Chapter IV

Croplands

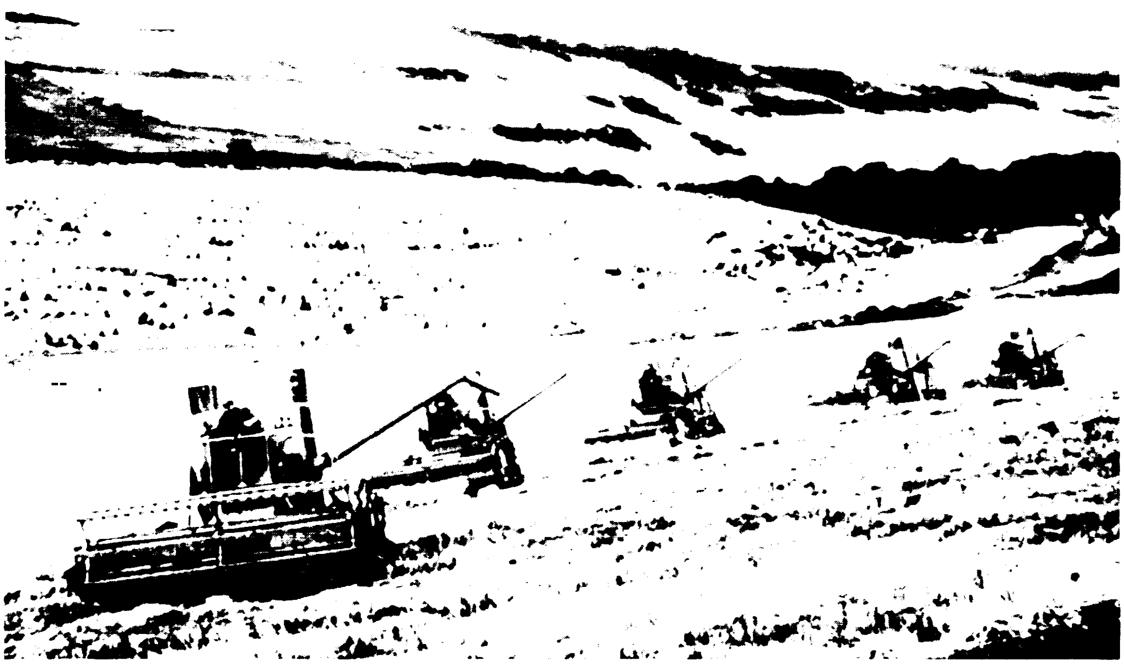


Photo credit: U.S. Department of Energy

Contents

List of Tables

List of Figures

Chapter IV

Croplands

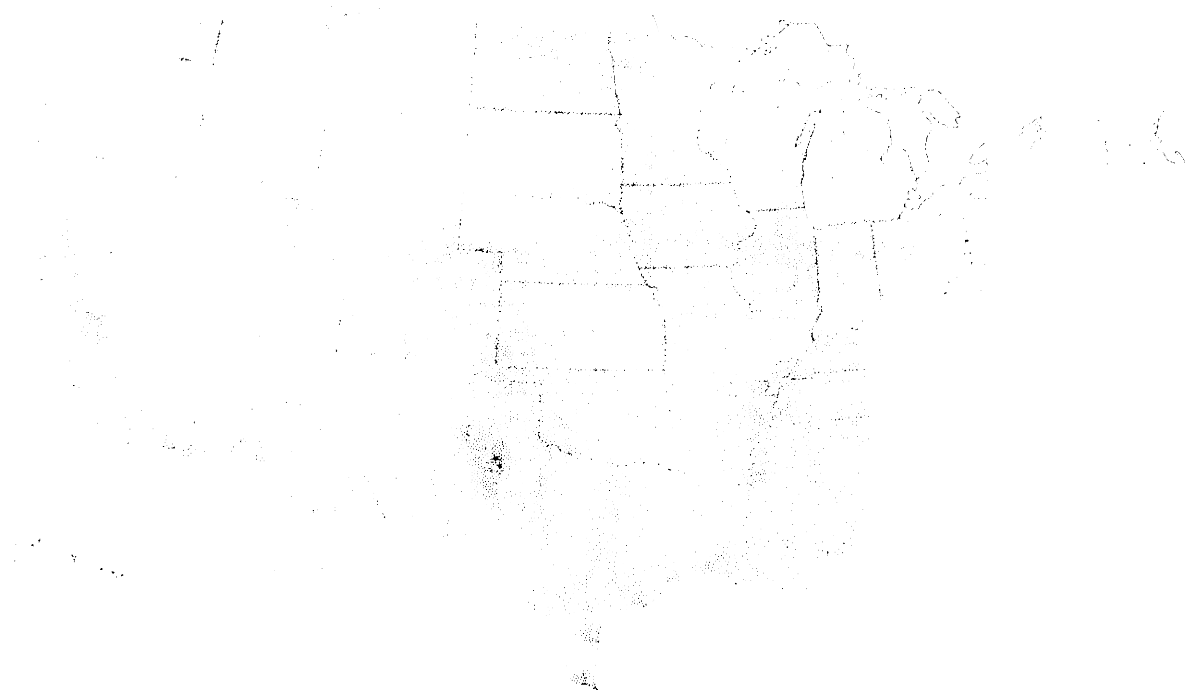
INTRODUCTION

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



Dot = *25,000* acres

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 tons a year. This is an average of 7 tons per acre each year for the Nation's total 413 million cropland acres.

