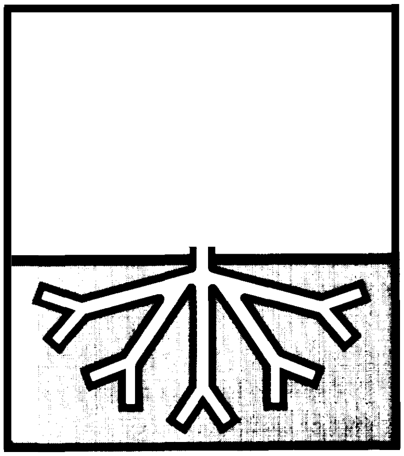

Technologies Affecting Soil Water

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Chapter VIII

Technologies Affecting Soil Water

Agricultural technologies that affect soil water have helped transform the "Great American Desert" into an area of high annual agricultural production. This change has occurred largely because of improved methods of conserving precipitation and the practice of irrigation. New technologies and changes in the amount and location of land to which they are applied continue to shape Western agriculture and evidence suggests that future changes will be as extensive as those of the past.

This chapter first discusses soil and water relationships, then examines some of the technologies that increase soil-water supplies. These technologies involve a gradient from conserved to added water. Some conserve precipitation, others supplement rainfall and snowfall with limited amounts of applied water, and another group provides enough additional water to fill the crop's requirements, "Irrigation" usually refers to the last type of technology, the one that uses the largest amount of applied water,

THE WATER SETTING: SOIL AND WATER RELATIONSHIPS

Additions of water to soil come from three sources: precipitation (snow, rain, sleet, or hail); application of irrigation water; and upward movement of water into the root zone from a water table (capillary rise). Losses from the soil occur through evaporation from the soil surface, transpiration by growing plants, and deep percolation (fig. 46). Soil plays a key role i n the hyrdrologic cycle. Its properties help determine how much water runs off the land, the a moun of water that can be supp1ied to growing plants, and the quantity of water that will percolate to the ground water.

Infiltration

Infiltration results from the interactions between soil, vegetation, landscape, and weather (e.g., rainfall intensity and duration), however, soil properties dominate the process. Coarse-textured soils ("texture" refers to the size of the soil particles), such as sands, or soils with good structure ('structure' refers to the arrangement of soil particles into aggregates) usually take in water quickly. Clay soils or those with a compacted surface layer take in water slowly (fig. 47). Another important determinant of i n filtration is initial soil-water content. Generally, dry soils absorb water readily; water will move more slowly into a soil that is wet.

Site conditions also affect infiltration. Where slopes are steep, water moves rapidly across the surface with little time for infiltration. Conversely, water will move more slowly across nearly level areas and these sites generally experience less runoff.

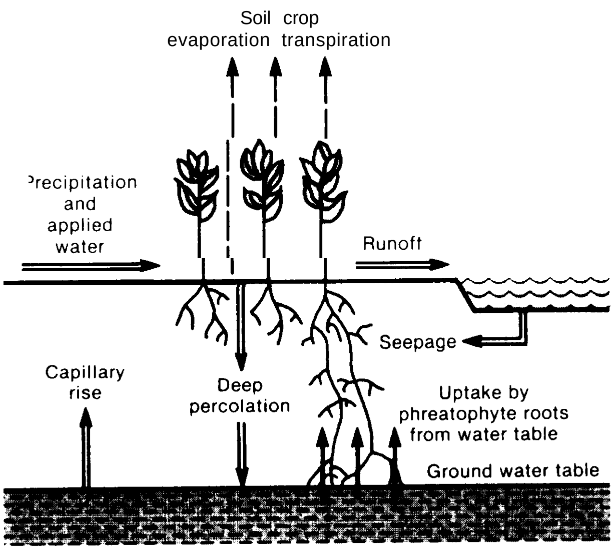
Vegetation can affect infiltration in several ways. Plants can intercept water before it reaches the soil surface and thereby reduce the amount of water available for infiltration. Vegetation can also facilitate water movement into soil by slowing its movement across the surface and allowing more time for infiltration and by protecting the soil surface from the impact of falling raindrops. Finally, plants and products of their decomposition can improve soil structure and thus infiltration.

Soil-Water Movement and Retention

Soil-water movement is a dynamic process. Soil water can move downward, upward, and laterally in response to different physical and biological conditions. During and after initial infiltration, for example, water generally moves

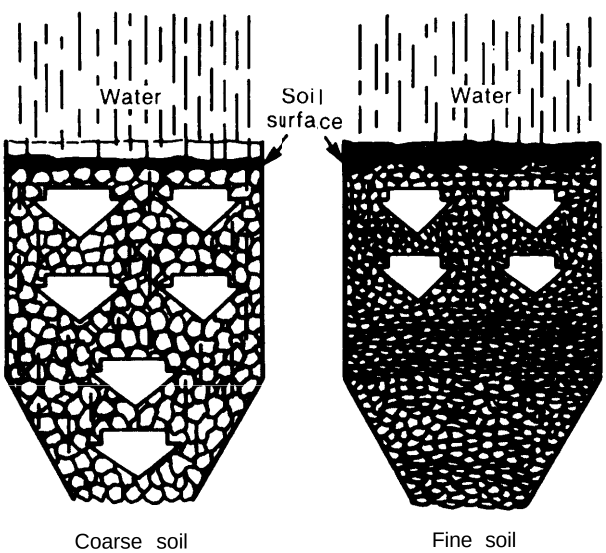
Figure 46.—The Role of Soil in the Hydrologic Cycle

Precipitation or applied water Infiltrates the soil surface and is used by a growing plant or is lost through evaporation, percolation, or surface runoff. Some water is also added to the soil profile through capillary rise.



