directed by a centrally managed process of dissemination, training and provision of resources and incentives

This centralized system is effective in promoting certain types of innovations. But it may not adequately disseminate innovations tha evolve as they diffuse and those that originat from sources other than the center. Diffusio processes also need to be shaped by user demands, in interactive arrangements wher problems are solved by innovations an sources of information among the users. Suc a decentralized diffusion system would depend mainly on peer networks for transferring technological innovations among local groups (Rogers, 1980).

Research into producers' rates of adoption of new technologies suggests that innovative producers often hear about new ideas from agricultural experts and specialized technica publications. Those who are slower to adop new practices usually get their general information from mass media. Early adopters ten to use the more expert sources at all stages i the adoption process, while slower adapter tend to use peer sources (Bohler, 1977).

According to an Iowa study that related farmers' information sources to the number of conservation practices being used, those farmers who had adopted five to eight practices were much more likely to use Government

agencies as their major source of conservation information (table 21). On the other hand, there was a more random distribution of information sources and a dependence on friends and relatives among the medium and low users of conservation practices (Lee, 1980). This suggests that decentralized diffusion may be an important approach for promoting technological innovations among certain producers in U.S. agriculture.

Access to knowledge and information are not distributed homogeneously across any group of farmers or ranchers. Producers have varying circumstances and capacities for effective adoption and implementation of technologies. Information is neither available nor diffused simultaneously through all parts of a system (Nowak, 1980). And information is passed via specific communication networks to which individuals have differential access. Furthermore, individuals have different base levels of knowledge as well as the capacity to assimilate new knowledge.

Thus, merely increasing the flow of knowledge into a group of farmers, the typical procedure in current educational programs, may magnify existing knowledge gaps rather than decrease them. General education programs will not necessarily inform farmers equally of the existence of a problem, create a need to do something about it, or instill the capacity to accept and implement technical or economic assistance.

Table 21.—Most Important Source of Soil Conservation Information by Users of Conservation Practices

	Sources of information (percent of total)				
Use	Friends and relatives	TV, radio, and print media	Farm supply dealers	Farmer organizations	Government agencies
Currently using one or two practices	13.6	9.1	13.6	4.5	59.1
Currently using three or four practices	17.8	14.3	3.6	7.1	57.1
Currently using five to eight practices	0.0	15.0	5.0	0.0	80.0

SOURCE: Linda K. Lee, "Relationship Between Land Tenure and Soil Conservation," OTA background paper, 1980. Information is from interviews with 135 individuals.

COMMUNICATIONS TECHNOLOGIES

Agricultural communications is in a period of rapid change. Worldwide there has been a staggering increase in the volume of scientific information produced, agriculture being no exception. And the information is more specialized and changeable than ever before, with new research, even new fields of inquiry, being added every day.

The other strong influence on the growing and changing content of agricultural communications is its clientele. There are fewer agricultural producers today than ever before—a decline from a peak of 13.6 million in 1916 to about 3.9 million in 1978 (Evans, 1980). As a total of the U.S. population, the farm segment fell from 23.2 percent in 1940 to 3.7 percent in 1978 (USDA, 1980). Yet because of the nature of modern agriculture, farmers have greater information demands than ever before. Thus, the various new electronic media, especially computers and other interactive systems, seem particularly suited to fulfill these needs.

Communications technologies are one step removed from actually affecting land productivity. They affect the farmer, making him more or less willing to adopt new technologies. The most basic communications medium in agriculture, word-of-mouth, is still the producer's primary way to gain, share, and evaluate information. But woven around primary interpersonal communications is a complex, dynamic system for moving agricultural information to and from farmers and ranchers and helping them make management decisions. Some of a producer's sources are public, such as agriculture study programs in schools, the local, State, and Federal extension systems, and other State and Federal agencies. Farmers and

ranchers also receive information through non-public media, including the telephone (found in 93 percent of U.S. rural farm homes); commercial farm periodicals (about seven are received in the average U.S. farm home); various breed organizations, commodity groups, and other agricultural organizations; agricultural supply and service dealers and marketers; and radio, television, and newspapers (Evans, 1980). But beyond these traditional communications methods lies a whole range of new communications channels born of recent advances in electronics. This does not mean that the importance of interpersonal and print communications will diminish in the future. Rather, the new electronic media complement the mainstay channels of voice and paper.

Emerging Communications Technologies

Computer Applications

Computer technologies are already affecting farms and ranches in many ways, although few producers actually own personal systems. Access to computer information is through farm management decision aids, computer-based information systems, computer-based instruction, and personal computers. Computers are especially useful because they are highly adaptable, easy to update, and allow the user to tailor information and tasks to his individual needs.

Photo credit: U.S. Department of Agricult

Douglas Duey, Extension Service farm management specialist and Wayne Nielsen of Lincoln, Nebr., look over computer printouts, with which Duey will help Nielsen analyze his cash flow and overall farm business situation

Radio

Radio is a prime information source for producers because it supplies timely reports of news, weather, and commodity market prices. As farm populations have declined, however, broadcast stations have reduced farm programing. Today, relatively little information about technical aspects of farming is aired. Also, the kinds of stations most active in farm programing have changed from clear-channel and other large stations toward smaller rural stations. There has been some increase in farm broadcasting on FM stations in recent years, but it is not prominent. Independent commercial program services—farm radio networks that distribute news and features—are increasingly available to sell agricultural information to stations that cannot afford farm reporters.

Telephone-Related Systems

Telephones are one of the main communications links for rural people. They are interactive, accessible, easy to use, flexible, and relatively low cost. Phones can be used to link the home television with a computer data base (known variously as viewdata, videotext, and wired teletext). For instance, Green Thumb, sponsored jointly by the National Weather Service, USDA, and the Kentucky Cooperative Extension System, is a pilot information service for farmers. With a TV and relatively inexpensive telephone/TV interface device, the

farmer has access to area news, local weather, and timely data on pest management, agricultural economics, forestry, animal science, plant pathology, and horticulture. However, the cost of such systems is still unknown.

Other phone-computer links might also prove useful. "Advance calling," for example, allows an extension advisor to call a computer, enter a message about impending pest infestations, approaching storms, etc., then enter the phone numbers of all those who should receive the message.

Finally, the telephone still has great potential in its basic "voice" format, especially for continuing education and extension. TeleNet, for example, links county and regional extension offices throughout Illinois with specialists at the University of Illinois; it also operates as a "party line" for group calling, educational meetings, etc. The audio can be supplemented with written instructional materials.

Audio Cassettes

Audio cassette technology is unsophisticated, yet holds valuable potential in this era of increasingly specialized agricultural information. Cassettes are widely used for continuing education and are particularly attractive because of their low cost, simplicity, and mobility, making it possible for a user to listen to a tape while doing chores or driving a tractor. Cassettes are inexpensive and easy to produce, so extension can distribute timely information at little cost.

Television Technologies

Adaptations of current video technologies may hold potential for farm and ranch audiences. Standard TV broadcasting (commercial and public) does not address farm audiences as much as radio because farm viewers account for such a small share of the total audience. Farm advertising occurs far more frequently than farm programing. However, TV has other uses. Broadcast teletext offers many of the same advantages as wired teletext (viewdata)—it links the home with computer data bases for immediate, timely information. Unlike viewdata, however, this is a one-way, noninteractive system and can handle only a limited data base. Television broadcast translator stations are low-power stations that receive incoming TV or FM signals, amplify them, convert them to a different output frequency, and retransmit them locally. They require relatively low capital inputs and low maintenance at total cost much lower than cable systems, especially in rural areas. A version of translator technology—mini-TV—has proven successful in bringing TV to rural Alaska. Mini-TV, teamed with videocassettes, gives local users greater control over programing than standard translator systems.

Cable and Satellite Transmission

Cable television (TV) may be the most significant of the new mass communications technologies because it greatly expands the scope of available programing. Interactive cable, such as QUBE in Columbus, Ohio, offers special promise for educational uses. But while cable programing could provide a range of information useful to farmers and ranchers, its potential is limited by the high capital costs involved in laying lines in rural areas. Farm subscribers are therefore an unpromising market for commercial cable. Further, there is concern that pay-TV may weaken the present "free" commercial radio and TV stations on which many rural people depend for information.

Agricultural producers already benefit from satellite systems that permit the monitoring of weather and crops, but other benefits may arise. Direct statellite broadcasting of TV programing is technically feasible and has proven value in delivering education and social services in Canada. A demonstration project in Alaska shows some potential, especially for adult education. Limitations, including cost, user-resistance, inadequate software, etc., make direct satellite broadcasting less promising in the short run than some other technologies available to U.S. farmers and ranchers. Regulatory and public policy questions also will be important to the future of this technology.

Videodisc and Videocassette

Although relatively few individuals own such systems, videodiscs and videocassettes are useful in agricultural education through schools, extension, and other organizations. The primary disadvantage is high initial cost. Videocassettes offer the advantage of allowing the user to record programs from TV and, with the addition of a camera, of producing one's own shows. Videocassettes, however, cost more than videodiscs, cannot be accessed randomly, and wear out faster than discs. For instructional purposes, videodiscs may be more useful, especially when linked with computers.

Expanded Print Media

Print media are becoming increasingly specialized and directed to specific audiences. More and more, "free controlled circulation" is used by publishers to send their publications free to producers who meet certain geographic, demographic, economic, or other criteria. Increases in direct mail, newsletters, and publishing of periodicals by farm organizations also are channels for reaching target groups. Farm publications are pioneering the concept of the "individualized issue," where through sophisticated binding systems each subscriber ceives an issue tailored to his specific site needs. This technique has great potential improving the kinds of information a partic farmer or rancher receives.

Print reference services, either commerc or public, are uncommon in the United Stat Elsewhere, however, this ringbinder-notebo style of indexed information sheets offe several advantages over traditional printed e tension publications. It can generate a wi range of highly specific information piec quickly, at lower cost, and is easily update The farmer, however, must be willing to mai tain his files.

Electronic publishing—newspapers, an other periodicals experimentally joining a na tional computer data network such as that be ing assembled by Computer Service Informa tion and Associated Press—is blurring th boundaries between print and electroni media. Publishers see this as a way to reduc printing and postal costs; readers get timel news but lose the portability of print. Withi agriculture, electronic publishing may find ea ly applications in directories, catalogs, an classified advertising (Evans, 1980).

CONSTRAINTS ON TECHNOLOGY ADOPTION

Some producers are unwilling or unable to adopt practices that preserve long-term land productivity. Moreover, there are significant differences between those who cannot and those who will not adopt recommended practices.

Conflicting Goals

One reason why producers may be unwilling to adopt a recommended practice can be that a conflicting goal, such as a desire to maintain traditional farming methods, may be valued more highly than conservation goals. Producers justify their unwillingness to use resource-conserving practices because of their real or perceived effect on immediate profitability. Profitmaking must be a primary concern or the farm-business would soon cease to exist. Thus, only if the level of profit is such that conservation costs do not jeopardize the farms' economic viability could policymakers employ disincentives such as fines, penalties, and taxes for resource degradation. Where these strategies would threaten financial stability, more voluntary implementation strategies are appropriate.

Adopting conservation practices has broad social benefits beyond the view of most producers and not reflected in farm markets. Thus, it may not be feasible or fair to place the entire responsibility for conservation on the shoulders of the producer. A recent study of

a 5.3-million-acre area in southern Iowa found that the immediate costs to the producer of reducing soil erosion to tolerable levels using available techniques were three times greater than immediate benefits. As the study concluded, this benefit-cost ratio leaves farmers unable to finance erosion control without cost sharing or similar public investment (Shrader, 1980).

Current economic conditions make farmers discount future benefits heavily. Many have extensive financial obligations and must maximize this year's profit to pay this year's mortgage. Moreover, many have based their investments in land and/or equipment, expecting high inflation rates to continue, rather than by calculating efficient input/output ratios (Woodruff, 1980). Current high interest rates also play a key role in shortening farmers' planning horizons, in effect making farmers work for short-term goals and neglect long-term consequences.

Recognizing these shortened individual planning horizons for agricultural decisions is critically important in examining the effectiveness of policy alternatives. For instance, some past analyses from the Center for Agricultural and Rural Development (CARD) at Iowa State University have assumed that long-run costs and benefits are variables of primary importance to farmers in their soil management decisions. However, recent CARD studies suggest a very different conclusion: that agricultural producers have a planning horizon closer to 1 year than to 25 years (Daines and Heady, 1980).

Yet practices that may not return the farmer's investment for even 25 years may be of great concern to the public as a whole. The public stake in the effects of stream pollution, reservoir sedimentation, water-supply contamination, erosion, and ground water overdraft are sound reasons for public investment. Social planning horizons can take into account the Nation's responsibility to maintain the productive capacity of the resource base for future generations.

Inadequate Information

Another reason why producers may be unwilling to adopt recommended practices is that they lack adequate information. They may need to know more about implementing the practice, how it fits into the larger operation, or the consequences of using the practice. Evidence suggests that farmers who are unwilling to adopt a recommended practice may gain information and change their perceptions if they adopt the practices on a trial basis. Thus, implementation strategies that focus on trial adoption could encourage the acceptance of recommended management practices.

Moreover, users and nonusers may perceive different conservation practices quite differently. Studies of farmer perception of three practices—minimum tillage, contour planting, and terracing—in Iowa suggest that users and nonusers have significantly different perceptions of the characteristics of the practices (table 22). For instance, a quarter of the farmers not using minimum tillage viewed the technology as having very high costs, while only 3 percent of the users viewed it as expensive (Nowak, 1980).

Farmers Unable to Adopt Practices

When individuals are unable to adopt recommended practices, a different situation exists. Farmers may be unable to adopt a practice because they lack the necessary management skills. Reduced tillage, for instance, has important conservation effects. But while fewer operations are involved in reduced-tillage farming, the sequence of operations and the correctness of each action is more critical than with conventional tillage. Educational strategies may be most appropriate to encourage adoption by this group of farmers, as neither penalties nor incentives would address the underlying problem.

Farmers also may be unable to adopt recommended practices because they lack the necessary capital and/or land. Small-scale, part-time, or marginal farms often have cash-flow problems that prohibit investment in additional

Table 22.—Perceived Characteristics of Soil Conservation Practices

	Minimum tillage		Contour planting		Terraces	
Characteristic	Users	Nonusers	Users	Nonusers	Users	Nonusers
Cost for using						
No cost	49.3%	38.2%	52.6%	21.0%	22.2%	2.6%
Moderate cost	47.4%	35.3%	43.1%	54.8%	51.9%	17.8%
Very high cost	3.3%	26.5%	4.3%	24.2%	25.9%	79.6%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Profitability						
Costs exceed returns	7.8%	21.9%	5.2%	45.9%	20.0%	58.2%
Costs equal returns	32.5%	46.9%	44.4%	37.7%	32.0%	27.4%
Returns exceed costs	59.7%	31.2%	50.4%	16.6%	48.0%	14.4%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Time/labor requirements						
More time/labor	7.8%	20.0%	66.4%	89.1%	53.8%	78.8%
No change	17.5%	28.6%	28.4%	10.9%	46.2%	18.6%
Less time/labor	74.7%	51.4%	5.2%	0.0%	0.0%	2.6%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Ease of use						
Very difficult	2.6%	20.6%	19.0%	54.0%	33.3%	63.9%
Moderate	22.2%	29.4%	36.2%	36.5%	33.4%	25.8%
Very easy	75.2%	50.0%	44.8%	9.5%	33.3%	10.3%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Compatibility						
Not compatible	3.9%	28.6%	11.2%	63.9%	18.5%	66.5%
Moderately compatible	15.6%	28.5%	25.9%	24.6%	33.4%	21.2%
Very compatible	80.5%	42.9%	62.9%	11.5%	48.1%	12.3%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Influence on soil erosion						
Worsened	1.4%	0.0%	1.8%	0.0%	0.0%	0.0%
No change	16.8%	50.0%	27.0%	61.0%	12.5%	45.0%
Improved	81.8%	50.0%	71.2%	39.0%	87.5%	55.0%
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

SOURCE: Peter Nowak, "Impacts of Technology on Cropland and Rangeland Productivity: Managerial Capacity of Farmers," report to OTA, Dec. 19, 1980.

farm implements or time-consuming practices. Their existing machinery limits their adoption of new agronomic practices. Further, off-farm employment may limit the amount of time these farmers have to establish new management procedures. Yet these types of farmers may be the owners of a disproportionately large share of the highly erosive or otherwise fragile land.

Strategies to maximize the effectiveness of conservation initiatives must try to minimize the number of producers who are put into the position of being unwilling or unable to adopt recommended practices. Consequently, conservation policy needs to include implementation strategies that explicitly recognize why producers are not adopting the recommended practices and that attempt to remove obstacles to adoption. Strategies must be flexible to accommodate critical social and economic variations among farm operations.

INFLUENCING TECHNOLOGY ADOPTION

When farmers assess new products or practices, their adoption decisions generally will be based on their judgment about relative advantage. Relative advantage generally is judged by: 1) the usefulness of the technology in terms of the producer's basic values, 2) the economic

costs relative to benefits, and 3) the payoff time (Bohler, 1977).

A technology's apparent advantages or disadvantages can be greatly influenced by how that technology is presented to the farming public. For instance, presenting minimum tillage as a way to enhance profits is likely to make it more attractive than promotional efforts that stress the system's ability to prevent erosion. In other words, a technology is more appealing if it does things rather than prevents things from happening. Promoting a practice as a preventive measure may emphasize characteristics that hinder adoption such as high initial costs, low profitability, unknown risks, few tangible rewards, and increased management complexity (Korsching and Nowak, 1980).

By emphasizing the positive benefits, conservation programs and promotions might garner greater attention. Changes could include:

- Emphasize the monetary and energy savings made possible by various techniques of conservation tillage and the fact that adoption of these techniques conserves the soil's natural fertility, reducing dependence on expensive fertilizers.
- Minimize the idea that adopters (producers) are reducing pollution; rather, emphasize that they are conserving their own resources.
- Integrate any economic incentives into educational programs that are built around the above strategies. Present the innovative technology as part of an overall program designed to increase the profitability of the farm operation.
- Minimize the connection between mandatory Government regulations and agricultural conservation practices. Integrate the mandatory regulations into the economic incentives that support agricultural conservation practices. It is important that conservation practices not be identified with "bureaucratic red tape."
- Redefine organizational goals and agency involvement so that conservation programs are presented in terms of economic gain rather than environmental degradation—e.g., Farmers Home Administration or Small Business Administration involvement rather than the Environmental Protection Agency.
- Increase involvement of commercial organizations and the Cooperative Extension Service in promoting soil conservation efforts. More social recognition and rewards for conservation efforts should be implemented in USDA-assisted groups—e.g., FFA, 4-H. Conservation awards should not be a separate category but should be combined with production awards—e.g., the highest production with an active conservation plan (Korsching and Nowak, 1980).

CONCLUSIONS

The main factors affecting farmers' decisions to adopt agricultural innovations include:

1. The personal and economic characteristics of the farmer, such as farm size, formal education, age, availability of capital, managerial capability, degree of contact with extension, and exposure to mass media (especially farm magazines).
2. The perceived characteristics of the agricultural innovation, such as the relative advantage of one practice over another (especially profitability); compatibility with farmers' prior experiences, beliefs, and values; the complexity of the innovation; visibility of results; and ease of trial uses (Rogers and Shoemaker, 1971).

It is not clear how land tenure problems affect conservation behavior. In some instances, absentee landowners seem to have less motivation to invest in protecting the land, but little research supports this hypothesis. A more pertinent factor seems to be farm income: the higher the income, the more prevalent is conservation. Age and education, too, are associ-

ated with management capabilities and openness to innovation. And importantly, access to information influences technology adoption and is the principal means by which policymakers can promote the use of productivity-sustaining technologies. The communications fields, in fact, will play increasingly vital roles in informing and educating farmers and in improving farm management.

To be more effective, conservation pro tion efforts need to be tailored to the partic circumstances of the farmers who have most severe conservation problems. Conse tion programs seem most successful when t emphasize the economic advantages of prod tivity-sustaining technologies rather than environmental disadvantages of not apply the recommended practices.

CHAPTER V REFERENCES

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Chapter VI

Role of Government

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Role of Government

Government policies and programs that affect agricultural technology use and land productivity generally fall into one of two categories: 1) those that promote economic or social goals, either by developing and promoting production technologies or by manipulating short-term economic factors; or 2) those that promote conservation of natural resource productivity, either by developing and promoting conservation technologies or by subsidizing investment in conservation. The two types of Government activities often operate simultaneously. Both influence farmers' decisions about technology use and about resource conservation, but the two influences are not always compatible.

This chapter reviews the major Government programs and policies related to these two goals—economic manipulation and conservation. It focuses primarily on Federal activities and concludes with a description of some State conservation initiatives that illustrate the potential for increased local involvement.

PROGRAMS AND POLICIES DESIGNED FOR ECONOMIC GOALS

Commodity Programs

Federal commodity and conservation programs were closely associated when they began in the 1930's, but during and after World War II they evolved in separate directions. Commodity programs generally focused on helping farmers adjust to changes in short-term market conditions with a minimum of economic dislocations, while conservation programs assisted farmers with long-term land productivity problems. The explicit economic goal of most commodity policies has been to raise farm incomes closer to average nonfarm incomes.

Since the establishment of the quasi-governmental Commodity Credit Corporation in 1933, farm income has been supported through artificial commodity pricing—supporting prices for certain products above what the market would otherwise pay. Other programs have since been developed to support farm income, including production controls (such as direct income-support payments, cropland set-asides, and crop acreage diversions), disaster relief payments, and, recently, subsidies for gasohol production.

Direct income-support payments were initiated in the 1970's so price supports could be reduced to world market levels without reducing the total income support to farmers. Set-asides and crop diversion programs have ranged from long-term commitments that withdraw acreage from production to 1-year agreements that divert portions of a farm's acreage from one crop to another. Under the Agriculture and Food Act of 1981, the Secretary of Agriculture could require farmers to set aside some of their wheat, feed grains, or upland cotton acreage as a condition of receiving commodity program benefits. The Secretary is also empowered to make payments to farmers who voluntarily divert cropland to soil-conserving crops, whether or not set-asides have been declared. Set-asides for wheat and feed grains removed 19 million acres from production in 1978, and 12 million acres in 1979 (Cook, 1980a).

Disaster relief programs were initiated on the premise that agriculture's unique dependence on biological processes and the weather requires that the risks of natural disaster be shared by society. Over the years, several disaster relief programs have been created, some in response to specific disasters. At present, some 20 aid programs offer a fairly comprehensive response to agricultural disasters.

Subsidies to produce biomass for gasohol are a recent development in farm income support programs. The Energy Security Act of 1980 (Public Law 96-294) provides subsidies to operations that convert biomass to ethanol for use in gasohol. Because of the economic incentives created by these subsidies, the demand for grains, especially corn, is increasing (USDA, 1981b).

An underlying, sometimes explicit, social goal of the commodity programs has been to assure a plentiful, reasonably priced supply of agricultural products for consumers. The rationale is that wide fluctuations in the profitability of agriculture would drive many, perhaps most, farmers out of business if some stability were not provided by Government programs. Thus, society would be left with too few producers and too little production. Largely because of increases in off-farm employment, average farm incomes are now on par with average nonfarm incomes in the Nation, so the income level goal of commodity programs is becoming less important. The income stability goal is likely to become even more important, however, if the role of U.S. agriculture as a supplier of world food continues to increase as expected.

Because farm incomes depend directly on market prices, farm economic policies and supporting programs historically have fluctuated with commodity price variations. This has generally been on a crisis-oriented basis which is not conducive to long-term income stability. In recent years, rapid market changes have intensified these fluctuations. As a result, new farm programs have been formulated almost on an annual basis. As one U.S. Department of Agriculture (USDA) report concludes:

> Times of a studied, deliberate approach to the design of a forward-looking farm policy, rather than adjustment of the previous statute, have been rare. Careful attention to more than the immediate national effects of the programs used to implement policy has likewise been scarce (USDA, 1981b).

A dearth of information or analysis also exists on the effects of commodity program activities on natural resources, even though 80 percent of the sheet, rill, and wind er occurring on U.S. croplands takes plac land used to grow the major crops cover those commodity programs: wheat, feed gr soybeans, and upland cotton (Benbrook, 1 Recently, research has begun to identify tain commodity programs and policies tha courage land-use practices that conflict conservation objectives.

Commodity programs seem to have moted specialization in farming by reduc economic risks and uncertainty for farm and ranchers (Emerson, 1978). Income prot tion afforded for acreage planted in progra crops adds a powerful incentive for farmers put more acres into those crops than th would if they bore all the risks. This causes decline in mixed-crop livestock operations favor of less diverse, cash-grain operation Cropland specialization reduces the use of cr rotations including cover crops, and thus i creases erosion and other land degradatic processes.

Controlling Production

Even though the main objectives of the com modity programs have been the economic ef fects, the set-aside and crop acreage diversion programs also have had significant conserva tion effects. Generally, participants have beer required to plant set-aside land in some covei or soil-conserving crop. Because farmers tenc to place their less productive land in these pro grams, the production control effect is com promised somewhat (Cook, 1980a). However the less productive land is often more erosion prone or otherwise fragile, so the conservatioı effects are enhanced.

Conservation benefits are reduced to som extent if farmers take less than the require amount of land out of production when set asides are in effect. Enforcing such program is difficult. Short-term production control programs (recently, most have lasted only 1 year) may also substantially reduce long-term conservation effects. Also, such benefits are only realized when production controls are in effect,

and diversions and set-asides were not used in 1974, 1977, or 1980. With increasing foreign demand for U.S. agricultural products, production control programs probably will not be common in the future.

Disaster Relief

Unlike production control programs, disaster relief may encourage cultivation of fragile lands. Disaster relief payments are calculated on the basis of total acreage planted and established yield-per-acre figures. The yield figures are set by local committees of farmers organized by the Agricultural Stabilization and Conservation Service (ASCS). In arid and semiarid regions, these yield figures are likely to be higher than the average yields over a drought cycle. Thus, disaster relief payments made for water stress and wind erosion damage in these areas are not so much insurance programs as they are subsidies, keeping farmers in the uneconomic business of farming erodible land with inappropriate row crop and small-grain technologies. Another problem is that basing the payments on acreage planted to the eligible crop discourages the use of stripcropping or stubble strips that could help control erosion (Sheridan, 1981).

The system used to determine qualifying acreages for commodity program payments may itself conflict with conservation objectives. The Food and Agriculture Act of 1977, for example, replaced an earlier allotment scheme with a new concept, the normal crop acreage for wheat, feed grains, and upland cotton. Instead of being established for individual crops planted over a historical period, the normal crop acreages are established for total acreage planted to program crops in the previous season. The old system to determine allotments had included a provision for a "conserving base," a portion of acreage that was to be fallow, in forage, or in crops grown for soil improvement, but that concept was eliminated. The 1981 farm act, like the 1977 one, does not allow grass strips planted for conservation purposes to be included in determining commodity benefit eligibility. As a result, farmers who set aside such strips had reduced eligibility when compared with improvident farmers. There have been reports of farmers plowing under grass in order to increase their normal crop acreage (Cook, 1980a). While USDA/ ASCS, the agency which oversees commodity programs, recognizes this conflict, no analysis of the actual effects has been made.

Another conflict between commodity program implementation and certain conservation technologies exists regarding organic agriculture. Little explicit Federal, State, or local public policy deals with organic farming practices, although these practices often incorporate conservation technologies. A 1980 USDA study, however, discovered that price support programs administered by the local ASCS committees discriminated against organic farmers. Criteria for eligibility in these programs included requirements for certain tillage practices and commercial fertilizer applications unacceptable to organic farmers (Geisler, et al., 1980).

Gasohol subsidy programs and policies raise additional considerations for conservation. Perhaps the most serious implication of an alcohol-fuels program will be the pressure to convert erosion-prone or otherwise fragile land into grain acreage. Without careful planning, policies that subsidize alcohol fuels could increase land degradation and loss of productivity. This potential problem is examined in OTA's report *Energy From Biological Processes* (U.S. Congress, 1980a).

Commodity policies and programs have a number of unplanned impacts on the structure and operation of the U.S. agriculture sector, and these probably have subsequent unmeasured effects on land productivity. These include: 1) program benefits becoming attached to the land, thus contributing to land price inflation and inhibiting entry of new or young owner-operators. This increases the trend toward tenant farming and concentrated wealth. 2) Artificially high commodity prices causing farmers to plant row crops and small grains on more land, and presumably on more fragile land, than they would if responding only to free market prices. 3) Farmers using more

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fertilizer and other inputs than they would if responding only to market prices (USDA, 1981b).

The combined effects of these unplanned influences caused by commodity programs may outweigh the effects of Federal conservation programs. Commodity programs do not have conservation of resource productivity as a primary goal, and only some acreage set-asides and diversions have had conservation as explicit secondary goals. Even in the few programs where conservation or land productivity was an explicit aim, there has been no built-in strategy to evaluate the programs to determine whether the conservation goal was being achieved. For these reasons, the interactions between commodity programs and agricultural technologies, and the consequences for land, have never been well understood. One important area to investigate is the relationship between conservation decisions and the improvements in net farm income and income stability achieved by the commodity programs.

Credit Programs

The ability of farmers and ranchers to obtain credit through private and public lenders has become an increasingly important factor in U.S. agricultural decisionmaking. As a percentage of net farm income, total farm debt increased from 91 to 428 percent from 1950 to 1977 (Schmiesing, 1980). Moreover, demand for borrowed funds is expected to continue increasing as the agriculture sector strives to meet growing global demands for food at the same time that operation costs are rising rapidly (USDA, 1981b).

The effects of credit policies on individual farms and ranches and on the resource base are not well understood. However, concern is growing that credit policies and programs, coupled with other economic factors such as inflation, are significantly shortening farmers' and ranchers' planning horizons and so reducing conservation investments.

Generally, farmers have had access to plentiful credit at competitive costs, often at rates lower than their counterparts in other sectors of the economy. Federal initiatives hav vided access to funds at cost through th profit Federal Credit System (FCS) bank to subsidized loans from public lending cies. In addition, agricultural customers become attractive to private lenders bec Federal emergency lending programs, p supports, and other commodity programs reduced farming risks. The plentiful and fa able supply of funds has encouraged farm to increase their reliance on borrowed mon to invest heavily in capital-intensive techn ogy, and to expand their use of purchased p duction supplies (e.g., fertilizers and pestici (USDA, 1981b).

In recent years, a less direct effect has come evident. Easy credit at good terms ga more purchasers the ability and incentive pay higher prices for land, thereby contributi to inflation. Consequently, land prices ha risen so high that beginning farmers are i creasingly unable to pay for land from its cu rent cash earnings. As a result, cropland ha become concentrated under the ownership established farmers and speculators (Schmie ing, 1980).

Farmers with nonprime land that is suscep tible to productivity damage often have tight budgets and little economic flexibility. For these farmers, high land costs become an important constraint on the adoption of expensive conservation practices, though not on the adoption of conservation tillage (USDA, 1981b Lee, 1981).

In the last two decades, most agricultura credit has come from the private sector, with FCS being the largest source of credit and related services to farmers, ranchers, and thei cooperatives. FCS holds about one-third of th Nation's total farm debt. It consists of thre separate banking systems—Federal Lan Banks, Federal Intermediate Credit Bank (FICBs), and Banks for Cooperatives. Unde FICBs, local Production Credit Associations have also been authorized to serve as retail outlets for credit.

In the public sector the Farmers Home Administration (FmHA) is the largest Federal

agency lending directly to farmers and ranchers. The Small Business Administration has a relatively new and limited program. Besides administering farm-operation and farm ownership loans, in 1979 FmHA also was responsible for at least 21 other programs, including emergency-disaster, economic emergency, individual housing, rural rental housing, water and waste, and business and industrial development loans.

Credit Programs for Production

What role do lenders play in influencing farmers' production and conservation decisions? Generally, financial institutions assess current cash flows to evaluate credit applications. This approach puts productivity-sustaining technologies at a disadvantage because it does not account for possible future changes in inputs and commodity prices or the long-term effects of soil conservation. Although the producer may eventually be penalized for having failed to use soil conservation practices, the implications of resource degradation may become evident in the loan evaluation process only after the producer has neglected conservation for several years.

The historic purpose of FmHA agricultural loan programs has been to assist farmers and ranchers who need, but cannot obtain, credit from commercial lenders. As a lender of the last resort, FmHA has been the major provider of subsidized credit and emergency loans. This image apparently has caused applicants to take more risks with their production and marketing plans. According to a recent USDA report, the emergency lending programs of FmHA "tend to reduce the overall threats farmers and ranchers face from the weather and the market . . . . (They) have been referred to as free insurance programs, with the overuse that predictably accompanies any 'free' goods" (USDA, 1981b).

Federal credit subsidies that encourage behavior beyond that reasonably prudent for an average operation have serious implications for producer decisionmaking and land productivity. Resource planning and wise use become less necessary as one transfers risks to the Government. The likely consequences are less efficient use of resources in the short run and adoption of technologies that are wasteful and resource-depleting in the longer term.

Federal credit programs, like commodity programs, have profound impacts on the planning horizons and technology decisions of farmers, and thus have indirect but important impacts on land productivity. In the recent past, inexpensive and easily available credit seems to have contributed to the inflated costs of farming, making profit margins so low that farmers cannot forgo current profits to conserve future productivity. Today's more expensive credit results in higher discount rates and fewer funds being available for investment in conservation technologies.

Programs that make credit available for current production also can have positive conservation effects. For example, if farmers have funds to apply optimum fertilizer, then crop residues and organic matter will increase, soil microbiology will improve, and erosion will diminish. The overriding problem is that maintaining land productivity is not an explicit objective with most agricultural credit programs. So, as with commodity programs, the substantial negative and positive conservation effects of past programs are poorly understood and the analytical methods to foresee impacts of current or future programs have not been developed.

Credit Programs and Conservation Practices

Although many credit programs are directed to current production, there are some programs that provide credit explicitly for conservation. In the private sector's FCS, full-time farmers are eligible for credit for a range of agricultural purposes including conservation investments, while part-time farmers can get credit for agricultural conservation practices but have restricted access to credit for other purposes (GAO, 1980a).

Credit institutions' policies, however, may discourage the adoption of innovative conser-

vation technologies. For example, financial institutions are generally reluctant to lend money for a farmer to convert to organic farming, though they willingly assist in a shift to conventional agriculture. Thus, organic farmers are likely to pay more for their capital needs, and those who have chosen to farm organically have done so in spite of financial incentives rather than because of them (Geisler, et al., 1980; Oelhaf, 1978).

No-till illustrates another credit problem. Whether a switch to no-till is financially attractive to a farmer is influenced by initial investment costs. For instance, a new no-till planter costs more than a conventional planter. For small-farm operators in particular, the decision to buy is strongly influenced by credit availability, yet their access to credit is generally more restricted than for large operations (Geisler, et al. 1980; Pereleman, 1977). The labor savings offered by no-till may not be sufficiently attractive to the small-farm operator to compensate for his relatively high capital cost. Thus, preferential access to credit makes it more likely that larger farms switch to no-till, but the steeply sloping land where the conservation effects of no-till are most significant are more characteristic of small farms.

Tax Policies and Programs

Congress frequently uses tax programs to stimulate economic activities in directions that will enhance particular policy goals. In recent years, many major agricultural tax programs have been intended to support family farm operations. There is an implicit, and occasionally explicit, social goal of ensuring continuation of an agriculture structure that is based on owner-operator family farms.

Tax programs designed to achieve this and other social and economic goals interact with conservation in various ways which are not well understood. Some of these tax programs, such as preferential estate tax treatment for farms, are thought to increase the use of conservation practices, though they may also have less direct effects that partially offset the conservation benefits. Other tax policies, such as the cash accounting rules for farms, have known impacts on long-term land producti

In general, tax programs affect long-t land productivity positively when they m it economically attractive for producers to longer planning horizons for their technol investments, and negatively when they ma shorter planning periods necessary. Tax po cies also affect landownership and land use ways that may have significant impacts on u or disuse of productivity-conserving techn ogies.

Tax programs generally have greatest influ ence on taxpayers who have substantial tax li bility or income to offset. Thus, tax program designed to aid family farms have made agr culture an attractive tax shelter for affluer nonfarmers, for limited partnerships, and fc other types of investment groups. Landowner ship and farm operation are likely to be separated when nonfarmer investors are attracted to agriculture, and this change may lead to decreased long-term investments in conservation. Tax policies have contributed to the trend toward concentrating U.S. agricultural production and wealth among fewer producers (USDA, 1981b), but no data exist to indicate whether the redistribution of land and wealth is causing changes in use of productivity-con serving technologies. Tax policies also have been a causal factor in the shift to more capital intensive (v. labor- or land-intensive) agricul tural technologies (USDA, 1981b).

Preferential estate tax provisions enacted a part of the Tax Reform Act of 1976, and mor recent revisions of tax laws, substantially re duce the estate-tax burden (Harl, 1980). The op portunity for reduced tax liabilities has a mixe effect on the maintenance and enhancemen of land productivity. The most obvious effec is to lengthen a family's planning horizon. I a farmer knows that his heirs will receive the benefit of his conservation efforts, he should be more willing to make investments or sacrifices of current income. Offsetting this benefit somewhat is the possibility that preferential treatment for farm estates helps inflate land prices, which is thought to have a generally negative effect on conservation.

Income tax provisions that allow producers to use cash accounting for the costs of developing an asset, while taxing future income derived from those assets as long-term capital gains, provide high tax benefits where there is substantial current income to offset. For example, certain perennial crops provide special tax shelters. Under the tax code, the costs of developing certain trees and vines that produce fruits and nuts can be deducted as current cost from ordinary income, while proceeds from these assets when sold can be treated as capital gains. Because the income and expenses may be reported under cash-accounting rules, the taxpayer has substantial freedom in choosing the time when the tax liabilities, if any, must be paid. Again, these provisions should encourage a longer planning horizon that would make conservation investments more attractive, but may also attract nonfarmers seeking tax shelters and so drive up the price of cropland and the incidence of tenant farming.

Other tax policies favor capital investments by reducing investment costs through appreciation-depreciation rules and special investment tax credits. These policies encourage and reward capital investments, including expanded use of machinery and equipment, rather than increased expenditures for labor and management. Such policies could also encourage investment in conservation structures, such as terraces or fences.

The 1981 USDA report on the structure of agriculture reaches a number of general conclusions about Federal tax programs and policies (USDA, 1981b):

- Tax law tends to perpetuate ownership of farm assets, particularly land.
- Tax law seems to encourage capital structures with a higher ratio of debt to assets and greater use of debt capital relative to other resources than would otherwise exist.
- Because labor is taxed while capital investments receive tax breaks, farmers have an incentive to substitute capital for labor.
- Recent changes in tax policy encourage increased use of corporations as a way of organizing agricultural operations.
- Management practices may be chosen because they allow the best use of tax rules. They may not be the best crop and animal management. The overall impact could be less efficient use of resources.

As a consequence, conservation may suffer, as when large labor-saving tractors (generally not well adapted to terraces, contour farming, stripcropping, and other conservation structures) are used in place of smaller machines that require less capital and more labor. On the other hand, some conservation practices and some production techniques that conserve productivity require substantial capital investments and benefit significantly from the tax programs that encourage such investment. These include the shift to no-till farming and the installation of well-designed irrigation and drainage systems.

Thus, if tax programs are to be an effective tool for encouraging conservation of land productivity, they should be quite specific about which types of capital equipment, structures, or land improvements qualify. Careful analysis of the likely consequences of tax programs must be conducted ahead of their implementation to avoid unplanned, counterproductive impacts.

RESOURCE CONSERVATION PROGRAMS

Evolution of the Federal Role

Federal soil conservation efforts began with the establishment of the Bureau of Chemistry at USDA in 1894. During the first decades of the 20th century, USDA issued publications and conducted some research on soil erosion. However, the concept of direct Federal action to control and prevent soil erosion did not gain major support until the late 1920's and early 1930's, when hard economic times for the agricultural producers and severe drought and duststorms in the Great Plains combined to attract national attention. Since then, the Federal

Government's role in natural resource conservation has grown in breadth and intensity. Table 23 shows the major Federal legislation through which Congress has established the Federal role.