Information about soil formation rates under cropland conditions is inadequate, but the highest likely rate on unconsolidated parent materials is probably 0.5 ton per acre. The rate is much slower for consolidated materials (rock). Thus, average soil erosion is more than 10 times greater than average soil formation on U.S. croplands (Hall, et a]., 1982; McCormack, et al., 1982).

Although erosion occurs to some extent on all cropland, it is much worse in some areas than in others. The severity of erosion varies depending on the type of crop grown, the management system used, terrain, climate, and other factors. Row crop and small-grain cropIand, which constitute 75 percent of all cropland, erode twice as much as other cropland (5.4 compared to 2,5 tons). Further, a high proportion of the Nation's soil loss occurs on a relatively small portion of the cropland—only 6 percent of the Nation's cropland (24 million acres) accounted for 43 percent of all sheet and rill erosion.

PRODUCTIVITY=SUSTAININ 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 biological approaches that use land, water, and energy resources efficiently,

Both types of technologies have been important 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 effective or more conserving of water and other resources, depending on specific local farming conditions. The following discussion is not intended to recommend any particular technology. Rather, it is to illustrate some of the technologies that are designed to enhance production and conservation at the same time.

Conservation Tillage

Spraying More, Tilling Less

Prior to the development of chemical herbicides in the 1940's, farmers relied on a variety of tillage practices to control unwanted plants (weeds) in their fields. It was not uncommon for Midwestern corn farmers to make as many as 10 trips across their fields before harvest, most of them to control weeds (Triplett and Van Doren, 1977).

Today, most producers of the major field crops have substituted herbicides for some of their tillage practices. Table 13 illustrates the magnitude of increase in herbicide use between 1966 and 1976 for the crops grown on most of the total U.S. cropland base. In every

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: Percent area treated	Herbicides: Percent of total herbicides used	Insecticides: Percent area treated	Insecticides: Percent of total insecticides used	Fungicides: Percent area treated	Fungicides: Percent of total fungicides used	All pesticides: Percent area treated	All pesticides: 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
Sorghurn	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		5	1	2	NA	41	1	29.8
Alfalfa and other hay	2	<;.5			—	NA	8	1	61.0
Pasture and rangeland	1	2	<:.5	<:,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 Tilkge 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, maybe 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

Tillage system	Corn residues on soil surface (t/a)[a]					
	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 NH3	Cultivation