SOURCE David C Davenport and Robert M Hagan Agricultural Water Conservation California *Water* Planning and Policy. E. Engelbert (ed.) Water Resources Center University of California at Davis 1979

Figure 47.—Soil Particle Size and infiltration



Generally, the larger the soil particle and aggregate size, the faster the rate of water intake.

SOURCE J Howard Turner and Carl L Anderson, Planning for an Irrigation *System* (Athens Ga American Association for Voctional Instructional Materials 1980)

downward and laterally in response to gravity and the "pull" of unwetted or drier soil particles. Water in excess of the soil's "storage capacity" will continue to move outward from the wetted soil.

Water also moves upward into the plant root zone by the process of capillary rise, which occurs where the water table is near the surface, or where fine-textured soils are present that can conduct water upward for considerable distances. Water movement is usually slow and except on some irrigated lands and in a few other areas, soil water derived from capillary rise does not account for a significant portion of soil-water supplies.

Soils differ in their ability to retain and redistribute moisture, and many of the factors that affect infiltration affect water retention and redistribution. These include: soil texture, soil structure, organic-matter content, clay type, depth of wetting and amount of water in the soil, the presence of impeding soil layers, and evapotranspiration. Generally, about one-half the water held in the soil after gravitational water (water that moves under the force of gravity and is not retained in the soil) has drained away can be used by plants. This quantity of water can be stored for a long period of time for later use by crops (table 53).

Soil-Water Losses

Water that could be used by plants can be "lost" in several ways. Losses can occur when water fails to infiltrate the soil and runs off the surface. After water is stored in the soil, evaporation, transpiration by plants of low economic value (e. g., weeds), and percolation beyond the plant root zone can reduce soil-water supplies. Evapotranspiration losses are especially critical in the arid and semiarid regions because water lost in this process cannot be recovered except through the course of the hydrologic cycle, Water lost in surface runoff and deep percolation generally remains a part of water supplies and can be recovered.

The amount of water lost in each process differs from site to site and changes over time,

Box P.—Soil Properties in the Arid and Semiarid Region

Soils are a product of climate, biological activity, topography, and mineral material acting together through time. These factors interact in varying degrees at a particular site and affect certain physical, chemical, and biological properties of soil. Some physical properties, such as texture and structure—i.e., the size of the soil particles and their arrangement into aggregates—are critical to soil-water relationships. Chemical properties such as nutrient status and acidity are important to plant growth. Biological properties—e.g., the presence of certain micro-organisms—are important in plant in animal decomposition and the recycling of plant nutrients.

Soil properties in the arid and semiarid region are dominated by climate, although its effect is modified by the other factors mentioned above. Low amounts of precipitation, for example, slow the rate of soil formation. Similarly, with low precipitation and sparse plant growth, soils that form on residual rock tend to be shallow. Plant root-restricting layers—e.g., caliche (a more or less cemented deposit of calcium carbonate)—may form because there is insufficient water to wash soluble minerals out of the soil.

Arid- and semiarid-climatic conditions are associated with other soil features. First, these soils are relatively fertile but often have high soluble salt levels that may restrict plant growth. Second, organic matter levels tend to be low because precipitation is not adequate for production of large amounts of vegetation. Consequently, soils often lack good structure. Recent research also suggests that soils with low organic matter do not support high microbial populations—e.g., fungi, bacteria, and algae—which are critical to decomposition of dead plants and animals and to nutrient recycling. Some essential plant nutrients—e.g., nitrogen and phosphorus—may be lacking because these elements are products of organic-matter decomposition. Finally, low levels of organic matter are associated with low nutrient-retention capacities.

Arid and semiarid soils are unique in other respects, particularly in their vulnerability to wind and water erosion, salinity, and compaction. More importantly, if these processes occur, the results are long lasting and not easily alleviated, given the slow rate of soil formation, low amounts of precipitation, and limited plant growth. The recently completed OTA assessment of the impacts of technology on the Nation's cropland and rangeland productivity (24) discusses these hazards in more detail.

Table 53.—Water Available to Plants per Foot of Soil for Various Soil Textures

Textural description	Available water (inches)
Coarse textured:	
Sands.	0.4 -0.75
Loamy sands	0.75-1.25
Moderate coarse textures (sandy loams, fine loamy sands)	1,25-1.75
Medium textured (loams, silt loams)	1,50-2.30
Moderate fine textured (clay loam, silty or sandy clay loam)	1.75-2.0
Fine textured (sandy or silty clay, clay)	1.60-2.50

SOURCE Hayden Ferguson. William Lyle, Charles Fenster, and Charles Wendt Dryland Agriculture OTA commissioned paper, August 1982

depending on weather, soil, crop, and season of the year. Generally, these losses can be ordered as:

Transpiration > Evaporation > Runoff > Percolation.

As an example, where annual precipitation is scant, as in the arid Southwest, evaporation represents less than 10 percent of seasonal evapotranspiration (13). In other areas where rainfall is more abundant—e. g., the Great Plains—up to 50 percent of the precipitation may evaporate (11).

Agricultural practices can improve soil-water supplies in several ways. They can help to:

- increase the amount of water moving into the soil;
- increase the amount of water retained in the soil: and
- decrease the amount of water lost in surface runoff, evaporation, and deep percolation,

This chapter considers some of these technologies. Measures that affect plant transpiration are considered in chapter IX. *

*For additional information on land and soil characteristics with agriculture see the OTA assessment, *Impacts of Technology on U.S. Cropland and Rangeland Productivity, OTA-F-166,* August 1982.