The first Soil Erosion Service, establish 1933, became the Soil Conservation Se (SCS) of USDA in 1935 with passage of the Conservation Act. That law authorized the retary of Agriculture to survey and investi

Table 23.—Evolution of the Federal Role in Resource Conservation

Resource	Authorizing legislation[a]	Lead agency	Conservation program	Public Law	U.S. Stat.	U.S. Code	Date of enactm
Soil and Water	Agricultural Credit Act	ASCS/FmHA	Emergency conservation to control wind erosion, conserve water, rehabilitate farmland harmed by erosion, floods, or other natural disasters; loan assistance	95-334	92 Stat. 433	16 U.S.C. 2204	1978
Natural Environment	Federal Pesticide Act	EPA	Program to streamline pesticide registration through generic registration, conditional registration, data compensation, & trade secret revisions	95-396 820	92 Stat.	—	1978
Rangeland	Forest & Rangeland Renewable Resources Research Act	USFS	Research & dissemination of findings to support resource protection & management	95-307	—	—	1978
Rangeland	Public Rangelands Improvement Act	BLM	Mandates on-the-ground improvement programs for public grazing lands & increases funding for this effort	95-514	92 Stat. 1803	43 U.S.C. 1901 et seq.	1978
Rangeland	Renewable Resources Extension Act	USFS/Science & Education Administration	Renewable Resources Extension Program for private landowners, natural resource conservation education	95-306	92 Stat. 349	16 U.S.C. 1671	1978
Soil and Water	Surface Mining Control & Reclamation Act	SCS	Conservation treatment of rural abandoned or inadequately reclaimed mined lands & waters	95-87 sec. 406	91 Stat. 460	30 U.S.C. 1236	1977
Soil and Water	Soil & Water Resources Conservation Act (RCA)	SCS	Resource Appraisal & Program Development	95-192	91 Stat. 1407	16 U.S.C. 2001 et seq.	1977
Water	Clean Water Act of 1977	EPA/SCS	Rural Clean Water Program to control nonpoint pollution from agricultural sources; financial & technical assistance	95-217 sec. 208	91 Stat. 1579	33 U.S.C. 1288	1977
Rangeland	Federal Land Policy & Management Act	BLM	Organic Act for BLM management & disposal of public lands; inventory, planning, and management for grazing leases	94-579	90 Stat. 2743	43 U.S.C. 1701 et seq.	1976
Rangeland	Forest & Rangeland Renewable Resources Planning Act (RPA)	USFS	Resource Appraisal & Program Planning & Development	93-378	88 Stat. 476	16 U.S.C. 1601-10	1974

Table 23.—Evolution of the Federal Role in Resource Conservation—Continued

Resource	Authorizing legislation[a]	Lead agency	Conservation program	Public Law	U.S. Stat.	U.S. Code	Date of enactment
Soil and Water	Agriculture & Consumer Protection Act	ASCS	Cost-sharing & technical assistance under the Agricultural Conservation Program (excludes certain Great Plains Conservation Program participants)	93-86	87 Stat. 241	16 U.S.C. 1501 et seq.	1973
Natural Environment	Federal Environmental Pesticide Act	EPA	Comprehensive registration of pesticides by use & enforcement authority over misuse	92-516	86 Stat. 973	—	1972
Soil and Water	Rural Development Act	SCS/FmHA	Land inventory & monitoring; loans for soil & water conservation	92-419	86 Stat. 670	7 U.S.C. 1010a	1972
Water	Water Bank Act	ASCS	Water Bank Program to conserve surface waters & wetlands	91-559	84 Stat. 1418	16 U.S.C. 1301 et seq.	1970
Natural Environment	National Environmental Policy Act	CEQ	Environmental impact assessments of Federal projects; national policy to minimize environmental damage	91-190	—	—	1969
Soil and Water	Appalachian Regional Development Act	ASCS	Appalachian Land Stabilization & Conservation Program (cost-sharing & technical assistance for erosion, sediment control, & other conservation measures	89-4	79 Stat. 5	—	1965
Water	Water Resources Planning Act	Water Resources Council	Conservation, development, & use of water & related land resources; formation of river basin commissions to coordinate, plan, & study resource	89-90	79 Stat. 244	42 U.S.C. 1962 et seq.	1965
Rangeland	Public Land Law Review Commission Organic Act	Public Land Law Review Commission	Appraisal of Federal land laws to improve Federal Government's custodian role to meet current & future needs	88-606	78 Stat. 982	43 U.S.C. 1391-1400	1964
Soil and Water	Food and Agriculture Act	SCS/FmHA	Resource Conservation and Development (loans & technical assistance to develop & carry out conservation plans)	87-703	76 Stat. 607	7 U.S.C. 1010-11a	1962
Soil and Water	Consolidated Farmers Home Administration Act	FmHA	Conservation loans to individuals	87-128 307	75 Stat. 1921	7 U.S.C.	1961
Rangeland	Multiple-Use Sustained-Yield Act	USFS	Mandate to develop renewable surface resources of the national forests for multiple use & sustained yield	86-517	74 Stat. 215	16 U.S.C. 528-31	1960
Soil and Water	Great Plains Conservation Program	SCS	Great Plains Conservation Program (long-term cost-sharing & technical assistance)	84-1021	70 Stat.	16 U.S.C. 1030	1956

Table 23.—Evolution of the Federal Role in Resource Conservation—Continued

Resource	Authorizing legislation[a]	Lead agency	Conservation program	Public Law	U.S. Stat.	U.S. Code	Date of enactment
Soil and Water	Agriculture Act of 1956	USDA	Soil Bank Program	84-540	—	—	1956
Water-sheds	Watershed Protection & Flood Prevention Act	SCS/FmHA	Watershed planning, operations, & emergency assistance; certain technical & financial assistance; river basin surveys & investigations; watershed loans	83-566	68 Stat. 666	16 U.S.C. 1001 et seq.	1954
Water-sheds	Flood Control Act	SCS	Emergency watershed operations	81-516 sec. 216	64 Stat. 184	33 U.S.C. 701 b-1	1950
Natural Environ-ment	Federal Insecticide, Fungicide, & Rodenticide Act	USDA	Pesticide registration in interstate commerce	80-104	61 Stat. 163	—	1947
Water-sheds	Flood Control Act	SCS	Installation of improvements in 11 watersheds & emergency watershed operations	78-534	58 Stat. 887	33 U.S.C. 701-1 et seq.	1944
Water-sheds	Flood Control Act	SCS	Watershed protection & flood protection (surveys & investigations to prevent soil erosion on watersheds)	74-738	49 Stat. 1570	33 U.S.C. 701a et seq.	1936
Soil and Water	Soil Conservation & Domestic Allotment Act	ASCS	Agricultural Conservation Program (ACP), provision of payments & grants in aid to carry out approved soil & water conservation measures	74-461	49 Stat. 1148	16 U.S.C. 590g-p (m), 590q	1936
Soil and Water	Original Soil Conservation & Domestic Allotment Act	SCS	Technical assistance, soil surveys, snow surveys, water supply forecasting, & research relating to soil erosion & measures to prevent it	74-46	49 Stat. 163	16 U.S.C. 590a	1935
Soil and Water	Soil Conservation & Domestic Allotment Act	SCS	Plant Material Centers	74-46	49 Stat. 163	16 U.S.C. 590a-f	1935
Rangeland	Organic Act of 1897	U.S. Forest Service (FS)	National Forest Systems	—	30 Stat.	16 U.S.C. 473-482	1897

[a]Authorizing legislation refers to basic authorities for each activity and does not include amendments to the original Acts.

SOURCE: Office of Technology Assessment.

soil erosion processes and the measures necessary to prevent and control those processes. It also authorized the Secretary to enter into agreements with any agency or person for the purpose of soil conservation, and established the Conservation Operations Program. The program's initial activities emphasized projects to demonstrate erosion control methods but soon evolved to emphasize more direct service to individuals, relying heavily on local Soil Conservation District organizations.

The 1935 act was amended and expanded by the Soil Conservation and Domestic Allotment Act of 1936. This provided cost-sharing assistance for approved conservation practices and authorized payments to farmers who shifted acreage from "soil-depleting" to "soil-conserving" crops. The Agricultural Conservation Program (ACP) was established to carry out the 1936 act. It initially focused on short-term needs, but in the 1940's its direction shifted toward more long-range needs, and permanent

conservation investments became the main purpose of the Federal cost-sharing programs under ACP.

Congress also increased its attention to renewable resources other than cropland soil in the 1930's. Decades of uncontrolled overgrazing had ruined many public rangelands. In the more environmentally fragile arid regions, forage production was greatly reduced. Then the drought of the 1930's drastically cut forage production in the Great Plains, which until then had been less arid and more resilient. The combination of reduced forage and low livestock prices meant economic ruin for many ranchers. It also resulted in calls for an active Federal role in applying the newly emerging principles of "range science" to the vast, publicly owned rangelands in the Western States. In 1934, Congress passed the Taylor Grazing Act and gave the Secretary of Interior broad powers for multiple-use management of rangelands in the public domain. It provided the basic authority for classifying, protecting, administering, regulating, and improving the rangelands under the jurisdiction of the Grazing Service, later the Bureau of Land Management (BLM).

Watershed protection and flood prevention also began to receive increased congressional attention during the 1930's. As erosion processes came to be better understood in the 1930's and 1940's, Congress passed a series of laws authorizing investigation and improvement of watersheds and providing emergency measures for flood control. Financial and technical support for conservation and land improvements increased in 1954 with passage of the Watershed Protection and Flood Prevention Act. Through the 1950's and 1960's, Congress established programs for regions with especially severe problems of resource degradation, including the Great Plains Conservation Program and the Appalachian Regional Development Act.

During the 1970's, Congress produced several major legislative packages reflecting growing national concern over the adequacy of existing programs to ensure long-term resource productivity. Natural resource appraisal and long-term planning were emphasized by the Soil and Water Conservation Act of 1977, the Forest and Rangeland Renewable Resources Planning Act of 1974, and the Federal Lands Policy Management Act of 1976. Regulation of agricultural chemicals, control of nonpoint source agricultural pollution, and the preservation of environmental quality also received broad and intensive legislative attention.

The major laws enacted during the past two decades that directly or indirectly affect rangeland and cropland resource use and productivity include:

- Multiple Use-Sustained Yield Act of 1960,
- Clean Air Act of 1963 (amendments 1970 and 1977),
- Wilderness Act of 1964 (amendments 1972 and 1977),
- National Environmental Policy Act of 1969,
- Federal Environmental Pesticide Control Act of 1972,
- Federal Water Pollution Control Act Amendments of 1972 (amendment—The Clean Water Act—1977),
- Endangered Species Act of 1973,
- Forest and Rangelands Renewable Resources Planning Act of 1974 (amendments 1976),
- Wild Horse and Burro Act of 1974,
- Archaeological and Historic Preservation Act of 1974,
- National Forest Management Act of 1976,
- Federal Land Policy and Management Act of 1976,
- Soil and Water Resources Conservation Act of 1977,
- Forest and Rangeland Resources Extension Act of 1978, and
- Public Rangelands Improvement Act of 1978.

Resource Appraisal and Protection

The Conservation Operations Program, administered by SCS, has been responsible for developing farm-level and local conservation plans for encouraging the use of soil and water

conservation techniques. ACP, administered by ASCS, provides cost-sharing assistance for conservation investments. These programs, however, are voluntary, and participation has been inadequate to control resource degradation on the Nation's croplands and rangelands. This inadequacy was widely recognized in the 1970's, and this led to enactment of the Soil and Water Resources Conservation Act of 1977.

Resources Conservation Act

The 1977 Resources Conservation Act established a process for natural resource appraisal and planning. That process is popularly known as "RCA." The purpose of RCA is to provide a mechanism for informed, long-range policy decisions regarding the conservation and improvement of the Nation's soil, water, and related resources. It is intended to serve not only the Federal Government but also State and local governments and private landowners and land users. The legislation mandates a continuing resource appraisal and inventory which is to be the basis of a comprehensive national policy. That policy is to include priorities for a national soil and water conservation program. Finally, there is to be continuing program evaluation to keep the program responsive to changing priorities.

The RCA appraisal was published in the summer of 1981. The proposed RCA program was distributed for public review in late 1981. The final program and publication are unlikely to be issued before late 1982. Meanwhile, there is some indication that the RCA process is not yet meeting the intent of Congress. A 1980 General Accounting Office (GAO) evaluation of the ongoing RCA found that 2 years and $11 million after beginning the process, USDA had not fully evaluated each of its 34 soil and water programs. The GAO report focused on whether RCA was developing useful and accurate information for water program decisions, and found considerable fault with the RCA analysis of conservation programs, techniques, and changing needs (GAO, 1980b). The program evaluations will be a key issue in assessing the soundness of the final RCA recommendations. There is a strong tendency for any department or agency to avoid self-cr evaluations, since these can be used by gress or the Office of Management and B as a rationale for cutting out the programs without such evaluations the agencies ar likely to make good use of the continuii source appraisal process.

Rangelands

The Federal Government's role in managi rangelands has concentrated mainly on the 2 million acres of federally owned rangeland o side Alaska. Excluding Alaska,* 64 percent U.S. rangeland is outside Federal ownersh but does get some service from SCS and AS programs. The rangeland work of those age cies is minor compared with their work croplands and improved pastures.

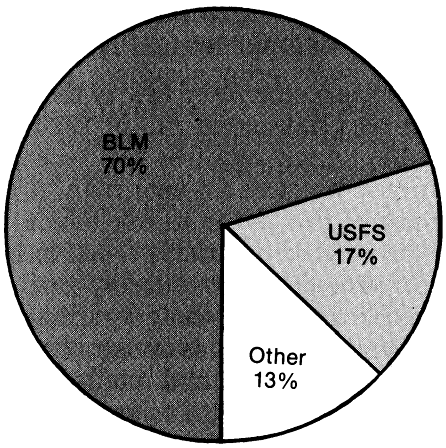
BLM administers 70 percent of the Feder rangeland outside Alaska, and the U.S. Fore Service (USFS) has jurisdiction over 17 per cent. The remainder is administered by variou agencies in the Departments of Defense and the Interior (fig. 15) (USDA, 1980b). The Taylo Grazing Act of 1934 was the guiding mandat for administering BLM lands for decades, an the Organic Act of 1897 was the basis of USF land management. Various laws influence Federal rangeland management from th 1930's through the 1960's. The Soil and Wate Resources Conservation Act provided som funds to restore productivity of the publi lands, and the Multiple-Use, Sustained-Yiel Act of 1960 mandated administration of the USFS lands for uses other than timber and forage. In the 1970's, however, Congress recognized that these laws were inadequate for sustaining the productivity of the public lands, and six important new laws were passed to guide the work of BLM and USFS.

THE FEDERAL LAND POLICY AND MANAGEMENT ACT AND PUBLIC RANGELANDS IMPROVEMENT ACT

Congress enacted two major pieces of legislation dealing with long-term planning and man-

*There are 231 million acres of land classified as range in Alaska, most of it federally owned, but that land is not heavily used or managed.

Figure 15.—Administration of Federal Rangeland Excluding Alaska



SOURCE: U.S. Department of Agriculture, Forest Service, "An Assessment of Forest and Rangeland Situation in the United States," 1980.

agement of land administered by BLM: the Federal Land Policy and Management Act of 1976 (FLPMA—Public Law 94-579) and the Public Rangelands Improvement Act of 1978 (PRIA—Public Law 95-514). The two acts give express policy recognition to the plight of public rangelands, mandate land-use plans, and provide funds for on-the-ground improvements.

FLPMA is the result of congressional concern over the deterioration of Federal lands and over the numerous, often-conflicting, and sometimes-antiquated acts related to public lands. Indeed, a major purpose is to give BLM enough authority to effectively carry out the public lands goals and objectives established by other laws.

The complete act has six titles with provisions ranging from broad types of BLM authority to specific policies on issues such as protecting wild horses and burros, managing the California desert area, and managing BLM's wilderness land.

FLPMA specifies that the Secretary of Interior will carry out resource planning for the BLM-controlled public lands by: 1) preparing and maintaining a resource inventory of all the lands, 2) developing and maintaining land-use plans for all lands by tract or area, and 3) developing management allotment plans for the lands designated during the planning stage as available for grazing. The land-use planning activity is guided by nine directives, including a mandatory provision for compliance with pollution laws and standards, and a requirement to balance long- and short-term benefits.

To strengthen the FLPMA program, Congress enacted PRIA. This act authorized substantially increased funds for restoring and improving Federal rangelands. In its declaration of policy, Congress recognized that rangelands are still in unsatisfactory condition and may decline further without more funds and improved management. It declared that such "unsatisfactory conditions on public rangelands present a high risk of soil loss, desertification, and a resultant underproduction for large acreages of the public lands" (43 U.S.C. 1901 (a)(3)).

In PRIA, Congress mandated improved management and more funds to be raised through fees collected from livestock grazing permits and leases on public lands. Fees have been charged for decades, but traditionally they have been below fair market value. While generating considerable debate prior to enactment, the legislation does specify that the fees charged are to represent "the economic value of the land to the user;" it designates the base and formula to be used for determining the fair market value (43 U.S.C. 1905(a)). Furthermore, the act mandates that over 80 percent of the funds generated are to be spent for on-the-ground range rehabilitation, maintenance, and the construction of range improvements (43 U.S.C. 1904(c)).

THE RESOURCE PLANNING ACT

The Forest and Rangeland Renewable Resources Planning Act of 1974, which generated the RPA process, is landmark legislation that requires USFS to engage in long-term planning. Congress enacted the law to improve the collection and analysis of data so that legislative and administrative decisions on policy and program design and funding will more adequately meet future demands on forests, rangelands, and associated renewable resources.

RPA requires that the administration prepare an updated inventory and assessment of resources and a detailed program for investment in, and use of, the forest system. The updated inventory and program are to be submitted to Congress for review every 5 years for the next four decades and a progress report is to be prepared by the administration annually. This resource assessment and planning process is to encourage the development of all the federally owned forest, range, and related lands as a unified system dedicated to long-term benefit for present and future generations. The scope of the RPA resource assessments reported thus far has not been limited to land administered by USFS, but the Forest Service is the lead agency, and so far the RPA program planning process has related mainly to USFS lands.

The legislation sets the year 2000 as the target year:

> . . . when the renewable resources of the National Forest System shall be in operating posture whereby all backlogs of needed treatment of their restoration shall be reduced to a current basis and the major portion of planned intensive multiple-use sustained-yield management procedures shall be installed and operating on an environmentally sound basis (16 U.S.C. 1607 (1974)).

THE NATIONAL FOREST MANAGEMENT ACT

A major amendment to RPA occurred in 1976 with the enactment of the National Forest Management Act (Public Law 94-588). While RPA provided the philosophy and factfinding basis for long-term planning, this amendment contains a more specific framework for developing and implementing multiple-use management plans for sustained yield use of specific resources. A key objective of the legislation is to develop USFS management programs that "will not produce substantial and permanent impairment of the productivity of the land" (16 U.S.C. 1604(g)(3)(C)(1976)).

THE FOREST AND RANGELAND RENEWABLE RESOURCES RESEARCH ACT AND THE RENEWABLE RESOURCES EXTENSION ACT

The Forest and Rangeland Renewable Resources Research Act (Public Law 95-307) of 1978 mandates a comprehensive program of forest and rangeland research and dissemination of the findings. Again, this act is expressly intended to complement RPA.

Another complementary law is the Renewable Resources Extension Act of 1978 (Public Law 95-306), which requires the Secretary of Agriculture to prepare a 5-year plan. A principal purpose of this act is to use education to increase the yield of privately owned forest and rangeland renewable resources, but it has broader implications. Jurisdiction distinctions among the various agencies constrain the coordination of forest, range, and cropland policies and programs, but Congress recognizes that these resources are intimately interrelated. This is evidenced, for example, by the act's directive that the 5-year plan include programs for managing trees and shrubs in shelterbelts because these "protect farm lands from wind and water erosion." The legislation states that:

> . . . to meet national goals, it is essential that all forest and rangeland renewable resources . . ., including fish and wildlife, forage, outdoor recreation opportunities, timber, and water, be fully considered in designing educational programs for landowners, processors, and users . . . . (16 U.S.C. 1671(2) (1978)).

These legislative developments guide management support of the practices and technologies necessary to ensure future productivity of publicly owned rangelands. In essence, it is a congressional mandate for land stewardship. A congressional white paper issued after the first series of RPA reports were submitted by the administration in June 1980 declared:

> . . . the role of the Federal Government in managing the National Forests is to protect and enhance the land, and to provide goods and services from those lands to the Nation's people. But the first consideration must be the enhancement and protection of the land, both forest and range (U.S. Congress, 1980b).

Even though the policy seems clear, implementation is not. No comprehensive analysis to determine the adequacy and completeness of the RPA process as a long-term planning instrument has been undertaken. However, in mid-1980 GAO reviewed BLM and USFS land

management activities and found that congressional expectations were not being achieved. BLM has a mandate for resource inventory and land-use planning, but no mandate to develop long-range resource programs. As a result, BLM has no rigorous basis for determining the production levels required to meet the Nation's long-term needs for the various benefits produced from its land.

GAO found that "neither the Bureau nor the Forest Service have land management plans for sizable portions of their lands" (GAO, 1980b). While both agencies have been working to develop better land management plans and planning procedures, many of the existing plans are inadequate because they:

- are based on incomplete or obsolete resource inventory data or
- do not identify specific actions required to meet production goals while achieving environmental protection objectives.

GAO recommended that Congress amend FLPMA to require a long-range renewable resource program development process for BLM. Improvements in the planning process are being made and more comprehensive plans are in progress, but these will take several years to complete. In the meantime both agencies "will continue to be guided by substandard plans or by the intuition and best guesses of land managers" (GAO, 1980b).

Finally, for both BLM and USFS, staff and funds have not kept pace with the new responsibilities and specific tasks assigned to the agencies by legislation, Executive orders, and court decisions. For example, the Renewable Resources Extension Act of 1978 remains unfunded. The problem is particularly acute in BLM, where since 1970 responsibilities for major resource management programs have increased rapidly while the agency's limited resources have hampered completion of even the most pressing mandates. The GAO report emphasizes the need to link agency program mandates to the budgeting process (GAO, 1980b).

Environmental Protection

During the 1970's, several types of programs were implemented to safeguard or restore the Nation's general environmental quality. Three of these are particularly significant for cropland and rangeland productivity: pesticide regulation, nonpoint source pollution control, and environmental impact assessment.

PESTICIDE REGULATION

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1947 regulated labeling and registration of pesticides sold interstate. The primary purpose of that law was to protect pesticide users from fraud. Since 1950, however, there has been a prodigious increase in the use of pesticides, which are potential pollutants of food, drinking water, and fish and wildlife habitat.* By the early 1970's Congress had recognized the need for Federal safeguards for the general environment and protection of the public from misuse of these dangerous chemicals. In 1972, FIFRA was amended to establish a sophisticated regulation system involving Federal, State, and local government agencies. In 1978, further amendments expedited the registration and classification process for pesticides by allowing generic chemical registration, conditional registration, special data-use compensation, State primary use enforcement, and special trade secret exceptions. The 1978 act further requires the Environmental Protection Agency (EPA) and USDA to coordinate efforts in integrated pest management. Because of these amendments and careful congressional oversight, EPA has made important strides to implement more responsive and efficient programs in pesticide regulation which protect the public and the resource.

NONPOINT SOURCE POLLUTION

The Federal Water Pollution Control Act (FWPCA) of 1972 (Public Law 92-500), as amended by the Clean Water Act of 1977, deals with the problem of nonpoint source pollution.

*U.S. production of pesticides rose from 680 million lb in 1962 to 1,420 million lb in 1980 (Harkin, et al., 1980).

It cites agricultural activity as one of the many, diffuse sources of such pollution. Section 208 of FWPCA is intended to affect the technological practices used on croplands and rangelands. It calls for areawide water quality management plans to achieve the goals of the act, including complete elimination of pollutant discharge by 1985 where technically, economically, and socially achievable. More specifically, the plans are to identify and set forth procedures and methods to control agricultural nonpoint pollution sources.

EPA is responsible for administering FWPCA. It has indicated that State governments should develop and implement "best management practices," described by section 208 as:

> . . . the control techniques that a State considers most reasonable and effective and which are suitable to local conditions at the time of implementation. Such practices include crop rotation, less intensive cropping systems, conservation tillage, and structural controls. It is significant to note that these best management practices are preventive measures—they are directed toward controlling soil erosion on-site rather than dealing with sediment after it has eroded (EPA, 1978).

The "208 planning process" has been under way since before 1978, when detailed management plans and implementation schedules for the States were due. The 1977 Clean Water Act expanded section 208 by establishing a new program authorizing USDA to provide technical and financial assistance to farmers, ranchers, and other rural land operators for installation and maintenance of the FWPCA best management practices. This cost sharing is to support implementation of the State water quality management plans for control of nonpoint source pollution. Programs have now been established by many States, although the cost-sharing funds have subsequently been reduced.

Overall, the section 208 program has moved slowly. EPA became more active after the 1977 amendments and relied heavily on USDA cost sharing. Many States opposed the program originally, however, and the progress will continue to be slow, in part because funds and technical expertise are limited. Also, the benefits of agricultural water pollution control accrue slowly to a widely dispersed set of beneficiaries who may not recognize the benefits when they occur.

ENVIRONMENTAL IMPACT ASSESSMENT

The National Environmental Policy Act of 1969 (NEPA—Public Law 91-190) requires Federal agencies to prepare an environmental impact statement (EIS) when a proposed action significantly affects the quality of the human environment. Even if a full EIS is not needed there must still be preliminary data collection and analysis to support a finding of no significant adverse impact. Consequently, where Federal involvement exists, NEPA generally will trigger at least some data collection and analysis of how the project is expected to affect natural resources.

The principal purpose of NEPA is to inform decisionmakers about the likely environmental and natural resource consequences of proposed major actions before the actions are taken, and where serious negative consequences are anticipated, to encourage consideration of alternative actions. NEPA has resulted in more complete environmental impact consideration for many projects than would otherwise have occurred. The fundamental purpose of promoting informed decisionmaking has seldom been faulted. However, at times the application of NEPA has led to controversy and criticism.

For example, in the mid-1970's, a citizens' organization brought a lawsuit against BLM challenging the adequacy of its programmatic grazing statement for public lands under its jurisdiction. The suit was settled in 1975, with a decision that BLM should prepare, by 1989, 145 EISs to cover its projects on over 170 million acres of public lands. The subsequent EIS process has been expensive, consuming a large portion of BLM's limited funds and, especially, of its limited expert personnel, and causing significant delays in needed rangeland development. Whether the EISs need to be so expensive is doubtful, but certainly the process caused more thorough planning than occurred

before the lawsuit. The EISs have revealed more severe range degradation than had formerly been recognized—or admitted—and it seems likely that the improved information will result in improved programs. It is possible that without being forced to prepare EISs, BLM still would have improved its planning as it worked out programs in response to the mandates of FLPMA and PRIA.

Federal Cost Sharing

Cost sharing has been an integral component of Federal conservation policy since 1936. The rationale is that each year society wants more row crops, small grains, beef, and other products than farmers and ranchers can produce from the most resilient prime agricultural lands. Therefore, nonprime and fragile croplands and rangelands must be used. But society does not pay high enough prices to the producers, relative to their costs, to implement the conservation practices needed to protect the long-term productivity of these fragile lands. (And it is not clear that if society did, the farmers would use the money for that purpose.) So, to the extent that society places a high value on future production, it must directly pay a share of the cost for conservation practices.

This rationale is convincing and widely accepted. A 1979 Harris Poll indicated that 72 percent of the American public supported the concept of public funding to help pay for soil conservation practices on private land (Cook, 1980a). Eight USDA programs have offered cost sharing to landowners for conservation purposes (table 24). Yet this has been the most

Table 24.—Conservation Programs and Their Purposes

		Conservation purpose[a]														
Agency	Conservation program	Flood control	Land reclamation	Water supply	Timber productivity	Watershed protection	Wind erosion	Pasture/range production	Water quality improvement	Waste management	Irrigation management	Drainage	Cropland productivity	Habitat development	Outdoor recreation	Type of program
ASCS	Agriculture conservation	4		5	1	5	5	3	5	5	5	1	5	2	1	Cost sharing
	Water bank	5		5		5	1							5	4	Cost sharing
	Emergency conservation	1	5	5		4	5	2	5	4	5	3	3	4		Cost sharing
FmHA	Irrigation and drainage loans	5	3	5	1	4	4	5	3	1	5	5	3	1		Loans
	Watershed loans	5	3	5	3	5	5	4	3	3	5	4	4	3	3	Loans
	Resource conservation loans	5	4	5	4	5	5	5	3	4	4	5	3	3	3	Loans
	Loans to individuals	5	4	5	4	4	5	4	3	3	5	5	3	2	1	Loans
USFS	State and private forestry	4	3	3	5	5	3	2	2	1				5	2	Technical assistance
	National forest system	3	4	4	4	5	1	4	2	3				5	5	Resource management
SEA-E	Conservation education	4	1	3		5	4	3	4	2	4	4	4			Education
SCS	Conservation operations		3	4	3	5	5	4	4	3	5	2	5	3	1	Technical assistance
	Watershed operations	5		4	4	5	2	4	4	2	4	2	3	4	3	Cost sharing/technical assistance
	Flood prevention	5		4	4	5	4	4	4	4	5	4	4	4	4	Cost sharing/technical assistance
	Emergency watershed					5										Cost sharing/technical assistance
	Resource conservation	3		3	2	3			4	3	3	1	3	3	3	Cost sharing/technical assistance
	Great Plains conservation	1		4	2	5	5	2	4	3	4		2	2		Cost sharing/technical assistance

[a]The most important purpose of each program is assigned a value of 5 with other purposes rated relative to this one on a scale from 1 to 5. If no rating is shown, the purpose is not relevant to the program.

SOURCE: *Overview: Program Linkages,* USDA Land and Water Conservation Task Force, Washington, D.C., December 1978; U.S. General Accounting Office, *Report to Congress: A Framework and Checklist for Evaluating Soil and Water Conservation Programs* (Washington, D.C.: March 1980), p. 15.

controversial of the Government approaches to the maintenance of agricultural land productivity.

Recent evaluations of the largest cost-sharing programs have indicated that they have not been a cost-effective approach to soil conservation. The controversy is over why this is so and what should be done about it—not over the basic rationale of cost sharing. The principal reasons offered for the lack of cost effectiveness are: 1) that funds intended for technologies to enhance long-term conservation have been used instead to increase short-term production and 2) that funds are spread so broadly and administered so loosely that they mainly subsidize conservation practices on land with few conservation problems and rarely reach the land with severe problems (Cook, 1980a).

The proposed solution to the first problem, already implemented to a considerable extent, is to have stricter guidelines for use of cost-sharing funds to exclude production-oriented technologies. The conservation effect of some "production" technologies such as drainage, however, may have been discounted too much.

The proposed solution for the second problem—i.e., "targeting" the cost-sharing programs on regions of the Nation with the most severe conservation problems and on particular farms with the most fragile lands—is receiving increased support, but will be politically difficult. Farmers have become used to conservation cost-sharing programs in every county—in every congressional district—and any major redistribution of funds or personnel is sure to be resisted. And experts do not all agree that "targeting" is the most effective approach. Much of the Nation's most productive land suffers constant, but not necessarily alarming, erosion and loss of productivity which might be neglected under the "targeting" approach. Further, comparing the long-term importance of preventing a small amount of soil loss from highly productive land to the importance of saving more soil on less productive land is an important, unresolved issue. This issue cannot be resolved for national policymaking, however, until improved models of land productivity and agricultural policy are developed.

Further controversy centers on whether completely voluntary approaches to conservation will ever involve enough farmers. One proposed alternative is to make inclusion in the various commodity and credit programs contingent on participation in the conservation programs. This approach is referred to as "cross compliance."

Agricultural Conservation Program

ACP is the country's largest cost-sharing program. Roughly $8 billion in Federal funds have been distributed to farmers through the program, which is available in every county in the Nation. In recent years the total annual program budget has been about $200 million divided among about 300,000 participating farms.

The program is administered at the national level by USDA's ASCS, but most of the important administrative decisions are made by farmer-elected county committees. The authority of the county committees includes identifying conservation problems, setting priorities, selecting appropriate cost-share practices, setting levels of cost sharing, approving applications, entering into contractual obligations, and making payments for completed conservation work (USDA, 1981a).

In 1976-77, GAO found that less than half of ACP funds actually had been used for soil conservation-oriented measures. Most of the money had supported measures that, although eligible for funding, were primarily production-oriented or that resulted in minimal soil conservation. The GAO report noted that most county committees did assign priority to the practices for which Federal cost-sharing funds were to be spent, but these commonly were not followed. In some cases, practices designated by county committees as high-priority or critically needed to control erosion received only a small percentage of the available funds, whereas other practices considered to be production-oriented or of a temporary nature were

approved by the committees and heavily funded on the basis of popular demand (GAO, 1977).

ASCS conducted its own evaluation of ACP in 1977 (USDA, 1981a). This study added a new dimension to the criticism, for it indicated that many of the practices specifically intended to control erosion were placed on land without severe erosion problems. Data collected nationally on nine erosion-control practices revealed that 52 percent of the erosion-control practices installed under ACP have gone on land where annual sheet and rill erosion was below 5 tons per acre. Moreover, ACP-funded practices had not effectively reached lands where sheet and rill erosion were known to be most severe. The ACP evaluation stated:

> Effectively targeting erosion control funds according to the potential for erosion reduction could more than triple the amount of soil saved through the program. Achieving these improvements hinges on the willingness of farmers with severe erosion problems to participate in the program (USDA, 1981a).

USDA's main cost-sharing program could be substantially more effective in controlling erosion if funds were reallocated among States, counties, and farms in proportion to their relative erosion problems. Achieving improvements this way depends not only on the willingness of the farmers with severe erosion problems but also on their ability to pay their share and to implement the practices. The necessary socioeconomic studies to identify the opportunities and constraints for directing cost-sharing programs have not been done, however.

ACP cost sharing has also been criticized for investing too much in the less efficient conservation practices and too little in the most efficient ones (table 25). Stricter guidelines for the county committees to adhere to priorities and select eligible practices could help eliminate this problem.

Even before this evaluation was released, steps had been taken to direct funds to critically eroding areas and to ensure that the most

Table 25.—Cost Per Ton of Erosion Reduction by Practice and Erosion Rate

	Type of practice									
Average annual soil loss before treatment (tons per acre)	Establishing permanent vegetative cover	Improving permanent vegetative cover	Stripcropping	Terrace	Diversions	Interim cover	Conservation tillage	Competitive shrub control	Vegetative cover on critical areas	Average cost for all practices
	—Average cost per ton of erosion reduction in dollars—									
0-1	57.48	69.80	7.57	9.48	28.98	65.52	63.47	11.20	68.39	45.40
1-1.9	15.97	9.01	7.10	6.91	18.52	61.39	4.98	3.16	5.77	14.23
2-2.9	6.36	4.91	6.28	3.43	11.24	31.53	2.35	1.58	—	5.05
3-3.9	4.32	3.04	2.15	3.14	12.18	29.13	1.76	1.64	0.29	4.19
4-4.9	3.81	2.76	0.92	4.13	9.91	18.43	1.50	0.83	4.38	4.70
5-5.9	2.93	2.05	1.61	3.60	3.04	15.30	0.90	0.78	4.37	3.10
6-6.9	1.89	1.72	1.14	2.68	2.98	15.19	0.98	0.51	2.96	3.46
7-7.9	1.81	1.38	0.52	2.57	4.67	9.49	0.53	0.61	0.38	2.33
8-8.9	1.60	1.21	0.88	2.66	1.52	7.69	0.53	0.46	0.44	2.40
9-9.9	1.31	1.07	1.07	2.08	3.79	7.21	0.61	0.13	0.89	2.16
10-10.9	1.20	1.03	1.43	1.68	2.16	6.77	0.39	0.33	8.4	2.16
11-11.9	1.00	0.84	—	1.95	0.49	5.77	0.39	0.33	0.59	1.57
12-12.9	0.85	0.66	0.30	1.43	0.57	5.95	0.83	0.66	0.21	1.54
13-13.9	0.89	0.64	1.07	1.12	0.99	3.99	0.61	1.06	0.49	0.94
14-14.9	0.80	0.57	—	1.21	0.54	3.90	0.21	0.30	0.42	1.12
15-19.9	0.59	0.54	0.69	0.99	0.61	3.94	0.32	0.19	0.27	0.84
20-24.9	0.45	0.45	0.06	0.87	0.44	3.07	0.29	0.32	0.21	0.54
25-29.9	0.38	0.36	—	0.76	0.63	2.38	—	0.03	0.26	0.48
30-49.9	0.26	0.24	0.02	0.44	0.29	1.81	0.08	0.31	0.23	0.39
50-74.9	0.17	0.14	—	0.15	0.14	2.21	0.13	—	0.46	0.24
75-99.9	0.14	0.13	—	0.03	0.08	2.19	0.04	—	0.15	0.22
over 100	0.10	0.06	0.01	—	0.07	1.36	—	0.01	0.16	0.21

SOURCE: National Summary Evaluation of the Agricultural Conservation Program, Phase I. USDA, ASCS, 1981. Data from a sample of Agricultural Conservation Program activities in 171 counties, 1975-78.

cost-effective erosion control measures would be used. However, the decision to reallocate ACP funds significantly resides with Congress. Data from the 1977 National Resource Inventories (NRI) provide an accurate basis for directing funds at sheet and rill erosion on croplands and improved pastures. The 1982 NRI is expected to improve substantially the data bases on wind erosion and gully erosion on croplands and pastures and to make some improvement in the data on rangeland erosion. RCA appraisals of problems, opportunities, and priorities at the State level could be used to reallocate the program resources among States. The State and county committees would remain vitally important because the NRI and RCA processes cannot be made precise to the county level, and conservation problems are always site specific.

Great Plains Conservation Program

An alternative to redistributing ACP funds is to establish new programs for areas where land productivity is being most severely degraded. The Great Plains Conservation Program (GPCP) is a model for this approach. This cost-sharing program was created in 1956 and has been extended through September 30, 1991. It authorizes the Secretary of Agriculture, through SCS, to make contracts with landowners and operators in the designated Great Plains area. The contracts, effective for periods of up to 10 years, provide cost-sharing assistance for conservation practices necessary to conserve, develop, protect, and use the soil and water resources.

The program is completely voluntary. However, each contract approval depends on the producer's plan of farming operations, including schedules for proposed changes and implementation of conservation measures. The plan must incorporate soil and water conservation practices for maximum mitigation of the area's climate hazards. It must also include practices and measures for: 1) enhancing fish, wildlife, and recreation resources; 2) promoting economic use of the land; and 3) reducing or controlling agriculturally related pollution (16 U.S.C. 590 p(b)(1)).

The Great Plains area was chosen because of its susceptibility to serious wind erosion. The program proposes to rehabilitate agriculture so that farms and ranches use more progressive soil and water conservation techniques. In 1961, amendments to the program extended contract authorization to land not in farming or ranching, but where severe erosion hazards were a threat to cropland or grazing land.

GAO has criticized GPCP for making unsatisfactory progress in alleviating soil erosion. Reasons included: 1) the frequent funding of projects that are locally popular rather than those that have highest conservation priority, 2) insufficient effort to promote the program in areas with highest conservation priority, and 3) inadequate extension work to encourage producers to maintain grass cover on the areas most susceptible to erosion. Further, much of the land that had been seeded into permanent vegetative cover was being converted back into cropland at the expiration of the contract period. GAO concluded that the program was making slow progress in attaining its primary objective—wind and water erosion control (GAO, 1977).

In 1974, USDA evaluated GPCP using linear programing models to examine the most cost-effective practices and funding distribution for optimal erosion control. The program was found to be achieving 56 percent of the technologically possible level of erosion reduction for the $11.5 million cost-sharing level then in effect. According to that analysis, reallocation of funds among States and optimal combinations of practices within each State could significantly improve erosion reduction and lower the associated Federal cost-share per ton (Cook, 1980b).

For either the nationwide ACP or regional programs modeled on GPCP, the importance of evaluation and adjustment is clear. ACP and GPCP would probably benefit by eliminating or curtailing the cost-sharing eligibility of the less cost-effective conservation practices—though this might best be done at the State level because of the site specificity of conservation

problems. Possible approaches to encourage farmers with severe erosion problems to participate include giving them preference in other ACP cost-sharing programs, raising the limit on total Federal spending per participant (currently $3,500 a year) for them but not for others, and increasing the Federal share of their costs. Another approach would be to discourage participation by those farmers who do not have severe erosion problems. These approaches were suggested by the GAO evaluation of GPCP, but most remain untried.

Cross Compliance

Among the novel policy proposals presented to Congress by Secretary of Agriculture Charles F. Brannan in 1949 was the idea of requiring approved conservation practices as a condition for farmer eligibility in Federal commodity programs (Rasmussen and Baker, 1979). This was the first public proposal for cross compliance. The idea, rejected in 1949 (along with most of the "Brannan Plan"), subsequently has not received much consideration by Congress.

In the 1980 Resources Conservation Act review draft, USDA discussed cross compliance as a possible conservation strategy. It noted that land users could be required to meet a certain standard of conservation performance, or to carry out certain conservation measures, in order to qualify for USDA program benefits (USDA, 1980a). The report suggested that USDA could remove all program benefits from land users who fail to comply, or it could offer special additional benefits and subsidies to those individuals who do comply. The range of benefits offered for compliance might include subsidized interest loans, crop or flood insurance adjustments, commodity payments, and payments for income foregone or for maintenance of conservation practices.

The rationale for cross compliance is fairly straightforward. The Federal Government, through its commodity and credit programs, assumes part of the individual farmer's economic risks. At the same time resource problems (primarily soil erosion), which have adverse social effects, occur on farms receiving the commodity and credit program benefits. So farmers who desire the society's protective farm programs might, in return, be expected to protect the socially valued resources. This rationale has some public support. A 1979 Harris public opinion poll, part of the RCA process, indicated that 41 percent of respondents believed that cross compliance would be fair to both farmers and taxpayers.