[a]Tons per acre

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

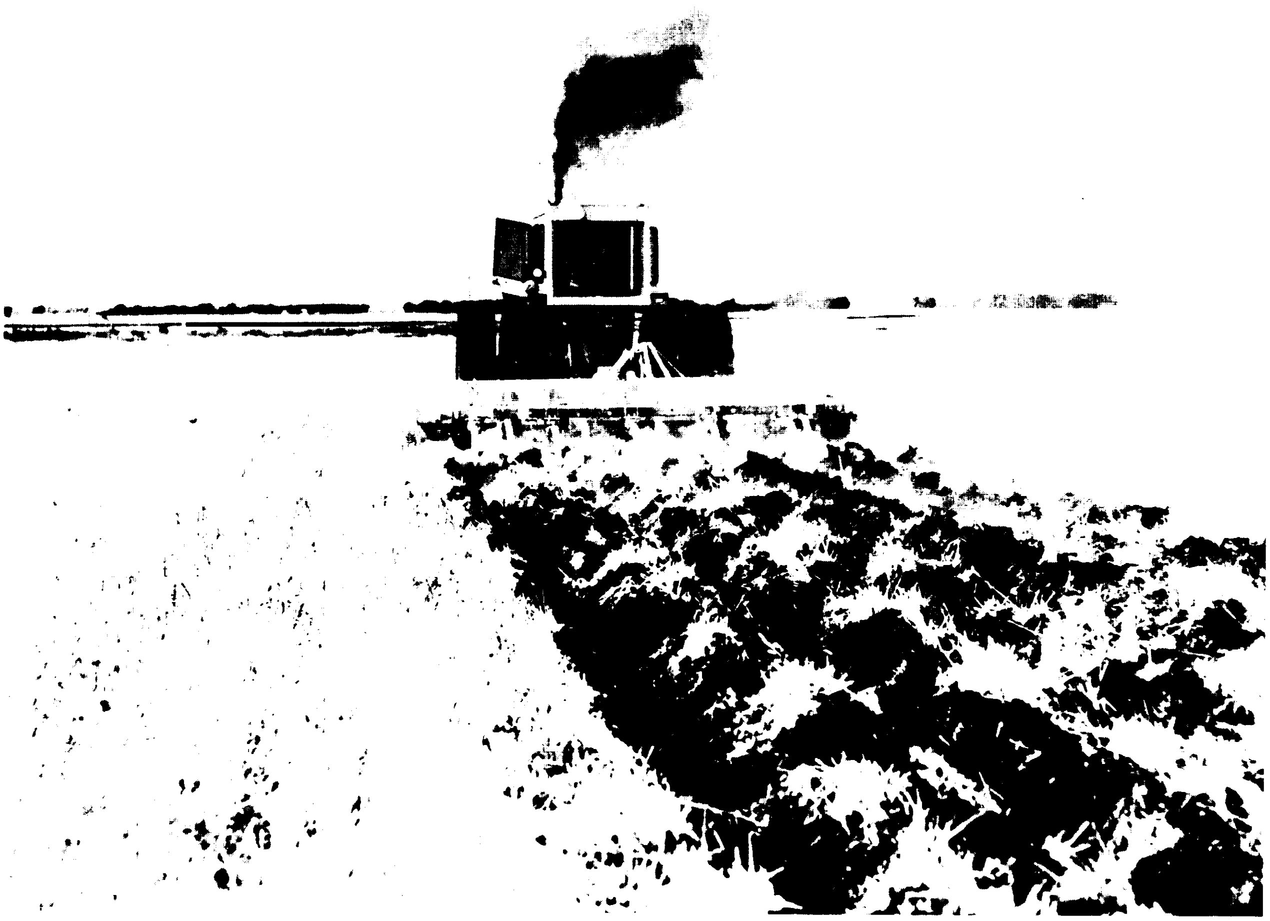


Photo credit. USDA—Soi/ Conservation Service

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 tiilage 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 pIowing 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 plan ting.–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 Consevation 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 *IVo-7'ill 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.i
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 Cross (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 tiIlage, ' 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 prac. tices, 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, maybe 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 limit for minimum tillage of 100 percent of cropland planted, OTA'S assessment uses a 75-percent upper limit for conservation tillage adoption. (This figure is a compromise between Crosson's estimated maximum of 50 to 60 percent adoption, and 84 percent estimated by the Resources Conservation Act (RCA)). The resulting projection is shown in figure 12 as an adoption curve. The earlier USDA projection is included in the figure for comparison. At present, conservation tillage is on the very steep part of the adoption curve. Because of the difference in assumed upper limits, by the year 2000 the gap between the two curves is over 10 percent of planted cropland—or anywhere 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

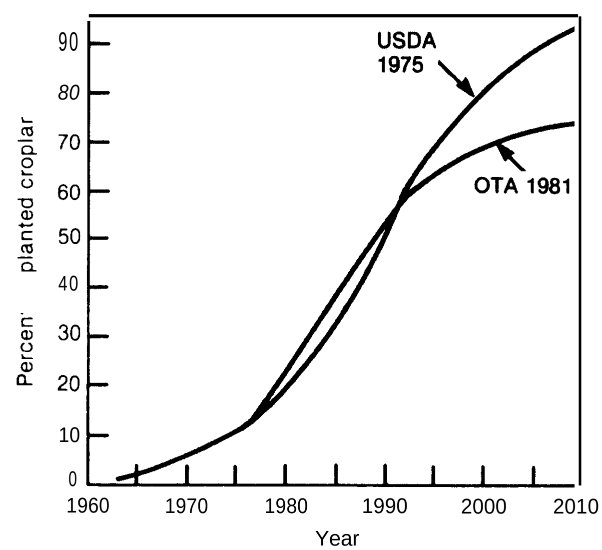
SOURCE No. Till *Farmer* magazine, Annual Survey, 1981

conomic INCINTIVES FOR ADOPTION

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

- *Reduced labor requirement t.* —Labo r requirements 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

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 tiel 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 this land can be planted to more profitable crops.

The long-term implications of this potential for row crop production on rolling terrain could be profound. The present classification of land capabilities, used for planning by SCS and other Government agencies, assumes a lower capability class for sloping land because of its susceptibility to erosion. With no-till techniques, more sloping land could be used for production without increasing erosion.