Box Q.—Soil-Water Measurement

A number of devices are used by researchers and farmers to measure soil-water conditions. These tools can help determine the amount of water available for plant growth. On irrigated fields, soil-water measurement can aid in determining water application schedules. It is important to note, however, that the ability of plants to remove water from soil is primarily related to the force with which water is held in the soil and not solely to soil-water content.

One of the oldest methods for measuring soil-water content is by gravimetric determination. In this process, soil samples are removed from desired depths and placed in cans to prevent moisture loss. Th samples are weighed, heated to boil away the water, and weighed again. Water content is calculated as a percentage of dry weight and converted to a volume basis (e.g., inches per foot of soil) if bulk density of the soil is known (mass per unit volume of an oven-dried soil).

Using electrical-resistance gypsum blocks is a second means of estimating soil water. In this method, two electrodes are embedded in gypsum blocks and placed in the soil. An electrical current is passed through the electrodes and the resistance across the electrodes is measured. Resistance across the electrodes increases as the water content of the soil decreases. A calibration curve is used to determine the soil-water content.

A third device for measuring soil water is a tensiometer. Tensiometers measure the "force of attraction" of the soil for water and are calibrated to determine soil-water content in each soil. These tools vary in form. One type, a vacuum-gage tensiometer consists of a porous, fired clay cup which is attached to a vacuum gage by a water-filled pipe. If the cup is buried in dry soil—i.e., where the water has less energy than the water in the cup water will move from the cup into the soil. When the system comes to equilibrium, the vacuum gage measures the potential as a tension* in the water. It indicates that plants must work against this tension to extract water from the soil. Wetting the soil releases the tension and water will move from the soil into the porous cup of the tensiometer.

The neutron probe is another tool used to measure soil-water content. The components of the system include a neutron source, a detector, an amplifier, and a scaler. The neutron source is placed in the soil at a desired depth and emitted neutrons strike hydrogen nuclei that are associated with water molecules. The scaler then senses the number of hydrogen nuclei and estimates water content of the soil.

● "Tension" is the pressure required to extract water from soil and indicates the tenacity with which water is held in the soilt.

TECHNOL0GIES

Soil-water supplies in the arid and semiarid region come mainly from two sources—precipitation and irrigation. Under each set of conditions, a distinct type of agriculture has evolved. Over large areas of the West, where soil-water supplies are derived from precipitation, dryland farming or rangeland agriculture is practiced. Where soil water is provided by supplemental water applications, irrigated agriculture is practiced.

The technologies described in this chapter are organized according to the type of agriculture for which they are most likely to be used. Where dryland farming or rangeland agriculture is practiced, methods that conserve precipitation are appropriate. On irrigated land, methods that manage supplemental water are applicable. Although each technology is discussed separately, effective use of precipitation or irrigation water often requires the use of more than one technology and skillful management of plants and soil.

Selection of technologies presented here was based on evaluations of a technology's ability to sustain agricultural productivity and potential use across broad geographic areas and in different types of agriculture. Although each technology will affect soil-water conditions to some extent, an estimate of the amount of water that could be conserved by adopting a particular practice is not presented. Reliable estimates are nearly impossible given the broad climatic, topographic, crop, and soil differences throughout the West, combined with uncertainty regarding the possible extent of application.

Conserving Precipitation

Technologies that conserve precipitation are aimed primarily at reducing water losses through surface runoff and evaporation (table 54). These goals can be achieved in three main ways. First, the soil surface can be shaped to hold water on the surface and facilitate' water movement into the soil, Second, soil cover consisting of either growing plants or their residues can be managed to reduce runoff and evaporation losses. Third, soil properties such as structure or micro-organism content can be manipulated to conserve soil water. These practices also can be used together.

Shaping Soil Surfaces

INTRODUCTION

One of the most important features of a soil is its ability to take in water. For many centuries, farmers achieved improvements in infiltration by altering the soil surface or by reshaping the land. The ancient Egyptians plowed their fields to lift and loosen the top layers of soil to allow more water to infiltrate. Ancient people also used terraces, embankments built across a slope, to hold precipitation on the land.

In modern agriculture, the purposes and types of practices used to alter and reshape the land surface are similar to those used in the past. Today, however, many modifications have been made in the types of tools used and in the degree to which soil and vegetative cover are disturbed. For example, plowing, which is one step in seedbed preparation, has been replaced in many farming operations by minimum tillage, which leaves crop residues on the soil surface. Another practice, pitting, is ap-

Table 54.—Use of Precipitation: Technology, Application, and Effect on Soil Water

Technology	Application: Range	Application: Dryland	Application: Irrigated	Comments
Mechanical land treatments	X	X	X	Slow surface runoff, increased infiltration, facilitated water movement through soil
Terraces	X	X	X	Slow surface runoff, increased infiltration
Land grading or leveling	—	X	X	Slow surface runoff, increased infiltration
Mulches	X	X	X	Slow surface runoff, increased infiltration, slow evaporation
Plant-barrier systems	—	x	x	Slow evaporation conserves snow.
Modification of plant canopies.	—	x	x	Slow evaporation
Mychorrizal fungi	x	x	x	Enhances plant-water uptake
Harvester ants and termites	x	—	—	Increased infiltration
Soil conditioners.	—	x	x	Increased water retention

SOURCE Office of Technology Assessment, 1982 plied on rangelands. It uses a mechanical device to form small, shallow basins in the soil surface to hold precipitation onsite. In contrast, deep plowing, a practice used on croplands, completely inverts and mixes the soil layers to improve infiltration and water movement through the soil.