In the spring of 1980, however, USDA received nearly 110,000 comments on the RCA draft's discussion of cross compliance. Overall, 49 percent of the comments supported the strategy and 51 percent were opposed. Environmental groups generally supported the idea, as did farm organizations in the Northeast and Midwest, whereas members of farm organizations in the South and West opposed it (USDA, 1980a).

One cross-compliance proposal would require participants to adhere to acceptable regional and crop-specific management practices to qualify for commodity program benefits. Participating farms would have, as an addendum to their commodity program contracts, an approved plan specifying an adequate conservation strategy consisting of management practices compatible with the farm's equipment and livestock feed needs. Specific practices would be recommended or required as the farm's erosion potential warranted, but practices contributing to excessive erosion would be explicitly prohibited (Benbrook, 1979; 1980). The incentives offered could include slightly higher target prices or loan rates, upward adjustment of disaster payments, relaxation of payment limitation, use of higher yield levels in payment formulas, and tax credits or deferrals.

Even a cross-compliance mechanism that might be politically palatable to farmers and to Congress could contain important practical difficulties. First, some of the land needing conservation treatment is not enrolled in Federal commodity programs. One USDA report indicates that only about 25 percent of the land needing conservation treatment would be cov-

ered by a cross-compliance requirement between USDA's commodity and conservation programs (USDA, 1980a). This is a rough estimate because the conservation status of commodity program participants is poorly documented. A large share of commodity program benefits is paid to a fairly small number of large, high-income farms. Generally, these farms are thought to have the better quality land, while smaller farms, having lower participation in Federal commodity programs, are often situated on more erosive land. Consequently, cross compliance might be more suitable for depletion problems other than soil erosion, such as water conservation in the Great Plains region.

Second, many farmers elect not to participate in commodity programs in periods of high market prices because program benefits are then negligible. Thus, they might discontinue conservation practices in those years. Yet these are the years when production pressures are greatest on agricultural resources. Thus, for cross compliance to be effective, conservation and commodity programs would have to be instituted on a multiyear basis, instead of the annual basis traditionally used. Were such a policy in effect, some farmers would probably drop out of the program, with the result that other, traditional commodity program goals would be compromised. For example, if the conservation requirements caused larger farms to withdraw, supply-control efforts would be hampered; a relatively small number of these larger farms make up a large proportion of program-controlled acreage and production. This is a familiar policy dilemma of any proposal that would affect large farms (USDA, 1981b).

Smaller farms are more likely to be affected adversely by cross-compliance schemes. These farms tend to have lower quality land, and require more expensive conservation practices. Because some practices such as terracing would be costly to install, or would reduce the farm's cash crop acreage by requiring crop rotation or stripcropping, owners of smaller farms might be unable to participate. If small farms did drop out, program benefits would be skewed to an even greater degree toward larger farms. Recognizing this dilemma, most proposals for cross compliance have stressed the need to retain complementary cost sharing, or loan or tax incentives for participating farmers.

A final, important drawback of cross compliance would arise if Government commodity programs were to become less active in the future. This could happen as the export demand for major crops expands. In such a case, target prices, set-asides, and diversion payments would be needed less often. However, some cross-compliance leverage will remain available in the future for certain commodities, such as cotton or tobacco. Also, disaster-payment or crop-insurance programs underwritten by the Federal Government possibly could tie conservation to credit and commodity policy. As commodity programs become oriented more toward achieving economic stability for farmers (v. achieving higher income levels), there may remain a place for some cross-compliance strategy.

Generally, the design of a cross-compliance strategy would depend on how the productivity-conserving practices imposed on the farmers or ranchers affect their profits. If the conservation practices do not jeopardize the economic viability of the farm, a penalty-oriented implementation strategy may be appropriate. Fines, cross compliance with USDA production subsidies, taxes, and penalties for excessive soil loss and water resource depletion might be considered. But if the conservation practice creates financial hardships, an incentive-oriented strategy would be more appropriate.

STATE INITIATIVES

Soil Conservation Districts

In 1935, following passage of the first major soil conservation legislation, a USDA Committee on Soil Conservation recommended that all erosion control work on private lands by the newly formed SCS be undertaken only through a legally constituted Soil Conservation Association. Thus began the concept of the Soil Conservation District, and in 1937 the President sent a model act for creating Soil Conservation Districts to each State Governor. By 1947, all States had enacted some form of enabling legislation. Today, nearly 3,000 Soil Conservation Districts exist, covering more than 99 percent of the Nation (USDA, 1980c).

These local conservation districts are governed by local citizens and are independent of Federal Government programs. However, SCS provides technical assistance through agreements with the districts. The conservation district committees also work with the local committees that oversee programs of ASCS, and with the staffs and advisory committees of the Extension Service and of FmHA. In areas with Federal lands, districts are encouraged to carry out cooperative efforts with USFS and BLM.

The existing system of Soil Conservation Districts has been criticized. First, a majority of the enabling statutes provide for district boundaries to conform to county lines rather than to watershed boundaries, the approach favored by SCS. This creates more districts than might have been necessary. Perhaps more importantly, this creates conflicts between counties over conservation efforts in the same watershed and sometimes results in an inability to deal with the needs of an entire watershed. Second, a number of States did not authorize districts to enact land-use regulations as provided for in the Standard Act; others have never used those provisions. Had local controls been more widely adopted to regulate farmers' actions on many of the lands suffering from severe erosion, needs might be fewer today.

Notwithstanding these criticisms, the local conservation districts approach has been valuable in bringing conservation efforts to the land. Over the years, many local conservation districts have expanded their roles and responsibilities to address a broader range of resource problems, including preparing agricultural plans for water quality, sediment control, coastal zone management, and rangeland improvement (USDA, 1980c). Soil Conservation Districts are an institutional base already in place coordinating Federal and State policies and programs at the local level. Through their State and National associations, they are in a position to communicate to policymakers the changing needs and priorities of local communities. As such, they are likely to become increasingly useful.

State Soil Conservation Planning

208 Plans

With the passage of FWPCA, State and local governments were called on to develop long-range water quality management plans (called "208 plans" in reference to the section of the act dealing with these plans). Several States completed the agricultural parts of the 208 plans through agreements with the conservation districts or State soil conservation agencies. Most plans had been certified and approved by EPA by the end of 1979.

In 1973, the Council of State Governments published a Model State Act for Soil Erosion and Sediment Control. It presented the basic requirements for amending State soil and

water conservation district laws to extend existing programs and to make them more effective. As of mid-1980, 20 States, the District of Columbia, and the Virgin Islands had enacted erosion and sediment control laws and many included provisions set out in the model act. All of the laws contain some provision for enforcement of conservation requirements, and many include mechanisms to regulate compliance with established soil loss limits.

RCA-Funded Long-Range Plans

Since the 1930's, local Soil Conservation Districts have been charged with preparing long-range programs for conservation of their areas' resources. State-level long-range programing was not used for many years, in part because Federal assistance went directly to the districts. In the late 1970's, however, with grants from USDA under the RCA process, State agencies increased their involvement in resource planning. In 1979, the National Association of Conservation Districts developed a sample outline for States to consider in formulating their long-range programs.

Two general types of planning are being used to develop the State long-range programs. One develops a statewide summary drawn from the long-range programs of each conservation district. The second relies on citizen meetings where statewide concerns are identified, priorities established, and actions planned. Both planning processes use extensive citizen involvement, but the second process is less dependent on the existence of a long-range program in every conservation district. A few States have completed their long-range planning; most others have it under way. A few probably will not be developing plans. Some States may have difficulty completing their plans because their initial RCA grants may run out before the planning is completed.

The planning processes vary, but the common goal is to develop statewide, long-range conservation programs that will foster closer working relationships among landowners, the districts, their State soil conservation agencies, SCS, other State and Federal agencies, and the public.

Iowa and Oregon were the first Stat complete their long-range programs as p the RCA process; their plans were releas 1980. Iowa relied on citizen meetings to i tify statewide concerns and to plan acti Oregon compiled its summary document f each conservation district's updated prog and public hearings. These two States, w very different topography, climate, and la use, exemplify the range of resource proble at the State level.

IOWA'S FIVE-YEAR RESOURCE CONSERVATION PLAN

Iowa's 5-year plan contains specific actio recommended by task forces organized in Iov as part of the RCA appraisal process. The pla identifies Iowa's major land productivity prob lems. The top three problems cited are soil ero sion, water quality, and land use. In Iowa's plan, soil erosion receives extended review and planning attention in areas including cost sharing, technical assistance, lengthening conservation construction periods through long-term agreements of 3 to 10 years, increasing landowners' awareness and acceptance of conservation practices, tax incentives, soil loss limits, and urban soil erosion.

The plan contains specific recommendations in each of its program areas. In 1979, to support the plan, the Iowa General Assembly enacted into law two of the plan's recommended State cost-sharing programs: the Iowa Till Program and the Wind Erosion Control Incentive Program. Other recommendations include an investment credit of up to 75 percent of the cost of installing permanent erosion control practices and strengthening existing soil loss limits legislation by expanding the complaint authority to include State and other government officials. Previously, only a farmer's neighbors had the authority to complain about his soil maintenance.

OREGON'S NATURAL RESOURCES CONSERVATION COMMITMENT, 1980-84

Oregon's plan applies primarily to 28 million acres under private ownership. It also takes note of public land management and the need

for coordination between responsible State and Federal land management agencies.

The plan identifies eight major concerns: rangeland management, forest management, soil erosion, drainage, irrigation water management, pasture and cropland management, water quality, and fish and wildlife habitat. It identifies practices to help revitalize deteriorated rangeland, emphasizing management plans that schedule proper stocking rates and periodic development input.

The Oregon plan contains fewer formal recommendations than does the Iowa plan. Oregon's plan is a broad policy document that recognizes State resource problems and suggests some preferred practices to overcome them. The document calls for cooperative action among individuals, organizations, and agencies to address problems and set priorities that will result in effective and enduring conservation.

State-Funded Cost-Sharing Programs

In recent years, possibilities for State cost sharing for practices that control erosion and sedimentation have received increased attention. This reflects a growing awareness that States receive long-term benefits from such measures and that the immediate costs may be more than an individual producer can reasonably be expected to bear.

As of July 1980, Iowa, Nebraska, Minnesota, Wisconsin, Ohio, and Kansas all had cost-sharing programs. Funds come from both State and local sources. The programs are administered in addition to and in cooperation with USDA's conservation programs.

In 1973, Iowa became the first State to begin financing a cost-share program for conservation. To supplement this effort, Iowa launched two experimental programs in 1979: The Till Program and the Wind Erosion Control Incentives programs. The Till Program authorizes Soil Conservation Districts to nominate tracts of land where owners of at least 80 percent of the land area agree to manage 50 percent of their row-cropped acres to maintain crop residue cover. For acreage with appropriate cover, the States make one cost-share payment of $30 an acre, if that acreage is maintained under the tillage practice for 5 years. Funds come from the State general fund and are limited to 10 percent of the State cost-sharing funds allocated annually ($5 million in 1979-80) (USDA, 1980c).

The Wind Erosion Control Incentive Program was enacted by the Iowa legislature in 1979. This program authorized one payment of $1,000 an acre for field windbreaks (trees) maintained for 10 years, one payment of $500 an acre for grass windbreaks maintained for 5 years, and one payment of $30 an acre for "Iowa Till" as described under the Iowa Till Program. Funds are derived from State road use tax revenue.

Minnesota amended its Soil and Water Conservation Law in 1977 to include the State Cost Share Program. Approximately $3 million in cost-sharing funds comes annually from the State general funds. The money is allocated to districts by the State Soil and Water Conservation Board, based on approval of each district's comprehensive plan. The State board considers its priority areas to be controlling soil erosion, sedimentation, and related water quality problems. Practices cost-shared by districts must be on the approved list, which in 1980 included erosion control structures, stripcropping, terraces, diversions, storm-water control systems, and critical area stabilization. Maximum cost-share levels are set by the State board. Cost-share levels on individual practices are set by the districts, so long as they do not exceed the maximum level. The maximum level for 1980 was 75 percent of the total cost.

COORDINATION OF COMMODITY AND CREDIT PROGRAMS WITH CONSERVATION PROGRAMS

In the past, the programs that manipulated agricultural economics and the programs to conserve resources seldom have had common objectives. As noted by the National Association of Conservation Districts (USDA, 1980a):

> Changing annual targets of commodity programs contrasted with the long-term objectives of conservation plans confuse and distort land management decisions. Some farmers have found themselves penalized by USDA programs when they carried out the USDA-encouraged conservation plans.

In light of increasing demands on the Nation's resource base, it becomes more urgent to coordinate goals and strategies. Food and fiber demands are growing because of: 1) rapidly increasing foreign demand, 2) the nascent demand for biomass energy production, and 3) increased concern for national self-reliance —i.e., producing crops that are imported now, such as rubber. Prices and supply/demand fluctuations increasingly will be affected by international forces outside the control of the American producer.

Thus, the 1980's appear to be a necessar time for integrating agricultural program State programs such as those recently deve oped by Iowa and Oregon have made substai tial progress toward effective integration c agricultural programs. It may also be a tim when integration at the Federal level is feas ble; policies and programs will be undergoin fundamental changes to adapt to major eco nomic changes. Analysts generally expect the principal goals for commodity and credit programs to change from production control and income enhancement to production stimulation and income stability. If this is the case, new strategies probably will put more programs on a multiyear basis, a change that would help integrate them with conservation programs. Production stimulation, however, may conflict with conservation if it causes fragile lands to be brought into row crop or small-grain production with conventional farming technologies.

CONCLUSIONS

This assessment finds that there are technologies being developed that can enhance short-term production and long-term productivity concurrently. In some cases, the beneficial effect on the resource base has been serendipitous, such as fertilizers' effect of increasing soil cover and crop residues. In other cases the benefits have been planned as a goal of the technology development, as with the erosion control effect of minimum tillage. If resource sustainability is set as an explicit goal of both the Government-funded technology development programs and the commodity and credit programs, and if production enhancement is made an explicit goal of the programs to develop and implement conservation technologies, it should become possible to increase total agricultural production and inherent land productivity simultaneously.

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Chapter VII

Issues and Options for Congress

Contents

Issues and Options for Congress*

The U.S. Government affects agricultural technology decisions through an extensive body of law, policy, and precedent. This in turn affects long-term inherent land productivity.

Congress has two main channels to affect the development and use of agricultural technology: through legislation, including budget appropriations; and through committee oversight of how existing laws and programs are administered. Generally, this assessment finds that existing agricultural legislation provides a sound basis for Government activities needed to accelerate the development and use of productivity-sustaining technologies. Consequently, many of the congressional options listed are related to oversight functions. There are also opportunities to change legislation to make existing conservation programs more effective and to cause other agriculture programs to support the objective of sustaining inherent land productivity.

Opportunities for congressional action relate to five policy issues:

1. integrating conservation policy with economic policy,
2. improving the effectiveness of Federal conservation programs,
3. enhancing Federal research on technologies that help sustain land productivity,
4. reducing pressure on fragile lands, and
5. encouraging State initiatives.

ISSUE 1: INTEGRATING CONSERVATION POLICY AND ECONOMIC POLICY

Various factors influence farmers' and ranchers' choices of technologies and their land management decisions, but economics is the overriding influence. Recognizing this decades ago, Congress established several cost-sharing and other programs to make conservation practices more economically attractive for land managers. Payments to farmers from these programs undoubtedly have had a significant impact on agricultural economics and thus on technology decisions. From 1969 to 1979, total Federal payments to farmers and ranchers were about $25.6 billion. Only $3.6 billion of this was cost sharing for conservation practices. The other $22 billion supported programs intended to affect agricultural economics for other purposes. Still other Federal programs do not make direct payments to farmers but change the economics of farming in other ways—e.g., by increasing foreign demand for U.S. crops.

Thus, the Federal Government has tremendous influence on agricultural practices. But only a relatively small part of this influence is used to achieve the goal of sustaining land productivity. This is not to say that the programs designed to affect production levels, stabilize prices, improve farm incomes, or accomplish other short-term economic goals all cause long-term deterioration of inherent land productivity. On the contrary, some of the programs to limit production have been credited with conserving soil and water resources and with enhancing wildlife habitat. However, others, such as the disaster relief programs, have been accused of encouraging cultivation of fragile

*While the draft of this report was being reviewed by U.S. Department of Agriculture (USDA) agencies and by many other experts during September, October, and early November of 1981, USDA released the 1981 Program Report and Environmental Impact Statement (revised draft). That report, which is part of the process required by the Resources Conservation Act (RCA), contains a chapter titled "Preferred Program" that offered some recommendations quite similar to certain options identified in this OTA assessment. The "Preferred Program" chapter of the RCA report is included as app. E to this report and the options in this chapter that are similar to the RCA options are identified with an asterisk.

land. The key words here are "credited with" and "accused of." In fact, little is known about how long-term productivity is affected by the important short-term economic influence wielded by Congress through the U.S. Department of Agriculture's (USDA's) programs.

Existing agricultural economic programs, proposed new programs, and program modifications are not regularly or systematically analyzed to forecast their long-term effects on land quality. Neither the administrative mechanism nor the analytical methods exist for such evaluation. Conservation cost-sharing programs only now are beginning to be evaluated to determine their effectiveness in achieving intended conservation goals, and these evaluations are leading to more enlightened public and congressional debate over how to modify the programs. The other, much larger, agricultural economics programs do not have conservation as a goal and so their evaluations seldom include an assessment of their long-term effects on the land resource.

OPTION 1

Congress could direct USDA to routinely and rigorously evaluate the long-term impacts of not only conservation programs but also all other programs that have a major effect on agricultural economics.

The information generated from such evaluations would foster more enlightened policy debates. It could greatly improve policy decisionmaking, even without regulations requiring that programs not cause long-term harm to agricultural productivity. There is a danger that mandating a routine evaluation would lead to a slow, expensive, and complex process, in which case the information might be too costly or might not be available soon enough to be useful for policy decisionmaking. Developing improved mathematical policy models, however, could enable USDA analysts to avoid that problem.

OPTION 2

Congress could direct USDA to develop analytical models suitable for evaluating how proposed program policy decisions would affect the inherent productivity agriculture's natural resource base.

To some extent, this is being done as a of the 1977 Resources Conservation Act (RC process, which mandated continuing eval tion of each of USDA's 34 soil and water c servation programs. Evaluations already co pleted have revealed opportunities to impro program effectiveness and presumably mo conservation programs will be evaluated f the 1985 RCA report. Several major mathema ical modeling efforts are being undertake under the auspices of the RCA program. How ever, only one of these is a modeling progra designed specifically to analyze policy impac and Congress has not directed the RCA to eva uate the larger and more powerful USDA ec nomic programs that are not considered co servation programs.

A new effort to develop simulation models to evaluate existing programs, program modifications, and alternatives could be undertaken without necessitating a major new allocation of funds to USDA. However, such an effort would have costs—personnel would have to be taken from other program efforts. The actual model development might be done by contractors, but USDA analysts would need to be assigned to run such a project. If new funding were not available, the idea would be resisted by offices whose funds might be diverted to it. One appropriate source of funds and personnel could be the commodity, loan, and insurance programs that comprise most of the Federal effort to influence agricultural economics.

A disadvantage to developing and using mathematical models is that too much credence may be given to the accuracy or precision of the analytical results. In fact, predictions made with complex policy models are not necessarily more precise than predictions from the "mental" models of experienced policy experts. The advantage of the mathematical models is that when experts disagree, they can use models to diagnose the causes of their disagreement and to communicate these objectively to Members of Congress and other policymakers.

OPTION 3

Congress could initiate a policy to require all new agricultural programs to include: 1) explictly stated, attainable objectives, one of which would be to sustain the inherent productivity of agriculture's natural resources; 2) management plans for achieving the objectives; 3) monitoring mechanisms to measure how well the program activities are achieving the objectives; and 4) a mechanism through which the monitoring of results could be used to make changes.

Explicitly stating that conserving the productivity of renewable resources is a major policy objective would force recognition that conservation and production are not conflicting goals. Designing programs to include monitoring mechanisms would keep agricultural programs flexible so that cost effectiveness could be improved continually and full use could be made of technology or management innovations.

This approach to integrating conservation and agriculture programs is more demanding than the program evaluations suggested by the first option. There may be some programs that Congress deems necessary but that come into conflict with conservation of inherent productivity. The debates regarding whether the social or economic objectives of such programs are worth the cost in long-term productivity could be enlightening, but might be expensive. This option, too, could lead to an expensive analysis process, but that could be avoided if appropriate mathematical policy models were developed.

Any action requiring explicit program goals and monitoring is likely to cause some agency objections and political repercussions. Disadvantages include: 1) political advantages that may be gained from using programs for implicit goals, such as distribution of funds to a large or special constituency, could be lost; 2) data from monitoring programs could be used to end programs before they have had a realistic opportunity to achieve their goals (this is especially likely with conservation programs, which are usually long-term solutions to long-term problems); 3) politicians and upper management could lose some control over program operations (with technicians gaining some control) if programs were made flexible enough to allow constant improvements in cost effectiveness.

ISSUE 2: IMPROVING THE EFFECTIVENESS OF FEDERAL CONSERVATION PROGRAMS

USDA conservation programs are administered to provide technical and financial assistance to agriculturalists. But the programs have not been effectively concentrated on the most severe land productivity problems, and USDA technology development and promotion efforts are not effectively focused on the most cost-effective erosion control techniques. The Soil Conservation Service did use national inventories of conservation needs in 1957 and 1967 to allocate some funding and personnel. However, the political need to provide assistance to the maximum number of farmers has remained an important factor in distributing program efforts.

The National Resource Inventories of 1977 provided, for the first time, statistically reliable data which indicate that very rapid soil erosion is concentrated on a relatively small proportion of America's agricultural land. The data now make it possible to determine, with considerable precision, the geographic location of highly erosive land. In 1979 and 1980 USDA recognized that there was still a paucity of precise information on how erosion relates to agricultural productivity for each major soil type. Thus, two new research efforts have been started to translate erosion rates into productivity loss rates. One will provide quick preliminary estimates of the relationship between ero-

sion and losses in yield; the other, longer study will more precisely describe these relationships with simulation models that reflect the complexity of modern farming. As these analyses develop, it should be possible to rank regions and specific sites by the severity of their erosion-caused productivity losses. Meanwhile, the available data on erosion rates can substitute for more exact information on productivity loss.

The information now becoming available has set the stage to redirect Federal conservation efforts (technical and financial assistance) to achieve improved erosion reduction—the so-called "targeting" approach, which formed the cornerstone of the conservation program proposed by the Secretary of Agriculture in October 1981. The emergence of water pollution control as a major national policy objective also shows a need to reorient Federal erosion control programs to achieve the greatest possible reductions in erosion rates rather than the widest geographic diffusion of program efforts. The political motivation to distribute programs widely still remains, however.

OPTION 1

Congress could direct the Agricultural Stabilization and Conservation Service (ASCS) and the Soil Conservation Service (SCS) to concentrate increased financial and technical assistance on agricultural land with severe erosion problems.

Such a concentration of effort could enhance the effectiveness of these programs. For example, ASCS has estimated that the Agricultural Conservation Program (ACP) could triple the amount of soil kept in place through its expenditures (mainly cost sharing) by directing erosion control funds to highly efficient techniques and to land with high potential for erosion reduction. SCS estimates that if 25 percent of USDA's technical and financial aid were redirected to "national priority areas," it would reduce gross national erosion by 300 million tons (6 percent) annually. Many soil conservation policy experts anticipate a continued decline in the buying power of the Federal conservation budget. If this occurs, improving the cost effectiveness of these funds by direc the program efforts to the worst sites w seem imperative. However, if appropriat remain level (implying a decline in real fun as they have over the past decade, any con tration of technical and financial assistanc critical areas will reduce or eliminate as ance elsewhere. The "targeting" option another problem: all conservation progr are voluntary and there is no guarantee farmers of highly erosive lands will use t financial or technical assistance made ava able. Some data suggest that much of the er sive and otherwise fragile lands are conce trated in the hands of farmers with less capa ty to manage the complex productivity-sustai ing farming technologies and/or less availat capital to finance their share of the conserv tion practices.

If cost sharing were directed to land simp according to erosion rates, it might miss lands with other significant productivity problems. There are areas that have shallow soils, poor subsoils, and other problems, and that thus in cur high rates of productivity degradation in spite of relatively low erosion rates. Nor are the areas with high erosion rates the only threat to water quality. Sedimentation and nutrient and pesticide runoff, for example, can be severe in areas where erosion rates are low to moderate. The relationship between erosion and these environmental problems varies great ly among watersheds. The new research pro grams to determine relationships between ero sion and yield reduction will resolve some o these uncertainties in redirecting the program efforts, but will leave the water quality issues largely unanswered.

This program redistribution option may no achieve greater cost effectiveness if the limi on the amount of assistance allowed per farme per year (currently $3,500 for ACP cost shar ing) is not raised. This is because many ero sion control practices (such as terraces) neces sary for highly erosive sites are expensive t implement. Another problem is that the cos of relocating field personnel presumably woul come from the agencies' existing budgets thereby reducing the funds available for other

functions. Finally, any major redistribution of Federal funds among States to reduce erosion might weaken other State and Federal efforts to conserve agricultural productivity.

OPTION 2

Congress could appropriate additional funds, or redirect existing funds, to expand in-service training programs for SCS and Extension Service field personnel to improve their expertise with innovative productivity-sustaining technologies.

New agricultural production technologies and new conservation practices are being developed that can conserve inherent land productivity effectively and simultaneously maintain or enhance farm or ranch profits. Often these technologies are not reaching farmers as quickly as they might because Extension agents and SCS field personnel lack experience in the new methods. Some of the Federal personnel, while having considerable engineering expertise, are not adequately prepared to advise farmers in new management approaches that might solve the same problems at lower cost. For example, in the last 5 to 10 years private industry and State-level research scientists have made substantial advances in designing no-till farming equipment, yet many Federal personnel still resist the technology because of early development problems that have since been solved.

Improved promotion and consequent wider adoption of technologies that are already "on the shelf" could greatly enhance the cost effectiveness of the overall Federal conservation effort. And if training efforts were coordinated to include both SCS and Extension personnel, farmers would be less likely to receive conflicting advice about solving their production problems while sustaining land productivity.

The disadvantage to this option is that in the absence of new funds for conservation technology training, money would have to come from existing programs. Also, if such training results in greater emphasis on conservation tillage, improved water distribution or timing, and similar management techniques, certain economic dislocations could result. (For example, local land improvement contractors who have done past work recommended by SCS and cost shared by ASCS or other agencies probably would have less business.)

OPTION 3

Congress could direct the Farmers' Home Administration (FmHA) to provide increased loan support for conservation practices, and to give preference among conservation loans to applicants who need capital for the initial costs of implementing new, more cost-effective management technologies for resource conservation. Congress also could direct FmHA to make conservation plans a criterion for ownership and operating loans.

Historically, FmHA agricultural loan programs primarily have assisted farmers and ranchers who have had difficulty obtaining credit from commercial lenders. Maintaining the farms' renewable resources has been one of several explicit goals for six of the agency's loan programs: the Operating Loan, Farm Ownership Loan, Soil and Water Loan, Resource Conservation and Development Loan, Emergency Loan, and Economic Emergency Loan programs. No rigorous evaluation of how well these programs are achieving conservation goals is available, but data on program expenditures suggest that only a small part of these programs' funds actually are used for conservation.

Increased emphasis on supplying startup costs for innovative crop or range management techniques (as contrasted with building engineering structures) could increase the cost effectiveness of the conservation loan programs and might substantially increase the pool of conservation loan applicants.

If conservation plans are required, they need not interfere with the agricultural production and income stability objectives of the loan programs because technologies are available that can conserve resources while maintaining farm profits in most situations. However, a loan program that requires conservation plans probably would have increased administrative

costs since the plans would have to be prepared and reviewed. Also, if implementing the plan was made a requirement either for the initial loan or for follow-up loans, Federal per would be needed to certify the implemer effort.

ISSUE 3: ENHANCING FEDERAL RESEARCH CAPABILITIES

This assessment, and other recent studies such as USDA's report on organic farming, have found a surprising lack of data on what would seem to be fundamental issues for developing agricultural production technologies that can sustain the quality of the natural resource base while simultaneously producing commodities for the Nation and profits for farmers and ranchers. For example, little is known about soil formation rates under modern farming systems. Little is known about what impacts agricultural chemicals have on soil microbe ecology or on species-specific microbe functions. Little is known about the dynamics of erosion or hydrology on rangelands under various management systems.

Some of the gaps in the data base are the result of agricultural research priorities developed during the era of relatively inexpensive energy and fertilizers. Options for improving the overall planning and coordination of agricultural research are presented in some detail in the OTA report *An Assessment of the U.S. Food and Agricultural Research System.*[1] The options given here relate more narrowly to the issues of research for inherent land productivity.

OPTION 1

In exercising its oversight responsibilities for agricultural research, Congress could encourage and closely monitor the modeling program proposed by the USDA National Soil Erosion-Soil Productivity Research Planning Committee in 1980, assuring that the program receives adequate funds and sufficient expert personnel. Further, once the research models can adequately describe the relationship between erosion and yield, Congress could encourage USDA to: 1) broad the models to include processes of product ity change other than erosion, and utilit of agricultural land other than crop yi (such as forage and water quality); a 2) simplify them for integration with poli models directly useful to Congress.

The soil erosion-soil productivity mod program now under way should greatly vance scientific understanding of the relat ships between erosion and inherent land ductivity. USDA has initiated the program enthusiasm and, apparently, an adequate c mitment of funds and personnel. However, any agricultural research program, the resu will not be immediate and the agency comm ment could wane as other priority needs scarce funds and personnel are identified. exercising vigilant oversight and by avoidi imposition of new responsibilities on the sa agencies without concomitant additions funds and personnel, Congress can ensure th the scientists will not be distracted from th important program.

The modeling program is analyzing the mo important process of productivity degradatio —soil erosion—first. It is defining the bound of its study by considering crop yield the mai dependent variable. This should produce a useful model within a reasonable budget and time frame. If the model is ready to be used for the 1985 Resources Conservation Act report, that report's usefulness to Congress will be greatly enhanced. Yet important gaps in the understanding of inherent land productivity will remain.

Precision in understanding erosion is impor tant, even essential, for adequate policy deci sions regarding how Federal conservation pro gram resources are distributed both geograph ically and among particular technologies. How ever, other processes such as aquifer depletior

[1]Office of Technology Assessment, *An Assessment of the U.S. Food and Agricultural Research System*, OTA-F-155 (Washington, D.C.: U.S. Government Printing Office, December 1981).

salinization, compaction, and changing rangeland ecology also are influencing the inherent productivity of U.S. croplands and rangelands. For all these processes, little is known about technological causes, national extent, or relationships to long-term agricultural production. Policies on how to distribute funds among programs that work with these productivity-change processes are based mainly on intuition and on political pressures, rather than on science. The intuition of scientists and experienced analysts is a good basis for interim policy decisions, but it should not be accepted as a long-term substitute for scientific knowledge.

Many aspects of productivity-change processes, such as the hydrological effects of range deterioration, have yet to be measured adequately. However, the most immediate need is to use the data that already exist for comprehensive analyses to indicate which data gaps are most significant for policy decisions and for technology development. Subsequent research could then be concentrated on those questions. Simulation modeling, the approach being used in the soil erosion-soil productivity study, is ideally suited for this kind of analysis. That program should expand its scope beyond erosion and yield to other processes affecting inherent land productivity as soon as it has described erosion-yield relationships with sufficient precision.

OPTION 2

Congress could direct the Agricultural Research Service to expedite research and development for potentially profitable cropping systems that reduce the need for tillage on highly erosive soils or that reduce the need for high irrigation rates in areas where ground water resources are being severely depleted.

The most promising innovative technology for reducing tillage, and thus reducing erosion, on highly erosive land is "no-till," which substitutes herbicides and other agricultural chemicals for weed, insect, and disease control. This technology has been developed by private sector and State-level scientists and tested by risk-taking farmers, with little Federal involvement. The private sector paid to develop the no-till techniques largely because of the potential for profits from sales of patented inputs (e.g., herbicides). However, neither no-till nor any other single technological approach is suitable for every fragile agricultural environment. Private funding cannot be relied on to develop the wide array of innovative cropping systems needed to sustain the inherent productivity of dry, erosive, or otherwise fragile agricultural lands. Some of the technologies needed will take too long to develop; others will not include any potential profits from exclusive sales of inputs to repay the development costs.

Developing new crops—or improving old crops—produced from perennial plants (trees, shrubs, and herbaceous perennials) is an example of technology development that might reduce the need for tillage or irrigation. Developing new, more profitable uses for crops that provide perennial cover is another example. (As one scientist advising this assessment suggested: "We need a research program to do for alfalfa what George Washington Carver did for peanuts.")

Congressional instructions to USDA's Cooperative Research Service (CRS) for implementing the Competitive Research Grants Program in 1977 included "research to develop and demonstrate new, promising crops" as one of four priority areas. Congress could provide additional recommendations to CRS to support research on crops that help sustain inherent land productivity.

Congressional oversight authority could also be used to promote such a research network. OTA's recent assessment on the U.S. food and agricultural research system found that the Federal research network for agriculture lacks explicit goals. Congress might choose to make sustaining the renewable resource base an element of such goals.

OPTION 3

Congress could direct USDA to develop a program for screening innovative technologies that might sustain land productivity, conducting preliminary tests of those that

have a sound scientific basis, and getting those that seem promising into the mainstream of technology development.

Agricultural scientists necessarily concentrate their efforts on rather specialized subjects for long periods in order to contribute significantly to agricultural technology development. The institutions that employ such scientists suffer from chronic funding shortages and can hardly afford to risk funds or personnel on fundamentally new approaches to agricultural production. This partly explains the seemingly conservative, methodical pace of agricultural technology development. "Breakthroughs," fundamentally new shifts of vision or technique, do occur, however. No-till farming is one of many examples. But given the projected demand for U.S. agricultural products and the degree of erosion, ground water depletion, and other negative effects that seem inevitable consequences of available production technologies, there is a great need to accelerate technological development. A program to provide objective, deliberate screening of innovative agricultural technologies and ideas developed both by scientists and nonscientists might serve this purpose. Various peer-review processes for research proposals and journal articles now screen ideas, but without an explicit commitment to locate and test fundamentally different approaches.

This option is not dissimilar to the ch given USDA's Competitive Research Gr Program, except that sustaining inherent ductivity was not an explicit criterion for program. The program met a great deal o sistance because it was not funded with appropriations, but rather used funds diver from established programs. Any new progr or program change designed to include scre ing and preliminary testing of innovative te nologies for sustaining inherent productiv probably would meet similar resistance a might ultimately fail without new appropr tions.

A related problem with this option is tha Congress gives the function to USDA's Agric tural Research Service, it could distract t agency from other important tasks such as i proving data analysis. The Agricultural R search Service and the network of associate federally sponsored research agencies cann perform an expanding agenda of responsibi ities without expanding funds and expert pe sonnel. However, if Congress should expan the Federal agricultural research establish ment, it should not be assumed that the new funding and resources would automatically be used to promote productivity-sustaining tech nologies. The need for congressional vigilance and oversight in this regard will remain.

ISSUE 4: REDUCING PRESSURES ON FRAGILE LANDS

A relatively small part of the Nation's range and cropland accounts for a large portion of the Nation's soil erosion. In the 1950's and 1960's, Federal land diversion and set-aside policies, intended primarily to control production, provided substantial incentives for farmers to remove highly erosive and otherwise fragile land from production. However, over the past decade, growing demands for agricultural commodities have virtually eliminated the incentives to keep land out of production. Continued growth in demand will cause additional land with high erosion hazards to come into production during the coming decades, and land diversion programs on the scale of former programs are not foreseen. As long as highly erosive lands are tilled for row crop or small-grain production with conventional agricultural technologies, they will continue to be a major cause of the Nation's soil losses and a major cause of the Nation's water quality problems.

OPTION 1

Congress could authorize ASCS to institute a special land diversion program for highly erosive or otherwise fragile lands that would reimburse farmers for removing these lands from row crop and small-grain production

whenever crop supplies are deemed by the Secretary of Agriculture to be adequate for domestic and export needs.

Cost-sharing programs focused on the most erosive lands might enable some farmers to protect that land from high erosion rates, but for much of the most erosive cropland, such protection is extremely expensive, no matter who pays for it. For such sites, paying the farmer the difference between the per-acre profit from the crops that cause erosion and the profit from alternative soil-conserving land uses, such as hay or pasture, may be a less expensive and more effective way of protecting long-term land productivity. Such a diversion could also serve to buffer farm prices in periods of surplus commodity production, reducing the need for periodic set-asides. The diversion could be canceled when low supplies are expected, thus avoiding pushing row crop and small-grain prices up to levels that are either too high for U.S. consumers or too high for the diversion program to afford.

A principal disadvantage to a diversion program with conservation as its primary objective is that it creates a need for additional appropriations. The program might reduce the need for expenditures in the Federal cost-sharing and technical assistance programs for conservation, but diverting funds from those programs probably would cause a long-term and substantial reduction in the Federal capability to provide technical service. Thus, services would be reduced for conscientious farmers who are willing to pay part of the costs for implementing conservation practices. Also, reducing the Federal capacity to provide technical conservation services would be a significant risk, since the diversion program might not attract enough farmers or commodity prices might dictate that the diversion not be in effect during many years.

There are other problems with this option. Availability of funds for farmers who retire fragile land from row crop and small-grain production could be an incentive for farmers to plant land now in pasture or hay to such crops in order to make such land eligible for the paid diversion program. This could increase program costs and, in years when the diversion payments were canceled, degrade land productivity where it would otherwise have been protected. That problem perhaps could be avoided by the use of some baseline year for eligibility, but that could leave fragile lands now called "potential cropland" out of the program. Finally, from the farmer's view, such a program could make it difficult to maintain equipment and flexibility enough to produce both row or small-grain crops and land-conserving crops on the same land.

OPTION 2

Congress could direct USDA to develop an incentive program to promote the intensive use of those lands able to sustain row crop and small-grain farming or livestock grazing that are not now used for those purposes.

The 1977 NRI indicated that some 36 million acres of land in the United States (excluding Alaska) had "high potential" for development as cropland. This included some land with relatively high erosion potential, but which is suitable for sustained, intensive crop production as long as conservation practices are applied. How much of this land may have been converted to cropland since 1977 is not known, but the 1982 NRI should give updated information on the potential cropland remaining. SCS has identified another 18 million acres of potential cropland in Alaska that is suitable for sustained production with appropriate conservation practices. Similarly, underused grazing land resources have been identified in Alaska and in the Nation's Eastern forests.

Production from these land resources, as they are developed, should help to meet the growing demand for agricultural commodities and, thus, help reduce pressure to grow row crops and small grains on those erosive or otherwise fragile lands where production costs are high or yields are low.

Most of the potential cropland and grazing land, including that identified as "high potential" in the 1977 NRI and the land in Alaska, will not sustain intensive use without conserva-

tion practices. Any accelerated development of this land will increase needs for SCS field personnel and technical services. It may also require some redeployment of SCS personnel or of other USDA conservation program activities.

ISSUE 5: ENCOURAGING STATE INITIATIVES

Soil conservation became a major public policy issue in the 1930's. When it became apparent that States were not able to cope with the problems of land productivity degradation, the Federal Government began providing most of the public investment in agricultural resource conservation. But the Federal investment has been shrinking over the past decade by 6 percent per year for financial assistance and 0.1 percent per year for technical assistance—in spite of increasing pressures on the resources as additional fragile lands are brought into production.

This also has been a decade of increasing State activity in land resource conservation. No data exist that measure how well State efforts have offset declines in Federal investment or how well State programs are meeting the increased conservation needs necessitated by increased cropland in production. To date, most State initiatives have been planning efforts and not all States are involved. Since much of the State activity seems to have been stimulated by specific congressional actions, there is good potential for further congressional action to promote State activity.

Over the past decade, Federal legislative requirements have prompted some major long-range planning efforts by States. For example, the Federal Water Pollution Control Act of 1972 requires State and local governments to develop long-range water quality management plans. The Resources Conservation Act provided grants for States to plan long-range resource conservation programs. Some States have completed these planning programs and have begun to implement them—the Iowa Till Program and the Wind Erosion Control Incentive Program are among the first fruits of this process. Unfortunately, the RCA grant funds are expected to run out before the program planning process has been completed in several States.

In addition to long-range, comprehensive planning, there have been State legislative initiatives. As of mid-1980, 20 States had enacted erosion and sediment control laws, prompted in part by a Model State Act for Soil Erosion and Sediment Control published by the Council of State Governments in 1973. A few States have recently begun programs in cost sharing, technical assistance, conservation education, tax incentives, and various regulation approaches to promote conservation technologies. In October 1981, the Secretary of Agriculture proposed shifting some Federal conservation funds to States via grants for technical and financial assistance or for other purposes related to federally approved State conservation programs.

OPTION 1

Congress could encourage State initiatives to enhance inherent land productivity by: 1) directing USDA to establish a special program to assist States in formulating long-term conservation plans and legislation; 2) providing small incentive grants to States that request assistance for formulating such plans and legislation; and 3) appropriating additional funds, or redirecting existing funds, to provide substantial matching grants to States either for designated or unrestricted use in agricultural resource conservation programs.