BARRIIRS TO ADOPTION

Weed, Insect, and Disease Problems.—The future expansion of conservation tillage and no-till depends on developing improved techniques for controlling weeds, particularly perennials (Crosson, **1981;** Worsham, 1980; Owens and Patterson, 1973). In fact, a 1979 survey of almost 1,000 farmers in the Lake Erie region showed weed control problems to he the number one barrier to adopting conservation tillage 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 conservation 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 no{ 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 y, 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%
	1 00.0":	1 00.0%
Profitability		
Costs exceed returns . . , .	7.8 %	21.9 %
Costs equal returns	32.5 %	46.9 %
Returns exceed costs.	59.7 %	31.2 %
	100,0 %	1 00.0"b
Time/labor requirements		
More time/labor	7.8 %	20.0 %
No change	1 7.5"b	28.6 '%
Less time/labor	74.7 %	51.4 '%
	1 00.0":	100.0"2,
Ease of use		
Very difficult ., ... , ...	2.6 %	20,6 %
Moderate.	22.2 %	29.4 %,
Very easy ., ...	75.2 %	50.0 %
	100.0%	1 00.0"h
Compatibility		
Not compatible	3.9%	28.6%
Moderately compatible	15.6 %	28.5 %
Very compatible	80.5 %	42.9 '%
	100.0%	1 00.0'%
Influence on soil erosion		
Worsened	1.4%	0.0 %
No change	1 6.8"h	50.0 %
Improved	8 1.8'YO	50.0 %
	1 00.0'%	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 score[a]
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 soil, 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 soluble or they adhere tightly to soil particles. In these cases erosion reduction prevents or greatly reduces the pesticide's entry into surface waters. Thus, conservation tillage and no-till act to lessen the impact of such pesticides, which include trifluralin, endrin, toxaphene, and paraquat, Several researchers have reported that pesticide losses are virtually eliminated under no-till, although less drastic reductions in tillage have lesser effects.

A problem can arise, however, where some soils are not able to capture the herbicides, For example, soil clays in wet tropical regions, such as Puerto Rico, do not bind the herbicides to their surfaces. In such environments, a large portion of the herbicide can be carried into water bodies regardless of the timing of application,

There is also the problem of persistent toxicity of some of the herbicides and other pesticides. whether the herbicide binding to clays is permanent is unknown. It may be that the chemical can be released in some changed form by microbial activity, with unknown consequences for soil microbiology. Although most of the insecticides degrade rapidly, the toxicity of the compounds produced by the degradation process is unknown,

Conservation tillage and no-till reduce water runoff, but do not eliminate it. Thus, the same question can be posed for pesticides as was posed for nutrient losses: Do higher concentrations of pesticides in runoff offset reductions in the sediment-associated pesticides under these systems? Several studies suggest that concentrations of specific pesticides are greater in lower runoff volumes, as happens under conservation tillage and no-till, possibly because pesticides on crop residues are easily washed off. In other instances pesticides seem to be filtered out as runoff passes over untreated soil and vegetation.

Because conservation tillage has such an increased reliance on pesticides, particularly herbicides, 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 metabolizes 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 z) 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 ineluding 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 acre per year, or about the rate that would occur with moldboard plowing and two passes with a disk (Helm, 1980). Thus, farmers can obtain the labor and fuel saving benefits of conservation tillage and no-till without necessarily saving much soil in the process.

The acreage of cropland treated with these conservation technologies probably will continue to increase, OTA projections show that 75 percent of U.S. cropland may have some form of conservation tillage by 201o. Yet the land most severely affected by erosion may still be missed, just as it has been missed by more traditional conservation measures. Table 19 shows that in 1977, conservation tillage was used on less erosive land. This poses several policy questions. First, it is commonly said that the benefits of reduced soil erosion with conservation tillage and no-till outweigh the risks posed by greater herbicide use, But this tradeoff is less justifiable if these technologies do 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 s-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 reIy on crop rotations, crop residues, animal manures, legumes, green manures, off-farm organic wastes, mechanical cultivation, mineral-bearing rocks, and biological pest controI to maintain soil productivity and tilth, to supply pIant 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 *non*-renewable 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 reformation 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 non-point 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 monoculture. * 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 complementarily 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 available water, and to avoid direct competition, a second crop is planted after the first crop has completed the major part of its development, but before it is harvested. Relay intercropping of soybeans into no-till wheat is being practiced as far north as Wooster, Ohio (Triplett, 1981). The success of this intercropping depends on the correct combination of timing and other variables to avoid shading, nutrient competition, or inhibition brought about by toxicity produced by the decomposition of previous crop residues.

Farmers also can get complementarily 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 monoculture. It is still uncertain whether the higher yields are the result of more efficient 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 susceptibility 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.

DISADVANTA61S

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 *disad-* ***vantages*** 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 agricuture. 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 catastrophes.

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 resource base. First and most obvious, new species could be domesticated. This presents both the greatest challenges and also the greatest potential rewards,

All of today's economically important crops were originally selected by pretechnological peoples. The traits for which they were selected, while refined in modern times, have shaped and dominated agricultural practices. Traits such as concentrated seed production, short ripening period, easy hulling, and palatability were selected because they made the plant more useful to humans. Some traits 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 PLANT%

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.