ASSESSMENT

Many land-shaping practices are effective in increasing the amount of water retained onsite for plant growth. In addition, these technologies can help conserve soil by reducing surface runoff. Generally, management requirements are low, and practices can be applied to rangeland, dryland, or irrigated areas.

The application of some practices is limited, however, by physical considerations. First, many technologies are site-specific; the water-conserving ability of each practice varies with soil type, topography, vegetation, and weather. Under natural rainfall conditions in arid areas, for example, these technologies will have little effect in improving soil-water conditions, A second limitation is the relatively short life-span of some technologies. Some tillage practices (e.g., basin tillage) must be applied each time a crop is planted. Similarly, the storage capacity of pits diminishes rapidly, and pits may disappear within 6 to 10 years depending on site conditions. Finally, excessive working of the soil, coupled with the use of heavy machinery needed for application of some practices, can alter soil structure, thereby aggravating the soil conditions that these operations are trying to improve.

The application of land-shaping practices may be limited also by economic considerations, For some ranchers and farmers, the expense associated with applying these technologies (i. e., special equipment, labor, fuel, land taken out of production) may outweigh their benefits in increased forage or crop production. Furthermore, economic evaluations of costs and benefits that could assist farmers and ranchers in planning their operations are often not available.

Land-shaping practices may not be applied to grazing lands for other reasons, Often these lands are too arid, or on soils too shallow or too infertile, to realize an increase in forage production with their use. On more productive areas, some ranchers may object to mechanical treatments of natural grasslands because these practices have not been applied traditionally. Finally, on public rangelands, an individual who has a grazing permit may be prohibited from applying these practices.

Mechanical Land Treatments

Mechanical land treatments include such operations as deep plowing or ripping, land imprinting, contour furrowing, basin tillage, and pitting, In general, these practices alter the soil

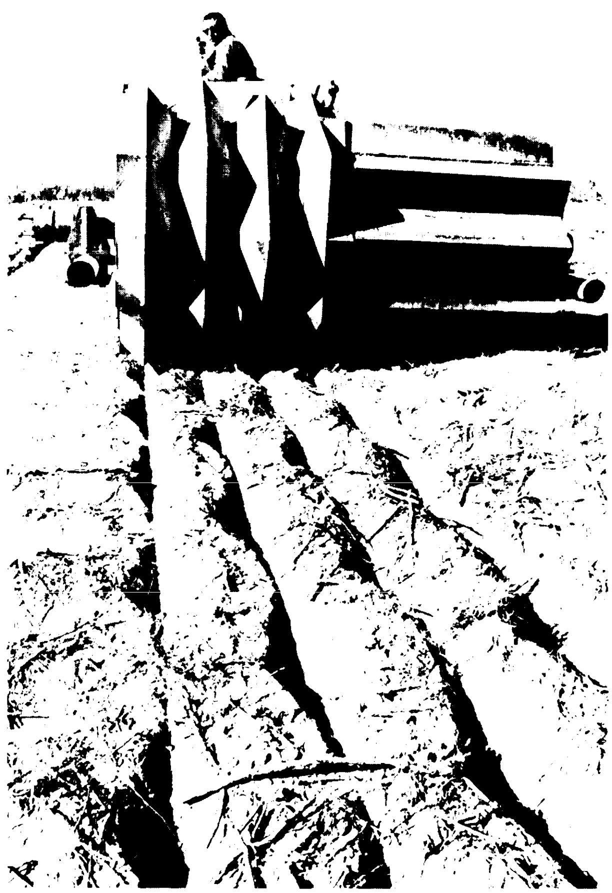


Photo credit USDA-Agricultural Research Service

The land imprinter can help establish grass on near-barren areas. The imprinter presses furrows and seedbeds of varying depths on the soil. The patterns direct runoff rainwater and concentrate it where new grass is seeded.

structure and attempt to increase the amount of water retained onsite. Their application can aid plant establishment and can increase existing plant production.

Many mechanical land treatments are effective in conserving water and are used presently. Contour furrowing, for example, has been applied on rangelands in the Great Plains and Interior Basin and has been especially useful on sodium-affected soils to improve infiltration, reduce the sodium hazard, and increase herbage production. Contour furrows have an additional benefit in that they can catch more snow than can nearby unfurrowed areas. Another treatment, basin tillage, has been used in row-crop production in the southern Great plains and has helped increase the amount of water stored in the soil. Deep ripping or plowing has been used on rangeland, dryland, and irrigated areas to break up compacted subsurface layers and to mix the different soil textures. Ranchers and farmers have reported increased forage and crop yields after this operation.

Extensive applications of mechanical land treatments are somewhat hindered by the site-specific nature of each technology, For example, some research indicates that pits are ineffective in areas of low precipitation and on clay soils (23 ,33). Where pits are used on range in poor condition, weed problems may develop, Ripping treatments on six Western range sites decreased perennial grass production, and researchers concluded that, in these areas, the relatively minor soil surface modifications did not have a marked effect on runoff or water retention (6).

Mechanical land treatments tend to have a limited lifespan. The storage capacity of pits and contour furrows diminishes rapidly with time, and basin tillage requires application each time a crop is grown. Where deep plowing is practiced, large soil pores and channels

Photo credit USDA Soil Conservation Service

Contour furrows are generally constructed to hold water onsite until it infiltrates the soil

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are difficult to maintain with subsequent tillage operations.