A coordinating program in USDA to gather and disseminate information from States where long-term plans and special conservation legislation have been successfully developed could save officials in other States from having to "reinvent the wheel," and allow them to focus on the unique needs of their particular

State. This should be a relatively inexpensive and cost-effective option. Extending the RCA grant program for States' conservation program planning would necessitate additional appropriations, but could accelerate the transfer of agricultural resource conservation responsibility to the States. This program has been effective for initiating promising resource conservation programs in those States that have taken full advantage of it.

Matching grants to the States to implement conservation programs would be an expensive option for the Federal Government. Such grants could encourage State legislatures to provide technical and financial assistance for farmers and for strengthening the institutions necessary to support large-scale conservation assistance programs. States could also benefit from unrestricted grants to initiate innovative planning, pilot projects, and other activities that neither the States nor the Federal Government currently support.

Each of these approaches to stimulate State conservation activity has disadvantages. If any detailed criteria or strict Federal review process is part of Federal grants for conservation planning or programs, it may be viewed as a subtle step toward Federal land-use planning. Another problem is that financially strapped or urban-dominated States may not be able to appropriate their share of funds for matching grant programs year after year. This could result in the Federal funds going disproportionately to the States that need them least.

Transferring increased responsibility to State governments could be used as a rationale for continued reduction in Federal funding for programs, especially if funding is tranferred directly from the Federal programs to matching grant or other types of Federal grants to the States. Any severe cuts in the Federal programs are likely to undermine efforts to improve Federal effectiveness by concentrating efforts in the areas with the greatest conservation needs. The processes stimulated by the Resources Conservation Act and other recent legislation are helping develop systems to monitor the effectiveness of Federal conservation programs. States may not develop such monitoring systems, and State programs may be even more susceptible than national programs have been to political pressures for distributing services to the maximum constituency or to special farmer groups other than those who have land with the greatest potential for conservation program effectiveness. Finally, many of the State programs that are being implemented are designed to complement preexisting Federal programs. If sufficient money cannot be appropriated by Congress to maintain the Federal programs while supplying grants to the States, the grants may simply be used to replace diminished Federal services. This would imply no new conservation benefits but adds another layer of administrative costs.

Appendixes

Contents

Appendix A

The Innovators: The Stories of Five Agriculturalists and Their Commitments to Land Stewardship

Introduction

Howard Hanford, Nicholas Cihylik, and Roger Gallup are farmers. Lazaro Urquiaga and Bob Skinner raise cattle. Ernie Brickner farms trees on eroded croplands. Each works the land, and cares for it, in his own way. These men are both similar to and very different from the breed that used cow, corn, and sweat to transform this land from wilderness to international power.

Skill is still the key, but hard labor is no longer enough. More than any other generation of agriculturists, these men have at their disposal a vast arsenal of technological help. How they use some of these tools to the benefit of their land's long-term productivity is the basis for five case studies (fig. A-1) conducted on farms and ranches in:

- Treichlers, Pa.—no-till farming with Nick Cihylik.

Figure A-1.—Case Study Sites

SOURCE: Office of Technology Assessment.

- Jordan Valley, Oreg.—range rehabilitation with Lazaro Urquiaga and Bob Skinner.
- Edelstein, Ill.—conservation farming with Roger Gallup.
- Whitehall, Wis.—farm rehabilitation with Ernie Brickner.
- Fort Benton, Mont.—saline seep prevention with Howard Hanford.

Five examples could never accurately represent the staggering diversity present in American agriculture. Nor should the conclusions drawn from these studies be thought generally applicable to farmers and ranchers throughout the Nation. But these five illustrations offer insight into the use of land-sustaining technologies in agriculture. They provide a firsthand view of the many economic, cultural, environmental, and ethical considerations that affect a farmer's commitment to land stewardship.

The farmers profiled may not be "typical." Instead, each was chosen because he had a reputation for innovativeness and serious concern for the long-term productivity of his land. Each of the men runs a very different operation. They farm on different scales and show different landownership patterns—some rent, some own. They raise a variety of products—from cattle, corn, soybeans, wheat, barley, and safflower to timber—and cultivate less marketable potentials such as recreation, education, and esthetic qualities.

Yet despite the differences, these farmers and ranchers express a number of common concerns—desires for more current and better information to help them manage their operations; worries about money, indebtedness, and fair pricing; and concern about the future—both about their ability to maintain the quality of their land and their frustrations with governmental constraints on passing the land on to their children.

The purpose of these case studies is twofold. First, the studies illustrate a range of beneficial, often innovative, land-sustaining technologies and their appropriateness for certain situations. Second, the studies explore how farmers and ranchers make decisions about implementing land-sustaining technologies—what public and private advisors they use and what role economics and attitudes play in determining the technologies that will be used on the land. Because technology is increasingly the essential link between man and land, decisions regarding its use are fundamentally important to the short-term productive capacity of agriculture and the long-term productivity of the land itself.

NO-TILL FARMING—TREICHLERS, PA.

To the thin, life-sustaining layer called soil, water is both midwife and assassin. As midwife, rain coaxes green growth from seemingly barren ground and nurtures it. As assassin, rain can attack the soil, sweeping it away and degrading the land.

Erosion is an ever-present, natural process, yet when aggravated or accelerated by human activities, it can cause serious problems: hillsides stripped to bedrock, lost soil nutrients, degraded water quality, and reduced crop outputs. For farmers, the threat is real; erosion can steal a farm's wealth and bankrupt it.

Tillage—plowing, disking, and harrowing—are generally thought to be synonymous with farming. But these operations hasten erosion by leaving unprotected soil exposed to water and weather.

"Plow-disk-harrow. It's tradition and it's hard to break with tradition." explains Nick Cihylik, 40, a corn farmer. "But tradition isn't always best. Some of my land is 17 percent slope; all of it is rolling. With the erosion I was getting I decided there had to be a better way."

The better way he chose was "no-till," a reduced tillage system that eliminates all tillage passes and leaves a protective cover of crop residues on the land. Instead of turning the soil with moldboard or chisel plow, a no-till farmer's implements merely cut a narrow slit in last year's stubble and drop in seeds. Advocates purport that no-till not only reduces erosion but reduces energy use and labor requirements (thereby allowing a farmer to work more acreage), increases water efficiency, extends drought tolerance, reduces machinery investments, and gives a farmer more flexibility in timing his planting and harvest operations.

Photo credit: OTA staff

Nick Cihylik working in a no-till field on his Pennsylvania corn farm

No-till, however, is no panacea; potential disadvantages exist in that no-till can increase weed, pest, and disease problems, increase dependence on agricultural chemicals, reduce crop yields, and lower soil temperatures, thus delaying planting. That means a producer must think carefully before switching to no-till. Soil type, climate, terrain, type of farming operation, even the farmer's management skill, must be considered before a farmer converts to no-till.

"I started no-till 10 years ago, before anyone really knew much about how it would work," Nick remembers. "I was like a bumblebee that's too heavy to fly on the size of his wings but does anyway—I didn't know enough about the difficulty of no-till farming to be wary."

Nick, who farms more than 1,300 acres in the hilly Lehigh Valley, rents almost all of his land, so traditional high-investment erosion controls, such as terracing, were out. Contour and stripcropping were not workable for his large, all-corn operation, either. So Nick went into no-till willing to sacrifice some yields for erosion control. But he did not have to. His yields are actually slightly higher now than before the switch.

"No-till is a deceiving word, though, because it says what you don't have to do. It should be called 'extra work farming.' What you're doing is changing the type of work—and taking on a lot more management decisions. You've got to be organized way in advance, you have to do all the soil tests, and figure out weed problems before they happen, and keep on top of your chemicals."

Agricultural chemicals take on added importance in no-till farming because without tillage, weed and pest control is left entirely to herbicides and pesticides. No-till's development, in fact, lay relatively static between the first experiments in the 1940's until the 1960's when Chevron Chemical Co. introduced Paraquat, a powerful contact herbicide that kills green plant tissue (whether weeds or a sod cover), then is quickly inactivated because it binds with clay in the soil.

Nick turned to Paraquat, and Chevron, for help early in his switch to no-till. Unlike most reduced tillage initiates, Nick did not experiment with small acreage trials before jumping full force into no-till. In 1970 he tried one season with no-till soybeans, barely managed to produce enough to pay back the seed, and then gambled 500 acres all to no-till corn the next season.

"Getting into no-till was like a wedding night. You had no idea what you were walking into," Nick recalls of his sudden, large-scale trial. "After my first season, I wanted more information but nobody knew much to help so I went into it alone."

It was a local Chevron representative who sat down with Nick and helped him lay out a thorough plan for his farm. Through the company Nick became involved in some of the first local and regional no-till conferences, meetings where early no-till farmers could trade stories and supposedly learn the latest about managing their new systems.

"Those first meetings were mostly advertising, but it was all we had. Ag extension didn't actively promote no-till, though they were willing to help where they could," says Nick, who speaks highly of Pennsylvania State University and its current no-till research.

"Chevron and Paraquat are one. And Paraquat is no-till. It was in their interest to promote no-till; they got actively involved in my operation because they wanted an example," Nick explains. "A successful example. And I needed the help."

"Of course we had selfish reasons for getting involved," interjects David Cote, Nick's Chevron representative and friend. "We make chemicals. We're a business and we want to show a profit. But our underlying concern is with the farmers' best interests—the economic and conservation benefits of no-till. We want to keep them in business because if the farmers aren't in business, a lot of us aren't, either. Selling isn't all we care about; we do tests and give advice about more than just Paraquat. It's sort of like the Santa in the movie 'Miracle on 34th Street.' "

David and Nick recall that during the early years, Chevron may have been overly zealous to "convert" farmers, but the company straightened out quickly as they started looking at no-till as a serious, sustainable system of agriculture. If farmers were going to stick with no-till for the long-term, they needed a workable, economically viable system, and Chevron decided to help develop one. Also, as Pennsylvania State University and other public institutions became more involved in no-till research, farmers had other information sources to turn to for confirmation of Chevron claims. And as for converts, they've become easier and easier to find, so the hard sell has become unnecessary.

"With fuel prices what they are, all farmers are forced to look for alternatives," Cote explains, "and they're all looking at some point to reduced tillage. Not necessarily strictly no-till, but at least to reducing the number of tillage passes they make over a field. They've got to."

In looking at no-till, either as a land-sustaining technology or a means to reduce energy costs, a farmer must be careful to consider the specifics of his operation in light of current knowledge about the management system. The first criteria seems to be environmental—whether no-till can be successful with his terrain, soils, and climate. In poorly drained soils, crop yields can suffer under no-till. And because a layer of crop mulch covers the soil, ground temperatures may remain cool in the spring and may delay planting. In short-season, northern climates, this delay can hurt yields. Some farmers will also have questions about the increased use of toxic chemicals and possible environmental repercussions.

The next thing a farmer might consider would be operational—is he willing to change the way he's been farming all his life and is he skilled enough to manage a no-till system successfully?

"You have to be a good conventional farmer to be a good no-till farmer," stresses Glen Ellenberger, Nick's county extension agent, now retired. "It takes extensive management—a precise use of chemicals, careful monitoring of pest and disease possibilities, soil tests, and planning. It's not a lazy man's operation."

The environmental and technical pros and cons are only some of many factors that can influence a farmer's decision to try no-till. In general, the acceptance of any new idea or technology can be influenced by:

1. the relative advantage offered by the change,
2. the compatibility of the innovation with the farmer's needs and type of operation as well as his past experiences and his values,
3. the complexity of the change,
4. the degree to which the innovation could be experimented with on a limited basis, as it is less risky to move piecemeal into a new system than jump totally from old to new, and
5. the degree to which the results of a new technology or idea are visible to prove its value. For instance, the adoption of preemergent weedkillers was slow in spite of its relative advantage because there were no dead weeds for potential users to see.

In Nick's case, the long-term advantage offered by reduced soil erosion was enough to offset the increased managerial complexity. He acknowledges that his increased chemical use might cause environmental problems but feels that erosion is a more real threat. Because no-till slows runoff, he feels it also reduces the amount of his chemicals that slip away to contaminate waterways. But while no-till is gaining relatively rapid acceptance in

many parts of the country, few of Nick's neighbors have followed his lead. The reason is more sociological than technological.

"Nick is different from his community. He's progressive and he stands out," explains Ellenberger. "He was born here, but he's not a native like his neighbors. They like clean, traditional fields, and no-till looks really messy, like you're not a good farmer."

Despite their reputation for independence, the agricultural community has subtle and direct influence on farmers, even innovative farmers such as Nick. For instance, it is a rare farmer today who does not rely heavily on banks, credit associations, and the like for loans to make his operation work. And the power of the purse strings can control what a manager can and cannot do on his land.

"Our involvement in farm management is minimal. We don't tell a farmer to switch from corn to beans," says Alan Greiss, of the Production Credit Association Nick uses. "But we can refuse loans, either because we think a scheme is harebrained (like the guy who wants to buy Clydesdale horses to walk treadmills to generate electricity) or because the farmer has low equity."

In other words, though the bank has some money to risk, they tend to want to finance sure-fire ventures. This can have a large impact on young farmers who, unlike Nick, have not built up much equity and do not have longstanding reputations as good farm managers. Because initial investments are small in no-till, banks have less influence on farmers switching to no-till than on farmers wanting to try more capital-intensive new technologies.

"A well-managed investment in the land pays for itself in time. Maybe not tomorrow . . . I do have children interested in farming, and I'm glad for that. I have to start something for them," says Nick.

"Your land, your farm, is your life. You've only got so many inches of topsoil—when you have an opportunity to help it stay put, you do it. The chance may never happen again."

Nick broke with the plow-disk-harrow tradition because he felt his land would benefit from less erosive management. The system he chose to adopt —no-till—proved to be both agriculturally and economically sound, as Nick's erosion losses are negligible now and his yields are as good or better than ever.

No-till is in many ways a good example of an innovative, land-sustaining technology. It can be good for the land—used properly and in the right situations. It can be economically viable, again, when it is matched with operational and environmental dictates. No-till shows, too, that the solutions to our agricultural problems will not be quick in coming; rather, many of the promising new technologies are managerially complex and are more demanding of the farmer's dedication, as well as his skills. And no-till illustrates that it is possible, even practical, for a farmer to take his stewardship seriously and still succeed from an agribusiness viewpoint.

RANGE REHABILITATION—JORDAN VALLEY, OREG.

The land around Jordan Valley, Oreg., is rugged and harsh—great expanses of dusty soil littered with rock and clumps of parched bunchgrasses. But it is valuable land. To the rancher, it is home to family and livelihood. To the Bureau of Land Management (BLM), this area—the Vale District—is a showcase of new range management ideas.

Ranchers such as Lazaro Urquiaga and Bob Skinner are part of a determined breed that settled this range despite the harshness. The isolation and the great distances that separate them from town and friends go unquestioned. They know the land, both its limitations and its potentials. They raise cattle because that is what the environment will tolerate. And that is what their families have done here in Jordan Valley for many generations.

Most of the land around Jordan Valley, and in fact 70 percent of Malheur County, is part of the Vale District of BLM—a 6.5-million-acre rectangle, 60 by 175 miles (100 by 280 km), in the southeast corner of Oregon. Such a strong Federal presence is not unique; in the Rocky Mountain and Pacific States (excluding Alaska and Hawaii), the Federal Government controls an average of 47 percent of all rangelands, whether through BLM, the Forest Service, or other agencies. In Oregon, 59 percent of the rangeland is managed by Federal authorities.

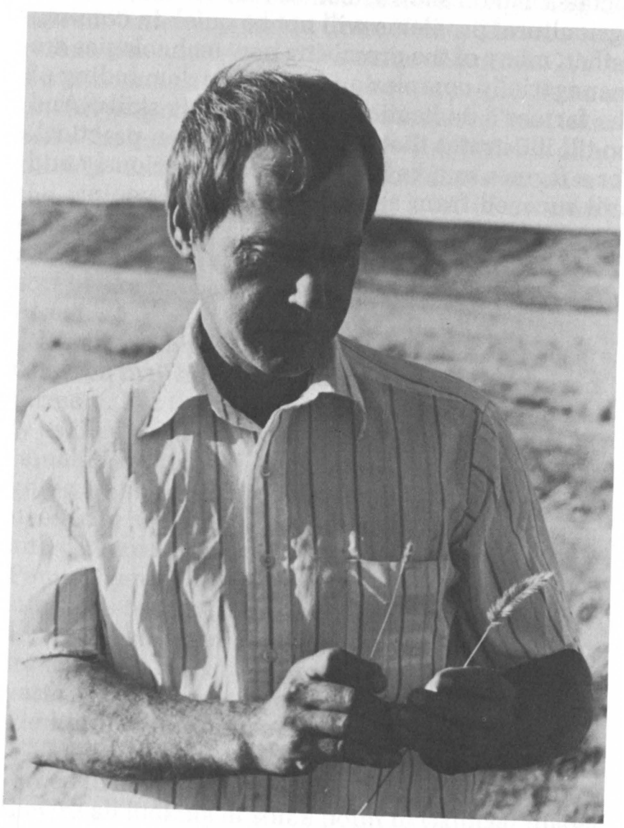


Photo credit: OTA staff

Lazaro Urquiaga comparing crested wheatgrass, an introduced species, with native forage

BLM, by law, manages its lands for the American people, trying to balance the environment's capacities with the needs of cattlemen, recreational users, wildlife, and other interests. For the ranchers who lease grazing rights from BLM here, the quality and availability of the range is no light matter. Cattle are the center of their world and have been for generations. So men such as Lazaro and his neighbor Bob Skinner are rightfully concerned about BLM's choice of management technologies for the range.

"This is some of the finest range you'll see in the Vale District," Lazaro, 30, points out. But it wasn't always so. Over 11 years, from 1963 to 1974, $10 million poured into the Vale Rangeland Rehabilitation Program. It transformed the district into a showplace of range management and restoration experiments—innovative seedings, water development, fencing, brush control, and grazing systems. And for the most part, BLM staff and local cattlemen agree that the restoration program for the once-abused range is an avowed success.

BLM and the ranchers did not always get along so well. Their disagreement over the management of the Vale range, in fact, is what initiated the rehabilitation program in 1963.

"Nobody really argued that the range wasn't overgrazed," remembers Bob Skinner, a 60-year-old Jordan Valley rancher who owns a sizable home spread and runs cattle on BLM land for 7 months each year. "It was the BLM's first proposal—to cut grazing an average of 58 percent—that got the ranchers to raise such a stink. That would've driven people out of business."

The suggested reductions in grazing that angered Skinner and many of his neighbors were not the first of the Vale area's range controversies. Exploitive use of the range, especially around limited water supplies, probably began even before the homesteading boom of the 1880's, and by 1900 range deterioration was severe. Since the land was public domain—open to cattlemen, itinerant sheepherders, miners, and settlers alike—little could be done to stop the degradation and erosion. By law, the land belonged to all. Yet no one was responsible for sound land use.

Area residents were not oblivious to the growing problems. Oregon ranchers spearheaded the drive

for the Taylor Grazing Act of 1934, legislation designed "to preserve the land and its resources from destruction or unnecessary injury, to provide for the orderly use, improvements, and development of the range." The act marked the end of the open homestead era, but not the end of controversy.

Settled ranchers used the act to halt migrant sheepherders, whose herds would strip the range mercilessly. But the powerful ranchers who sat on the new Grazing Service's advisory board were not entirely altruistic; when it came to allocating grazing rights, they did so on the basis of past use and commensurate property, not on the carrying capacity of the range. So while the ranchers were eager to maintain their ranges to stay in business and sometimes built fences, developed water, and even controlled sagebrush, for the most part they were interested in practical matters—low grazing fees and high profits from running as many head as possible.

By the late 1950's, the Vale range was in poor condition and everyone knew it. What neither cattlemen nor BLM staff knew for certain, however, was how to save the range.

The easy answer was to reduce the herds. "There was no question that something had to be done, but not straight-out reductions," remembers Dominique Urquiaga, Lazaro's father. That action would have hurt more than just the cattlemen. Malheur County is cattle country, and indirectly everyone—bankers, merchants, and townspeople—was a part of the cattle industry. They all opposed drastic cuts. Grazing cuts were a threat to their economic livelihoods and to a century of tradition.

"The ranchers felt threatened, rightfully, by the proposed cuts," says Bob Kindschy, the Vale District wildlife biologist who has been at Vale through the entire project. "In 1962, a group of them got together and requested a congressional inquiry, which Congressmen Ullman and Morse held here. BLM seized the opportunity to write up an alternative proposal—a plan to rehabilitate the range. We brought in all sorts of experts to present ideas and got everybody interested in a compromise approach."

"Conservation is like apple pie; you can't be against it," he remembers. "The Congressmen took the idea back to Washington and pushed it through. And we got a chance to show that with cooperation and funding, you can do great things with deteriorating range."

"The thing that hits home hardest," Skinner adds, "is that now we're actually harvesting all the forage we pay for. If we went back to the way things were, well, first take 60 to 70 percent of the cattle out there and wipe them off the slate—the old range couldn't have supported them. Then take all the tangential impacts on town and the rest . . . the project was a success, alright."

Range is range because of its physical limitations; the land simply cannot support more intensive use. Ranchers and range managers learn to work within those limitations. Southeast Oregon, including the Vale District and the Skinner and Urquiaga ranches, is a dry, inhospitable environment. Precipitation averages only 7 to 12 inches per year. Vegetation is sparse; dependable surface water is scarce. Although there is some irrigated agriculture in the bottomlands, for the most part cows are the only viable "crop" for the environment.

Depending on the quality of the range, it can take from 2 to 5 acres of range just to support one cow for a month (called an AUM, or animal unit month). But rangelands, like croplands, can be improved through proper management. The question in Vale was where do you start? The Vale District encompasses almost 6.5 million acres (2.6 million ha). Not only cattle but pronghorn antelope, waterfowl, raptors, mule deer, hunters, and fishermen had to be accommodated under BLM's multiple-use mandate and its broad definition of land productivity. Obviously, there was no one "right" management technology for all that terrain. In fact, there was no way to actually treat the entire, immense acreage.

Instead, the district's plan was to intensively treat only part of the range—scattered tracts totaling about 10 percent of the land. They hoped that these treated sites, combined with overall sound management and some temporary herd reductions, would alleviate grazing pressures on degraded native range and give it time to recover. Some of the treatments—for instance, seedings of introduced grasses such as crested wheatgrass—were not expected to be permanent improvements, just stop-gap measures to provide good forage while the native ranges rested. It was an added plum, then, when during the course of the decade-long program the district staff discovered that the introduced seedings adapted perfectly, reproduced, and became self-sustaining pastures.

"We're trying for sustained yields. The grazing program's goal is to make the range available forever; we strive to manage for the long-term. We say we can graze this country and keep its productivity high and stable, for cattle and otherwise," explains Phil Rumple, a range manager. "If cattle are one bite ahead of the grass, you have to lower their numbers until they are one bite behind."

The mix of management practices and land treatments used differed among the 164 tracts designated for rehabilitation. Sites were selected by their potential for improvement, not degree of deterioration. Treatments were planned through the combined efforts of the district's range conservationists, wildlife biologist, and watershed engineers.

Brush control is an important first step in range rehabilitation. As native range is overgrazed, more and more of the desirable forage plants are eaten; what grows in their place are less palatable species. Once established, most brush species are extremely difficult to remove.

The rangeland disk-plow—a special tool designed with each disk mounted on an independent shaft for rough terrain—was developed early in the Vale program to help control brush. Big sagebrush—a common, unpalatable species—had invaded many denuded pastures and taken over, compounding the degradation. But two passes with a plow could kill 90 percent of the nuisance plants as well as prepare the ground for seeding.

Range managers also experimented with sprayed herbicides for brush control, but not without controversy.

"Paraquat could be a tremendous help here, but it's banned on Federal range," explains Lazaro. "It's an economical way to control a burn—you spray the perimeter and then you can safely burn the area within the border. But we can't use it."

"I wouldn't ignore legitimate environmental problems," he adds, "what I don't understand, though, is why something is okay on private land but not on Federal. Is there a different safety factor for some reason?"

Burning, the method that historically kept the sage in balance, proved to be an effective brush control technique, too. In fact, areas that suffered either experimental controlled burns or wildfires had the lowest average density of sagebrush of any treatment.

To reestablish good pastures, a special rangeland drill was developed to drill seed into the rugged terrain. After many trials with a variety of grasses in-

Photo credit: Bob Kindschy

Rangeland disk-plowing

cluding pubescent wheatgrass, tall wheatgrass, western wheatgrass, and various clovers, crested wheatgrass emerged as the most consistently successful grass to plant. Crested wheatgrass, a species native to Siberia and adapted to animal grazing, was greeted with some skepticism by area ranchers when it was first planted; some called it "macaroni grass" and belittled BLM for bothering with it.

"When the first seedings went in, some of us refused to run our cattle in them. We weren't going to run our cows in 'broom straw.' " Skinner recalled. "Then Max Laurance, from BLM, came down in person and basically begged us to try a seeding. Once we'd tried it, you couldn't get us not to use it. It was that good."

To various extents, the success of many of the treatments and the overall range management schemes used at Vale depended on water. Managing the range meant managing the land and water resources. For no matter how good the range—native or introduced—no cows will graze without adequate water. And, conversely, the cattle will concentrate, and often abuse, the range nearest available water. Grazing pressures were especially severe on fragile riparian environments and the many species of bird and animal life that congregate there.

"A carpenter needs tools—a hammer and saw—to practice his trade. Similarly, seeding, fencing, brush control, and water developments are tools to allow intensive range management. You work with these tools to get a good distribution of grazing pressures," explains Vale Wildlife Biologist, Bob Kindschy.

Range managers use such tools together with their knowledge of animal and plant science to set up sustainable grazing systems. No longer do ranchers simply release cattle onto the growing pastures of early April and round them up with the first snow. Instead, they work with range managers to plan for the cattle to be rotated throughout the range, alternately using and resting pastures and enhancing the sustainable productivity.

Lazaro favors close working relationships between BLM managers and cattlemen who use the range. He thinks that both sides would benefit from a new kind of policy regarding stewardship for the land—a way to encourage ranchers to make improvements on the Federal range.

"There is a 'stewardship experiment' in Challis,

Photo credit: Bob Kindschy

Rangeland drilling of seed

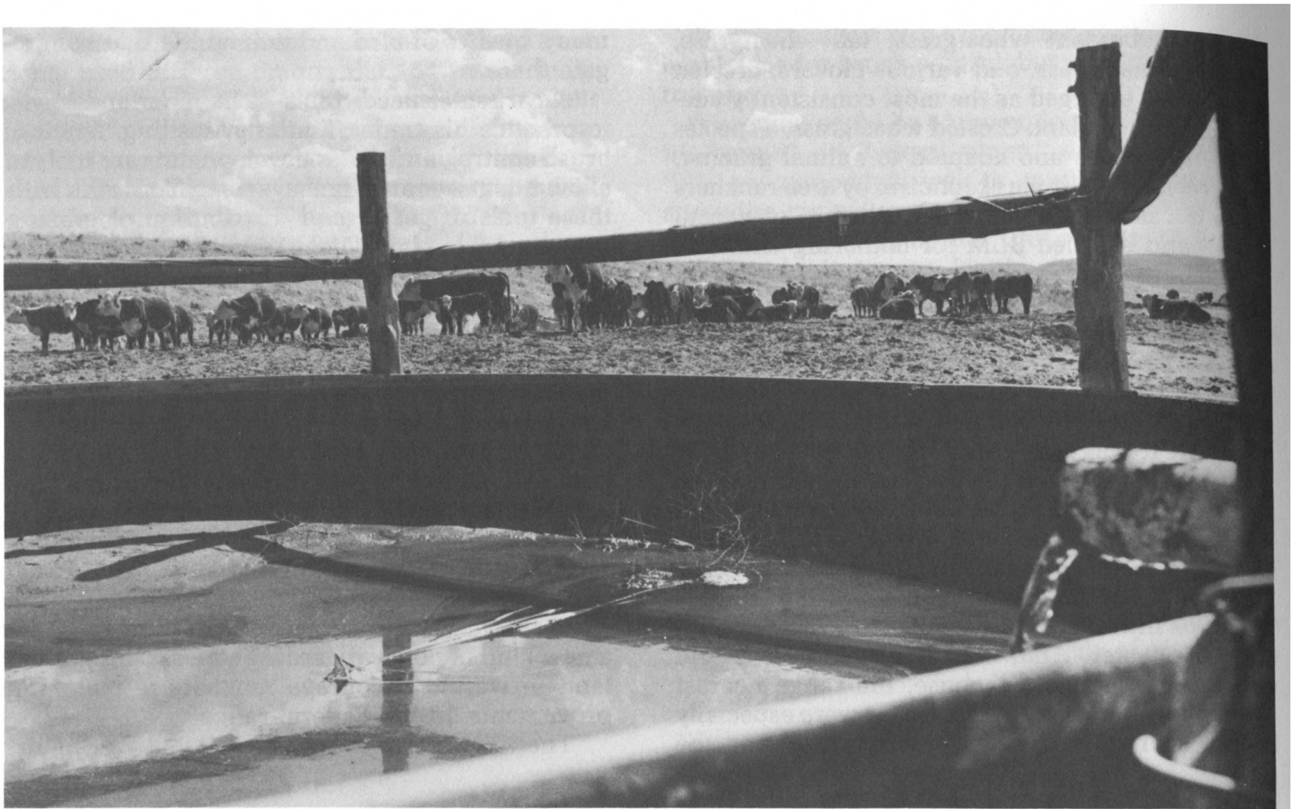


Photo credit: OTA staff

Developing adequate water supplies is essential to sound range management

Idaho, that shows what I mean," Lazaro explains. "If the range supports 1,000 AUM, and a rancher improves that to 3,000 AUM, that rancher would get the extra rights. He'd still pay for them. This way you create more user involvement, more personal involvement. You'd need a written agreement, of course, so that you get a stable position on the range and a guarantee that you'd actually benefit from your labors."

To increase water availability at Vale and hence broaden the cattle's range and widen management options, BLM staff built a number of new wells, pipelines, and reservoirs. But they had more than cattle in mind.

In keeping with BLM's multiple-use mandate and their commitment to diverse and sustained land use, BLM planned for wildlife as well as cattle when they developed water. "Noodle bowls," for instance, are hilltop water catchments fed by springs that distribute water by gravity pipelines to surrounding pastures. Range managers keep these reservoirs open through the dry season, even when cattle are on other ranges, for the benefit of wildlife. Another wildlife watering device, called a "guzzler" or "bird bath," is a small catchment and tank that stores precipitation. More than 30 have been built on the range, strictly for wildlife. This way all the life on the range gains from the restoration.

The various range treatments and rotations are not without their shortcomings. Managing for multiple uses inevitably causes some conflicts. Sometimes change itself—no matter how benign—is resisted in favor of tradition. Even the physical management techniques—seedings, plowing, and brush control methods—can cause problems. Plowing at the wrong time can bury native, desirable seed too deep to grow. Planting only one species can eliminate the diversity needed for wildlife browse and shelter. New fences, even those built with an unbarbed bottom wire to reduce hide cuts on antelope, can kill some animals who charge unaware into the obstructions. And controversies over fire and herbicide use seem unlikely to subside.

Problems arise, too; Bob Skinner points out that it is not uncommon to see game, whole herds of

Photo credit: OTA staff

BLM experimental range showing a reseeded section v. native grasses. Note predominance of unpalatable sagebrush on left

deer, from the BLM range feeding heartily on nearby, privately owned alfalfa.

Vale's experiments have not solved every problem on the range, but the work done there has provided other range managers with some new and useful tools. They have learned what grasses to use in seedings, how to manage riparian areas more carefully, and how to diffuse grazing pressures, improve forage, and incorporate wildlife needs early into the management strategy. And, importantly, the Vale Range Rehabilitation Program proved that severely degraded range could be improved and maintained without undue local hardship—given support, knowledge, and cooperation.

The lessons learned at Vale can guide sound range use elsewhere in the intermountain-type ranges—the "cold desert steppe" rangeland that extends through Oregon, Washington, and parts of Montana. Some broader lessons, too, are transferable to different types of range throughout the Nation.

Though the major thrust of work at Vale has ceased, the district stands as an example of sound resource management. Research continues—experimentation with new grasses, new fencing techniques, sophisticated grazing systems, and the like—but slowly. The work makes Vale an important record of what can and cannot be done for deteriorating rangelands.

Like the other case study sites, the Vale District illustrates that sustaining land productivity requires a greater, and sometimes more laborious, sense of stewardship. It requires more managerial skills, more openness to change, and often more financial and philosophical commitments. But unlike most farmers, the Vale ranchers do not hold primary responsibility for managing their range. Decisions about how technology will be used to restore and maintain the grazinglands and accommodate the many, sometimes competing demands rest with BLM. And responsibility for careful use is shared by the more than 400 ranchers who run cattle on the "commons." Such joint stewardship poses special problems; it calls for cooperative planning and a strong sense of commitment from all the people benefiting from the shared resource.

"The BLM is a stabilizing influence on the range and is necessary," Lazaro says. "The idea of local control is misleading because realistically you still need the same people—watershed people, range specialists, wildlife people. But what we do need, all of us here, is a stable relationship with the Feds. That would be an important step toward better range use."

CONSERVATION FARMING—EDELSTEIN, ILL.

It was a powerful piece of paper that lured Joseph Gallup halfway across the country, from Connecticut to Illinois, in the 1850's. And it is that same property deed that ties Roger, his great-great-grandson, to crazy-quilt contour farming on hilly land while just 2 miles down the road his neighbors plow straight rows on level fields, fence row to fence row.

For Joseph and his wife, those 200 acres of rolling grassland and woodland were just what an 1850's pioneer family needed. The soil on the nearby prairie was rich and deep, but drainage on that level land was poor. Besides, there was no easy way to break up the root-bound prairie sod. And a homesteading farmer needed timber close by for building, fencing, and fuel; prairie land was treeless.

It would take the steel-moldboard plow, drainage technology, and a transportation system to lure the next wave of settlers out onto the prairie: a plow to turn the heavy soil, drainage to carry off water formerly taken up by prairie grasses; and roads and a railroad to haul in fuel, lumber, and other supplies. Once the prairie was tamed, its farmers found themselves on top of some of the richest farmland in the world. But in the meanwhile early settlers such as the Gallups stayed near the prairie fringe—along the rivers and in the hilly, wooded lands.

Today, 43-year-old Roger and his father, Dwight, sometimes wish their farm were out on the flatlands their neighbors till. But it's too late to move. The Gallups' equipment, their buildings and storage facilities, and their way of farming are tied to their own land. "Besides," Roger says simply, "this is home."

Roger; his wife, Sharon; and their children, Renee and Loren, live in a big, sturdy brick house built by Roger's grandfather, a man who clearly planned to stay. Two miles west, on the edge of the farm, Roger's father, Dwight, and his wife, have built a modern ranch-style home—the kind you see more and more on the farmscape.

Next to Dwight's house looms a massive steel grain storage bin, the elevator at its peak connected to smaller bins by metal pipes splayed out like the legs of a giant spider. The Gallups can store up to 60,000 bushels of grain here until the market price

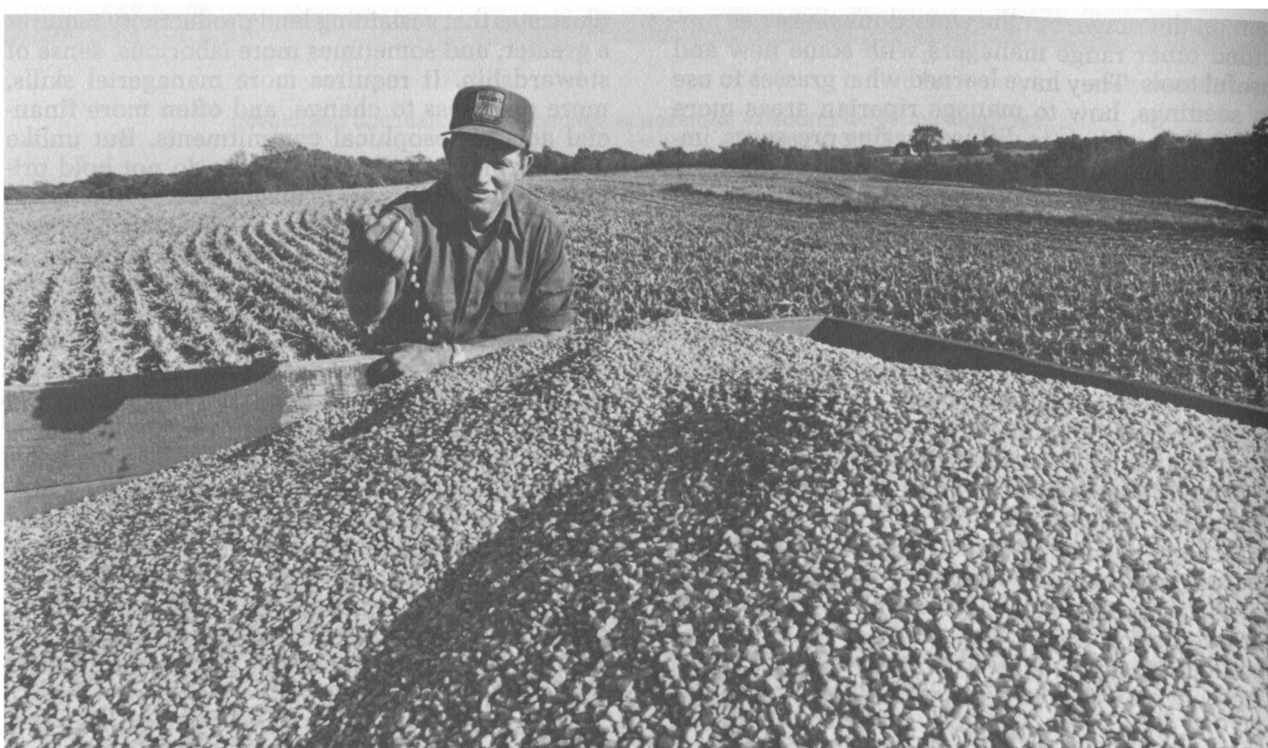


Photo credit: OTA staff

Roger Gallup checking wagonload of corn

is to their liking. Much of the Gallups' farm lies between Dwight's new house and his son's place. The Gallup land, now 860 acres, is part of twin bands of rolling topography, 4 or 5 miles wide, that edge the Illinois River. Water running off the flatlands converges and gains momentum near the river, carving gentle hills in the landscape. Slopes here range as high as 13 percent.

Until about 1960, this land supported a variety of livestock: dairy and beef cattle, hogs, sheep, and poultry. The steepest hillsides were maintained in permanent pastures. Only the more gentle slopes were plowed and planted to annual row crops such as corn and small grains. Even this modest acreage of row cropland was "rested" by regularly returning the fields to pasture and hay crops.

But cornbelt farming has undergone a major change in the last two decades, and Roger and Dwight had to change their operation to keep in the black.

Today the Gallups grow cash crops—corn, wheat, and soybeans—and nothing else. "We gradually moved away from livestock," Roger says. "We simply reached a point where there was no return on cattle. More livestock would be better for overall U.S. productivity and for the land, but the returns for stock compared to crops just don't justify the switch for most farmers."

So the Gallups plowed under the green hillside pastures and planted row crops. But with the slopes laid bare much of the year, the Gallups faced a major problem—erosion.

Though erosion is partial to sloping land, it nibbles away flatland fields, too. But flatland fields are blanketed with a thick layer of topsoil—glacial till covered with loessial (windblown) particles and enriched by organic matter from thousands of years of prairie growth. So on flatland the annual thievery is more subtle; it can be masked by improved crop varieties and heavier fertilizer applications.

When the Gallups' hillsides were protected by perennial pasture, erosion was easier to handle. They controlled grazing intensity and held back runoff with fence wire and straw barriers strung across waterways. But row cropping leaves whole hillsides vulnerable, so Roger and Dwight have to take major erosion control measures. They plow and plant on the contour rather than straight up and down the slopes so that each furrow catches and holds runoff. They do plow in the fall, but with

Photo credit: OTA staff

Combining corn along a terrace that follows the contours of the Gallups' hilly Illinois land

a chisel plow, which fluffs up the soil, leaving air spaces in the top layer and trash on the surface. Chiseling can leave more than 2,000 lb of residue on an acre of cropland. That is enough to reduce soil erosion by roughly 50 percent on sloping land.

Another necessary conservation measure has been more difficult and more costly. Contour farming, even with conservation tillage, is not enough to hold the soil on the steeper slopes. For better protection, Roger and his father also had to construct terraces on much of their land. Terraces are step-like soil embankments bulldozed up along the contour of a slope. Like individual furrows plowed on the contour, the terrace is designed to hold back and slow runoff, but on a much larger scale.

Roger says terraces will last about 15 years with proper maintenance. During the last 5 years, the Gallups put in nearly 7,000 ft of terraces covering about 100 acres. Though these new barriers are broader and more compatible with larger equipment than old-style terraces, they still limit the width of field implements the Gallups can use and are awkward to maneuver around, especially where rows converge. And terrace farming is not so profitable as flatland farming.

"Take all our waterways and terraces . . . they're completely wasted land," Dwight complains. "We can't crop them, yet they're taxed just like the rest of the land. And it takes more fuel and roughly twice as long to farm terraced land."