Polymdture 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 monoculture.

Herbaceous perennials are nonwoody pkmts, 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 monoculture 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.

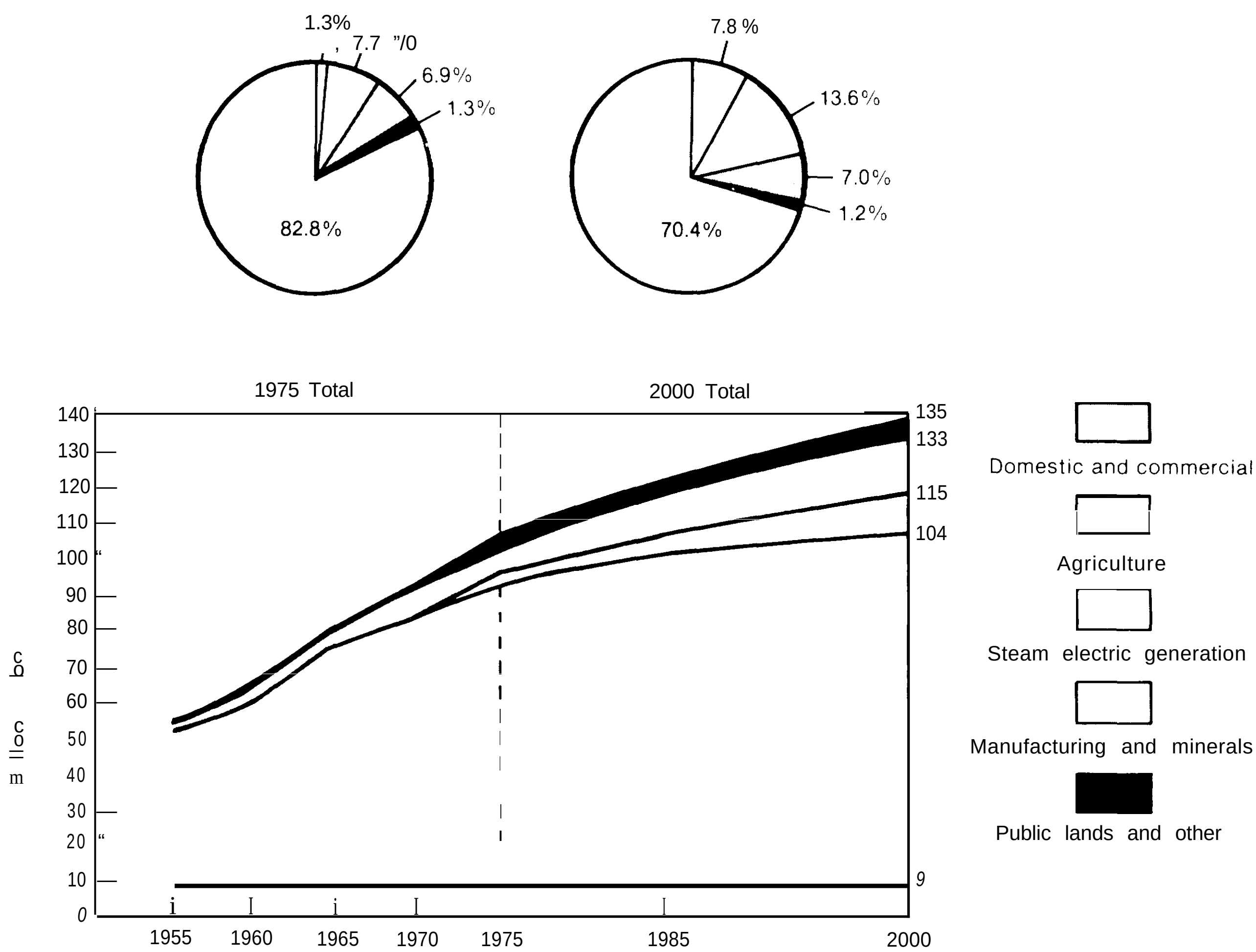
Drip Irrigation

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, 01979). 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 eIements 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

lemons limes ,roes, 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, olies, figs, passion fruit, Christmas tree, etc, Street medians and turf —both for homes and golf coures -- 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,,