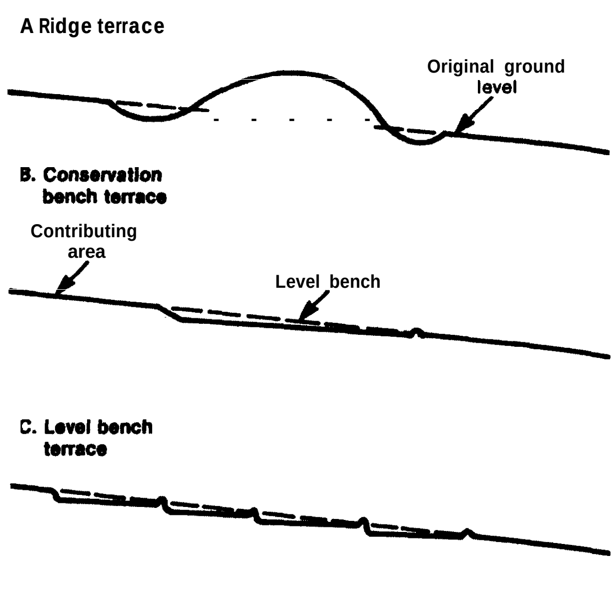
Finally, the application of these practices tends to be energy- and capital-intensive, Generally, special equipment is needed that maybe too expensive for some operators. Equipment design also limits application of some practices. For example, basin tillage is limited currently to row-crop (e. g., corn, soybeans, and cotton) production, although it could be applied to close-growing, small-grains (e.g., wheat and barley) production if planting equipment *were* modified.

Terraces

Terraces are earthen embankments, channels, or combinations of embankments and channels built across the slope of the land (fig. 48). By reducing the length of a slope, terraces help conserve precipitation and irrigation water by reducing surface runoff. In addition, terraces trap snow and increase over-winter water storage. In semiarid regions, terraces have been used traditionally in dryland agriculture. Irrigators may also use terraces to reduce their irrigation water requirements.

Figure 48.—Diagrammatic Cross-Sections of Three Terrace Types

Terraces have been used for centuries and several types exist. The ridge terrace (A) is constructed on the contour to retain water on the land. Conservation bench terraces (B) are constructed to spread runoff across a level cropped area. Level bench terraces (C) retain water that falls on level cropped areas.



SOURCE: K. G. Brengle, *Principles and Practices of Dryland Farming* (Boulder, Colo.: Colorado Associated University Press, 1982)

Besides controlling runoff, terraces have other benefits. They help reduce soil erosion and sediment content in runoff water, improve formability of sloping lands, and reduce peak runoff rates to installations downstream.

Several problems limit the use of terraces, however. One major difficulty is that terrace design has not kept pace with changes in farm machinery and maneuverability of farm equipment is sometimes difficult. A second problem is that construction generally entails the removal of topsoil from large areas and the use of heavy equipment. These two factors may combine to cause surface compaction and may result in reduced crop and forage production. Initially, construction may interfere with seasonal agricultural operations and uneven drying, pending, and severe erosion in different parts of the same terrace channel are also common in the first 3 to 5 years after construction. Finally, during wet years, weed and insect control may be difficult,

Economic considerations may pose a barrier to the adoption of terrace systems, Terraces are often costly, although some technical and financial assistance may be available to producers for design and construction. Maintenance requirements are high, and labor and energy costs may increase more on terraced fields than on nonterraced areas. In addition, some land is lost from crop production because of the terraces.

Land Grading or Leveling

Land grading or leveling is a technology that consists of smoothing a field's surface to make it level, A leveled field allows more uniform water distribution, eliminates dry or waterlogged spots, and slows runoff. Currently, the practice is applied most often to irrigated fields but can be used on dry-farmed lands.

Although land leveling is effective for many areas, the technology is not suited to some fields. When first applied, leveling may reduce infiltration and accelerate soil erosion because the vegetative cover is disturbed and soil aggregates are destroyed. Second, some soils have a thin topsoil, and extensive leveling operations expose generally less productive subsoil. On these soils, to maintain productivity, topsoil may have to be set aside and spread back onto the site after the grading is completed. Finally, leveling operations may fill in low depressions, some of which are important to wildlife,

Application of land leveling is affected by a number of economic considerations, as well. Government agencies and irrigation districts may have technical and cost-share provisions for land leveling on irrigated land that can reduce water costs, increase crop yields, and improve farm profits. For most dryland crops, however, the benefits derived from land leveling do not pay for its application. Laser leveling is particularly expensive at present, * Basic laser equipment costs from $12,000 to $20,000, and scrapers that can be laser controlled range in cost from $9,000 to $30,000 (17).

Managing Soil Cover

INTRODUCTION

Agricultural practices often have dramatic effects on the ground cover and consequently on soil and water relationships. This relationship has been long recognized by agriculturalists. In semiarid regions of the West, for example, early proponents of fallow systems (a type of dryland farming in which, generally, a crop is harvested every 2 years) believed that a covering of soil, or "dust mulch, " left on the surface in alternate years would prevent water from evaporating from the surface. Although these claims were valid to some extent, wind tended to blow away the mulch and the amount of water conserved was negligible.

*Traditional lan(l-surveying techniques that determine the extent of leveling needed have been replaced i n some areas by laser-[; ontrolled devices that permit more precise le~'cling and provide for more uniform distribution of water.

Technologies that affect soil cover aim to reduce surface runoff, increase infiltration, and reduce soil erosion. These practices include plant-residue management, application of materials that act like plant residues, and manipulation of growing vegetation (see box R).