Terraces are expensive. In Illinois it costs an average of $200 to $400 to protect an acre with terraces. But the Government will pay up to 75 percent of the construction cost, which Roger thinks is an equitable arrangement. "The general public has to accept both some of the responsibilities and some of the costs in return for the long-term benefits of soil erosion protection and improved water quality."

For Roger and Dwight, terracing is more than a costly project that may pay off some day. It is part of their land ethic—the craft of farming. For less successful farmers, however, terracing and land stewardship can be unaffordable luxuries. "Hundreds of thousands of acres that are now in row crops should not be because the soil erodes too easily," says Harold Dodd, president of the Illinois Farmers Union. "But a farmer has to put every inch of land into those kinds of crops just to make ends meet." And he is encouraged to do so by a Nation that depends on his produce to help pay rising energy costs and to add muscle to diplomatic policy.

Bankers will not finance terracing if a farmer is short on available cash. And many landowners will not sink money into expensive land-moving ects that promise to protect long-term prod ity while contributing nothing to immediate itability.

Roger points out the dilemma faced by a ten farmer working land he knows should be terrac The traditional sharecropping agreement betw tenant and landowner assumes that the owne responsible for long-range improvements. "And the land is owned by an elderly person who has children to inherit it," Roger asks, "how could y honestly convince her (or him) to invest in a lon range improvement like terracing? In this case, th land is strictly an investment—a retirement fund. The tenant, on the other hand, has no incentive to pay for improvements because he has no assurance the rental agreement will be lasting.

Simple conservation tillage is a less costly technique that offers varying degrees of erosion control, depending on the slope, soil type, and amount of residue left on the surface. But conservation tillage has tradeoffs. With moldboard plowing, the share actually folds over the top layer of soil, burying crop residue, insect eggs and larvae, and disease-carrying micro-organisms. Chiseling, when done properly, merely "stirs" the soil. Insect eggs and weed seeds, as well as soil-protecting crop residues, remain on the surface, so the farmer may have to increase the rate of his pesticide applications. Chiseled soil can take longer to warm up and dry out in the spring, too. And for farmers accustomed to tidy, trash-free fields, chisel plowing is hard to accept just on the basis of appearance.

Roger looks forward to the day when he can abandon a few terraces in favor of no-till farming. (See previous case study in this appendix for full explanation of no-till farming.) Right now he is willing to give it a try on a field or two, but he is not ready to tear out his terraces. "We're waiting for the machinery manufacturers to perfect the equipment," Dwight says. "And for the chemical companies to come up with more herbicide flexibility in a no-till system," Roger adds.

Looking into the future, Roger sees two innovations that may rescue soil-conserving farmers from dependence on terracing or no-till. Someday it may pay to seed rye from an airplane as a winter cover crop and as green manure, Roger projects. Or a perennial biomass crop with soil-holding and income-generating capacity may be developed.

Changes in technology are never without costs, Roger says. First, it is costly to purchase new technology. Second, adopting a new cropping system is an anxious time for the careful farmer, so it is

costly in frayed nerves. Finally, unfamiliar technology invites management mistakes. For instance, the advantages of the chisel plow are lost unless the farmer knows how deep to set the chisels for his particular soil type and moisture and for the horsepower of his tractor. And he may overcompensate with herbicide for the extra weeds he expects the chisel to leave.

A farmer must keep abreast of technological advances. Traditionally, his most trusted sources for information are his fellow farmers. When two farmers meet the conversation invariably turns to farming. They compare notes on new tillage equipment or a new herbicide combination, or perhaps a modification one has made in an implement. Roger, like most farmers, also turns to other sources including equipment and fertilizer dealers or pesticide and seed company representatives. He reads agricultural publications, mostly in the winter, and for particularly confounding problems he may turn to experts at the University of Illinois.

But the advisor Roger turns to most often is his father. "I sound out ideas and decisions with Dad," Roger says. Dwight brings together not only the experiences and insight of a lifetime, he adds to that a wisdom that accumulates in a family that has stayed put for generations.

Though some farmers may not seek the banker's counsel, the costs of new technology, compounded by inflation and formidably high interest rates, have made the bank the farmer's business partner. For Midwestern farmers, the credit line has become the umbilical cord that ties them inextricably to various financial institutions. These institutions put them in business and keep capital flowing to meet operating expenses and investments in land and equipment. The credit leverage enables banks and savings and loan establishments to assert powerful influence over the farmer's investments, his grain and livestock sales, even his management decisions.

What has kept many farmers afloat, and what has pumped money into farm expansion, is equity—equity from land that tripled in value in the 1970's as a result of a short-lived leap in grain prices, farmers competing for land, and rival investors seeking a hedge against inflation.

"The trend today is toward larger farms," Dwight says, with a hint of nostalgia. "There is no other way it can go. It used to be a family could live on 160 acres. But today you couldn't afford machinery with just 160 acres."

Since 1950, the acreage of the average Illinois farm has doubled. Nationwide the average farm size is now about 420 acres. A recent USDA study[1] projects that if current trends persist, the middle-size farm will be nearly obsolete by the year 2000.

It is hard to say which comes first with farmers: more land or the technology to farm more land. Roger points out that sometimes it makes sense to buy bigger equipment with the intention of finding compensatory land. Few can borrow enough money and service the debt on a simultaneous acquisition of additional land and, for example, a $100,000 combine needed to cover more territory. Instead, expansion usually takes place in a seesaw fashion—first land, then equipment, then land, and so on, or vice versa.

Illinois Farm Business Management Records[2] show that machine and labor costs per acre decline up to about 800 acres. For example, machinery costs on a 214-acre grain farm run roughly $62 an acre; on a farm four times bigger they run about $53 an acre. Labor costs averaged $53 per acre on the smaller farm; on a farm four times bigger, they ran an estimated $24 per acre, less than half as much.[3] The Gallups use larger equipment to farm their expanded acreage, but it takes roughly the same number of management decisions and equivalent amount of labor to farm 850 acres as it would to farm half that much land.

Net return after taxes also favors farm expansion. Taxes do not rise as fast as income. Farmers such as the Gallups are in a better position than small farmers to use investment credit and to depreciate equipment faster. Likewise, the implement dealer can give a big farmer a better deal because he buys more. And it is easier for the larger landowners to borrow money and get lower interest rates.

Another reason why a farmer may feel obligated to increase his acreage is if he wants to pass on enough land to allow more than one of his offspring to get a start in farming. "I don't want my kids to think they have to farm to please Dad," Roger admits. But just in case, he is making sure there will be enough land to split into two viable units.

This year Roger and Dwight will farm 860 acres. By cornbelt standards that is moderate acreage. Roger waited 20 years to annex land to the 500-acre farm his father had established, but it was not lack of money that held him back. Because Roger's land

[1]U.S. Department of Agriculture, Economics, Statistics, and Cooperatives Service, technical bulletin No. 1625, William Lin, George Coffman, J. B. Penn, "U.S. Farm Numbers, Sizes, and Related Structural Dimensions: Projections to Year 2000."

[2]1979 Summary of Illinois Farm Business Records, Extension Circular No. 1179.

[3]Wilken, Del, University of Illinois, agricultural economist.

is valued at over $3,000 an acre, and because he is known as a skillful farm manager, his credit line can stretch to cover a land purchase. What postponed the investment was the scarcity of nearby farmable land for sale. (Gallup's equipment is too big to conveniently move cross-country.) While he waited, Roger leased the land he needed.

In some cases, a farmer recognizes the home property is too small to provide income for both him and an offspring who wants to farm. And heavy debt makes land sale the only way to retire securely. For other families, inheritance taxes prove more than the sons and daughters can afford. So they must sell some, or most, of the land to retain the rest. If the remaining unit is too small to generate a living, it must be rented out or sold.

Still another factor encourages the established farmer to add to his holdings. U.S. tax policies allow the big farmer to buy land and write off a big chunk of the cost. "We give enormous subsidies, carefully hidden in the tax code, to persons who are sheltering income," said former Agriculture Secretary Bob Bergland. "That's one of the major reasons why young people have an impossible time buying land in competition with people who can pay more for the land than it's worth as an income producer."

The complexities of big farm management have risen with the costs. When labor shifted from man to machine, it brought about many changes in agriculture. Thirty years ago the Gallup work force was larger and more elastic than it is today. It included three families, a full-time hired man, and a crew to help at harvest time. The modern Gallup farm is almost twice the size it was 30 years ago, yet it supports only two families. Now Roger and Dwight alone do most of the work, with help as needed from a seasonal hired man, the Gallup wives, and Roger's two children—and, of course, the equipment. When Dwight was a boy, 10 draft horses provided the power. Today Gallup's fleet of tractors and the implements they pull have the power of hundreds of horses and do the work of dozens of men.

As the complexities of management have grown, farmwork patterns have changed. The farming Roger and Dwight knew as boys was based on livestock; it was 365 days a year of chores. The year's work on today's cash crop farms is squeezed into 6 or 7 hectic months of plowing, fertilizing, planting, cultivating, crossing fingers, repairing equipment, and harvesting. Much of the rest of the year is spent maintaining equipment and buildings, marketing the grain, and planning the next season's work. Dwight recalls that when he was a boy there was no "off-season," even in winter. When all the other work was done, there was always firewood to cut.

"I'm glad those days are over," says the 67-year-old, semiretired farmer. "I mean, the other day it was snowing and blowing, and I could just sit in the house, warm and cozy, and watch TV."

"Yes, but the pressure is just as bad," Dwight's wife, Hazel, interjects. "With all the modern equipment, you still have the responsibility to maintain everything."

Maintenance was not much of a problem in the past. For the most part horses maintained themselves, although you had to set aside a sizable portion of your land for their feed. But with the blessing of modern equipment comes the burden of maintenance. Roger and Dwight must be expert motor mechanics, welders, sheet metal workers, machinists, and much more. With the large amount of land that they must work in a limited time and with limited manpower, there is no time to take a broken-down tractor to the dealer's shop. And you cannot afford to keep a spare piece of expensive equipment on hand. So repairing and maintaining modern farm equipment probably is the single most important part of farming. Roger's enormous maintenance shop is a steel structure, resembling a Quonset hut, big enough to hold the combine and a couple of tractors.

Economics dictate that a farmer must closely match equipment size to crop acreage. Equipment that is too small may not cover enough ground during the critical period dictated by weather, soil conditions, or the sensitivities of a particular crop. Older equipment is, generally, more prone to breakdowns that can cut yields. On the other hand, a farmer who is overequipped is wasting capital—that is, unless he intends to offset his equipment size with more acreage. But if a crop fails or the grain market plunges and his credit line snaps, the farmer's overextension may get him in trouble.

John Fuelbirth, farm loan advisor with Herget National Bank in Pekin, Ill., says, "Farmers tend to be conservative. But they want to spend too much on machinery. And the investment tax encourages them to spend it."

In the past, farm efficiency has been gaged too often by the amount of food a farmer could produce, no matter what the energy or resource requirements. But the Gallups, and people like them, recognize that, in order to sustain production rates in the long term, the definition of efficiency must include the protection of the root source of this

bounty—the land itself. The future's challenge is to improve and spread soil-saving technology with the same energy with which our forebears opened up this land, and to encourge farmers to adopt a land stewardship ethic—by making it pay.

FARM REHABILITATION—WHITEHALL, WIS.

From the ridgetop, the deep gouges in the slope look like soft, tree-covered folds. But a closer inspection reveals the unmistakable scars of decades of abuse.

Eighty years of farming this western Wisconsin land had almost destroyed it. A parade of owners and occupants had stripped the hilly land of its protective vegetation and fertility with cows and row crops until yields dropped so low that the land could no longer support the farm families. By the late 1950's the hillsides were bare except for an occasional gnarly old oak. The farm stood abandoned and what poor soil remained was washing away at a fierce rate.

Poor-quality land such as this often gets swallowed up by bigger farms. The ridges are cropped, the slopes pastured, and the farmer is content to let productivity limp along.

But this Whitehall, Wis., farm is different. It was purchased in 1959 for $25 an acre by a man who said he wanted "a place to plant some trees." And that he did. To date, Ernie Brickner has planted 160,000 trees on those 229 acres. The 70-year-old planted 135,000 of them by machine and carried another 35,000 up the steepest slopes and planted them by hand.

"It wasn't easy," Ernie admits. Some of his slopes approach a 45-degree angle; they were skirted by the glaciers that scoured and smoothed other regions of the State.

Before man shaved the surface and began cultivation, prairie grasses dominated the landscape. They gathered nourishment from the soil and, in turn, enriched and protected the land.

Then came a procession of farm families, each trying and failing to earn a livelihood from what Wisconsin Department of Natural Resources forester Ed Godel calls a "two-story farm." The upper story—the ridgeland—and the lower story—the valley—were planted to row crops; the sloping land in between was pastured by some of its caretakers and cropped by others.

It was a malevolent partnership of man and nature. Man planted his row crops on cleared hillsides and grazed his livestock on wooded ones. The tilled soil often lay bare to the forces of erosion. Livestock tramping on the wooded hillsides ate away protective underbrush and packed the spongy soil into a hard, inpenetrable surface. As these pastured slopes lost their ability to soak up water, runoff from spring rains stole soil and flooded the valleys below.

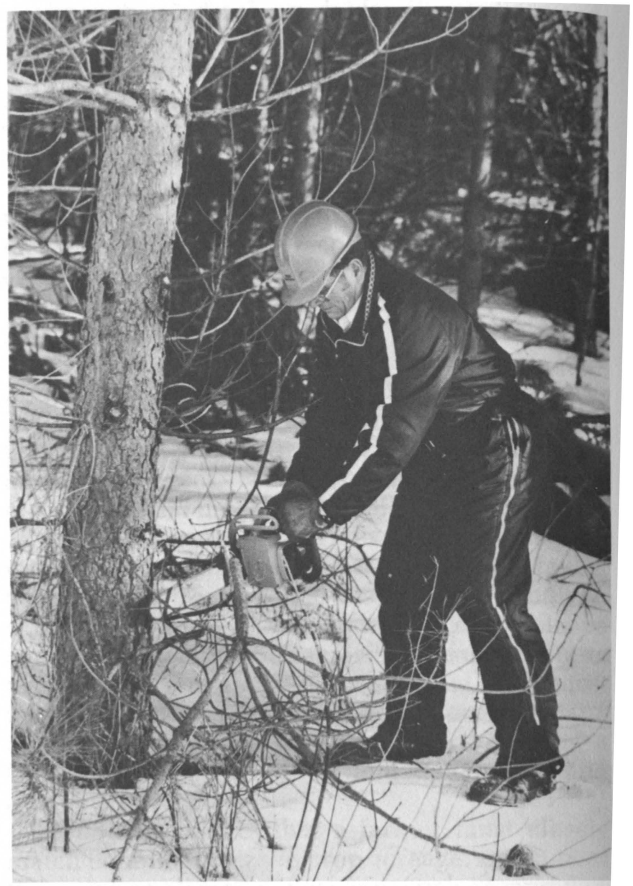


Photo credit: OTA staff

Ernie Brickner pruning a red pine to encourage straight, knot-free growth

The only way to transport grain down from the ridgetop fields was along a horse trail—called a dugway. It was so steep that even teams pulling empty wagons had to be rested three or four times on the way up the incline. This discouraged hauling manure up to fertilize the ridgeway, so the fertility gradually ebbed.

The land's history speaks of the failure of nine owners and four renters to generate income from the craggy terrain. And the deep gullies, some big enough to bury a barn, reveal the damage incurred by unrestrained use of agricultural technology.

Ernie says the land would have been easier to manage as a farming unit had it been parceled out according to natural boundaries, such as creeks and ridges, instead of the surveyor's line. But Wiscon-

sin was part of the Northwest Territory, so farms were laid out in 160-acre squares.

But when the land is planted to trees, nature's boundaries do not prove so formidable. With the help of Godel, his county forester, Ernie prepared a detailed plan for the land. The men plotted where the pine plantations should stand, where the black walnuts should be planted, and which hardwoods Ernie would cull and which he would preserve for wildlife food and habitat or save for eventual harvest.

In drafting the plan they considered soil type and slope; market value for tree species; time span before trees would reach marketable age; and, most of all, Ernie's dream for the land.

His dream was much bigger than planting trees for timber production. A former teacher and superintendent of schools in Whitehall, and later education officer in charge of a youth conservation program in the Superior National Forest in Minnesota, Ernie used forestry projects to excite boys disillusioned with classroom learning. Ernie returned to his Buffalo County land steeped in multiple-use philosophy toward woodland management.

With his submarginal acreage he could put the concept to a rigorous test. He would plant, cull, thin, and prune trees not just for timber production but for water-quality control downstream, wildlife habitat, recreational use, and—his special interest—educational opportunities.

In just 22 years, he has succeeded. He thinned his pine plantation 2 years ago and sold the immature trunks for posts, poles, and pulp. He left the pine tops and trimmings on the ground as cover for grouse and rabbit. He has cut "weed" species and damaged hardwood trees to leave more sunlight, space, water, and nutrients for their more commercially valuable neighbors. From the cuttings, some logs are made into railroad ties or shavings for livestock bedding; others become firewood.

But Ernie is careful to leave a few "wolf" trees and "den" trees standing. Wolf trees are the giant old patriarchs of the forest, ancestors to many of the naturally propagated trees. Den trees are often hollow and dying, but they are still valuable to Ernie for the shelter they afford wildlife.

In fact, Ernie's forest is a wildlife paradise; hickory and walnut are the squirrels' delight. Then there are raccoons, fox, ring-necked pheasant, hawks, even eagles. Ernie has counted at least 35 species of songbirds on the property.

The wildlife, in turn, draws hunters. Under Wisconsin's Forest Crop Law, Ernie agrees to open his land for hunting and pays a severance tax on harvested timber in exchange for a property tax deferral. But with or without the law, Ernie has no desire to hoard his woodland. It is open year-round, by permission, to hunters, snowmobilers, skiers, hikers, berrypickers, and birdwatchers.

Ernie probably gets the greatest joy out of the educational value his woodland provides. "I really get a lot of pleasure out of walking through here and telling people what I know about forest management . . . especially the kids." Ernie remembers the thank-you note he received from one young visitor who had trekked the hills and firelanes with his seventh grade classmates: "I really like your woods," the boy wrote, "especially the fire escapes."

Ernie is willing to share his property with neighbors and friends and with groups of all sorts—environmental organizations, church groups, community clubs, 4-H'ers, farmer groups, professional and student foresters, conservation classes, and the like.

Perhaps the most important use of Ernie's trees, in the long run, is to protect the land base from erosion and to keep water and nutrients from flooding the lowland fields down the valley. Moreover, Ernie's land no longer contributes to the sedimentation and eutrophication of water downstream to Trempealeau River and, ultimately, the Mississippi.

Ernie's woodland, however, is a small island amidst farm fields and wooded pastures that spread on all sides. It is not that trees are scarce in Buffalo County—roughly 40 percent of the land is wooded. What is in short supply is woodland fenced off from the munching and stomping of dairy cattle.

Dairying is big business in this part of Wisconsin. "And the milk check is the thing that the farmer is interested in right now," says Brickner. "He's not too interested in what will come off that land 30 or 40 years from now."

"Big farmers—successful farmers—are tied up in their farming activities," says forester Godel. "They have little time for woodland management."

It is estimated that up to 50 times more runoff flows from grazed woodland than from ungrazed woodland. Ernie says grazing creates a threefold problem: soil compaction, loss of undergrowth, and damage to established trees.

The average dairy cow weighs about 1,400 lb. That weight, concentrated under the hooves, exerts a great force on the soil. Under repeated pressure, soil particles are compressed until, eventually, the earth can neither absorb rainfall quickly nor leave adequate passageway for roots.

Also, cattle have a penchant for tender undergrowth. They eat the more desirable young trees, such as maple and oak, and leave undesirable species, such as black locust.

"By eating shrubbery that's necessary for the accumulation of humus, cattle are eating prospective mulch," Ernie says. In ungrazed woodland, soil acts like a sponge, absorbing and holding water. And healthy trees consume more water and keep the water table lower.

"And frost doesn't penetrate as deep under thick mulch." Consequently, more melting snow can seep into the soil.

A healthy understory also softens the impact of raindrops on the soil. Direct hits by these drops can gouge out soil particles. "On unprotected land, I've seen chunks of soil 4 or 5 ft across—peat soil, it's lighter and will float—torn away in my valley and float all the way down to Independence and wash out into the pasture where the floods were coming down, enough in one big chunk to fill a manure spreader, to say nothing about the smaller pieces that are torn away."

Farmers often solve the flooding problem not by treating the cause but by bandaging the wounds. Wing dams built into hillsides impound runoff and can prevent flooding.

"These dams hold the water back so it doesn't cut down through their farms and do the flooding right on the farm," says Ernie. "But it would be a waste of my money for me to build dams. The water stays right on these wooded hillsides."

Most agronomists and foresters agree that it is usually best to divorce tree-growing from cattle-raising. University of Wisconsin forester Dr. Gordon Cunningham points to research that shows that good-quality open pasture yields about 30 times more protein than wooded pasture.

Foresters and ardent tree farmers such as Ernie espouse a simple remedy for reducing runoff and improving timber quality: keep the cows out and harvest the trees when they are ready. By doing so, a landowner can gather firewood and harvest quality timber. "Mother Nature has lots of time," Godel insists, "and the woodland damage will repair itself if you take the cows out."

"Trees aren't nearly as demanding of nutrients as agricultural crops," Godel explains. "A tree has an extensive root system. And unlike an annual crop that concentrates its nutrients in the grain head which is removed in harvest each year, a tree keeps adding organic matter to the soil."

But unlike the annual payback that dairy cows and row crops offer, a tree is slow to bring a financial reward. In fact, it will be beyond Ernie's lifetime when the walnuts he planted and pruned yield their precious veneer. And it wasn't his sons that he had in mind when he planted them . . . it was their children.

"Growing trees makes you farsighted," Ernie says. "You have to look to the future when you plant trees."

Besides the economic value of the trees, Ernie wants to hand down to his children and grandchildren a place to enjoy the things that would have fulfilled him.

"I've enjoyed the woods throughout my life—hunting and fishing—and that's what has given me the feeling of stewardship toward the land."

Some woodland owners think of management and preservation as at cross purposes. To them, culling trees and harvesting mature timber destroy the pristine quality of a forest. But Ernie's woods offer ample testimony that you can manage woodland for both esthetics and timber improvement. And such management can greatly enhance the productivity of U.S. lands.

Although the net annual timber output has increased 56 percent in the last 30 years, according to Rexford Resler, vice president of the American Forestry Association, the Nation's forests are only producing about three-fifths of the net growth per acre that could be obtained with proper management of natural stands. But few people see the potential.

"Most intensive woodland management on private lands is done by someone who makes his income from another source," Godel points out. People such as Ernie Brickner who are firmly entrenched in the conservation ethic are not tied to the land for immediate income . . . they often make the best stewards and managers of timber acreages, he says.

Ernie remembers that 20 years ago you could stand on the ridge and look down on bare hillsides eroded by decades of unwise farming. Today the steep slopes and valleys are cloaked with trees—pine, spruce, birch, and other hardwoods.

Ernie's dream has been to reclaim some dying land, reforest it, and make it valuable again—valuable not only for the timber it can produce but for wildlife, recreation, and education. His commitment and dedication epitomize the forces driving the land ethic emerging in American society.

SALINE SEEP CONTROL—FORT BENTON, MONT.

When farmers on Montana's Highwood Bench realized that they were losing 20 percent of their land—20,000 acres—they got angry. Enough is enough. So some 75 of them gathered one night in 1969 and decided it was time to act.

The culprit was not the Government. It was not land speculators. It was nature, gone slightly awry. Saline seeps—recently developed outcrops of wet, salty soils on nonirrigated lands—were breaking out and spreading on many of their fields, more than ever before, and rendering the land infertile. No one was certain why, or what to do to stop them. The farmers decided it was high time to find some answers.

Howard Hanford relates the history of the Highwood Alkali Control Association (HACA) with some pride—his father was one of the organizers and Howard himself has been chairman of the group. And it was the HACA's initiative—they taxed themselves to support needed research—that brought State, Federal, and local people together to work on a problem of increasing severity and importance for Montana and much of the northern Great Plains.

"All the farmers around here had seeps. Everybody knew that they got bigger in wet years, that they were progressively getting worse, but nobody put things together," explains Howard.

The story of saline seeps is a mire of geologic, hydrologic, and technological variables. It is an example of the role that technology, in this case crop management, can play in both causing and resolving resource problems.

"The Highwood Bench south of Fort Benton was one of the first areas in Montana to really suffer the effects of saline seeps," explains Dr. Marvin Miller, a hydrogeologist with the Montana Bureau of Mines and Technology. "They had 20,000 acres in salt in 1971."

Many factors can foster the formation of saline seeps on individual sites, but two elements play key roles: local geology and summer fallow crop management. Summer fallow (sometimes called crop-fallow) is a traditional crop management scheme

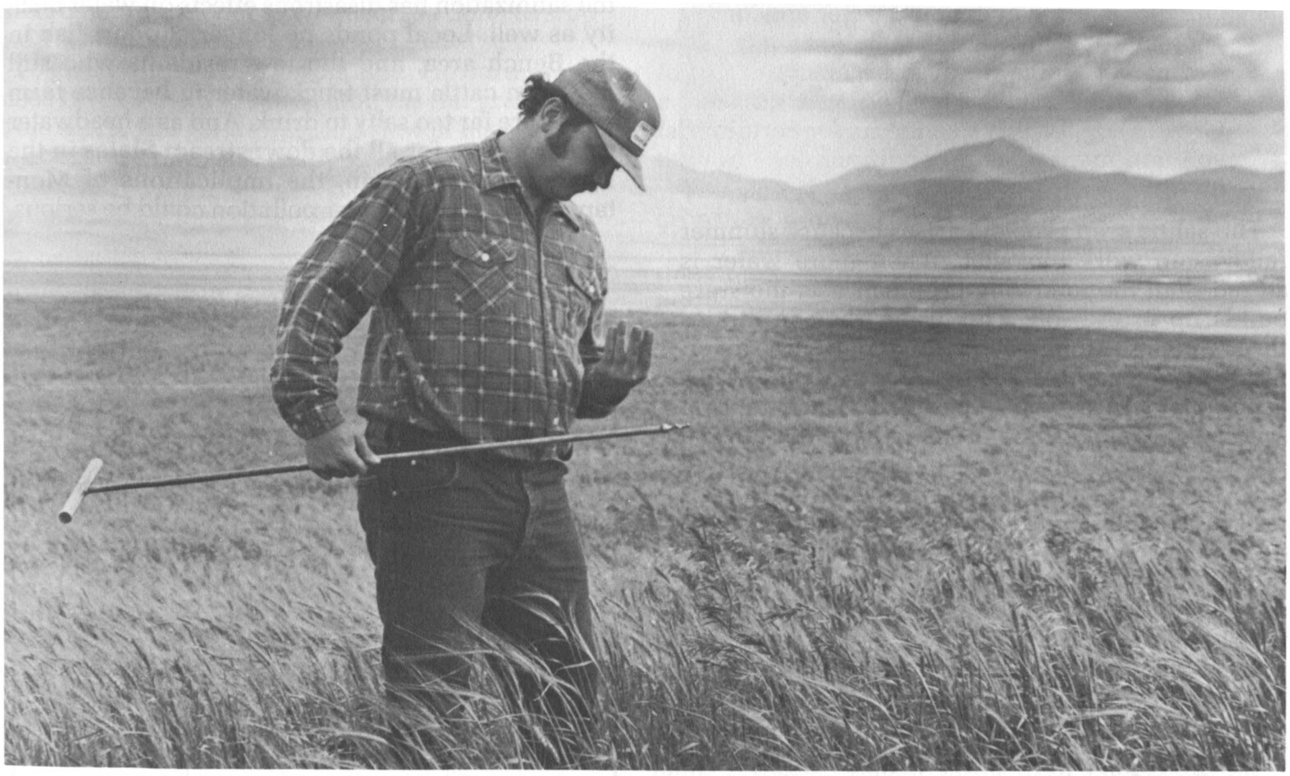


Photo credit: OTA staff

Howard Hanford using soil moisture probe to assess the available moisure supporting his growing barley crop

used almost exclusively on the Montana plains since the major land openings of the 1940's. The system is designed to conserve moisture in dryland regions where precipitation is not adequate to guarantee successful continuous crops. Under summer fallow, the farmer crops half his land each year and leaves half fallow, alternating cropped and bare strips each planting. The unplanted strips accumulate moisture in the soil to be used by the next season's crops. But this common crop management technology has proven inappropriate for the terrain.

Advantages of Summer Fallow

- Higher yield per planted acre.
- More stable production.
- Higher soil water content.
- Greater supply of available nitrogen in the soil.
- Aid in distributing the farmers' work load.
- Reduction of insect and disease problems.

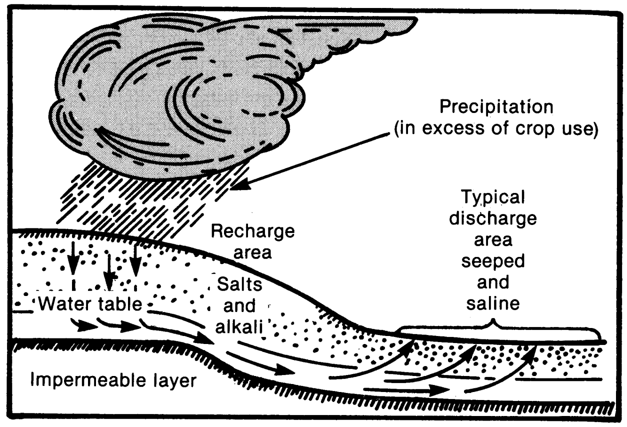
Disadvantages of Summer Fallow

- Greatly increased wind and water erosion.
- Increased air and water pollution.
- Lower soil water storage efficiency.
- Lower water use efficiency.
- Greater soil fertility decline under certain soil and management conditions.

The saline seep problem arises because summer fallow can work too well. When more water is stored than the following crop can use, moisture builds up in the soil. This water then infiltrates through the soil and reaches an underlying, impermeable layer of shale (see fig. A-2). Here the water accumulates, creating a "perched" water table (a secondary water table perched above the normal ground water level). Because of the nature of the soils, the water picks up numerous salts during this process. Eventually the salt-laden water migrates downslope. Where it breaks to the surface, either in lowlands or where the shale outcrops, a saline seep forms. As more and more water accumulates, the seep grows.

"Right now we have about 200,000 acres of farmland forced out of production by seeps, over 80,000 acres in Montana alone. And that's totally unusable. You can't even farm across it because your machinery will stick in the mire," says Dr. Paul Brown, a USDA soil scientist who, until his retirement, was the backbone of seep research in the region.

Figure A-2.—How Dryland Saline Seepage Occurs

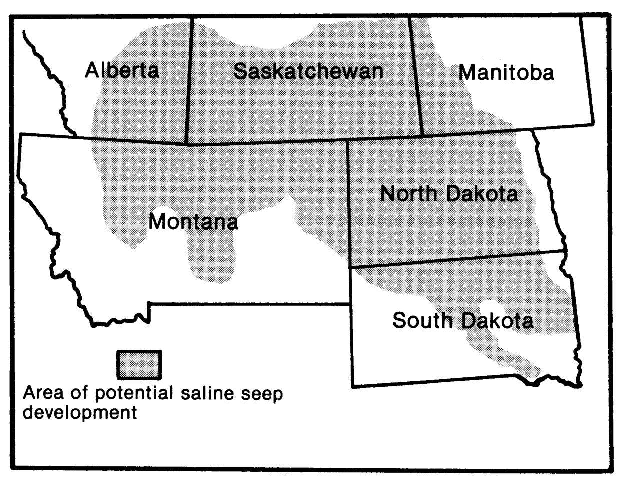


SOURCE: Dryland Saline Seep Control, AGDEX 518-5, Alberta Ag Ext. Offices, 1979.

"The problem affects a whole geologic region including much of Montana, South Dakota, North Dakota, Wyoming, and Canada's prairie provinces, with seep acreage growing by about 10 percent a year," he adds (see fig. A-3).

More than the land is degraded by saline seeps; the salinization has disastrous effects on water quality as well. Local ponds no longer support fish in the Bench area, and the few residents who still maintain cattle must truck water in because farm ponds are far too salty to drink. And as a headwater recharge area for all the downstream States in the Missouri River Basin, the implications of Montana's seep-caused water pollution could be serious.

Figure A-3.—Northern Great Plains Region, Showing Area of Potential Saline Seep Development



SOURCE: Saline Seep in Montana, Loren L. Bahls, ecologist, Marvin R. Miller, hydrologist, 1979.

When a seep first breaks out, it can look innocuous—just a small, wet pothole you have to skirt with the planter. Generally, farmers do not even realize they have a problem until a seep grows to a quarter acre or so. But depending on the site, saline seeps have grown as large as 200 acres, and that is a substantial amount of land to lose. During dry weather, seeps look something like black bathtubs with white salt rings—that is how much salt can actually accumulate on the surface as the seep water evaporates. Most seeps will be barren, almost swampy. Sometimes Kochia, a salt-tolerant weed, will grow around the edges, but most plants cannot live in such a saline environment.

"Montana farmers have an inherent disbelief that excess water could be a long-term problem on their land," Dr. Miller says. After all, theirs is a notoriously dry climate. And they grew up with stories of the great droughts, the giant dust clouds, and the many who were forced "bust" by the lack of water. So it can take some convincing to show certain farmers that too much water could be a problem.

Howard Hanford was one farmer who did not need convincing. The 1,500 acres that he farms with his wife, two small children, and one full-time hired hand is a model of what can be done to stop and reclaim saline seeps.

To give visitors a feel for his land, Howard sometimes invites them to lunch atop his flat grain bin. From there, you get a sweeping view of his ocean—an ocean of grain, still richly green, undulating in the winds. His fields stretch, seemingly unbroken, all the way to the base of the Highwood Mountains to the north.

Photo credit: OTA staff

Large saline seep broken out on traditional summer-fallow land in Montana

The fact that the growth goes unbroken is notable; the alternating strips of fallowed land so common on the Montana landscape are missing. Under the cropping management system Howard uses—flexible cropping—whether he plants or not is dictated by the environment rather than by tradition. It is a system that makes Howard an innovator in the fight against saline seeps.

Flexible cropping, as the name implies, casts aside fixed cropping patterns. Instead, this method calls for the farmer to decide whether to plant or fallow a field based on the actual amount of stored soil moisture in the root zone and the average growing season precipitation.

"Measuring soil moisture is pretty easy with the soil moisture probe that Paul Brown invented," Howard claims. The probe is a simple tool—a solid metal rod with a small auger at the tip. The farmer merely twists the rod down into the ground; when the pushing gets difficult, the probe has reached the bottom of the moist soil layer. The auger then brings up a small soil sample.

For example, wheat needs about 9 inches of soil water. If the average rainfall is 6 inches, there needs to be 3 inches of stored soil water available to raise a good crop. If adequate water is not available, farmers using flexible cropping are still free to leave the field fallow.

The new system's flexibility extends to what crops are grown, too. Beyond the region's usual wheat and barley crops, this system includes rotations with alfalfa and oil seed crops such as safflower and sunflower. Such crops use more water and draw it from deeper in the soil, and so play a special role in the management of seep recharge areas.

By taking full advantage of all available moisture, flexible cropping allows farmers to grow more crops because they no longer leave half their land fallow. "Of course, it's not so simple as doubling your acreage and doubling your income. Some 20 percent of your land may be in sunflower or safflower, which don't generate the same income. And you don't plant as much wheat and barley," Dr. Miller explains. "But you have an advantage—five crops for five markets. If one market is down, you still have four others."

But perhaps more importantly, flexible cropping helps farmers prevent saline seep formation. By managing both soil and water more carefully, Montana's farmers can avoid losing land—and productivity—to seeps.

But there are tradeoffs. First and foremost in many farmers' minds, flexible cropping demands more work in planning and in operating the farm.

"My 1,500-acre farm in summer fallow would be a cinch," says Howard. "With continuous crops, you need more manpower, more equipment. You have to move fast; you've got 2 weeks to plant all your acreage. You've got to harvest it all before some hailstorm lays the whole crop flat." This need for speed often urges farmers to bigger equipment and therefore added investments.

And because the system is flexible, it requires more managerial decisions: planning to avert potential seep problems or reclaim existing ones, testing to monitor moisture and fertility, extra commitment to combatting weeds and diseases, and special efforts to find markets for hay and oil seed crops in a region tuned to a small-grain economy.

In long-term economics, saline seep causes deflated land values, higher operative costs, lost crop income, lost tax money to the State, and lost wheat to the Nation. But seep control methods such as flexible cropping cannot succeed if the costs of control exceed the cost of doing nothing. So far, the new cropping pattern seems relatively successful.

"The successes up here on the Bench are important examples for the rest of the State," Dr. Miller comments. "These people have a genuine sense of concern for their land, a pride."

In Chouteau County, which includes the Highwood Bench, more than 60 percent of the farmers are involved in seep control. Overall in the State, however, total involvement is closer to 1 percent. The high acceptance in Chouteau is because the Bench was the original focal point for seep research and control and because of the strong presence of HACA and local, State, and USDA/SEA-AR specialists.

To promote seep control over a wider area, the Triangle Conservation District, including 10 seep-prone counties, was formed. The strength of the district's efforts are its field personnel—people such as Ted Dodge and Jane Holzer who spend their time traveling in the district, meeting with farmers, and

Photo credit: OTA staff

Dr. Marvin Miller checks a well, monitoring subsurface water levels

discussing strategies for their particular problems.

"We work farm by farm," Mr. Dodge explains. "After a farmer applies for our help, we go out for an on-site visit. We'll map the seeps, drill a grid of wells to determine water movement below the ground, determine where the problem recharge and discharge areas are, and help with planning control measures."

Proximity and visibility give real boosts to farmer acceptance of seep management. "Our biggest draw is the drill rig. You get that out in one man's field and all his neighbors will appear, like a parade, to follow along and watch," Mr. Dodge recalls. The district almost always receives more applications after that.

Land lost to saline seeps is difficult to reclaim. "You can't just clean up after the problem, you have to prevent it," explains Dr. Brown. But experts have made progress in designing management schemes to prevent seeps and even bring some degraded land back into use.

First, the cause of the seep needs to be eliminated. To do this, the field team traces ground water movement to find the field or fields that are accumulating water. Since most seeps break out within a few hundred yards of their recharge area, the mapping is relatively localized. It is helpful that the scale of cause and consequence is so small; very often, seep recharge and discharge areas are on the same farm, making control easier. When seep problems do cross property lines, it can be more difficult to convince both landowners to participate in the cleanup.

"Generally, though, we've had really good luck getting neighbors to work together to mutual advantage," says Ms. Holzer.

Once the cause is determined, the prevention option chosen most often is to recrop the offending field with deep-rooted, water-loving perennials—for example, alfalfa. The hay crop will act as a sort of sponge, soaking up moisture from deep below the soil. The plants' leaves wick the excess water away into the air. Once the water regime is stabilized, the farmer often can return the field to more profitable crops as long as he monitors moisture levels carefully and alternates grains with high-water-use oil seed crops and hay. Some recharge areas, however, may have to remain in pasture or revert to natural grasslands to guarantee seep prevention.

When the flow of excess water is stopped, existing seeps should stop growing. But they are unlikely to disappear. Sometimes, as the seep area dries, the farmer can begin planting the edges of the patch with salt-tolerant crops and gradually bring it back into production. Many large seeps, however, cannot be reclaimed with present methods.

"Controlling seeps requires a delicate balance," Dr. Miller says. "A little mismanagement . . . and you could be right back where you were."

"The more progressive farmers are beginning to realize that they can't farm just by what's on the surface," adds Herb Pasha, the president of the Triangle Conservation District.

"We're learning that the technological fix often brings unforeseen consequences," says Dr. Miller. "For seeps, the hardware approach said 'if you have a problem with too much water, drain it.' But that doesn't work. We tried draining an acre seep to reclaim it; what we did was create a 5-acre seep further downslope."

"We have to look at the consequences of our actions first; you don't forge ahead without thinking ahead," he adds.

"It's one thing to define the problem; it's another to get solutions established on the land," says Dr. Brown.

For some, and not just the scientists, continued research is the key: "As long as that goes on, we keep learning," Howard Hanford insists. "That's why HACA was formed. But it's hard to get the Government to understand us; letters go back and forth, but we can't sem to connect. When Paul retires, I hope we don't lose our research base—there's too much more that needs to be done."

"A farmer is not your average character," Howard explains. "He is a little bit stubborn and stuck in his ways. An article in some paper won't convince him. He needs to see the field personnel, to see proof."

Proof in the field is especially important when some long-accepted practice such as summer fallow is in question. Saying it is an inappropriate technology is not enough; the alternative—flexible cropping—must be opened to scrutiny, tested, and refined for practical use. After all, it is not unreasonable for farmers to ride with proven methods, even if they have certain negative repercussions, if the alternative is an unknown.

Maintaining land productivity will be a continuing challenge for American agriculture, one that can be both enhanced and hindered by technology. As illustrated in Fort Benton, the most sustainable methods may not always be easiest. But when the threat is highly visible—wet, salty potholes swallowing the land—and the people are truly concerned, farmers, and agriculture, can and do change.