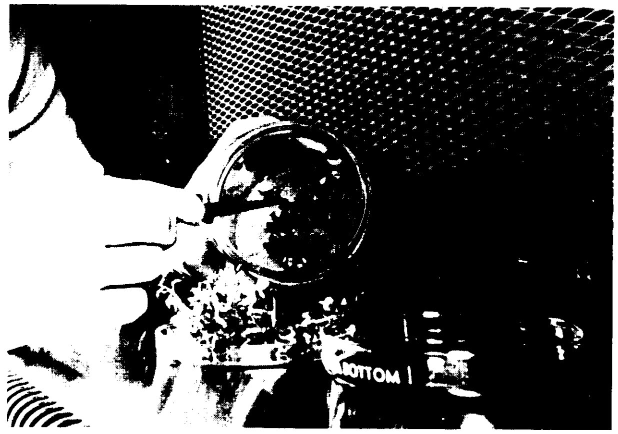
Salt-tolerant cultivars would not solve salinity problems, but they could provide an opportunity for enhancing the productivity of some lands. Research on salt tolerance is increasing, though not substantially. Epstein, et al. (1980), conducted research on barley, wheat, and tomatoes to determine their 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 unique ways of transporting ions and different ways of accumulating and excluding salt. When the two cultivars were crossed, they produced a plant that could survive, flower, and set fruit the size of a small cherry tomato when irrigated with 70 percent seawater (Epstein, 1980], This experiment is important because it indicates that salt tolerance can be transferred from wild species to those of commercial value.

Other research shows that tissue and cell culture techniques may speed up the process of identifying and selecting salt-tolerant plant cells, Through these techniques, individual plant cells can be introduced into a culture medium that is designed to support the growth 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 mild, 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 c;rops 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 e research.

Impacts

[f 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 raiscs 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 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 informat-ion, 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 used wherever appropriate facilities exist. Few educational programs tailored for farm and ranch use have been developed, however, though computer question-and-answer courses on a wide variety of topics have been included in Control Data's agricultural business center,

If region-specific models are developed to help farmers calculate complex tradeoffs between short-term benefits and long-term costs, or vice versa, it is likely that agricultural uses will be better matched to the capability of the land. However, the economics of making interactive computer programs or models that are site specific enough for such purposes have yet to be determined, If the models must be made so specific that they cover a region with too few customers to pay for the development costs, Government subsidies may be necessary. As the work of risk-taking entrepreneurs progresses, the economics of computers being used to enhance long-term land productivity will become more clear.

Soii 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 most of them is doubtful, To some extent, they are 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 stabilization 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, pending, 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 on 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, anci 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.

MANAGIMINT 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 Con-rol

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 become more apparent. Extrapolations from 1977 NRI data show erosion rates on erosive lands treated with minimum tillage alone average 69 percent less than the corresponding rates for untreated cultivated land (Miller, 1981).

Cover Crops

Cover can also be maintained by planting cover crops when land is bare between regular crops. Cover crops hold soil in place and thus reduce erosion. Cover crops are well suited to humid areas and may also be used on irrigated land where irrigation water can give quick germination and growth. They are less practical in drier areas where wind erosion can be severe because they compete for limited supplies of soil moisture. However, one practical method to avoid the moisture depletion problem is to plant crops that grow before winter kill, leaving plant residues for protection with no additional water requirements, Similar results also can be obtained by using a herbicide to kill a crop after it has provided some protective growth.

Mulches and Nonvegetaive 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 prvailing winds, and with factors affecting field erodibility~.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. [compatibility 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 por0sity of the harriers. Nearly any plant that reaches substantial height and retains its lower leaves can be used as a harrier. 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 hanks ha havee also been used for windbreaks.

The USe) of windbreaks to control wind erosion is declinin, 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 tillagc 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 t ill age implements, including chisel plow's 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, pro f-itability, 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 improvments on U.S. farms, which experienced rapid expansion from 1935 to 1955, are now deteriorating in ovrall 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 (hot h 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 rapidly throughout the U.S. agricultural sector. They tend to require smaller initial investments than permanent erosion control methods, with much of the investment made in special equipment required to implement the practice. (Consequently, such investments do not show up as conservation investments in the Economics, Statistics, and Cooperatives Service figures quoted above.) Some management practices, such as contour plowing, involve higher operating costs than conventional practices and may not produce sufficient gains in land productivity to maintain profits on a short-term basis (USDA Land and Water Task Force, 1979).

Because costs for conversion to productivity-conserving systems—e. g., equipment purchases and higher current operating costs—are incurred over an indefinite period of time, cost sharing to promote them is difficult. Loan programs or tax credits to promote equipment purchases might prove to be more effective incentive mechanisms. However, the major constraints 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 prac- t ices, " 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. 11 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 w' ind erosion.

The greatest potential for improving current technologies lies in improving conservation tillage systems. Increased effectiveness of chemicals for cent rolling 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 cloudiness 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 stabilizing 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 reporting severity of erosion, would improve erosion control by providing concrete information on the value of control techniques for maintaining soil productivity.

New technology for forecasting wind erosion could greatly improve our ability to cope with the problem. Using probability functions to convert basic wind erosion equations to stochastic projections would be required. Remote sensing support would also be needed.

Continued efforts in weather modification might have potential for reducing the wind erosion problem, especially those aimed directly at preventing drought by enhancing precipitation. But weather modification is justifiably controversial. Improved irrigation technologies to reduce seepage, evaporation, and transpiration losses could also reduce wind erosion indirectly, by conserving scarce ground water resources, thereby reducing the need to revert to dryland farming in many areas of the country.