ASSESSMENT

Managing soil cover is an effective means to increase the efficiency of precipitation storage, but several limitations to their use exist. First, management requirements are high. With improved soil-water conditions, weeds and other crop pests may build up and require control by mechanical or chemical means. Second, soil covers may lower soil temperatures and reduce seed germination, a consideration in cooler regions. Third, these practices are largely limited to dryland and irrigated regions because of the economics of their application and maintenance.

Mulches

Surface mulches are protective soil coverings that are spread or left on the soil surface and used to increase infiltration, decrease surface runoff and erosion, and slow evaporation losses. * They can be used in irrigated, dryland, and rangeland agriculture, and consist of crop residues applied where they are produced or of introduced layers of plant materials, gravel, black plastic, or sewage sludge.

Residual Mulches.—The use of crop residues as surface mulch became a common practice during the 1930's to reduce the effects of wind and water erosion. Since then, farming practices and equipment have been developed to till the soil and plant crops without inverting or burying the residue. On rangeland, slash or debris from brush and trees are used as mulch.

The value of mulch for collecting and storing available precipitation in dryland agriculture has been documented by numerous inves-

*Depending on the amount of crop residue available, some nontranspiring vegetation, such as standing wheat stubble, can reduce evaporation losses. However, if plant residues are scant, as in many arid and semiarid areas, the reduction in evaporation is minimal.

Box R.—Conservation Tillage: A New Way to Farm?

Prior to the 1940's, farmers relied on a variety of tillage practices to prepare a seedbed, control weeds, and bury plant residues. With the advent of chemical herbicides, many producers began to substitute chemical weed control and "conservation tillage" for some of the traditional tillage operations.

Although conservation tillage has attracted much attention in recent years, the practice is quite old. In 1814, James Hall of Virginia secured a patent for a method of planting corn in an unplowed field. He marked the land in squares; each square was a certain dimension and distance from other plots and contained a given number of corn plants. Only these squares were cultivated, manured, and mulched; the rest of the field remained in grass. Hall had little success with his idea. The corn was unable to withstand dry weather, and many farmers criticized the practice as slovenly.

The term "conservation tillage" is inexact in meaning. Generally, the practice uses fewer operations to produce crops than does conventional tillage. Three other characteristics distinguish conservation tillage: it uses implements other than the moldboard plow; it leaves residues on the soil surface; and, it depends primarily on herbicides for weed control, although the degree of dependence on herbicides varies.

In the arid and semiarid region, conservation tillage is important, especially for its use in conserving water and soil. Small-grain producers can find its application particularly beneficial, and the advent of large chisel-type air seeders that can plant large acreages in a short period of time has made conservation tillage profitable for these farmers. Conservation tillage has lower farm labor and preharvest fuel requirements than does conventional tillage. It can be used on sloping lands and can enable some producers to plant more than one crop in a season (multiple-cropping) or omit the fallow period (continuous cropping).

These advantages are countered by several physical and economic constraints that include high management requirements needed for control of weeds and other pests and for fertilizer placement, high costs of herbicides, adverse effects of herbicide use on human health and the environment, limited application in some cool dryland regions and some irrigated areas, high costs of seeding equipment, and availability of plant varieties that will germinate in thick residue.

SOURCE: William T. Dishman, advisory panel member, personal communication. 1983; Hayden Ferguson, William Lyle, Charles Fenster, and Charles Wendt, *Dryland Agriculture*, OTA commissioned paper, July 1982; *Impacts of Technology on U.S. Cropland and Rangeland Productivity* (Washington, D. C.: U.S. Congress, Office of Technology Assessment, OTA-F-166, 1982); Andrew C. Revkin, "Paraquat-A Potent Weed Killer is Killing People," *Science Digest* 91:36-38, 42, 100-104, 1983.

tigators (11). Mulch reduces runoff and tends to increase soil-water storage by protecting the soil surface from the impact of precipitation and by allowing more time for infiltration to occur. In colder regions, standing stubble mulch traps snow. Additional benefits include higher crop yields, increased soil organic-matter content, more stable soil aggregates, and decreased wind and water erosion.

Mulches are used widely in dryland crop production but less extensively on rangeland and irrigated fields. On rangeland, a lack of plant residues restricts application to critical areas—e.g., surface-mined sites or saline-affected soils (34). On irrigated land, mulches are used most often under sprinkler irrigation systems. Farmers who attempt to use mulches in surface irrigation may experience difficulty in getting supplemental water through a field (13).

Crop residues also are difficult to maintain because relatively low amounts are produced in most dryland areas and a large portion is destroyed during tillage operations. For example, stubble-mulch tillage, a method of cultivation practiced widely in small-grain production, attempts to maintain surface residues through each tillage operation. However, this practice destroys approximately 15 percent of

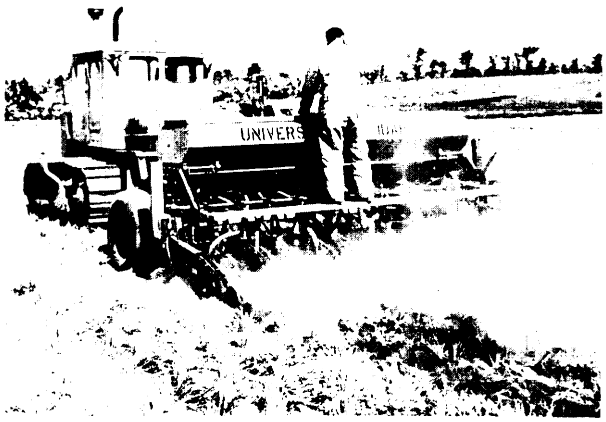


Photo credit: U.S.DA. Soil Conservation Service

A no-till drill, designed by the University of Idaho, used on an Idaho farm. No-till is one form of conservation tillage to reduce soil erosion and soil-water loss (see Box R)

the residue each time; over a fallow period, stubble-mulch tillage will destroy about 75 percent of the original residue (11).