Appendix B

Virgin Lands

Introduction

When potentially productive virgin lands are brought into use, the relative profitability of farming or ranching on lands with lower inherent productivity can be reduced. Thus, one indirect consequence of developing high-quality virgin lands may be that some fragile lands are protected, perhaps converted from row crops to pasture as happened in New England when the fertile lands of the Midwest were developed. Sometimes opening new high-quality lands also can reduce the rate at which pasture sites are converted to cropland.

Some 36 million acres of non-Federal land had a high potential for conversion to cropland in 1977 (see table B-1), according to the National Agricultural Lands Study (CEQ, 1981). This land had favorable physical characteristics to support high-yield crop production and would require minimal efforts to be converted. Most of this land was used as pasture in 1977; presumably much of it already has been converted to cropland. Another 91 million acres of non-Federal land were identified as having a medium potential for conversion to cropland. Most of this was pasture or rangeland; some was forest. Clearing, erosion protection, or other costs would make development of this land significantly more expensive than on the high-potential land.

The issue of converting land into and out of agriculture, and from one use to another within agriculture, has been investigated by the National Agricultural Lands Study, and so it is not treated in detail in this report. That study did not, however, consider the potential for agriculture development in Alaska, where large areas of potentially arable lands are found.

Table B-1.—Potential Cropland of Non-Federal Land (million acres)

Conversion potential:	High	Medium	Low	Zero
Pastureland	18	33	47	35
Rangeland	9	30	97	271
Forestland	7	24	109	230
Other land	2	4	15	52
Total	36	91	268	588

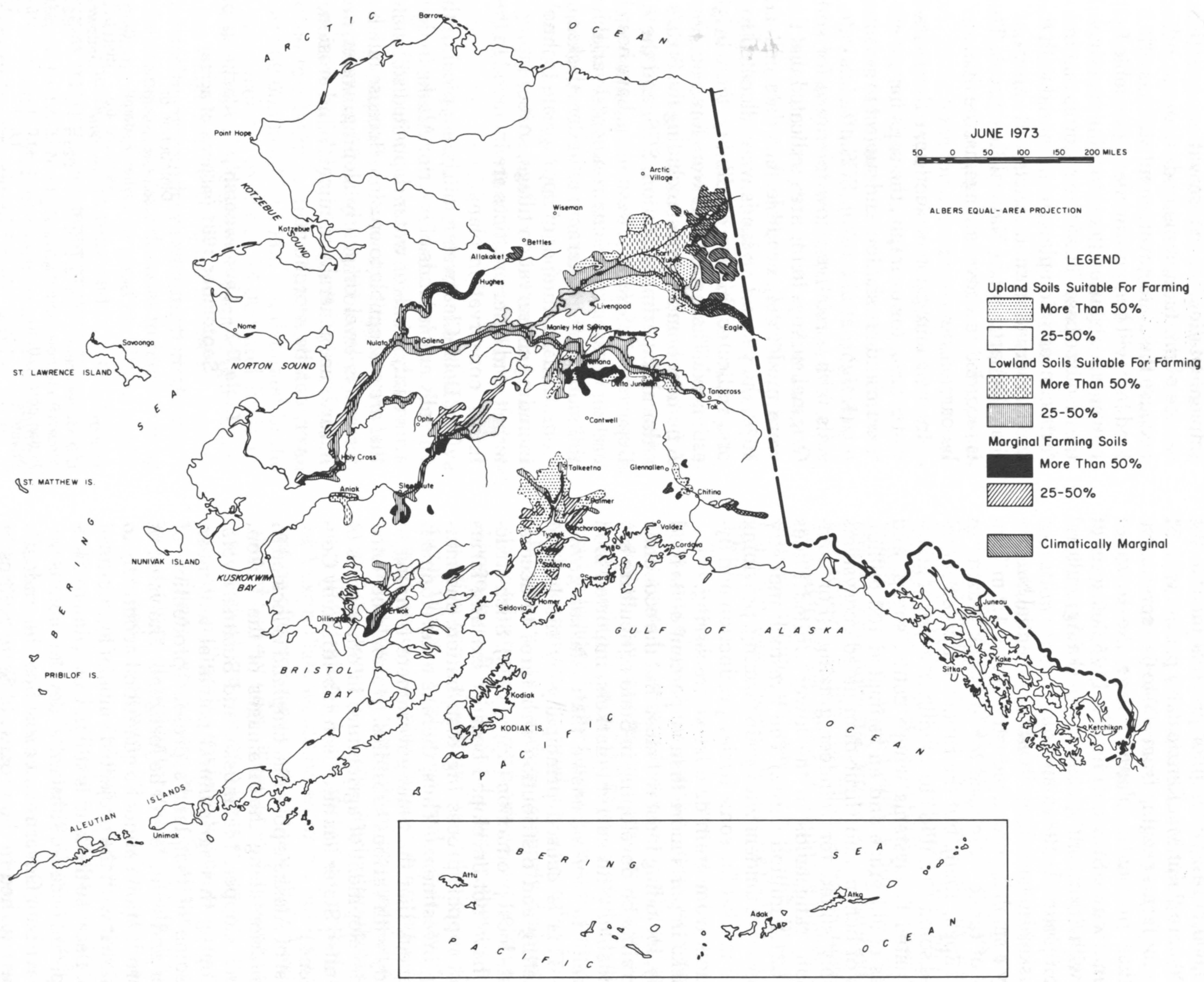
SOURCE: U.S. Department of Agriculture, "Resources Conservation Act: Appraisal 1980," 1980.

Alaska's Virgin Lands

How much of Alaska's virgin lands are potential croplands is not known precisely. The Soil Conservation Service (SCS) cites 18.5 million acres of Alaska land suitable for farming (USDA-SCS, 1980) (see fig. B-1). This is Class II and III land with soils that have no severe erosion hazard, but that generally do require conservation measures to sustain productivity. But previous analyses of the same data reported that Alaska had 8.9 million potentially arable acres. The substantial increase in the estimate of potentially arable land from 8.9 million to 18.5 million acres was not the result of new data on the extent of land available but rather a changed understanding of what constitutes arable land under Alaskan climate conditions.

There is a mistaken perception that the Alaskan climate precludes substantial agricultural development. Although this is generally true of areas in the arctic climate zone, much of the State is in the continental climate zone, where the frost-free growing season is about 100 to 110 days (Epps, 1980; Alaska Rural Development Council, 1974.) This is a short season relative to most other parts of the United States, but it is adequate for many crops. Soil and air temperatures during the growing season can constrain the growth of some crops, such as corn, but there are other including barley, oats, some wheat cultivars, potatoes, vegetables, and the oilseed canola that produce well in this climate. Some of these, notably barley, oats, canola, and several vegetables, apparently can take advantage of the very long hours of sunlight during the Alaskan summer (up to 20 hours per day). Barley yields, for example, can double those achieved in the Midwest.

Alaska has some active cropland—about 380 farms with 30,000 acres of crops in 1980. (For comparison, cropland in the lower United States totals 413 million acres.) The State government is committed to converting 500,000 more acres to cropland by 1990. To do this, the State is subsidizing rapid agricultural development with large-scale pilot projects. The largest of these is the Delta Project in the Tanana River drainage, where 22 farmers took ownership of about 2,600 acres each in August 1978. Clearing and development proceeded rapidly and over half of the 58,000-acre project was in


JUNE 1973
50 0 50 100 150 200 MILES
ALBERS EQUAL-AREA PROJECTION
LEGEND
Upland Soils Suitable For Farming
More Than 50%
25-50%
Lowland Soils Suitable For Farming
More Than 50%
25-50%
Marginal Farming Soils
More Than 50%
25-50%
Climatically Marginal
ARCTIC OCEAN
Barrow
Point Hope
Arctic Village
Wiseman
KOTZEBUE SOUND
Kotzebue
Bettles
Allakaket
Hughes
Livengood
Eagle
Manley Hot Springs
Nome
Savoonga
ST. LAWRENCE ISLAND
NORTON SOUND
Nulato
Galena
Delta Junction
Tanacross
Tok
Cantwell
BERING SEA
Ophir
Holy Cross
ST. MATTHEW IS.
Aniak
Talkeetna
Glennallen
Chitina
Palmer
Anchorage
Valdez
Cordova
NUNIVAK ISLAND
KUSKOKWIM BAY
Dillingham
Seldovia
Homer
Seward
Juneau
GULF OF ALASKA
PRIBILOF IS.
BRISTOL BAY
Kake
Sitka
Kodiak
KODIAK IS.
Ketchikan
PACIFIC OCEAN
ALEUTIAN ISLANDS
Unimak
Attu
Adak
Atka

production by 1981. The project is to be expanded by 60,000 acres. Other pilot projects include the 15,000-acre Point MacKenzie dairy project with 31 tracts for farms ranging from 300 to 640 acres each. Another project is planned near the town of Nenana, where SCS has identified 175,000 acres of soils with "excellent" potential (Alaska Agricultural Action Council, 1981a and b).

Alaska also has a large livestock potential but currently a small livestock industry. About 1.2 million acres of range were used for livestock grazing in 1978 (Epps, 1980), but the rangeland potential includes some 10 million to 13 million acres of grass-dominated ecosystems where cattle, sheep, and horses could graze and an estimated 100 million acres of lichen- and shrub-dominated ecosystems possibly suited for reindeer grazing. (For comparison, rangelands in the lower United States total 621.4 million acres.) The livestock industry may grow in tandem with grain farming, providing a local market for some barley production and by-products from grain or oilseed processing.

Alaska imports more than 90 percent of its food supply, including most red meat. But the economic constraints on developing in-State agriculture are formidable. With current markets, imported food generally is less expensive than Alaskan-grown food. This is caused principally by the lack of marketing and distribution structures to accommodate local production (Epps, 1980). Such structures have not developed because existing farms cannot support processing, distribution, and marketing investments. Thus, there is a development bottleneck that the State government is trying to remedy with various subsidies. (It should be noted that development of agriculture in other parts of the United States has also been subsidized by Government.)

Most of Alaska's potential cropland is located in the interior along the drainages of the Yukon, Tanana, Copper, Matanuska, and Susitna rivers. Developing this agricultural potential will mean that some of that land's present production of timber and wildlife will be foregone. The value of this production cannot be quantified accurately to compare it with the projected value of agricultural crops. Because the land is still in Government ownership, and because substantial development is unlikely without Government subsidies, the tradeoffs will be weighed in the process of State politics in Alaska. In any case, development will be a deliberate and gradual process that could profit from the study of development mistakes made in other States and from advances in the understanding of agricultural ecology.

Alaska probably has more control over farmers' implementation of conservation practices and choice of production methods than any other State, because the State government still has title to most land that will become farmland (see table B-2). This power is being used to protect the sustainability of the resource base. The State requires that individual farm conservation plans be prepared with the local soil conservation subdistricts and approved by the State Department of Natural Resources. The plan is recorded as a covenant against the title, so it must be carried out.

In the main pilot project near the Delta-Clearwater area, for example, the soils have a silt-loam texture and are shallow and subject to seasonal drying (Knight, et al., 1979). SCS officials rate these soils with a relatively low tolerance for soil loss. Original surveys in the area indicated that the soils were moderately erodible, but data collected in 1978, the year when lands were allocated to farmers, indicated higher erodibility than originally estimated. These problems were foreseen, however. A number of institutions, including the State's Agricultural Experiment Station, SCS, and the Alaska Department of Natural Resources, have been cooperating in research on environmental variables and soil management alternatives under Alaskan conditions. Thus, a number of appropriate technologies including conservation tillage, stripcropping, shelterbelt, and other practices are included in the new farms' conservation plans.

The Delta-Clearwater soils are typical of the potentially arable lands of interior Alaska in that they are mainly wind- or water-deposited soil materials that are susceptible to erosion. Because much of the terrain is level or gently sloping, water erosion hazards are generally minimal. Wind erosion, however, can be a problem.

Table B-2.—Landownership in Alaska as of September 1981 (millions of acres)

Landowner	Distribution of landownership when Federal transfers are complete[a]	Current distribution of landownership
U.S. Government	225.5	302.4
Alaska State government	104.5	53.0[b]
Indian corporation	44.0	18.6[c]
Private	1.0	1.0
Total	375.0	375.0

[a]Table does not include transfers from State to private lands.
[b]Alaska State government selection period ends January 1994.
[c]The balance of Indian Corp. lands has been selected but title transfer has not yet been approved.

SOURCE: Beaumont McClure, Bureau of Land Management, Alaska Programs Staff, September 1981.

With range ecosystems, as with croplands, the environmental parameters that determine which Alaskan land is suitable for grazing are still being determined. The 1979 RPA report notes that Alaskan ecosystems generally have low productivity levels. Only the shrub thickets and the Aleutian moist tundra with the tall bluejoint reedgrass produce over a ton of herbage and browse per acre on their best sites. The report indicates that there are about 19 million acres in these two types of rangelands but does not say what part comprises the best sites (USDA, 1979). (One ton of herbage per acre is a fairly severe test—only about one-eighth of the rangelands in the contiguous States are expected to produce at this level, even when in top condition.)

The grass-dominated, rangeland ecosystems located in the south-central coastal region and on the eastern Aleutian Islands did not evolve under intensive grazing by native herbivores. Thus, the existing plant communities may change substantially if grazed by domestic livestock. Secondary environmental effects will need to be monitored carefully as the livestock industry expands. Another consideration is the rate of nutrient cycling under Alaskan rangeland conditions. Research on native hay yields indicates that once-per-year harvests without fertilization tend to cut production in half, and persistent use by livestock could have more severe effects (Mitchell, 1974). Fertilizer can sustain production, but fertilizing rangelands is rarely economically feasible.

Tundra rangelands are much more extensive than grasslands, and reindeer, which graze the lichen- and shrub-dominated tundra and are physiologically adapted to survive the long winters with little supplemental feeding, could be used to expand the livestock industry in Alaska. Reindeer were introduced to Alaska in 1891. The herds increased to over 600,000 head by 1932, but declined in the next two decades to about 25,000 and have increased only slightly since. Overstocking and consequent range failure are cited as partial reasons for the decline of reindeer ranching (USDA, 1980).

Lichens and shrubs take decades to recover from overgrazing but are now in good condition again. Recently there has been renewed interest in reindeer, and range management plans now are being deesigned to avoid overgrazing. Forage on summer range is plentiful and the main range management problem is to provide sufficient winter range to allow for long rest periods in a rest-rotation grazing system. (After a lichen has been disturbed by reindeer, it takes 2 years for remaining fragments to start new plants. Thus, winter sites are rested for 4 to 8 years in the new grazing systems (U. Alaska, 1980)). SCS and the University of Alaska initiated resource surveys on tundra rangelands in 1976 using imagery from Landsat, the National Aeronautics and Space Administration's Earth resources satellite, and extensive field surveys. Conservation range plans are now nearly complete for 15 million acres of the Seward Peninsula.

Some native animals that are well adapted to tundra and other Alaskan habitats probably are suitable for domestication to produce food and fiber. For example, small-scale husbandry of musk oxen, which produce high-quality wool, has demonstrated some potential. However, intensified management of caribou or other animals now considered to be "game" would require a philosophical attitude change on the part of the public and resource management professionals (USDA-RPA, 1979).

The impact of cropland development and increasing herds of exotic livestock on the native wildlife resources of Alaska is likely to remain an issue as the State develops its resource potentials. For example, a large part of the State's potentially tillable land is located in the Upper Yukon Basin, an area with extraordinarily productive waterfowl habitat. The waterfowl reproduce in poorly drained flood plains which abound with oxbow and pothole lakes. Above these flood plains, however, there are some 3 million acres of well-drained tillable soils (Drew, 1979). Whether to plan eventual development of the Upper Yukon Basin's tillable soils has been a point of contention and the topic of congressional hearings (U.S. Congress, 1979). Agriculturalists recognize that draining and clearing the pothole areas of Yukon Flats would be an error, but believe the option of developing some of the well-drained lands should be kept open. They note that some wildlife and agriculture can coexist and predict that producing small grains could enhance waterfowl habitat. Other experts are less optimistic about the coexistence of agriculture and wildlife. They are concerned, for example, that agricultural development in the Upper Yukon region would eventually bring pressures to regulate the flow of the river, which in turn would harm waterfowl reproduction.

Other conflicts may arise as agriculture develops. Irrigation is likely for some arable areas, and ground water use could become controversial in permafrost regions. Irrigation and agricultural runoff also could affect salmon spawning areas.

Conclusions

Many important questions remain to be answered about both farming and livestock enterprises in Alaska. The State is in the unique position of being able to learn from the decades of agricultural experience in the lower 48 States. But direct transfer of agricultural technologies from lower latitude research and development is not sufficient because crop production and range management in Alaska involve significantly different soil temperatures, climate, and growing seasons. The ecology of agriculture—dynamics of nutrient cycles, soil formation, and plant physiology, for example—need to be better known in order to design farm and range management programs that will sustain the initially high productivity of Alaska's virgin agricultural resources.

A major threat to the long-term maintenance of Alaska's inherent land productivity is the prospect of making decisions with inadequate data. For example, the majority of Alaska's potential agricultural soils are intermingled with or adjacent to forestlands and yet only very limited assessments have been made of the interrelationships between forest management and agricultural land management. Inadequate climate data is another example. Under cool weather growing conditions, the timing of chemical inputs and other farming practices is critically important. But knowledge of microclimates and data bases for weather forecasting are inadequate to support optimum decisions. The soils data used to identify the 18.5 million acres of potentially tillable soils is a preliminary survey, adequate for broad planning but not for project- or farm-level decisions. Similarly, not enough is known about the ground water hydrology of the potential agriculture lands to foresee the conflicts that may arise.

Thus, Alaska must maintain a strong research program if it is to develop its agricultural potential and help to reduce the economic pressure to consume land resources elsewhere. The role of the Federal Government will be to support the necessary research for site-specific management decisions and to provide sufficient expert personnel in such agencies as SCS to continue the conservation planning momentum that has characterized the accelerating agricultural development of the past 3 years.

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Appendix C

Soil Productivity Variables

Organic Matter

Soil organic matter is important to soil productivity because it: 1) contributes to the development of soil aggregates, which enhance root development and reduce the energy needed to work the soil; 2) increases the air- and water-holding capacity of the soil, which is necessary for plant growth and helps to reduce erosion; 3) releases essential plant nutrients as it decays; 4) holds nutrients from fertilizer in storage until the plants need them; and 5) enhances the abundance and distribution of vital soil biota. The importance of these functions varies greatly from one soil type to another.

The best soils for plant production possess substantial water-holding and ion-exchange capacities, good physical structure, and thriving populations of bacteria, fungi, and invertebrates. These attributes are highly correlated with soil organic matter content derived from plant remains and microbial synthesis. Good soil structure depends on aggregation of colloidal clay minerals held together by organic molecules. These organic molecules are being consumed continually by microbes and other invertebrates, so maintaining soil organic matter requires a steady influx of plant biomass from root decay and aboveground organic residues (Jenny, 1980).

Effects on Productivity

Increased soil organic matter commonly improves water infiltration, decreases evaporation, fosters more extensive and deeper root systems which may make more moisture available to crops, and improves the efficiency of water use by the crop.

Major benefits to soil fertility are derived from soil organic matter largely through its effect on aggregation of soil particles. Increased particle aggregation lowers soil bulk density, consequently improving tilth, increasing soil percolation and aeration characteristics, and improving soil drainage, microbial activity, and temperatures. Fine-grained organic matter and soil clay minerals form soil colloids, which play major roles in supplying nutrients to plants. Some soil colloids have the ability to hold abundant plant nutrients on their surfaces where the nutrients are easily exchangeable with hydrogen ions produced by plant roots.

The main natural source of nitrogen for plant growth is soil organic matter. Mineral soils ordinarily contain about 400 to 6,000 lb per acre of nitrogen in the plow layer and somewhat lesser amounts in subsoils. However, most of the nitrogen is in soil organic matter and is unavailable to plants until it is converted into ammonia and nitrates by micro-organisms (Allison, 1973).

Soil organic matter may contain from 15 to 80 percent of the total soil phosphorus, an important plant nutrient. Micro-organisms use inorganic phosphorus and synthesize organic phosphorus, subsequently providing an important link in the soil/phosphorus plant chain. Like nitrogen, there are active and inactive forms of phosphorus in soil organic matter. The active substances chiefly are residues that have not yet been transformed by microbial processes. A substantial amount of organic phosphorus released during the plants' growing season comes from decomposition of this soil organic matter. The literature contains numerous statements that the addition of farmyard manure and green manures will increase the availability of soil phosphorus to plants; however, experimental evidence to support such statements is scarce (Allison, 1973).

Soil organic matter helps control the supply of potassium for plant growth. Potassium is adsorbed on organic colloids and is present in organic residues and living micro-organisms (Mulder, 1950). As these reservoirs of available potassium are depleted, they are replenished both by potassium released from inorganic compounds and from added organic residues. Under many conditions, the organic residues are the important factor in maintaining the soil's plant-available potassium.

Even though required in only small amounts, the micronutrients sulfur, calcium, magnesium, iron, copper, manganese, zinc, boron, and molybdenum also are essential for general plant growth. Here, too, soil organic matter plays a major role in assuring that these trace elements remain available for plant uptake.

Maintenance and Loss of Soil Organic Matter

Farming practices affect the organic matter content of soil. Where the land is plowed, soil organic matter decreases through oxidation. Keeping fresh-

ly broken virgin land bare for long periods markedly decreases soil organic matter. The decrease occurs mostly in the first 25 years after the soil is broken; after that a new, but lower, steady state of organic matter content is reached.

Under cultivation, much of the vegetation produced is removed, water and wind erosion are accelerated, and frequent cultivations favor oxidation of organic matter. The reduction of soil organic matter content can be reduced significantly by adopting cropping systems that reduce the frequency and degree of tillage and keep the soil protected by vegetation as much of the time as possible. Field experiments at Mandan, N. Dak., showed that the loss of nitrogen during the first 33 years of cropping was 34 percent for continuous corn while the loss with continuous small grains was 14 percent (Allison and Sterling, 1949). Where grass sods are maintained, even in regions of heavy rainfall, there is little loss of nitrogen or organic matter.

The smaller the crop and the more completely it is removed from the soil, the more rapidly the soil humus will decrease, and conversely, the larger the crop and the more of it that is returned to the soil, the higher the level of organic matter that can be maintained. Nevertheless, the level in any tilled soil usually will be considerably below that of the original virgin soil.

Research on Changes in Soil Organic Matter

Changes in the amount of organic matter in soils occur relatively slowly. Research of several years' duration is required for properly documenting the effect of cropping systems, soil treatments, and other management practices on the soil organic matter. Few such studies have been initiated in recent years, in part because many agronomists and soil scientists feel that the effects of many management practices on soil organic matter are reasonably predictable. Another reason is that funding for long-term research generally is not as available as for shorter term research.

Data on the effects of management practices on soil organic matter come mostly from studies initiated years ago, many of which now have been discontinued. However, some long-term studies still are under way, notably the Morrow Plots in Illinois and Sanborn field in Missouri. European studies include those of Rothamsted Experimental Station in England, and those at Grignon, France.

Information Needs

Improved data and understanding in a number of areas will assist in determining the long-term impacts of new and old technologies on soil productivity. Further information is needed on how soil organic matter affects soil productivity under various cultural practices and climatic conditions, and on how cultural practices affect organic matter. Improved data are needed on optimum levels of soil organic matter for specific sites, specific crops, and specific cropping systems. As the cost of commercial fertilizers increases, new data on the interrelationships of soil organic matter and commercial fertilizers will become increasingly important. Similarly, by enhancing soil tilth, organic matter ultimately may help reduce the amount of fossil fuel used during plowing, planting, and other such field activities.

As organic wastes, some containing high levels of toxic heavy metals, are introduced into agricultural practices, further understanding of how soil organic matter holds or releases these toxic substances will become increasingly important.

Biota

Most soils are inhabited by a diversity of life forms. The soil biota include numerous microbes, a wide variety of invertebrate animals, and a few vertebrates. Most soil biota are microscopic or, at the largest, tiny to the naked eye. Some larger soil invertebrates such as earthworms, ants, other soil insects, and land snails and slugs are also important. Small mammals are the dominant vertebrate animals found below ground, but some amphibians, reptiles, and even a few birds live at least a part of their lives within soils.

Soil organisms often modify and enhance the soil by their activities. They are vital to the formation and maintenance of the natural soil system and perform functions essential for plant growth. Before the widespread availability of commercial fertilizers, nutrients recycled by the biota were recognized as a major component of land productivity and so soil ecology ranked high among the agricultural sciences. In recent decades, however, there has been much less emphasis on soil biology.

Scientists generally are not alarmed about the possibility of pesticide use causing severe harm to soil ecology in the near future. Insecticides and herbicides in use are tested for their impact on soil

biota. Inhibition of some biological processes and suppression of particular groups of biota occur, but generally the gross effect of each pesticide application seems neither great nor long-lived. Pesticides do cause changes in soil insect and earthworm populations, but the impact of these changes on long-term land productivity is not known.

Frequent applications of toxic chemicals probably are changing the composition of soil biota communities, favoring species that can adapt to the new chemical environment. However, methods are not well-enough developed to make practical differentiation among microbe species in the field, and soil invertebrates have been studied so little that many are still unknown. Thus, the cumulative effects of agricultural technologies on productivity will not be measured until advances are made in the science of soil biology.

Micro-organisms

Soil micro-organisms include bacteria, fungi, actinomycetes, and protozoa. A critical function they perform is to generate nutrients essential for plant growth. Micro-organisms are either the sole or chief natural means for converting unavailable forms of nitrogen, sulfur, phosphorus, and other elements in soil into products that plants use. Thus, the rate at which micro-organisms convert organic nitrogen and other nutrients to inorganic products determines the rate of plant growth. Hence any action deleterious to microbial processes critical to plant nutrition would have adverse consequences.

Soil micro-organisms also modify soil structure by forming humus that binds minute soil particles into larger aggregates. These larger structures are beneficial because they promote root development, improve soil aeration, and lead to improved soil moisture.

Microscopic forms of life are responsible for decomposing organic matter and releasing elements not used directly as plant nutrients. Some of these elements may be converted to gaseous form, as in the case of carbon and nitrogen. By such conversions, micro-organisms in part regulate the chemistry of the atmosphere and the Earth's surface. Microbial decay of plant remains is useful because some crop residues contain naturally occurring toxic substances that at high concentrations are deleterious to plants (Alexander, 1980).

Further, soil micro-organisms are responsible for decomposing a wide array of synthetic chemicals deliberately or inadvertently released into agricultural soils and water, including pesticides, industrial wastes, and air pollutants. Micro-organisms convert many chemicals to inorganic products. The breakdown process may lead to detoxification of toxic chemicals, the formation of short- or long-lived toxicants, or the synthesis of nontoxic products. Scientists have investigated only a few of the multitude of chemicals to determine what breakdown products are formed when micro-organisms encounter chemicals in natural systems (Alexander, 1981).

Some data are available on micro-organisms and their effects on soil chemistry, but numerous and considerable voids exist in the data base. The processes most frequently studied are the decomposition of soil organic matter, nitrogen mineralization, nitrification, the decomposition of added organic materials, and nitrogen fixation.

Most of the major technological innovations that might affect the microbiology of agricultural and rangeland soils have been evaluated for their impacts on microbiology, at least in part. Thus, the likely impact of a particular type of technological change or agricultural operation on soil microbiology can be predicted, but only in relatively gross, qualitative terms. The studies generally have not been conducted in a fashion that would allow extrapolation from the particular investigation to conditions prevailing elsewhere. Thus, generalizations cannot be made on the quantitative responses of microbial populations in different soil types, different climatic regions, and areas that have different types of vegetation (Alexander, 1980).

Essentially no models have been devised to predict how agricultural technologies will affect the aggregate of microbial activities that are important to crop production and rangeland management. Specific interactions among micro-organisms, and between microbial predators and their prey, are not known. Thus, practical methods do not exist for scientific advisors, farmers, and policymakers to predict the impact of existing or alternative technologies on microbial plant production or soil fertility (Alexander, 1980).

Because policymakers, public interest groups, and sometimes Federal agencies have been acting largely with inadequate information, the impacts on microbial activities may sometimes be overdramatized, whereas in other instances a significant problem may be wholly ignored. In addition, this lack of data on microbial populations and activ-

ities means that the risks, costs, or profits that farmers incur by applying new agricultural technologies are largely unknown (Alexander, 1980).

Soil Invertebrates and Vertebrates

Soil invertebrates include such animals as earthworms, slugs, land snails, ants, and other insects. These animals carry out the early stages of the physical and chemical decomposition of all types of organic debris in or on the soil. Most soil invertebrates also act as carriers of microbial propagules (e.g., seeds, spores) and so they inoculate the organic matter as it is passed through their bodies. The final stages of biochemical decomposition are also accomplished by microbes, thus recycling nutrients, forming humus, and fostering soil particle aggregation (Dindal, 1980).

Historically, most research on the biology and ecology of soil invertebrates has been carried out in Europe and Russia. Although there were occasional American publications on soil organisms before the late 1960's, it was not until then that a major research thrust was initiated in this country. Even today, few U.S. colleges and universities offer courses in soil biology. Consequently, much of the understanding of the general functions of soil invertebrates comes from the works of foreign scientists. This is exemplified by the recent International Colloquium of Soil Zoology held in Syracuse in 1979, "Soil Biology as Related to Land-Use Practices." Of the 96 papers presented, 20 dealt with effects of agriculture on soil fauna, and only one of these 20 papers described work conducted in the United States (Dindal, 1980).

This dearth of research in the United States can be explained by several factors: 1) agricultural practices in the United States have not been developed to take advantage of soil organisms; 2) a lack of funding and of an organization with "lead agency" status to oversee research in this area; 3) a lack of employment opportunities in this field of research; 4) a lack of cooperation between Federal agencies and soil invertebrate ecologists; and 5) the lack of research is partially a result of the nature of the research itself (i.e., procedures may be extremely rigorous, tedious, and time-consuming).

Research on soil invertebrates generally encounters one or more of the following problems. First, to get useful data on how changes in soil invertebrate ecology occur, many (generally 10 or more per site) small samples per year must be taken from treated and control areas. Second, few croplands have been sampled for soil fauna because the soil is regularly disturbed by plowing, planting, cultivation, and harvests, thus hindering needed control. Third, the sheer numbers of soil organisms per sample can become overwhelming to assess. For example, a soil sample 5 cm in diameter by 3 cm deep in a central Ohio field may have a range of 30 to 1,000 individual microarthropods in it (Dindal, Folts, and Norton, 1975).

The massive number of organisms in a soil sample increases the problems of sorting, counting, identifying, and determining the ecological roles of these creatures within a reasonable time, and demands extreme patience and technical knowledge. To complicate such research further, between 5 and 25 percent of the microarthropods alone found on most new study sites will be species never before described taxonomically. Further, the available taxonomic keys to identify soil biota are European or Russian and do not apply adequately to many U.S. fauna. Life history details of these new forms also are unknown, thus demanding further time-consuming laboratory and field consideration (Dindal, 1980). Finally, soil invertebrates and vertebrates exist as part of a microcommunity within the soil. The structure and function of this community, too, must be assessed.

Despite the lack of quantitative data on the impact of agricultural technology on invertebrates in most U.S. soils, some qualitative information exists. The situation is not the same for soil vertebrates, which include such animals as moles, gophers, mice, other burrowing mammals, and some reptiles and amphibians. Even though some people worry that agricultural technologies may harm beneficial soil invertebrates, the activities of soil vertebrates are commonly and narrowly viewed as negative—e.g., making burrows in which farm machinery can become entrapped, or consuming valuable grain or forage. Some studies of soil vertebrates suggest that they may also have beneficial impacts, such as breaking up hardpan a foot or more below the surface, thus improving drainage and increasing rooting depth (Ross, et al., 1968). Unfortunately, such ecology studies typically are conducted on virgin land and are difficult to relate to agricultural productivity.

Soil animals play an integral, if limited, part in humus formation. Their chief contribution to land productivity lies in the degree that microbial activity is enhanced by their activities. Together, soil fauna and microbiota play an indispensable role in soil formation, soil profile modification, nutrient release, and the mixing of organic and inorganic materials. Holistic field studies of invertebrate-soil, vertebrate-plant productivity associations are practically nonexistent. Until such studies have been

undertaken on different soils under various agricultural conditions, scientists and farmers will lack the information needed to design and implement farming systems that can make optimum use of scarce resources.

Soil Chemistry

Each agricultural crop, whether plant or animal, that is removed from the land carries with it some soil nutrients. This nutrient loss is in addition to the losses from soil erosion, leaching, denitrification, and volatilization of certain elements. If the nutrient supply is not replenished, the soil's fertility will decrease.

Commercial fertilizer helps maintain the supply of soil nutrients needed for continued agricultural production. Most people are aware that large amounts of commercial fertilizers are applied to U.S. lands each year, but are less aware of the soil nutrients that are taken from the land in the form of agricultural products. For example, 30 lb of phosphorus are removed with 50 bushels of wheat (3,000 lb) (Shacklette, 1977). Similarly, Hawaii exports 2,200 tons of potassium each year in its pineapple crop alone. Losses of nitrogen and sulfur follow the same general trend as those of phosphorus and potassium. Even well-maintained organic farms that carefully collect and return the farm's unused crop residues and animal wastes to the soil can only reduce but not eliminate nutrient losses.

Natural weathering produces new soil and releases additional nutrients, but the process is exceedingly slow and thus unable to keep pace with modern agriculture's needs. Whether soil nutrient replacement is accomplished by addition of natural or commercial fertilizers is an individual's choice, but agriculture has to replace what it has taken from the soil if it expects to accomplish long-term, sustainable crop production.

Judicious use of fertilizers is the key. Additions that are too low result in nutrient deficiencies in the soil and lower crop yields. Where fertilizers are applied too heavily, chemical excesses in the soil, runoff, and ground water not only are unnecessary capital expenses but also detriments to other parts of the natural resource base.

Most of America's croplands are fertilized so that the exchangeable concentration of nutrients remains at a level that will sustain high yields. Normally, fertilization requires frequent (usually annual) input of nutrients. The cost of fertilizing is spiraling because its production is highly energy intensive, especially nitrogen fertilizers. In fact, of the on-farm energy expenditures for food production in 1977, 36 percent was for fertilizer (Pimentel, et al., 1973; Olson, 1977). Thus, the on-farm production costs of food can be expected to continue to rise with the cost of energy as long as present energy-intensive fertilizer technology is used.

Commercial Fertilizers

Commercial fertilizers generally are synthesized or manufactured through various industrial processes and contain one or more of the essential plant nutrients (Fertilizer Institute, 1976). These include important soluble compounds of nitrogen, phosphorus, and potassium. Limestone, gypsum, dolomite, greensand (glauconite), rock phosphate, and granite are common rocks that when ground to a fine particle size also can be added to cropland soils to provide calcium, magnesium, potassium, and phosphorus. These finely ground, less soluble natural materials usually are not included in the category "commercial fertilizers." They were the basic inorganic soil nutrient inputs prior to industrial synthesis of commercial fertilizers. Because commercial fertilizers are synthesized, highly soluble, and concentrated, some people are concerned that such fertilizers may have certain long-term adverse impacts on soils, the soil biota, water supplies, and other parts of the natural resource base. The following discussion briefly examines the impacts of the common commercial fertilizers on land productivity.

NITROGEN FERTILIZER

The nitrogen fertilizers used today are acid-forming. This can be a benefit or a potential problem depending on the specific soil. In naturally alkaline soils, acid-forming fertilizers can increase productivity. However, in naturally acid soils, fertilizers can increase the soil's acidity and reduce crop yields unless lime is applied to neutralize the acidity. Thus, depending on soil properties and management, the residual acidity formed could be a problem, but one that is easily managed.

The rate of application of fertilizer nitrogen to croplands can influence the amount of nitrate leaving fields via subsurface waters or drain tiles. When the percentage of the applied nitrogen used by the crop decreases, the amount available for leaching increases. Fertilizer use on cultivated crops can increase the nitrogen loss from soils, but how this effects nitrogen concentration in streams is still unclear.

Nitrogen can be lost through surface runoff, too. Most of the nitrogen removed by surface runoff is organic nitrogen associated with sediment. Even though it is possible to lose significant fertilizer nitrogen in surface runoff if heavy rains immediately follow application, this accounts for only a small proportion of nitrogen lost from soils or of the fertilizer nitrogen applied (Mengel, 1980). Nevertheless, spring measurements of nitrate in surface waters in Illinois showed that at least 55 to 60 percent originated from fertilizer nitrogen (Kohl, et al., 1971).

The amounts of fertilizer nitrogen either lost to, or found in transit to, ground water are quite variable. In general, in the Southeastern United States nitrate enrichment of shallow ground water does occur, though no enrichment of deep ground water is known. Denitrification of nitrate in shallow ground water also has been noted. In the Midwest, significant amounts of nitrogen can be found below the root zone (Mengel, 1980).

The problem of leaching nitrates from fertilizer to ground water is greater in irrigated areas. Nitrogen fertilizer use on irrigated sandy soils shows a high correlation with nitrate-contaminated aquifers (Spalding, et al., 1978; Reeves and Miller, 1978).

PHOSPHORUS AND POTASSIUM

Unlike nitrogen, which has a relatively short residual activity in soils, phosphorus tends to accumulate in soils in relatively insoluble inorganic forms. Thus, phosphorus fertilization leads to increased soil phosphorus levels over time. In many intensively managed soils, particularly where high-value crops such as vegetables are grown, phosphorus levels have become quite high. The questions then asked are: at what level is soil phosphorus high enough that no additional phosphorus is needed and how long can soil reserves adequately supply plant needs? Fertilization emphasis thus shifts to maintaining soil phosphorus at a level adequate for optimum crop growth.

Phosphorus buildup is of practical significance. Soil test reports indicate that soil phosphorus levels are increasing in some States, and in many instances have become adequate to supply the phosphorus needed for crop production with only small additions (Mengel, 1980). Only a very small amount of fertilizer phosphorus is lost from soils if erosion is controlled. However, even these small amounts can be significant and can accelerate surface water eutrophication. Phosphorus loss can be minimized through proper erosion control.

Although some phosphorus is lost by movement into ground waters through leaching, the amounts generally are insignificant from both agronomic and water-quality standpoints. However, significant phosphorus may enter ground water where the water table is high or approaches the plow layer. Similarly, flooding may provide anaerobic conditions in soils, and in such cases phosphorus concentrations can be fairly large in effluent from tile drains and can be a ground water pollutant.

Like phosphorus, potassium from fertilizers can accumulate in soils over time. Soils in humid areas of the United States are inherently low in potassium, so yields can be enhanced by potassium application. Many soils in the more arid regions contain adequate potassium levels, and potassium fertilization can actually decrease yields (Rehm, et al., 1979). Thus, care is needed to ensure that potassium is applied only on soils with low natural potassium levels. Potassium fertilizer does not appear to be a potential source of pollution for either surface or ground water.

COMMERCIAL FERTILIZER EFFECTS ON SOIL INVERTEBRATES ON MICRO-ORGANISMS

Although little-studied, fertilizers seem to have considerable effects on soil invertebrates through alterations of plant species diversity and composition (Morris, 1978). Field studies of fertilizer-caused changes in the diversity of invertebrate populations show that the impacts diminish in successively higher levels in the food chain (Hurd and Wolf, 1974). Similarly, the population of microarthropods in several test plots treated with commercial fertilizers or with manure showed a small population increase with the commercial fertilizer and a large one with manure (Wallwork, 1976). Combinations of commercial and organic fertilizers may produce the most beneficial effects.

The activities of soil micro-organisms, and the impact of commercial fertilizers on them, have been studied extensively in other countries, but less in the United States. *Convincing data for a long-term detriment caused by synthetic fertilizers do not exist.* Although individual studies do in fact show temporary inhibitions of microbial activity, the suppressions do not appear to be long term or to affect significantly the microbial processes important to soil fertility. This does not mean that detrimental effects do not occur, however. It may be that the science of soil biology is not able to detect the effects.

The commercial fertilizer anhydrous ammonia is a special case because of the high concentrations that normally are applied to a narrow region of the soil. It is toxic to specific microbial processes for a short period after application. However, the ammonia is converted in several days or weeks to the nontoxic product nitrate so that it is not certain whether the inhibition has long-term significance (Alexander, 1980).

Pesticides

Pesticides are chemicals used primarily to combat pests that affect food and fiber production or cause a public health hazard. They are broadly classified on the basis of the kinds of pests they control—namely, insecticides, herbicides, fungicides, nematicides, rodenticides, and miticides. Also, chemicals used for defoliation, desiccation, soil fumigation, and plant-growth regulation also are classified as pesticides (Harkin, et al., 1980).

Most pesticides are organic chemicals. Some are manmade and some are of natural origin. Many contain chlorine, nitrogen, sulfur, or phosphorus which serve to determine the toxicological impacts of the compounds.

The U.S. consumption of pesticides represents 45 percent of total world use. Approximately 36,000 pesticide labels are now registered with the U.S. Environmental Protection Agency (EPA), although only a few substances are used extensively. The agricultural sector is the major user of pesticides and the amounts used are increasing at a more rapid rate than use by homeowners, industry, institutions, and Government.