Improved methods for calculating optimum site-specific fertility management decisions could aid farmers in achieving maximum crop cover to minimize erosion and produce optimal yields, The increasing availability of computers makes improvements in mathematical models for analyzing fertility —e.g., models that account for the fertility effects of soil moisture management—of significant practical value to 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 techniques 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 arc 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.

CHAPTER IV REFERENCES

American Society of Agronomy, "Multiple Cropping, *Proceedings of Symposium*, Special Publication No. 27, 1976.

Boosalis, M. G., and Cook, G. E. "Plant Diseases, " *Conservation Tillage: The Proceedings of a National Conference*, Soil Conservation Society of America, 1973.

Conrad, Daniel L., U.S. Department of Agriculture-SCS, personal communication, January 1981.

Cosper, Harold R., "Soil Taxonomy as a Guide to Economic Feasibility of Soil Tillage Systems in Reducing Non Point Pollution, " Natural Resources Economic Division, Economics and Statistics Service, U.S. Department of Agriculture, 1979.

Council for Agricultural Science and Technology, *Organic and Conventional Farming Compared*, report No. 84, October 1980.

Council on Environmental Quality, *National Agricultural Lands Study, Interim Report No. 4, Soil Degradation: Effects on Agricultural Productivity*, 1981,

Crosson, Pierre, *Conservation and Conventional Tillage: A Comparative Assessment*, Soil Conservation Society of America, 1981.

Eichers, Theodore, personal communication, Economics and Statistics Service, data from U.S. Department of Agriculture 1966 and 1976 pesticide surveys, 1981.

Epstein, E., "Impact of Applied Genetics on Agriculturally Important Plants: Mineral Metabolism, " OTA background paper, 1980.

Epstein, E., et al., "Saline Culture of Crops: A Genetic Approach, " *Science* 210:399-404, 1980.

Fenster, Charles R., "Stubble Mulching, " *Conservation Tillage: A Handbook for Farmers*, Soil Conservation Society of America, 1973, pp. 29-34.

Forster, D. Lynn, "Adoption of Reduced Tillage and Other Conservation Practices in the Lake Erie Basin, " Department of Agricultural Economics and Rural Sociology, The Ohio State University and Ohio Agricultural Research and Development Center, unpublished mimeo, 1979.

Giere, John P., Johnson, Keith M., and Perkins, John H., "A Closer Look at No-Till Farming, " *Environment*, July-August 1980.

Gliessman, Stephen R., " Multiple Cropping Systems: A Basis for Developing an Alternative Agriculture, " OTA background paper, 1980.

Gustafson, C. Don, "History and Trends in Drip Irrigation, " *Avocado Grower* IV(12), December 1980.

Hall, B. J., Farm Advisor, University of California, San Diego, personal communication, February 1980, including "Labor and Cultural Management of Drip Irrigation" and "Management of Drip-Trickle Irrigation, " undated mimeographed material.

Hall, G. F., Daniels, R. B., and Foss, J. E., "Rate of Soil Formation and Renewal in the USA," in *Determinants of Soil Loss Tolerance,* Soil Science Society of America Symposium, Fort Collins, ASA Special Publication No. 45, 1982,

Halliday, Jake, "Agrotechnologies Based on Symbiotic Systems That Fix Nitrogen, " in *Innovative Biological Technologies for Lesser Developed Countries,* an Office of Technology Assessment report for the U.S. Congress, September 1981,

Harkin, J. M., Simsiman, G. V., and Chesters, G., "Description and Evaluation of Pesticidal Effects on the Productivity y of the Croplands and Rangelands of the United States, " OTA background paper, 1980.

Hayes, William A., "Double Cropping, " *Conservation Tillage: Handbook for Farmers,* Soil Conservation Society of America, 1973, pp. 35-4o.

Helm, Jack, Soil Conservation for Howard County, Md., personal communication, 1980.

Howell, T. A., Bucks, D. A., and Chesness, J. L., ''Advances in Trickle Irrigation, " *Proceedings of Second National Irrigation Symposium,* American Society of Agricultural Engineers, 1981, pp. 69-94.

Jackson, Wes, and Bender, Marty, "New Roots for American Agriculture, " OTA background paper, 1980.

Kohl, Daniel H., Lockeretz, William, and Shearer, Georgia, "Organic Farming in the Corn Belt, " *Science* 24, Feb. 6, 1981.

Larson, William E., "Protecting the Soil Resource Base, " *journal of Soil and Water Conservation* 36(1):13-16, January-February 1981.

Lockeretz, W. R., et al., "Organic and Conventional Crop Production in the Corn Belt: A Comparison of Economic Performance and Energy Use for Selected Farms, " Center for the Biology of Natural Systems, Washington University, St, Louis, Me., June 1976.