Weeds and insect pests may build up when crop-residue mulches are used. In addition, in cooler dryland regions—e.g., the northern Great Plains and the Pacific Northwest-crop yields are sometimes lower under a residue mulch than would be expected, considering the amount of water available. Cool soil temperatures during critical stages of crop growth or reduced levels of nitrates during certain periods of the year are possible reasons for yield reductions.

Another limitation to the use of crop-residue mulches to conserve available water is the increased risk of development of saline seeps (fig, 49). This is a hazard especially in the northern

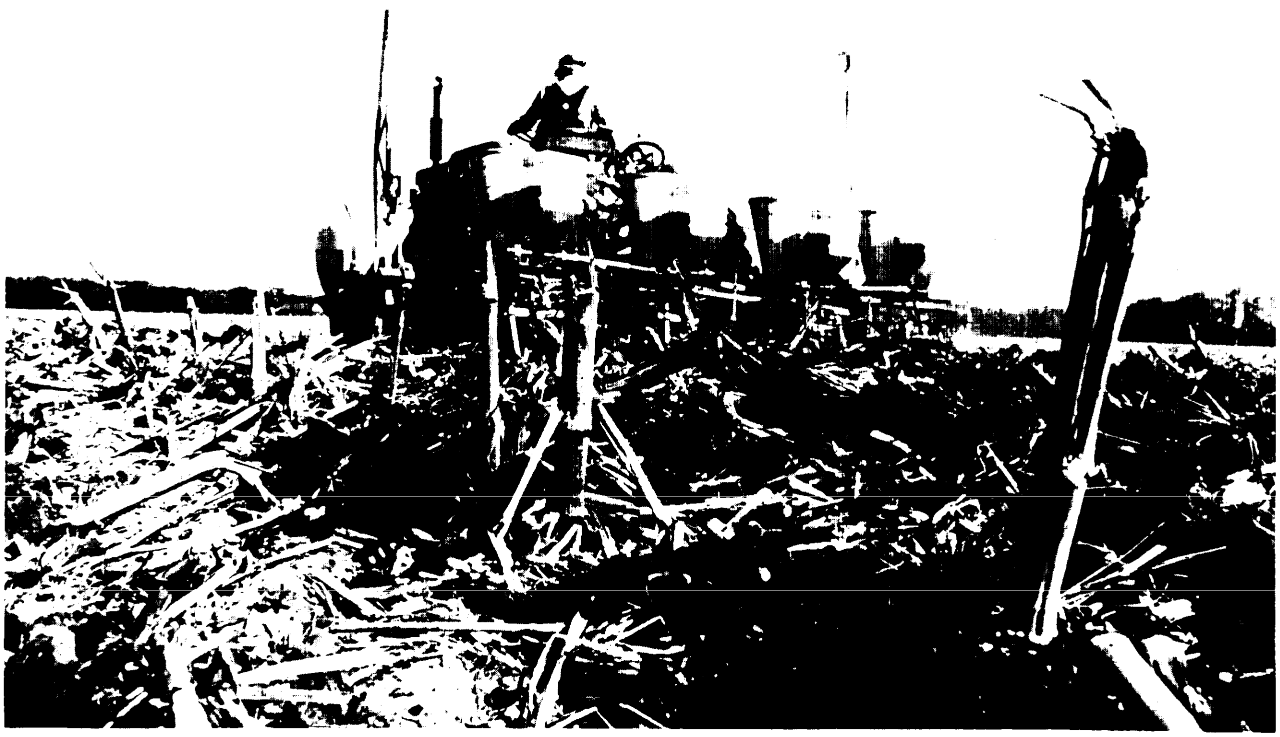
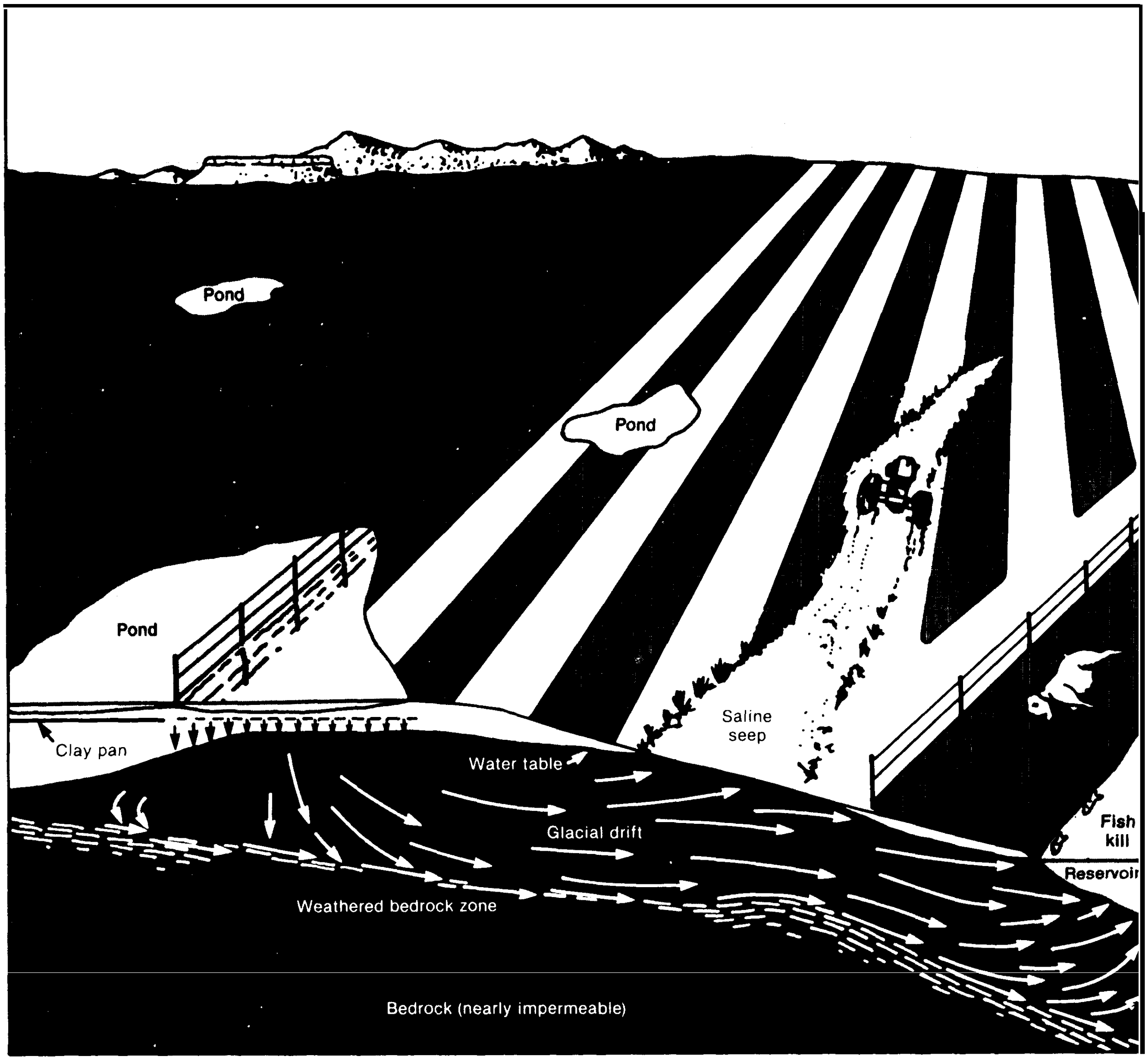