During the past decade a significant shift occurred in the agricultural use of insecticides with an increase in the use of organophosphorus and carbamate compounds and a decline in the use of organochlorine compounds. The decline in organochlorine insecticides will continue as a result of Government restrictions on their use because of their adverse environmental impacts.

Mankind has benefited markedly from the use of pesticides, notably in terms of high production of food and fiber at relatively low cost and in improved public health. The demand for pesticides is expected to continue to increase because there are few feasible alternatives for pest control. Integrated pest management, if widely practiced, could reduce pesticide use on croplands (U.S. Congress, OTA, 1979).

Since the early 1960's when environmental awareness became acute, increasing concern has been expressed over the potential hazards associated with pesticide use and their long-term impacts. Pesticides are potential pollutants of food, drinking water, and fish and wildlife habitats. The impacts of pesticide use on the environment are determined by the environmental transport of the chemicals, their persistence, degradation, and dissipation in the environment, and the hazards associated with pesticides and the products created when they are decomposed or metabolized.

PESTICIDE EFFECTS ON GROUND WATER, SURFACE WATER, AND PRECIPITATION

The presence of pesticide residues in surface runoff is well documented, and numerous short-term environmental impacts are noted such as fishkills, contamination of mollusks, etc. (Ehrlich, et al., 1977). Longer term impacts that could affect overall land productivity include the effect of pesticides carried by surface water into marsh and estuarine ecosystems that provide the breeding grounds for many animal species, including many which are economically important (Heckman, 1982). Pesticide pollution of ground water has been documented (see ground water section). The problem seems to be most severe for shallow ground water and sites having sandy, permeable soils.

The contamination of rainfall by pesticides has been documented for the organochlorinated compounds. Recent studies show that toxaphene can be carried long distances from its use site and deposited through rainfall elsewhere in concentrations high enough to damage fisheries. Transportation of the chemical seems to result from vaporization and subsequent adsorption on airborne particles (Bidleman, et al., 1979).

PESTICIDE EFFECTS ON SOIL INVERTEBRATES

The effects of pesticides on soil fauna is a highly complex issue and researchers have had difficulty making generalizations. Variables include: 1) the abundance of biocidal compounds from various chemical families, 2) great differences in persistence of pesticide compounds in the environment, 3) the diversity of invertebrate organisms in different soil communities, 4) metabolic products of different organisms that ingest pesticides, 5) the many chemical and physical varieties of different agricultural soil ecosystems, and 6) the psychological, cultural, and traditional agricultural practices of people who use pesticides (Dindal, 1980).

Where effects of pesticides have been observed and analyzed, the biotic responses are equally variable: 1) soil fauna may exhibit either a direct response to pesticides or more often an indirect sec-

ondary response; 2) only certain organisms are affected in a detrimental fashion, some populations actually increase; 3) certain pesticide residues accumulate in tissues of some soil organisms with no apparent ill effects; and 4) certain sensitive species are killed from acute or chronic exposure to biocides. In almost all cases, the structures and functions of soil communities are modified by pesticide use (Dindal, 1980).

Although much knowledge exists on the effects of individual pesticides, much more research is needed to determine the combined effects of many pesticides used on the same site.

EFFECTS ON SOIL MICROBES

Although pesticides are designed to control pest species, the extent of their selectivity for pests in some cases is not great and other organisms are injured, including soil micro-organisms.

Inhibitions of microbial activity are most pronounced from fungicides and fumigants and the suppression may remain for long periods. The impact may be so great that the natural balance among the resident soil microbial populations is upset and new organisms, such as plant disease vectors, become prominent. Moreover, certain nutrient cycles regulated by micro-organisms are inhibited by fungicides and fumigants in such a way that significant adverse effects on plant growth and nutrition become evident. The lack of widespread concern for these antimicrobial agents is not because of their lack of toxicity but rather because they are not as widely used as are the other two major classes of pesticides (Alexander, 1980).

Insecticides have received most attention in the past. These compounds may be applied directly to soil for the control of soil-borne insects, or they may reach the soil from drifting sprays or when treated plant remains fall to the ground or are mixed with the soil during normal farming practices. Inhibition of some microbial processes or suppressions of individual populations of bacteria, fungi, or actinomycetes occur. On the other hand, the toxicity is generally not marked, and the beneficial effects of the insecticides in controlling insect pests argue for their use. U.S. regulatory agencies have not acted on the basis of possible long-term harm insecticides might have on microbial processes, but few instances of major suppressions of microbial activities in the field have been noted, so that a change in policy in regard to their use does not appear warranted (Alexander, 1980).

Herbicides are designed to control the growth of seed-bearing plants. The amount of herbicide used per unit of land area is small and the compounds are reasonably selective for target plants, so little or no inhibition of other soil processes has been noted. In some instances, herbicides alter microbial activities, but such changes probably are associated with suppression of target plant species which limits organic nutrients needed by the micro-organisms around its roots. These effects seem slight and have not warranted questioning the use to particular chemicals (Alexander, 1980). Herbicide use in no-till agriculture, however, is a matter of increasing concern because of the increased amounts applied.

The general consensus among soil microbiologists seems to be that a few of the registered pesticides affect microbial processes in the short term, but the influence is not sufficient to warrant banning the chemicals. Continual assessment of the effects of new pesticides on microbial processing as required by current EPA regulations is certainly worthwhile.

Effects of Toxic Wastes

The addition of toxic waste products to agricultural land can occur inadvertently when waste materials are applied as fertilizers. Some toxic substances such as heavy metals, polychlorinated biphenyls (PCBs), and other industrial chemicals can reach agricultural land through the atmosphere or surface water.

Collectively, such toxic wastes provide a wide spectrum of pressures on all living creatures. Some organic toxicants on or in the soil can be decomposed or at least modified by biological decomposers, but others cannot. Some of the compounds, however, are able to sublimate, volatilize, or disperse throughout the soil microenvironments. The cause-and-effect relationships between many of the priority pollutants and soil biota are yet to be investigated (Dindal, 1980).

Heavy metals, from whatever source, can threaten soil biotic systems. Research in Holland shows that earthworm growth and reproductive capacity can be reduced by copper and worms were eradicated from soils having copper accumulations over 80 parts per million (Rhee, 1969). Interestingly, other preliminary studies show that other heavy metals may accumulate to high levels in earthworms without being lethal (Dindal, 1980).

Much is known about the toxicity of cadmium, zinc, copper, nickel, lead, mercury, and certain other elements, individually and in combination, on several major soil microbial processes, including

decomposition of litter and soil organic matter, certain steps in the nitrogen cycle, and enzymatic activities. Moreover, a variety of individual microbial groups has been tested showing that heavy metals indeed inhibit microbial processes at low concentrations. The extent of the toxicity depends on the particularly heavy metal, its concentration, soil type, soil pH, and the individual microbial process or group (Alexander, 1980).

Impacts of Soil Chemistry Changes on Human and Animal Nutrition

A persistent rumor holds that modern food is not as good as it used to be. But whether this is true is not known. The chemical makeup of plants varies with: 1) the chemical and physical makeup of the soil on which the plant is grown, and 2) climatological factors. Nutrient deficiencies in soil tend to restrict growth and yield of plants so that the plants that survive and produce well enough to harvest show little, if any, nutrient deficiency.

Until recently no systematic work had been undertaken to determine if variation in cultural techniques—e.g., organic v. conventional farming methods—affects the nutritional content of crops. Therefore, there are little data to shed light on this question.

However, reasoning a priori, it is possible to make the following statements:

1. The bulk of the crops grown in this country are grains. Variations in soil and weather conditions are most likely to affect the nonseed part of the plant; therefore, it is unlikely that the nutritional content of grain products eaten by humans is changed by cultural techniques.
2. Most of the grain raised in the United States is fed to animals which subsequently nourish humans. Generally, the makeup of mammalian muscle and milk and avian eggs are genetically determined; therefore, the probability of any nutritional difference in a plant being passed on to humans through animal products is small. Mammalian liver is the one animal product whose nutritional content could be affected significantly by diet.
3. It is impossible to determine the extent to which U.S. soil is more or less able to produce nutritious crops than when it was virgin because of several factors: the lack, until recently, of sufficiently sensitive assay procedures to detect such differences accurately and reproducibly, especially with regard to the vitamins and trace elements; the lack of available virgin soil to conduct a comparison study; the disappearance of many of the crop varieties eaten by our ancestors; and changes in weather and increases in air pollution.

The question of whether cultural techniques cause the levels of either naturally or adventitiously occurring compounds to vary is difficult, though answerable. Tests for sensory qualities have been developed to a level of sufficient accuracy to allow for meaningful comparisons. The levels of naturally occurring toxins in plants, as well as harmful contaminants such as heavy metals, pesticides, or chlorinated hydrocarbons, now can be detected, measured, and discriminated among with accuracy. However, no data base comparing agricultural techniques with the presence of these factors exists.

Summary

There are no economically feasible substitutes for the significant agricultural productivity functions of organic matter and soil biota, so their maintenance in croplands and rangelands is critical. Soil organic matter can be regenerated in degraded soils by using various agricultural practices. By doing so, general soil structure, soil nutrient-holding capacity, and the soil's resistance to erosion can be improved.

Soil clay minerals also have a nutrient-holding capacity, but once these fine-grained materials are lost to erosion, they cannot be regenerated quickly by known agricultural methods. Generally, the soil clays play a less dominant role in maintaining good soil structure than does soil organic matter. Consequently, maintaining soil organic matter in productive soils and regenerating it in degraded soils probably is one of the most economically efficient ways of sustaining the land's agricultural productivity.

Soil invertebrates and micro-organisms assist in breaking down plant remains, which produces new organic compounds that promote good soil structure and converts soil nutrients to forms usable by plants. The microbes are also necessary to break down pesticides and other toxic chemicals. Without the soil biota, the organic matter from plant residues and manure would be of little use.

Commercial and natural fertilizers must be added to most soils to sustain present and projected levels of crop production. Commercial fertilizers are becoming increasingly costly, so maximum benefit of their application is being sought and this depends in part on improved knowledge of the dynamics of soil organic matter and soil biota.

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Analytic Tools and Data Bases for Determining the Effects of National Policies on Land Productivity

OTA's analysis indicates that one pressing short-term need is to develop mathematical models that can estimate the effects of Federal, State, and local policies on land productivity. Knowing the probable impacts of education programs, cost-sharing, tax incentives, subsidies, regulations, and other measures could help the Nation shape effective policies to check cropland and rangeland degradation.

Mathematical models provide a documentable, explicit, and replicable method to analyze the effects of an action or series of actions on a complex system. Models use equations to represent relationships among components of an agricultural system. They reduce systems to their most important elements and estimate how changes in one or more components of the system will affect other components. Models can be particularly useful to compare the expected effects of different policy options.

The alternative to model-based analysis is intuition—the use of mental models. Even though mathematical models often appear bewilderingly complex, mental models can be equally (or more) complex. Mental models cannot, however, be as explicit nor can they be replicated by other analysts.

Mathmetical models cannot replace the judgment of experienced people. They also cannot analyze cause-effect relationships that cannot be quantified. For an individual farm or ranch, the operator's mental model may predict more accurately than a mathematical model. However, when numerous decisionmakers are involved, as is the case with policymaking and program administration, it becomes difficult to rely on mental models. Mental models of complex systems can seldom be as explict or objective as mathematical models, and so are less valuable tools for policymakers.

Different mental models are difficult or impossible to compare. Thus when policymaking is based on mental models of complex interactions, as is the case with most current agricultural policy, the ideas championed by the more articulate or more powerful analyst are likely to prevail, whether or not they are the most accurate. Mathematical models, on the other hand, can undergo rigorous testing for internal consistency and for consistency with historical data. Further, different models can be compared.

Two major model types are used to analyze agricultural policy: *econometric models* and *systems simulation models.* Econometric models are based on widely accepted principles of economic behavior—for instance, that individuals, firms, and industrial sectors will continue to increase their use of an input until the cost of purchasing it equals the price received for the output it produces. These models have been developed extensively. Many are mathematically complex and costly to run. Because they are based primarily on economic analysis, they typically are used to describe one-way, cause-effect relationships, or "open" systems, but economic models can be designed to account for some feedbacks.

Econometric models generally are quite sensitive to errors in the data used in their equations. Their strength lies in their ability to consider the economic basis of behaviors at many levels, from individual producers to that of the national economy. Such models can break down, or "disaggregate," their analysis to account for differences in variables such as soil types, farm operations, and local economies, and then reintegrate the outcomes to National, State, or regional levels.

Systems simulation models are valuable primarily for their breadth and integrative capabilities. These models are well suited to analyze nonmonetary benefits and costs, including changes in qualities such as wildlife habitat quality, water quality, or changes in plant genetic resources. They generally are not used for detailed analysis of the economic implications of actions or policies.

Systems simulations have one particular advantage for studying land productivity. Changes in the behavior of a system can be simulated using "feedback loops"—a mechanism that relates changes in the cause-effect variables of a system to changes in the system's underlying modes of behavior. Feedback loops are useful to reflect, for example, that both soil enhancement and soil degradation are

processes in which this year's change causes a greater change next year. A positive feedback loop can model the concept that erosion is a self-perpetuating process—i.e., that continuing erosion makes topsoil increasingly erodible.* Conversely, a negative feedback loop will describe the stabilizing effects of land conservation practices.

Just as no single farming technology can solve all conservation-related problems, no single modeling technique can provide all the information necessary for policy analysis. But they can provide decisionmakers with valuable guidance. Systems and econometric models have different capabilities and their results need to be linked to provide comprehensive information on questions relating to land productivity and policy. Because individual universities tend to specialize in developing and advancing one particular modeling approach, attempts to combine the strengths of different modeling methods have been limited.

Necessary Elements for a Policy Analysis Model

A model capable of assessing the effects of agricultural technologies on land productivity must include the following elements:

- *Representation of the Natural System.* The major physical, chemical, and biological processes must be represented and causally linked. It is not sufficient to represent erosion rates alone. Mechanisms to show both increasing and decreasing productivity must be included to determine the sustained land productivity level for any technology mix.
- *Explicit Linkage of Technologies to Natural System Elements.* At whatever level of detail a policy study is made, the direction and magnitude of the effect of each class of technology must be identified.
- *The Microeconomics of Technology Choice.* The economics of an operator's technology choice, which determine the magnitude of use and the economic conditions under which the technology may tend to proliferate, must be analyzed. The analysis should not presume that perfect, unbiased information is available to farmers.
- *The Interaction of the Technology and Changing Social Values.* Changes in farmers' planning horizons,* how such changes affect technology choice, and the relationship between planning horizons and social and economic trends must be included.

In addition to these elements, some additional characteristics of a useful policy decision model include:

- The planning horizon of the model must be at least a generation to register significant trends in soil productivity and long-term social and economic consequences.
- Any formal model should explicitly portray the important feedback effects occurring throughout the system.
- A useful, understandable model for national policy analysis must necessarily be aggregate, testing generic types of technologies and policies. For implementation purposes, it may be necessary to examine policies at the regional level. The high degree of variation even within regions means that "representative" data sets would likely have to be constructed.

State of the Art of Mathematical Models

Iowa State University Linear Programing Model

The most advanced of the current agricultural policy models is the Iowa State University Linear Programing (ISU-LP) Model. The model projects factor** demands, crop and livestock output, farm income, and some environmental effects for 105 producing areas, 28 market regions, and 8 major zones in the United States. Designed to minimize the cost of crop and livestock production, model projections are based on estimates of total demand, subject to such constraints as crop rotation requirements, limitations on water supply, and conservation practices.

*The soil erosion "feedback" loop is often overlooked in analyses of the economics of erosion, but its significance may be great. For example, 30 inches of topsoil would take 450 years to erode completely away if net erosion were a steady 1/15th inch per year. However, it would take only 171 years if the net erosion rate is 1/15th inch/year at the beginning of the analysis and each year's rate is just 1 percent greater than the preceding year's. If the rate of increase were 10 percent a year, the 30 inches of soil would last only 40 years.

**Planning horizon*—A farmer's planning horizon is the length of time he considers when making an investment of his capital, labor, or land resources. It may be as short as one crop season or as long as his children's lifetimes. The term includes the concept of discounted value that the farmer places on future income or future costs compared to present income or costs. The terms "planning period," "payback period," and "time horizon" are often used interchangeably with "planning horizon."

**Factor: A good or service used in the process of production, thus factor demand is the demand for an input to production.

The model's chief environmental projection is to estimate the erosion resulting from a given crop rotation, management practice, and geographical setting, as calculated by the universal soil loss equation. The model can test the cost of a given conservation policy and will calculate resulting shifts in such things as crop patterns, factor inputs, and transportation requirements.

U.S. Department of Agriculture (USDA) analysts chose the ISU-LP Model to provide information about future resource needs in the congressionally mandated RCA report (USDA-RCA, 1980). The report was produced in response to provisions in the Soil and Water Resources Conservation Act of 1977 (RCA), directing the Secretary of Agriculture to carry out a continuing appraisal of the soil, water, and related resources of the Nation.

Yield/Soil Loss Simulator

In order to expand the capabilities of the ISU-LP Model for dealing with causes and consequences of changes in land productivity, a USDA team developed an additional model—the Yield/Soil Loss Simulator (Y/SL)—specifically for the RCA analysis. The Y/SL model permitted USDA analysts to forecast changes in crop yield resulting from soil losses associated with various cropping and management practices. The model calculated effects of water erosion and conservation practices on soil depth and linked expected future yields to rates of change in soil depth.

The resulting analyses for the RCA report are the best and most comprehensive available; still, they fall short of the goal set by Congress for USDA's appraisal of the agricultural resource base. Substantial questions have been raised about the accuracy of the Y/SL model's characterization of the relationship between soil depth and yield (Benbrook, 1980). Effects on productivity such as changes in soil texture and water-holding capacity are not accounted for, nor can they be incorporated into the model with existing data. Comparisons of Y/SL estimated crop yield reductions per inch of eroded soil with actual studies show Y/SL loss estimates to be relatively conservative.

The ISU-LP Model, as supplemented by Y/SL, is the most complete representation of technological impacts on productivity available. However, it does not analyze the dynamics of natural soil systems nor the effects of technologies on the components of intrinsic productivity. It cannot account adequately for causal interactions among: 1) factors besides soil depth that comprise land productivity, 2) processes besides water erosion that cause changes in productivity, 3) technologies besides conservation practices that increase or decrease rates of change in productivity, 4) farmers' decisions regarding choice and implementaton of technologies, 5) social and economic factors that influence the farmers' planning horizons and the technology choice options, and 6) Government programs that affect, directly or indirectly, farmers' decisions (USDA-RCA, 1980; Benbrook, 1980; Picardi, 1981).

Efforts are under way at USDA and Iowa State University to develop more comprehensive research tools for assessing soil productivity. Recognition of the inadequacies in the Y/SL approach has spurred the development of other models to deal with a wider variety of soil productivity processes. However, such models are primarily research tools and are probably too complex to aid in policy development. Although improvements to the Y/SL model have been suggested, the model seems to have been shelved and no substitute policy analysis tool is being developed at USDA (Benbrook, 1981).

Phenological Models

Recently UDSA's Science and Education Administration's Wheat Yield Group began designing a series of "phenological models" that simulate the dynamics of plant (crop) growth and how this is affected by physical and biological processes and the environment (Dyke, 1980). The models will analyze the effects of runoff, soil texture, organic matter, nutrient cycles, infiltration, and residue decomposition. No soil biota analysis is planned. In this modeling approach, agricultural technologies will be linked to the specific process that they affect instead of merely correlated with yield. The models will be crop- and soil-specific and have a 50- to 100-year planning horizon to simulate long-term productivity changes. The models for sorghum and wheat are already operational.

This approach will be better able to capture the feedback dynamics of the natural system including nutrient cycles and organic matter dynamics. These models are intended to be linked to the ISU-LP model. If successfully merged, they will provide important feedback simulation that has been missing from the present ISU-LP structure.

A disadvantage of the phenological model is that, even though they deal only with natural systems, they are extremely complex, with over 400 subroutines, and they can only deal with one crop and one location at a time. The models are research tools more than policy analysis programs (Picardi, 1981).

However, scientists working with the phenological models hope to have them sufficiently complete by 1985 to be useful for drafting the 1985 Resources Conservation Act report.

Current Developments and Future Needs

The Center for Agricultural and Rural Development (CARD) at Iowa State University is rapidly moving to develop linked econometric and simulation models. One recently completed model estimates farmer and consumer reaction vis-a-vis such factors as changes in land and water use, production, conservation, and erosion. Estimates are provided by region and specific location, and can account for interregional interactions. Another model under development for the International Institute of Applied Systems Analysis relates crop production systems, conservation practices, tillage methods, etc., to livestock systems, soil loss, and yield and productivity changes over time. The model is intended to trace the effects of erosion and/or technology on yield over time.

Both academic institutions and USDA are focusing on complex, scientifically advanced modeling. This approach is likely to further the state of knowledge about the underlying processes involved in land productivity. However, the policy analysis needs of Congress and program administrators are not being met by these efforts. Two needs require particular attention:

1. Models that relate land productivity to factors beyond crop yields—i.e., benefits such as genetic diversity of resident plant species, wildlife habitat, and water quality effects. Losses in these areas have major long-term economic implications for agriculture, recreation, and human health but cannot be reliably quantified with existing techniques.
2. Quick, inexpensive models to estimate national effects of resource policy decisions that have a simple structure and clear documentation and are readily understandable not only by economists, but also by analysts trained in other disciplines. (Without this clarity, a mathematical policy model is no more explicit to most policy analysts than is a mental model.) Current models deal with regional and subregional variation but often sacrifice ease of use and cost-efficiency for richness of detail. Congressional scrutiny of alternative policy initiatives could be enhanced if models were available that focus directly on Federal program capabilities to enhance or degrade soil productivity.

Data Availability and Requirements for Further Model Development

To develop policy models, two kinds of data are needed: 1) causal interaction information describing how each element of a system affects each other element, and 2) time-series descriptive data about important variables—e.g., changes over time in levels of soil organic matter or levels of application for various technologies. Generally, to be usable in national policy models, data must also: 1) be in the form of electronically readable data sets, having national coverage, 2) have been collected in a consistent fashion or selected according to a consistent set of criteria, and 3) contain information usable for assessing technological impacts on soil productivity.

Table D-1 describes 12 major data sets that meet the latter three criteria. The sets are representative of available data but do not comprise a complete list. Although other sets contain useful data—e.g., on specific technologies, specific crops, national weather data, or regional water inventories—it is fairly certain that none is significantly better suited for assessing productivity than those listed in table D-1. The table describes the *type* of data included in the set but does not catalog all the information included.

The Soil Conservation Service (SCS) performs soil surveys containing a wealth of information on soil classes, subclasses, and series, and provides chemical, physical, and land-use information for 12,000 different soil types. Soil surveys have classified and located soils for 65 percent of the counties in the United States. Much of the descriptive information on soil classes has been computerized in the "Soils V" data base (table D-1, #10); however, "Soil V" does not include geographic location data (USDA, 1979).

Geographic area and soil type can be linked through the two data sets: The Agricultural Research and Inventory Surveys through Areal Remote Sensing (AgRISTARS) (table D-1, #12), and the National Pedon Data System (table D-1, #6). AgRISTARS contains data on the most representative soil type in 25-mile squares for a national grid, whereas the National Pedon Data System inventories all the soils that are received by the National Soils Survey Lab in Lincoln, Nebr. Efforts are being made to coordinate the two systems by selecting the most representative soil type in each county for analysis and inclusion in the National Pedon Data System. When they are completed, these data sets are expected to serve as general resource bases for research purposes.

Table D-1.—Characteristics of Various Agricultural Data Sets Related to Soil Productivity

Data set	Date	Author	Location	Electronic	Public	FIPS[a] code	Policy models	Aggregation	Data
1. Conservation Needs Inventory (CNI)	1967	Soil Conservation Service (SCS)	D.C.	Yes	?	Yes	None	County	Land class, present use, slope management factor, and irrigation
2. Potential Cropland Study	1977	SCS	D.C.	Yes	Yes	Yes	National Agricultural Lands Study (NALS)	Primary sampling unit	Potential arable cropland, present use, potential for reconversion to cropland, Universal Soil Loss Equation parameters, soil and water problems
3. National Resources Inventory (NRI)	1977, 1982, ongoing	SCS	D.C.	Yes	?	Yes	NALS, RCA, Iowa LP	Major land resource area	R-factor, slope, length, present use, soil class, conservation practice, treatment needs, potential cropland, erodability, type irrigation, ownership, crop management, dominant problems, and associated water bodies
4. Crop Consumptive Irrigation Requirements	1976	SCS	D.C.	Yes	Yes, public access via extension	No	Used in ISU-LP	Crop specific in each county	Irrigation requirements net of rainfall for each crop in each county
5. Agricultural Census, OBERS	1974, 1978, 1982 every four years	Department of Commerce (DOC), ESS of DOA	D.C.	Yes	Limited distribution for labor statistics ESS data public	Yes	Inputs to NIRAP model	Water Resource Council Regions	Farm income, production, value of farm, outputs, factor inputs, land cropped, irrigated land, tenure, and employment
6. National Pedon Data System	Ongoing	National Soils Survey Lab, DOA	Lincoln, Nebr.	Yes	Yes	Yes	None specifically	Site-specific with geographic coordination	Site description, slope, drainage, cultural uses, 7 horizon files, physical and chemical lab tests, minerology data, some engineering data, closest weather station, climate data. Most representative soils in each country being coded first
7. Yield/Soil Loss Simulator data (Y/SL)	1980	DOA SEA	D.C.	Yes	Yes	Yes	Yield/Soil Loss Simulator Model, SEA	Soil mapping unit	240,000 observations, variety of crops, texture, slope, class, country, SCS yield, and normalized yield
8. Crop Reporting Board	Yearly	Economics & Statistics Service, DOA	D.C.	Yes	Yes	Yes	Yearly crop yield projections	County	Yield data for all major crops, and factor inputs
9. Phenological Model Data	Being developed	SEA of DOA	Temple, Tex.	Yes	Yes	Yes	Input to Iowa State LP model	Crop and soil type specific	Physical, chemical and botanical data relating technologies to yields, hydrology and soil class to erosion and productivity
10. Soils V	Ongoing	SCS	D.C.	Series-yes Maps-no	Yes	No	Yield/Soil Loss	No geographic reference	12,000 soil series records, cultural data on use suitability, survey maps show soil types for locations, 65 percent of country classified, yield and performance ratings, cost of restoration. Soil survey information such as slope, texture, capability class, use, erosion phase, and irrigation practice
11. National Woodland Data System, Range Data System	Ongoing	SCS	Fort Collins, Colo.	Yes	?	Not yet	None yet	Site specific	Growth rates of trees on specific kinds of soil for over 20,000 sites; range data system contains forage production and species composition
12. Agricultural Research and Inventory Surveys through Areal Remote Sensing, AgRISTARS	Ongoing	DOA SEA	Temple, Tex.	Yes	Yes	Yes	Phenological models	25x25 mile grid	Information on the most representative soil series in each 25-mile square for a National grid, soil survey information, land use, cultivation practice, location of nearest weather station

[a]FIPS: Federal Information Processing Standard code, which allows users to label data entries consistently among all Government agencies.

SOURCE: Office of Technology Assessment.

Available land inventory surveys include the Conservation Needs Inventory (1958, 1967), the Potential Croplands Interim Study (USDA, 1977), and the National Resource Inventory (NRI), which began in 1977 and will continue periodically (USDA, ESCS, 1980).

These surveys use sampling techniques to select sites for rigorous observation by SCS personnel of existing land use, crops, irrigation, soil type, potential for reconversion to cropland from nonagricultural uses, erosion status, and needed conservation practices. Each successive inventory has become more intensive, covering a wider range of land-related concerns, and less extensive, directly surveying a smaller fraction of the land base. The data from the 1967 Conservation Needs Inventory and the 1977 NRI were used to calculate sheet and rill erosion rates for each sampled point, and these calculated rates were aggregated to indicate regional erosion rates. The 1967 sampling procedure was seriously flawed, however, and its erosion rate figures are grossly different from the 1977 figures. (For instance, the national average erosion rate from the 1967 survey is nearly twice the rate from the 1977 survey.) Thus, no time-series data are available for trend analysis. The 1982 NRI should provide the first time-series data on a national scale.

The soil surveys and national inventories provide the following kinds of information required for assessing soil productivity:

- soil type, including organic matter content and nutrients available;
- yields and crop patterns that would allow weighted average yields;
- information necessary for calculating sheet and rill erosion;
- present technology inputs recognized as conservation or irrigation practices (but not *actual* water application rates);
- land-use conversion rates and information relating to some of the social and economic forces affecting planning horizons and the profitability of farming;
- information about erosion problems, ownership, type of restorative treatment needed, and irrigation practices; and
- indices that allow data to be aggregated at various geographic levels.

County-specific data on yield and economic parameters are collected and computerized annually by the Crop Reporting Board at the Economics and Statistics Service (ESS) of USDA and periodically by the Department of Commerce via the Agricultural Census. Relevant types of data available from these sources include:

- yields, prices, and the values of all factor inputs in the agricultural sector for deriving marginal values of products; and
- ESS forecasts of expected prices and factor costs for estimating expected profitability.

SCS maintains a data base on crop consumptive water needs which, in conjunction with climatological data (available from the National Oceanic and Atmospheric Administration) can be used to estimate irrigation requirements. This file contains no information on actual water consumed. Moreover, no uniform nationally compiled information system on irrigation water application rates exists (Lehr, 1980). This SCS data base does include estimates of irrigation needs that could aid in determining ground water extraction rates.

Data developed to estimate coefficients for the Y/SL have been stored as an independent data set, although all of the data can be found in previously mentioned sources. Information on erosion rates, management practices, and yields is included, but these data do not appear sufficient for a causally structured model, since causal models specify that erosion rates result from changes in chemical, physical, and biological properties as well as from management practices (Hagen and Dyke, 1980).

The National Woodlands Data System quantifies production or yield response to soil type for a wide range of forest and forage species. This type of data may be used to develop yield equations for models.

The Production Records/Range Data System (RDS) is a plant materials data system with over 3,000 entries for rangelands of the Western and Southeastern United States. Most information is identified with range sites, soil series, and land capability classes to the State level. The system also records production as influenced by climate, elevation, and condition class. This information is to be computerized by 1985. It is expected to be very useful for management decisions; whether it will prove useful for a policy model of rangelands is not clear yet.

Finally, the Agricultural Research Service of USDA is developing a data base to use with the crop-specific phenological simulation models. For each major soil class and crop rotation, information modules are to be developed to simulate crop growth, soil runoff, soil texture, organic matter, nutrient levels, water infiltration, and residue decomposition. This data set will thus be the only computerized file that relates yields to soil produc-

tivity and, in turn, relates productivity to the physical, chemical, and biological processes at work. Data useful to assess land productivity will be:

- the physical, biological, or chemical impacts of a specific technology on the natural system;
- the causal mechanisms underlying erosion, organic matter accumulation, and decomposition;
- the dynamics of the nitrogen and phosphorus nutrient cycles; and
- the linkage between the natural system and runoff, which is necessary to estimate pollution loads in streams and ground water recharge.

Other relevant data sets not described here include the Soil Vegetation Inventory Method of the Bureau of Land Management; the Plant Information Network, covering Colorado, Montana, Wyoming, and North Dakota; Run Wild, covering wildlife and vegetation for Arizona and New Mexico; the Forest-Range Environment Study, containing data on forest and rangeland resources, and the National Water Data Exchange index of water-related data sets.

Missing Data

In summary, a number of national, accessible electronic data sets are available. These data sets provide some of the qualitative or quantitative information necessary for determining:

- long-term land-use change rates;
- levels of factor input use; and
- some causal factors affecting determinants of productivity such as erosion and the level of organic matter.

This data is largely descriptive, however. It should be possible to use data from the ESS Crop Reporting Board to estimate time-series information such as levels of factor inputs and yields. Erosion time-series data and other information from the various land inventories might be developed, although this could be a difficult task. Data are lacking for a number of important areas:

- Data on soil formation rates. Information is needed on both the rates at which the top layer of soil is enriched to become what is called "topsoil" and on the rates at which parent materials form subsoils to be able to assess long-term effects of wind and erosion.
- Data on soil fauna and flora. Biological organisms are significantly linked to rates of decomposition, tilth formation, and nitrogen fixation.
- Data on water withdrawals from aquifers. In addition, the causal linkages between chemical application and aquifer pollution have yet to be developed and organized in a way useful for policy analysis.
- Data on the socioeconomic determinants of: 1) ground water use for irrigation, and 2) reversion to dryland farming or abandonment when farmers are faced with the combined effects of water costs, pollution, subsidence, and salinization.
- Data on the links between farm profitability and farmers' planning horizons, on how these and other social factors combine to change factor inputs, and whether such changes will accelerate or slow changes in profitability.
- Data on how farmers perceive and value long-term effects of technology use on productivity.
- Data on the extent to which short-term input decisions result from social, ecological, health, and other "noneconomic" concerns.
- Data on inherent land productivity by area in the United States and on the role of inherent land productivity in total factor yields.
- Data on the cause-effect interactions between vegetative systems and the ground water system. Some individual linkages may be quantified, such as the effect of water on yields, but no information exists on important links such as how deteriorating water quality affects yields, or on how crop or range cover affects ground water recharge. Local hydrological cycles are only beginning to be modeled in sufficient detail to permit assessments of the systemwide effects of aquifer pollution and overdraft (Vanlier, 1980; Lehr, 1980).

Causal data exist on physical-chemical soil relationships for specific soils in specific regions, but it needs to be organized, standardized, and assessed in order to give reasonably accurate estimates of cause-effect dynamics for an aggregated policy model. The USDA wheat yield group at Temple, Tex., is involved in such data development for its phenological models. For actual productivity and for rates of soil formation, however, many necessary scientific experiments have yet to be done. In the area of economic decisionmaking, there is an almost total lack of data on how farmers perceive productivity and what this means for their decisionmaking. Information is also lacking on the role of productivity in long-term decisionmaking regarding the conversion of productive cropland to other uses.

The quantitative extent to which inherent land productivity has been changing is unknown. Although it is known that productivity declines are strongly correlated with relatively high erosion rates, less is known about system changes that result in enhanced productivity.

Because of missing data in the above areas, the models that can be developed to test agricultural technologies will be incomplete. Data gaps should not, however, be used as a rationale for reducing modeling efforts. Present information is sufficient to allow models to improve current policy decision processes substantially and to facilitate the integration of production-oriented policies and programs with conservation-oriented policies and programs. Further, models can be used to identify the relative importance of missing or inadequate data to policy-related information needs. This analysis can improve the cost-effectiveness of resource inventory efforts, allowing agencies to direct data-collection resources toward the data most needed for policy-making.

Mathematical models may eventually be developed to understand various influences on inherent land productivity. Such models would also need to incorporate other elements to examine total agricultural production. Until that time, national agricultural research priorities will be set mainly from the mental models of agricultural scientists and policy experts.

In February 1981 natural resources and agricultural scientists convened a national workshop to determine research priorities for the Nation. The list of priorities that was developed is described in a publication from the Soil Science Society of America (Larson, et al., 1981). The workshop did not rank the priorities, but organized them according to subject. Areas included: sustaining soil productivity, developing conservation technology, managing water in stressed environments, protecting water quality, improving and implementing conservation policy, and assessing soil and water resources.

This OTA assessment cannot improve on the priorities identified by the more than 100 technical and policy experts who participated in that workshop. However, for the policymaking needs of Congress, OTA concludes that two of the data gaps are critically important: soil-loss tolerance and social and economic factors affecting the implementation of productivity-sustaining technologies.

Appendix D References

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Appendix E

The Resources Conservation Act Preferred Program*

CHAPTER 7
THE PREFERRED PROGRAM

After considering the alternatives as presented in chapter 6, the Secretary of Agriculture selected alternative 3 as the one most likely to approach, within the overall budgetary guidelines of this Administration, the requirements for protection of the Nation's soil and water resources.

The preferred program is based on cooperative actions among local and state governments and the federal government for solving resource problems. Cooperative solutions to resource problems are not new. Local conservation districts, county Agricultural Stabilization and Conservation (ASC) committees, and extension advisory committees work closely with the local offices of the Soil Conservation Service (SCS), Agricultural Stabilization and Conservation Service (ASCS), and Extension Service (ES) to provide technical assistance, financial assistance, and information and education services to land owners. The preferred program retains these existing organizations and relationships to expand the capacity of state and local governments to recognize and solve resource problems.

The preferred program moves away from the "cafeteria," or "first come, first served," approach of traditional conservation programs conducted by the United States Department of Agriculture. It addresses instead specific national resource conservation priorities. The top priority is the reduction of soil erosion, and the second priority is the reduction of upstream flood damages. The cornerstone of the preferred program is the targeting of soil conservation actions to reduce soil erosion and related conservation problems that impair the Nation's agricultural productivity.

USDA developed the preferred program after carefully considering the responses received during the 1980 RCA public comment period and views obtained from the 1979 public opinion survey conducted by Louis Harris and Associates, Inc. These activities show that the public favors a program that achieves conservation objectives through voluntary participation with more emphasis on decisions made at local and state levels. People view soil, water, and related resources as national assets that should be used but not wasted and are concerned that not enough is being done to preserve the capacity of the Nation's resources to meet future needs. The public says that adopting specific objectives would lead to more effective action on addressing critical resource problems and that agricultural use should be given priority over other uses of these scarce resources.

Most of all, the public expects a cooperative partnership among land owners and users, local and state governments, and the federal government in meeting national priorities and protecting the public interest in the conservation of soil and water resources. Therefore, the preferred program is the most responsive and practical approach for meeting national, state, and local needs as identified in the appraisal, the analysis of alternatives, and the public's comments.

7-1

*From U.S. Department of Agriculture, "Soil and Water Resources Conservation Act: Program Report and Environmental Impact Statement," revised draft, 1981.

This chapter presents an overview of the preferred program. To review a full description of alternative 3, see again pages 6-18 through 6-33.

Highlights of the Preferred Program

The preferred program--

- o establishes clear national priorities for addressing problems associated with soil, water, and related resources over the next 5 years. The highest priority is reduction of soil erosion to maintain the long-term productivity of agricultural land. The next highest priority is reduction of flood damages in upstream areas. Water conservation and supply management, water quality improvement, and community related conservation problems have next priority. Fish and wildlife habitat improvement and organic waste management are an integral part of solutions to these problems.

- o strengthens the existing partnership among land owners and users, local and state governments, and the federal government. This partnership will identify needs and develop and implement soil and water conservation programs. Through this partnership, the program--

  - provides federal matching block grants to states for an expanded role in developing and implementing conservation programs, the federal funds to be obtained by reducing current federal conservation program funds.

  - provides for a Local Conservation Coordinating Board made up of representatives of the conservation district, county ASC committee, extension advisory committee, and other interested parties. This board will appraise local conditions and needs, develop programs, and work through existing local, state, and federal institutions. The local board will concentrate on solving problems and achieving program objectives.

  - provides for a State Conservation Coordinating Board, with members appointed by the Governor, to appraise overall state conditions and needs. The state board will use programs adopted at the local level to develop and implement state soil and water conservation programs.

  - establishes a USDA National Conservation Board to advise the Secretary of Agriculture on conservation matters.

  - bases state and federal cooperative conservation actions on an agreement between each Governor and the Secretary of Agriculture.

- o provides for increased and more efficient cooperation and budget coordination among USDA agencies with conservation program responsibilities.

- o continues or initiates the following program actions to achieve conservation objectives. The program--

- targets an increased proportion of USDA conservation program funds and personnel to critical areas where soil erosion or other resource problems threaten the long-term productive capacity of soil and water resources.

- emphasizes conservation tillage and other cost-efficient measures for reducing soil erosion and solving related problems.

- calls for evaluation of tax incentives as an inducement to increased use of conservation systems.

- increases emphasis on technical and financial assistance to farmers and ranchers who plan and install needed and cost-efficient conservation systems.

- targets USDA research, education, and information services toward immediate and long-term objectives that will protect and maintain the productive capacity of agricultural lands.

- permits and supports the use of pilot projects to evaluate solutions for persistent resource problems and to test potential new solutions.

- requires conservation plans consistent with locally determined standards for recipients of Farmers Home Administration loans.

- minimizes conflicts among features of USDA programs that limit achievement of conservation objectives.

- strengthens collection and analysis of data on resource conditions and trends and conservation needs and provides data useful at the state and local levels.

- provides for systematic evaluations and analyses of conservation programs to determine their effectiveness and progress in achieving conservation objectives.

- expands the use of long-term agreements in providing technical and financial assistance to farmers and ranchers.

Effectiveness of the Preferred Program

Evaluations of current soil and water conservation programs were considered in formulating the preferred program, as discussed in chapter 5. Therefore, the preferred program--

o establishes clear program objectives to increase efficiency.

o sets priorities to help field personnel plan and schedule their work to improve program implementation.

- o recognizes the diversity of resource conditions and formulates national policies and procedures that can be adapted to state and regional needs to increase program effectiveness.
- o encourages the involvement of individuals and organizations in changing the program to make it more effective and acceptable.
- o emphasizes increased research, education, and technical assistance to develop resource management and conservation systems that are cost-efficient.
- o provides for better coordination among USDA agencies to achieve unanimity of purpose in planning and budgeting for conservation programs.
- o requires monitoring and evaluation that lead to prompt adjustments in the program to achieve maximum effectiveness and acceptability.