McCormack, D. E., Young, K. K., and Kimberlin, I.. W., "Current Criteria for Determining Soil Loss Tolerance," in *Determinants of Soil Loss Tolerance,* Soil Science Society of America Symposium, Fort Collins, ASA Special Publication No. 45, 1982.

Menge, J. A., "Mycorrhiza Agriculture Technologies, " OTA background paper, 1980.

Miller, Arnold, "Expanding Crop Production and Soil Erosion: Land Resources, Conservation Practices and Policy Choices, " U.S. Department of Agriculture, Office of Budget, Planning, and Evaluation, draft, June 15, 1981.

______, "Impact of Expanding Agricultural Production of Soil Erosion: Land Resources, Production Practices and Policy Choices, " prepared for the Structure of Agriculture Project, U.S. Department of Agriculture, 1978. Computed from National Resource Inventories data, USDA-SCS. (In preparation)

Mitchell, J. Kent, Branch, John C., and Swanson, Earl R., "Costs and Benefits of Terraces for Erosion Control," *Journal of Soil and Water Conservation,* September-October 1980, pp. 233-236.

Myers, Norman, *The Sinking Ark,* Pergamon Press, 1979.

Nebeker, Gordon, personal communication, 1981.

No-Till Farmer, March 1981.

Nowak, Peter J., "Impacts of Technology on Cropland and Rangeland Productivity: Managerial Capacity of Farmers, " OTA background paper, 1980, data cited were taken from "Effect of Agricultural Land Use Practices on Stream Water Quality: Sociological Factors in the Adoption of Best Management Practices, " study conducted by Iowa State University under EPA grant No. R806814-01-2.

Oelhaf, Robert C., *Organic Agriculture: Economic and Ecological Comparisons With Con ventional Methods* (Montclair, N. J.: Allanheld, Osmun & Co. Publishers, Inc., 1978).

Office of Technology Assessment, *Pest Management Strategies,* Volume I, Summary, October 1979.

Owens, Harold I., and Patterson, Ralph E., "Information and Education, " *Conservation Tillage,* Soil Conservation Society of America, 1973, pp. 227-230.

Phillips, R. E., et al., "No-Tillage Agriculture, " *Science* 208, June 6, 1980.

Schuhart, Anne, "Irrigation Drop by Drop, " Soil *Conservation 43(3),* U.S. Department of Agriculture, October 1977.

Shrader, W. D., personal communications, 1980.

Taylor, Robert, Frohberg, Klaus K., and Seitz, Wesley D., "Potential Erosion and Fertilizer Controls in the Corn Belt: An Economic Analysis " *Jour. of Soil and Water Conservation,* July-August 1978.

Triplett, Jr., G.B., and Van Doren, Jr., D. M., "Agriculture Without Till age, *Scientific American,* January 1977.

Triplett, Glover, member of project advisory panel, personal [communication, 1981.

Troech, F. R., Hobbs, J. Arthur, and Donahue, Roy L., *Soil and Water Conservation for Productivity and Environmental Protection* (Englewood Cliffs, N. J.: Prentice Hall, 1980).

Trouse, A., U.S. Department of Agriculture Tillage Laboratory, Auburn University, persona] communication, 1981.

U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service, "National Summary Evaluation of the Agricultural Conservation Program—Phase 1, 1981, p. 80.

U.S. Department of Agriculture, "Basic Statistics: 1977 National Resource Inventories (N RI]," revised February 1980.

U.S. Department of Agriculture, Study Team on Organic Farming, *Report and Recommendations on Organic Farming,* July **1980.**

U. s, Department of Agriculture, Economics, Statistics, and Cooperatives Service, "National Resource Capital in U.S. Agriculture, ' G. Parelis, 1979.

U.S. Department of Agriculture, Land and Water Task Force, 1979, pp. 326-327.

U.S. Department of Agriculture, Office of Planning and Evaluation, *Minimum Tillage: A Preliminary Technology Assessment,* May 1975.

U.S. Water Resources Council, *The Nation's Water Resources:* 1975-2000, vol. 1, summary, December 1978.

University of California, Division of Agricultural Sciences, *Drip Irrigation,* leaflet No. 2740, April 1979.

Wauchope, R. D., McDowell, L. L., and Hagen, L. J., "Weed Control in Limited Tillage Systems," forthcoming in *Weed Control in Limited Tillage Systems,* draft, 1981.

Wauchope, R. D., "The Pesticide Content of Surface Water Draining From Agricultural Fields –A Review, " *Jour. of Env. Qual. 7(4),* October-December 1978.

Wittwer, Sylvan H., ''Research and Technology Needs for the 21st Century," in *Global Aspects of Food Production,* and Michigan Agricultural Experiment Station Publication No. 9502, September 1980.

Worsham, A. D., "No-Till Corn-Its out look for the 80's, " *Proceedings of the Corn and Sorghum Research and Productivity Conference, 1980.*