Funding for the Preferred Program

The distribution of federal funds under the preferred program over the next 5 years is shown in table 7-1.

Chapter 8 shows the expected consequences of implementing the preferred program.

Table 7-1.--Projected fifth-year distribution of funds among major components, preferred program 1/

Major component	1981 (base year)	Funding: Level funding	Upper bound	Lower bound
	(millions of dollars)			
1. Technical assistance----	198	211	212	185
2. Financial assistance:				
a. Cost shares to operators-----------	278	164	166	179
b. For project activities----------	177	167	211	134
c. Subtotal financial assistance----------	(455)	(331)	(377)	(313)
3. USDA matching funds-----	---	105	175	30
4. Education/Information (Extension Service)-----	12	14	15	10
5. Research and technology development-------------	74	80	88	71
6. Data collection and analysis----------------	81	79	87	72
7. Emergency programs 2/---	17	17	17	17
TOTAL-----------------------	837	837	971	698
Loans-----------------------	(77)	(72)	(82)	(60)

1/ All funds are shown in millions of constant 1979 dollars rounded to the nearest million.
2/ Held constant because it is impossible to predict emergencies.

Commissioned Papers

The discussions, findings, and options presented in this report are in a large part based on 35 technical papers commissioned by OTA for this assessment. These papers were reviewed and critiqued by the study's advisory panel and numerous outside reviewers. The papers will be available in late fall of 1982 through the National Technical Information Service. (Requests for papers from the National Technical Information Service should be directed to NTIS, U.S. Department of Commerce, Springfield, VA 22151.) The papers included are:

1. How Agricultural Technologies Affect Productivity of Croplands and Rangelands by Affecting Microbial Activity in Soil
   —Martin Alexander: Department of Agronomy, Cornell University
2. Impacts of Technologies on Range Productivity in the Mountain, Intermountain and Pacific Northwest States
   —Thadis W. Box: College of Natural Resources, Utah State University
3. Livestock Grazing on the Forested Lands of the Eastern United States
   —Evert K. Byington: Winrock International Livestock Research and Training Center
4. Problems of Cost-Sharing Programs for Long-Term Conservation: The Example of the Agricultural Conservation Program
   —Kenneth A. Cook: Agricultural Policy Consultant
5. Influences of Commodity Programs on Long-Term Land Productivity (Conservation)
   —Kenneth A. Cook: Agricultural Policy Consultant
6. Impacts of Rangeland Technologies and of Grazing on Productivity of Riparian Environments in United States Rangelands
   —Oliver B. Cope: Rangeland Consultant, Golden, Colo.
7. Data Base Assessment of Effects of Agricultural Technology on Soil Macro-Fauna and the Resultant Faunal Impact on Crop and Range Productivity
   —Daniel L. Dindal: SUNY College of Environmental Science and Forestry
8. Impacts of Technologies on Productivity and Quality of Southwestern Rangelands
   —Don D. Dwyer: Range Science Department, Utah State University
9. Technology Issues in Developing Sustained Agricultural Productivity of Alaskan Virgin Lands
   —Alan C. Epps: University of Alaska
10. Impact of Communications Technology on Productivity of Land
    —James F. Evans: Office of Agricultural Communications, University of Illinois
11. Land-Use Planning Technologies Applied to Croplands and Rangelands
    —Janet Franklin, Alan H. Strahler, and Curtin E. Woodcock: Geography Remote Sensing Unit, University of California
12. Sustained Land Productivity: Equity Consequences of Technological Alternatives
    —Charles C. Geisler, J. Tadlock Cowan, and Michael R. Hattery: Department of Rural Sociology, and Harvey M. Jacobs: Department of City and Regional Planning, Cornell University.
13. Multiple Cropping Systems: A Basis for Developing An Alternative Agriculture
    —Stephen R. Gliessman: College of Environmental Studies, University of California
14. Description and Evaluation of Pesticidal Effects on the Productivity of the Croplands and Rangelands of the United States
    —J. M. Harkin, G. V. Simsiman, and G. Chesters: Water Resources Center, University of Wisconsin
15. New Roots for American Agriculture
    —Wes Jackson and Marty Bender: The Land Institute, Salina, Kans.
16. An Overview of Major Legal and Policy Issues Related to the Impact of Technology on the Productivity of the Land
    —Barbara J. Lausche: Natural Resources Lawyer
17. Relationships Between Land Tenure and Soil Conservation
    —Linda K. Lee: Department of Agricultural Economics, Oklahoma State University
18. Database on Ground Water Quality and Availability: Effects on Productivity of U.S. Croplands and Rangelands

—Jay H. Lehr: National Water Well Association, Worthinton, Ohio

19. Impacts of Technologies on Productivity and Quality of Rangelands in the Great Plains Region
—James K. Lewis and David M. Engle: Department of Animal Science, South Dakota State University
20. The Impacts of Grazing and Rangeland Management Technology Upon Wildlife
—Carroll D. Littlefield, Wildlife Consultant; Denzel Ferguson: Malheur Field Station, Princeton, Oreg.; and Karl E. Holte: Biology Department, Idaho State University
21. A Review of Current Water Erosion Control Technologies, Including Potential Changes To Enhance Their Effectiveness
—Leonard R. Massie: Department of Agricultural Engineering, University of Wisconsin
22. Technology Issues in Developing Sustained Agricultural Productivity on Virgin and Abandoned Lands in the United States
—Cyrus M. McKell: Plant Resources Institute, Salt Lake City, Utah
23. The Effects of Long-Term Fertilizer Use on Soil Productivity
—David B. Mengel: Department of Agronomy, Purdue University
24. The Data Base for Assessment of the Impacts of Technologies on Productivity of Rangeland Resources
—John W. Menke: Department of Agronomy and Range Science, University of California; and C. Wayne Cook: Department of Range Science, Colorado State University
25. Impacts of Technology on Cropland and Rangeland Productivity: Managerial Capacity of Farmers
—Peter J. Nowak: College of Agriculture, Iowa State University
26. Data Availability for the Assessment of Technologies and Public Policies Relating to Agricultural Productivity
—Anthony C. Picardi: Charles River Associates, Inc., Boston, Mass.
27. The Adoption and Diffusion of Technological Innovations in U.S. Agriculture
—Everett M. Rogers: Institute for Communication Research, Stanford University
28. Credit and Credit Institutions as Factors Affecting the Long-Term Productivity of U.S. Rangelands and Croplands
—Brian H. Schmiesing: Department of Business and Agribusiness Management, Southwest State University
29. Emerging Innovative Technologies for Rangeland
—Charles J. Scifres: Department of Range Science, Texas A&M University
30. Effect of Erosion and Other Physical Processes on Productivity of U.S. Croplands and Rangelands
—W. D. Shrader: Professor Emeritus, Iowa State University
31. Changes in the Capacity of Croplands and Rangelands to Sustain Productivity of Environmental Services
—Robert L. Todd: Department of Agronomy and Institute of Ecology, University of Georgia
32. Groundwater and Agricultural Productivity: The Information and Database
—Kenneth E. Vanlier: Hydrogeologist, Reston, Va.
33. Productivity of Soil as Related to Chemical Changes
—L. F. Welch: Department of Agronomy, University of Illinois
34. Wind Erosion and Control Technology
—N. P. Woodruff: Facilities Planning Office, Kansas State University
35. California Annual Grasslands
—James A. Young and Raymond A. Evans: USDA/SEA-AR

Appendix G

Glossary

Most of these definitions are adapted from the Resource Conservation Glossary of the Soil Conservation Society of America, 2d ed., 1976.

Abiotic: Nonliving, basic elements and compounds of the environment.

Acid rain: Atmospheric precipitation that is composed of the hydrolized byproducts from oxidized halogen, nitrogen, and sulfur substances.

Aggregation, soil: The cementing or binding together of several to many soil particles into a secondary unit, aggregate, or granule. Water-stable aggregates, which will not disintegrate easily, are of special importance to soil structure.

Agrichemicals: Chemical materials used in agriculture; sometimes used erroneously to emphasize a supposed difference between "chemical materials" and "natural materials."

Agricultural land: Land in farms regularly used for agricultural production; all land devoted to crop or livestock enterprises—e.g., farmstead lands, drainage and irrigation ditches, water supply, cropland, and grazing land of every kind on farms.

Agricultural pollution: Liquid and solid wastes from all types of farming, including runoff from pesticides, fertilizers, and feedlots; erosion and runoff from plowing, animal manure and carcasses; and crop residues and debris.

Alluvial: Pertaining to material that is transported and deposited by running water.

Animal unit month (AUM): A measure of forage or feed required to maintain one animal for a period of 30 days.

Annual plant: A plant that completes its lifecycle and dies in 1 year or less.

Appraisal, range: An evaluation of the capacity of rangelands to produce income, which includes not only consideration of grazing capacity but also facilities for handling livestock, accessibility, and relation to other feed sources. The classification and evaluation of a range from an economic and production standpoint.

Aquifer: A geologic formation or structure that transmits water in sufficient quantity to supply the needs for a water development; usually saturated sands, gravel, fractures, and cavernous and vesicular rock. The term waterbearing is sometimes used synonymously with aquifer when a stratum furnishes water for a specific use.

Arable land: Land so located that production of cultivated crops is economical and practical.

Arid: Regions or climates that lack sufficient moisture for crop production without irrigation. The limits of precipitation vary considerably according to temperature conditions, with an upper annual limit for cool regions of 10 inches or less and for tropical regions as much as 15 to 20 inches.

Available nutrient: That portion of any element or compound in the soil that readily can be absorbed and assimilated by growing plants (not to be confused with exchangeable).

Basin: 1. In hydrology, the area drained by a river. 2. In irrigation, a level plot of field, surrounded by dikes, which may be flood irrigated.

Bedrock: The solid rock underlying soils and the regolith in depths ranging from zero (where exposed by erosion) to several hundred feet.

Biennial plant: A plant that requires 2 years to complete its lifecycle.

Biological control: A method of controlling pest organisms by means of introduced or naturally occurring predatory organisms, sterilization, the use of inhibiting hormones, or other methods, rather than by chemical means.

Biomass: 1. The total amount of living material in a particular habitat or area. 2. An expression of the total weight of a given population of organisms.

Biome: A major biotic unit consisting of plant and animal communities having similarities in form and environmental conditions.

Biota: The flora and fauna of a region.

Biota influence: The influence of animals and plants on associated plant oranimal life as contrasted with climatic influences and edaphic (soil) influences.

Browse: Twigs or shoots, with or without attached leaves, of shrubs, trees, or woody vines available as forage for domestic and wild browsing animals.

Brush: A growth of shrubs or small trees.

Brush management: Management and manipulation of stands of brush by mechanical, chemical, or biological means or by prescribed burning.

Buffer strips: Strips of grass or other erosion-resisting vegetation between or below cultivated strips or fields.

Camping: A form of recreation in which living out-of-doors in a more-or-less close relationship with the natural environment is significant.

Capital: All the durable and nondurable items used in production.

Capital goods: Tangible economic goods, other than land, that are used in production.

Carrying capacity: 1. In recreation, the amount of use a recreation area can sustain without deterioration of its quality. 2. In wildlife, the maximum number of animals an area can support during a given period of the year.

Cash-grain farm: A farm on which corn, sorghums, small grains, soybeans or field beans, and peas account for at least 50 percent of the value of farm products sold.

Chiseling: Breaking or loosening the soil, without inversion, with a chisel cultivator or chisel plow.

Chisel planting: Seedbed preparation by chiseling without inversion of the soil, leaving a protective cover of crop residue on the surface for erosion control. Seedbed preparation and planting may or may not be in the same operation.

Chisel plow: Plow consisting of a series of curved, sprung steel shanks with teeth spaced 18 to 30 inches apart. Because design does not turn soil over, the chisel plow disturbs less surface soil and leaves more crop residue on the surface than does a traditional moldboard plow.

Claypan: A dense, compact layer in the subsoil having a much higher clay content than the overlying material from which it is separated by a sharply defined boundary; formed by downward movement of clay or by synthesis of clay in place during soil formation. Claypans are usually hard when dry, and plastic and sticky when wet. They usually impede movement of water and air, and the growth of plant roots. See *Hardpan.*

Clean tillage: Cultivation of a field so as to cover all plant residues and to prevent the growth of all vegetation except the particular crop desired.

Compaction: 1. To unite firmly; the act or process of becoming compact. 2. In geology, the changing of loose sediment into hard, firm rock. 3. In soil engineering, the process by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another, thereby increasing the weight of solid material per cubic foot.

Companion crop: A crop sown with another crop. Used particularly for small grains with which forage crops are sown. Preferred to the term "nurse crop."

Conservation: The protection, improvement, and use of natural resources according to principles that will assure their highest economic or social benefits.

Conservation district: A public organization created under State enabling law as a special-purpose district to develop and carry out a program of soil, water, and related resource conservation, use, and development within its boundaries; usually a subdivision of State government with a local governing body. Often called a soil conservation district or a soil and water conservation district.

Conservation plan for farm, ranch, or nonagricultural land unit: The properly recorded decisions of the cooperating landowner or operator on how he plans, within practical limits, to use his land in an operating unit within its capability and to treat it according to its needs for maintenance or improvement of the soil, water, and plant resources.

Conservation tillage: Any tillage system that reduces loss of soil or water compared to unridged or clean tillage.

Contact herbicide: A herbicide that kills primarily by contact with plant tissue rather than as a result of translocation.

Continuous grazing: Domestic livestock grazing a specific area throughout the grazing season. Not necessarily synonymous with year-long grazing.

Contour farming: Conducting field operations, such as plowing, planting, cultivating, and harvesting, on the contour.

Contour stripcropping: Layout of crops in comparatively narrow strips in which the farming operations are performed approximately on the contour. Usually strips of grass, close-growing crops, or fallow are alternated with those in cultivated crops.

Conventional tillage: The combined primary and secondary tillage operations normally performed in preparing a seedbed for a given crop grown in a given geographical area.

Cover: 1. Vegetation or other material providing protection. 2. Fish, a variety of items including undercut banks, trees, roots, and rocks in the water where fish seek necessary protection or security. 3. In forestry, low-growing shrubs, vines, and herbaceous plants under the trees. 4. Ground and soils, any vegetation producing a protecting mat on or just above the soil surface. 5. Stream, generally trees, large shrubs, grasses, or forbs that shade and otherwise protect the

stream from erosion, temperature elevation, or sloughing of banks. 6. Vegetation, all plants of all sizes and species found on an area, irrespective of whether they have forage or other value. 7. Wildlife, plants, or objects used by wild animals for nesting, rearing young, resting, escape from predators, or protection from adverse environmental conditions.

Cover crop: A close-growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production or between trees and vines in orchards and vineyards.

Cropland: Land used primarily for the production of adapted, cultivated, close-growing fruit or nut crops for harvest, alone or in association with sod crops.

Crop residue: The portion of a plant or crop left in the field after harvest.

Crop residue management: Use of that portion of the plant or crop left in the field after harvest for protection or improvement of the soil.

Crop rotation: Growing different crops in recurring succession on the same land.

Cultivar: An assemblage of cultivated plants which is clearly distinguished by its characters (morphological, physiological, cytological, chemical, or others) and which when reproduced (sexually or asexually) retains those distinguishing characters. The terms "cultivar" and "variety" are exact equivalents.

Deferred grazing: Discontinuance of livestock grazing on an area for a specified period of time during the growing season to promote plant reproduction, establishment of new plants, or restoration of vigor by old plants.

Deferred-rotation grazing: A systematic rotation of deferred grazing.

Diversion terrace: Diversions, which differ from terraces in that they consist of individually designed channels across a hillside; may be used to protect bottom land from hillside runoff or may be needed above a terrace system for protection against runoff from an unterraced area; may also divert water out of active gullies, protect farm buildings from runoff, reduce the number of waterways, and sometimes used in connection with stripcropping to shorten the length of slope so that the strips can effectively control erosion. See *Terrace*.

Diversity: The variety of species within a given association of organisms. Areas of high diversity are characterized by a great variety of species; usually relatively few individuals represent any one species. Areas with low diversity are characterized by a few species; often relatively large numbers of individuals represent each species.

Drainage: 1. The removal of excess surface water or ground water from land by means of surface or subsurface drains. 2. Soil characteristics that affect natural drainage.

Drainage, soil: As a natural condition of the soil, soil drainage refers to the frequency and duration of periods when the soil is free of saturation—for example, in well-drained soils the water is removed readily but not rapidly; in poorly drained soils the root zone is waterlogged for long periods unless artificially drained, and the roots of ordinary crop plants cannot get enough oxygen; in excessively drained soils the water is removed so completely that most crop plants suffer from lack of water.

Dryland farming: The practice of crop cultivation in low rainfall areas without irrigation.

Ecology: The study of interrelationships of organisms to one another and to their environment.

Ecosystem: A community, including all the component organisms, together with the environment, forming an interacting system.

Ecotone: A transition line or strip of vegetation between two communities, having characteristics of both kinds of neighboring vegetation as well as characteristics of its own.

Edaphic factor: A condition or characteristic of the soil (chemical, physical, or biological) which influences organisms.

Environment: The sum total of all the external conditions that may act on an organism or community to influence its development or existence.

Erosion: 1. The wearing away of the land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. 2. Detachment and movement of soil or rock fragments by water, wind, ice, or gravity. The following terms are used to describe different types of water erosion:

Accelerated erosion: Erosion much more rapid than normal, natural, or geologic erosion, primarily as a result of the influence of man or, in some cases, of other animals or natural catastrophes that expose base surfaces—for example, fires.

Geological erosion: The normal or natural erosion caused by geological processes acting over long geologic periods and resulting in the

wearing away of mountains, the building up of flood plains, coastal plains, etc. Also called natural erosion.

Gully erosion: The erosion process whereby water accumulates in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths, ranging from 1 to 2 ft to as much as 75 to 100 ft.

Natural erosion: Wearing away of the Earth's surface by water, ice, or other natural agents under natural environmental conditions of climate, vegetation, etc., undisturbed by man. Also called geological erosion.

Normal erosion: The gradual erosion of land used by man which does not greatly exceed natural erosion.

Rill erosion: An erosion process in which numerous small channels only several inches deep are formed; occurs mainly on recently cultivated soils.

Sheet erosion: The removal of a fairly uniform layer of soil from the land surface by runoff water.

Splash erosion: The spattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and spattered particles may or may not be subsequently removed by surface runoff.

Erosion classes (soil survey): A grouping of erosion conditions based on the degree of erosion or on characteristic patterns; applied to accelerated erosion, not to normal, natural, or geological erosion. Four erosion classes are recognized for water erosion and three for wind erosion. For details see Soil Survey Staff, U.S. Department of Agriculture, Soil Survey Manual, 1951. USDA Handbook 18, U.S. Government Printing Office, Washington, D.C.

Eutrophication: A means of aging lakes whereby aquatic plants are abundant and waters are deficient in oxygen. The process is usually accelerated by enrichment of waters with surface runoff containing nitrogen and phosphorus.

Evapotranspiration: The combined loss of water from a given area and during a specific period of time by evaporation from the soil surface and by transpiration from plants.

Fallow: Allowing cropland to lie idle, either tilled or untilled, during the whole or greater portion of the growing season.

Family farm: A farm business in which the operating family does most of the work, most of the managing, and takes the risks.

Farm: Any place from which $1,000 or more of agricultural products were sold, or normally would have been sold, during the census year.

Farm management: The organization and administration of farm resources, including land, labor, crops, livestock, and equipment.

Fertility (soil): The quality of a soil that enables it to provide nutrients in adequate amounts and in proper balance for the growth of specified plants when other growth factors, such as light, moisture, temperature, and the physical condition of the soil, are favorable.

Fertilizer: Any organic or inorganic material of natural or synthetic origin that is added to a soil to supply elements essential to plant growth.

Fixed costs: Costs that are largely determined in advance of the year's operation and subject to little or no control on the part of the farmer or businessman—e.g., rent of land or buildings, payment of taxes, interest on borrowed money, and upkeep of buildings, fences, and drains; costs not affected by the amount of use.

Fodder: The dried, cured plants of tall, coarse grain crops, such as corn and soybeans, including the grain, stems, and leaves; grain parts not snapped off or threshed.

Forage: All browse and herbaceous food that is available to livestock or game animals, used for grazing or harvested for feeding.

Forage production: The weight of forage that is produced within a designated period of time on a given area. The weight may be expressed as either green, air-dry, or oven-dry. The term may also be modified as to time of production such as annual, current year's, or seasonal forage production.

Forb: A herbaceous plant that is not a grass, sedge, or rush.

Grass: A member of the botanical family Gramineae, characterized by bladelike leaves arranged on the culm or stem in two ranks.

Grassed waterway: A natural or constructed waterway, usually broad and shallow, covered with erosion-resistant grasses, used to conduct surface water from cropland.

Grasslike plants: A plant that resembles a true grass—e.g., sedges and rushes—but is taxonomically different.

Grazable woodland: Forestland on which the understory includes, as an integral part of the forest plant community, plants that can be grazed without significantly impairing other forest values.

Grazing: The eating of any kind of standing vegetation by domestic livestock or wild animals.

Grazing capacity: The maximum stocking rate possible without inducing damage to vegetation or related resources.

Grazingland: Land used regularly for grazing. The term is not confined to land suitable only for grazing. Cropland and pasture used in connection with a system of farm crop rotation are usually not included.

Grazing permit: A document authorizing the use of public or other lands for grazing purposes under specified conditions, issued to the livestock operator by the agency administering the lands.

Grazing season: The portion of the year that livestock graze or are permitted to graze on a given range or pasture. Sometimes called grazing period.

Grazing system: The manipulation of grazing animals to accomplish a desired result.

Green manure crop: Any crop grown for the purpose of being turned under while green or soon after maturity for soil improvement, especially nitrogen additions.

Growing season: The period and/or number of days between the last freeze in the spring and the first frost in the fall for the freeze threshold temperature of the crop or other designated temperature threshold.

Habitat: The environment in which the life needs of a plant or animal organism, population, or community are supplied.

Halophyte: A plant adapted to existence in a saline environment, such as greasewood *(Sarcobatus),* saltgrass *(Distichlis),* and the saltbushes *(Atriplex spp.).*

Hardpan: A hardened soil layer in the lower A or in the B horizon caused by cementation of soil particles with organic matter or with materials such as silica, sesquioxides, or calcium carbonate. The hardness does not change appreciably with changes in the moisture content, and pieces of the hard layer do not flake in water.

Herbicide: A chemical substance used for killing plants, especially weeds.

Impervious soil: A soil through which water, air, or roots cannot penetrate. No soil is impervious to water and air all the time.

Indigenous: Born, growing, or produced naturally in a region or country; native.

Intensive cropping: Maximum use of the land by means of frequent succession of harvested crops.

Interplanting: 1. In cropland, the planting of several crops together on the same land—e.g., the planting of beans with corn. 2. In orchards, the planting of farm crops among the trees, especially while the trees are too small to occupy the land completely. 3. In woodland, the planting of young trees among existing trees or brushy growth.

Interseeding: Seeding into an established vegetation.

Irrigation: Application of water to lands for agricultural purposes. Different systems include:

Center-pivot: Automated sprinkler irrigation achieved by automatically rotating the sprinkler pipe or boom, supplying water to the sprinkler heads or nozzles, as a radius from the center of the field to be irrigated. Water is delivered to the center or pivot point of the system. The pipe is supported above the crop by towers at fixed spacings and propelled by pneumatic, mechanical, hydraulic, or electric power on wheels or skids in fixed circular paths at uniform angular speeds. Water is applied at a uniform rate by progressive increase of nozzle size from the pivot to the end of the line. Single units are ordinarily about 1,250 to 1,300 ft long and irrigate approximately a 130-acre circular area.

Drip: A planned irrigation system where all necessary facilities have been installed for the efficient application of water directly to the root zone of plants by means of applicators (orrices, emitters, porous tubing, perforated pipe, etc.) operated under low pressure. The applicators may be placed on or below the surface of the ground.

Sprinkler: A planned irrigation system where all necessary facilities have been installed for the efficient application of water for irrigation by means of perforated pipe or nozzles operated under pressure.

Irrigation application efficiency: Percentage of irrigation water applied to an area that is stored in the soil for crop use.

Irrigation lateral: A branch of the main canal conveying water to the farm ditches, sometimes used in reference to farm ditches.

Land: The total natural and cultural environment within which production takes place; a broader term than soil. In addition to soil, its attributes include other physical conditions, such as mineral deposits, climate, and water supply; location in relation to centers of commerce, populations, and other land; the size of the individual tracts

or holdings; and existing plant cover, works of improvement, and the like.

Land capability: The suitability of land for use without permanent damage. Land capability, as ordinarily used in the United States, is an expression of the effect of physical land conditions, including climate, on the total suitability for use without damage for crops that require regular tillage, for grazing, for woodland, and for wildlife. Land capability involves consideration of: 1) the risks of land damage from erosion and other causes; and 2) the difficulties in land use owing to physical land characteristics, including climate.

Land capability class: One of the eight classes of land in the land capability classification of the Soil Conservation Service; distinguished according to the risk of land damage or the difficulty of land use; they include:

Land suitable for cultivation and other uses:

Class I: Soils that have few limitations restricting their use.

Class II: Soils that have some limitations, reducing the choice of plants or requiring moderate conservation practices.

Class III: Soils that have severe limitations that reduce the choice of plants or require special conservation practices, or both.

Class IV: Soils that have very severe limitations that restrict the choice of plants, require very careful management, or both.

Land generally not suitable for cultivation (without major treatment):

Class V: Soils that have little or no erosion hazard, but that have other limitations, impractical to remove, that limit their use largely to pasture, range, woodland, or wildlife food and cover.

Class VI: Soils that have severe limitations that make them generally unsuited for cultivation and limit their use largely to pasture or range, woodland, or wildlife food and cover.

Class VII: Soils that have very severe limitations that make them unsuited to cultivation and that restrict their use largely to grazing, woodland, or wildlife.

Class VIII: Soils and landforms that preclude their use for commercial plant production and restrict their use to recreation, wildlife, water supply, or esthetic purposes.

Land tenure: The holding of land and the rights that go with such holding, including all forms of holding from fee simple title embracing all possible rights within the general limitations imposed by the Government, to the various forms of tenancy or holding of land owned by another.

Legume: A member of the pulse family, one of the most important and widely distributed plant families. The fruit is a pod that opens along two sutures when ripe. Leaves are alternate, have stipules, and are usually compound. Includes many valuable food and forage species, such as peas, beans, peanuts, clovers, alfalfas, sweet clovers, lespedezas, vetches, and kudzu. Practically all legumes are nitrogen-fixing plants.

Loamy: Intermediate in texture and properties between fine- and coarse-textured soils; includes all textural classes with the words "loamy" or "loam" as a part of the class name, such as clay loam or loamy sand.

Loess: Material transported and deposited by wind and consisting of predominantly silt-sized particles.

Macro-organisms: Those organisms retained on a U.S. standard sieve No. 30 (openings of 0.589 mm); those organisms visible to the unaided eye. See *Micro-organisms.*

Micro-organisms: Those organisms retained on a U.S. standard sieve No. 100 (openings of 0.149 mm); those minute organisms invisible or only barely visible to the unaided eye. See *Macro-organisms.*

Minimum tillage: Limiting the number of soil-disturbing operations to those that are properly timed and essential to produce a crop and prevent soil damage.

Moldboard plow: A traditional plow with a curved plate attached above a plowshare to lift and turn the soil. Invented by John Deere; first implement to successfully break prairie sod.

Monoculture: Raising crops of a single species, generally even-aged.

Mulch: A natural or artificial layer of plant residue or other materials, such as sand or paper, on the soil surface.

Mulch tillage: Soil tillage that employs plant residues or other materials to cover the ground surface.

Multiple use: Harmonious use of land for more than one purpose—i.e., grazing livestock, wildlife production, recreation, watershed, and timber production. Not necessarily the combination of uses that will yield the highest economic return or greatest unit output.

Niche: A habitat that supplies the factors necessary for the existence of an organism or species.

Nitrification: The biological oxidation of ammoni-

um to nitrite and the further oxidation of nitrite to nitrate.

Nitrogen assimilation: The incorporation of nitrogen compounds into cell substances by living organisms.

Nitrogen fixation: The conversion of elemental nitrogen (N_2) to organic combinations or to forms readily usable in biological processes.

Nitrogen-fixing plant: A plant that can assimilate and fix the free nitrogen of the atmosphere with the aid of bacteria living in the root nodules. Legumes with associated rhizobium bacteria in the root nodules are the most important nitrogen-fixing plants.

Nonpoint pollution: Pollution whose sources cannot be pinpointed; can best be controlled by proper soil, water, and land management practices.

Nonrenewable natural resources: Natural resources that, once used, cannot be replaced.

No-tillage: A method of planting crops that involves no seedbed preparation other than opening the soil for the purpose of placing the seed at the intended depth. This usually involves opening a small slit or punching a hole into the soil. There is usually no cultivation during crop production. Chemical weed control is normally used. Also referred to as slot planting or zero tillage.

Noxious species: A plant that is undesirable because it conflicts, restricts, or otherwise causes problems under the management objectives. Not to be confused with species declared noxious by laws.

Nutrients: 1. Elements, or compounds, essential as raw materials for organism growth and development, such as carbon, oxygen, nitrogen, phosphorus, etc. 2. The dissolved solids and gases of the water of an area.

Organic content: Synonymous with volatile solids, except for small traces of some inorganic materials, such as calcium carbonate, that lose weight at temperatures used in determining volatile solids.

Organic fertilizer: Byproduct from the processing of animal or vegetable substances that contain sufficient plant nutrients to be of value as fertilizers.

Overgrazed range: A range that has lost its productive potential because of overgrazing.

Overgrazing: Grazing so heavy that it impairs future forage production and causes deterioration through damage to plants, soil, or both.

Palatability: Plant characteristic or condition that stimulates a selective response in animals.

Pan, pressure or induced: A subsurface horizon or soil layer having a high bulk density and a lower total porosity than the soil directly above or below it as a result of pressure applied by normal tillage operations or by other artificial means; frequently referred to as plow pan, plow sole, tillage pan, or traffic pan.

Pasture: An area intensively managed for the production of forage, introduced or native, and harvested by grazing.

Percolation: The downward movement of water through soil, especially the downward flow of water in saturated or nearly saturated soil at hydraulic gradients of the order of 1.0 or less.

Perennial plant: A plant that normally lives 3 or more years, sending forth shoots each spring from roots or rhizomes.

Permeability, soil: The quality of a soil horizon that enables water or air to move through it. The permeability of a soil may be limited by the presence of one nearly impermeable horizon even though the others are permeable.

Pesticide: Any chemical agent used for control of specific organisms, such as insecticides, herbicides, fungicides, etc.

Planning horizon: A farmer's planning horizon is the length of time considered when making an investment of capital, labor, or land resources. It may be as short as one crop season or as long as his children's lifetimes. The term includes the concept of discounted value that the farmer places on future income or future costs compared with present income or costs. The terms "planning period," "payback period," and "time horizon" are often used interchangeably with "planning horizon."

Plow: An implement used to cut, lift, and turn over soil, especially in preparing a seedbed.

Plow layer: The soil ordinarily moved in tillage; equivalent to surface soil or surface layer.

Point row: A row that forms an angle with another row instead of paralleling it to the end of the field. A row that "comes to a point," ending part way across the field instead of at the edge of the field.

Polyculture: Growing more than one crop on the same land in 1 year, or growing two or more crops simultaneously. Variations include multiple cropping, intercropping, interculture, and mixed cropping.

Postemergence (crop production): Application of chemicals, fertilizers, or other materials and operations associated with crop production after the crop has emerged through the soil surface.

Preemergence (crop production): Application of chemicals, fertilizers, or other materials and operations associated with crop production before the crop has emerged through the soil surface.

Prescribed burning: The deliberate use of fire under conditions where the area to be burned is predetermined and the intensity of the fire is controlled.

Prime agricultural land: Land that is best suited for producing food, feed, forage, fiber, and oilseed crops, and also available for those uses; includes cropland, pastureland, rangeland, forestlands, but not urbanized land or water. It has the soil quality, growing season, and moisture supply needed to produce sustained high yields of crops economically when treated and managed, including water management, according to modern agricultural methods.

Range condition: The present state of the plant community on a range site in relation to the potential natural plant community for that site.

Range condition class: One of a series of arbitrary categories used to classify range condition, usually expressed as either excellent, good, fair, or poor.

Rangeland: Land on which the native vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs suitable for grazing or browsing use. Includes lands revegetated naturally or artificially to provide a forage cover that is managed like native vegetation. Rangelands include natural grasslands, savannas, shrublands, most deserts, tundra, alpine communities, coastal marshes, and wet meadows.

Range management: A distinct discipline founded on ecological principles and dealing with the husbandry of all rangeland and range resources.

Reduced tillage: A tillage sequence designed to reduce or eliminate secondary tillage operations.

Renewable natural resources: Resources that can be restored and improved.

Rest-rotation grazing: A form of deferred-rotation grazing in which at least one grazing unit is rested from grazing for a full year.

Riparian land: Land situated along the bank of a stream or other body of water.

Rotary tillage: An operation using a power driven rotary tillage tool to loosen and mix soil.

Rotation grazing: System of use embracing short periods of heavy stocking followed by periods of rest for herbage recovery during the same season; generally used on tame pasture or cropland pasture.

Row crop: A crop planted in rows, normally to allow cultivation between rows during the growing season.

Runoff (hydraulics): That portion of the precipitation on a drainage area that is discharged from the area in stream channels. Types include surface runoff, ground water runoff, or seepage.

Saline soil: A nonsodic soil containing sufficient soluble salts to impair its productivity but not containing excessive exchangeable sodium. This name was formerly applied to any soil containing sufficient soluble salts to interfere with plant growth, commonly greater than 3,000 parts per million.

Sedimentation: The process or action of depositing sediment.

Selective grazing: The tendency for livestock and other grazing animals to graze certain plants in preference to others.

Selective herbicide: A pesticide intended to kill only certain types of plants, especially broadleafed weeds, and not harm other plants such as farm crops or lawn grasses.

Shrub: A woody or perennial plant differing from a tree by its low stature and by generally producing several basal shoots instead of a single bole.

Siltation: The process of depositing silt. See *Sedimentation.*

Slope: The degree of deviation of a surface from horizontal, measured in a numerical ratio, percent, or degrees.

Soil: 1. The unconsolidated mineral and organic material on the immediate surface of the Earth that serves as a natural medium for the growth of land plants. 2. The unconsolidated mineral matter on the surface of the Earth that has been subjected to and influenced by genetic and environmental factors of parent material, climate (including moisture and temperature effects), macro- and micro-organisms, and topography, all acting over a period of time and producing a product—soil—that differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics. 3. A kind of soil is the collection of soils that are alike in specified combinations of characteristics. Kinds of soil are given names in the system of soil classification. The terms "the soil" and "soil" are collective terms used for all soils, equivalent to the word "vegetation" for all plants.

Soil amendment: Any material, such as lime, gypsum, sawdust, or synthetic conditioner, that is

worked into the soil to make it more amenable to plant growth.

Soil classification: The systematic arrangement of soils into groups or categories on the basis of their characteristics. Broad groupings are made on the basis of general characteristics, subdivisions on the basis of more detailed differences in specific properties.

Soil conditioner: Any material added to a soil for the purpose of improving its physical condition.

Soil conservation: Using the soil within the limits of its physical characteristics and protecting it from unalterable limitations of climate and topography.

Soil-conserving crops: Crops that prevent or retard erosion and maintain or replenish rather than deplete soil organic matter.

Soil-depleting crops: Crops that under the usual management tend to deplete nutrients and organic matter in the soil and permit deterioration of soil structure.

Soil erosion: The detachment and movement of soil from the land surface by wind or water. See *Erosion.*

Soil fertility: The quality of a soil that enables it to provide nutrients in adequate amounts and in proper balance for the growth of specified plants, when other growth factors, such as light, moisture, temperature, and physical condition of soil, are favorable.

Soil-formation factors: The variables, usually interrelated natural agencies, active in and responsible for the formation of soil. The factors are usually grouped as follows: parent material, climate, organisms, topography, and time. Many people believe that activities of man in his use and manipulation of soil become such an important influence on soil formation that he should be added as a sixth variable. Others consider man as an organism.

Soil loss tolerance: The maximum average annual soil loss in tons per acre per year that should be permitted on a given soil.

Soil management: The sum total of all tillage operations, cropping practices, fertilizer, lime, and other treatments conducted on, or applied to, a soil for the production of plants.

Soil survey: A general term for the systematic examination of soils in the field and in laboratories; their description and classification; the mapping of kinds of soil; the interpretation of soils according to their adaptability for various crops, grasses, and trees; their behavior under use or treatment for plant production or for other purposes; and their productivity under different management systems.

Stripcropping: Growing crops in a systematic arrangement of strips or bands which serve as barriers to wind and water erosion. See *Buffer strips, Contour stripcropping.*

Strip tillage: Tillage operations for seedbed preparation that are limited to a strip not to exceed one-third of the distance between rows; the area between is left untilled with a protective cover of crop residue on the surface for erosion control. Planting and tillage are accompanied in the same operation.

Stubble: The basal portion of plants remaining after the top portion has been harvested; also, the portion of the plants, principally grasses, remaining after grazing is completed.

Stubble mulch: The stubble of crops or crop residues left essentially in place on the land as a surface cover during fallow and the growing of a succeeding crop.

Subsidence: A downward movement of the ground surface caused by solution and collapse of underlying soluble deposits, rearrangements of particles upon removal of coal, or reduction of fluid pressures within an aquifer or petroleum reservoir.

Subsoil: The B horizons of soils with distinct profiles. In soils with weak profile development, the subsoil can be defined as the soil below the plowed soil (or its equivalent of surface soil) in which roots normally grow. Although a common term, it cannot be defined accurately. It has been carried over from early days when "soil" was conceived only as the plowed soil and that under it was the "subsoil."

Subsoiling: The tillage of subsurface soil, without inversion, for the purpose of breaking up dense layers that restrict water movement and root penetration.

Terrace: An embankment or combination of an embankment and channel constructed across a slope to control erosion by diverting or storing surface runoff instead of permitting it to flow uninterrupted down the slope. Terraces or terrace systems may be classified by their alignment, gradient, outlet, and cross-section. Alignment may be parallel or nonparallel. Gradient may be level, uniformly graded, or variably graded. Grade is often incorporated to permit paralleling the terraces. Outlets may be soil infiltration only, vegetated waterways, tile outlets, or combinations

thereof. Cross-section may be narrow base, broad base, bench, steep backslope, flat channel, or channel.

Terrace outlet channel: Channel, usually having a vegetative cover, into which the flow from one or more terraces is discharged and conveyed from the field.

Tile, drain: Pipe made of burned clay, concrete, or similar material, in short lengths, usually laid with open joints to collect and carry excess water from the soil.

Tile drainage: Land drainage by means of a series of tile lines laid a specified depth and grade.

Tillage: The operation of implements through the soil to prepare seedbeds and root beds.

Tilth: The physical condition of soil as related to its ease of tillage, fitness as a seedbed, and impedance to seedling emergence and root penetration.

Undergrazing: An intensity of grazing in which the forage available for consumption under a system of conservation pasture management is not used to best advantage.

Undesirable species: 1. Plant species that are not readily eaten by animals. 2. Species that conflict with or do not contribute to the management objectives.

Universal soil loss equation: An equation used to design water erosion control systems: A = RKLSPC wherein A is average annual soil loss in tons per acre per year; R is the rainfall factor; K is the soil erodibility; L is the length of slope; S is the percent slope; P is the conservation practice factor; and C is the cropping and management factor. (T = soil loss tolerance value that has been assigned each soil, expressed in tons per acre per year.)

Utility: The ability of a good to satisfy human wants.

Variable costs: Costs subject to the year's production schedule. As such, they may be largely controlled by the operator. Examples are the use of fertilizer and insecticides, hauling grain, etc.

Water management: Application of practices to obtain added benefits from precipitation, water, or water flow in any of a number of areas, such as irrigation, drainage, wildlife and recreation, water supply, watershed management, and water storage in soil for crop production.

Water table: The upper surface of ground water or that level below which the soil is saturated with water; locus of points in soil water at which the hydraulic pressure is equal to atmospheric pressure.

Water use efficiency: Crop production per unit of water used, irrespective of water source, expressed in units of weight per unit of water depth per unit area. This concept of utilization applies to both dryland and irrigated agriculture.

Windbreak: 1. A living barrier of trees or combination of trees and shrubs located adjacent to farm or ranch headquarters and designed to protect the area from cold or hot winds and drifting snow. 2. A narrow barrier of living trees or combination of trees and shrubs, usually from one to five rows, established within or around a field or for the protection of land and crops from wind.

Wind erosion: An equation used for the design of wind erosion control systems: E = f (IKCLV) wherein E is the average annual soil loss, expressed in tons per acre per year; I is the soil erodibility; K is the soil ridge roughness; C is the climatic factor; L is the unsheltered distance across the field along the wind erosion direction; and V is the vegetative cover.

Wind stripcropping: The production of crops in relatively narrow strips placed perpendicular to the direction of the prevailing winds.

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