Photo credit: USDA Soil Conservation Service

Minimum till planting in corn stubble, Gage County, Nebr. (see box R)

Figure 49. - Development of a Saline Seep



Saline seeps form when soil water percolates downward beneath the root zone, picks up soluble salts in the soil, and accumulates on shallow, less permeable soil layers. A perched water table forms, and lateral flow then moves saline water from recharge to discharge areas, where it evaporates and leaves a salt deposit on the soil surface. These areas, often identifiable by a white salt crust on the soil surface, tend to reduce or eliminate crop and grass production, and the consumption of salts may result in animal kills.

SOURCE: M. R. Miller, P. L. Brown, J. J. Donovan, R. N. Bergation, J. L. Sonderegger, and F. A. Schmidt, "Saline Seep Development and Control in the North American Great Plains—Hydrogeological Aspects," *Agric. Water Manage.* 4:115-141, 1981.

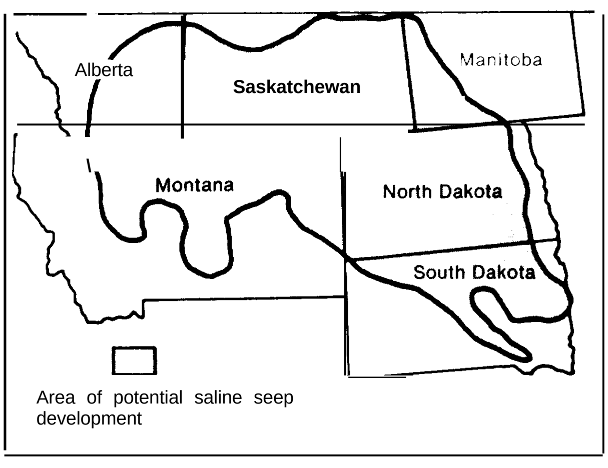
Great Plains (Montana, North and South Dakota), where a wheat-fallow rotation is followed, because of the geology and climate of the region (fig. 50). Black, et al. (5), estimate that 2 million acres (approximately 800,000 hectares) of land used for dryland agriculture have been affected by saline seeps. (Ch. XI discusses flexible cropping, a possible way to reduce this hazard.)

Introduced Plant Residues and Artificial Materials. —Introduced materials used for mulching have comparable purposes as residue mulches. Materials vary; straw (grain stalks after threshing) and wood chips, sewage sludge, gravel mulches, and black plastic have been used,

Introduced mulches are used in both rangeland and dryland farming regions with success. Mulches have been especially useful on rangeland to help in reseeding and plant establishment efforts. In dryland regions, Choriki (8) showed that layers of "pea" gravel about 2 inches deep on the soil surface increased the storage efficiency of summer precipitation by some 60 percent and made annual cropping feasible in the low rainfall area.

The major limitations of introduced mulches are similar to those associated with residual mulches—e.g., cooler soil temperatures that may inhibit seed germination and accelerate plant pest buildup. In addition, introduced mulches are sometimes difficult and expensive to acquire, transport, apply, and maintain. The ability to reverse the effects of an introduced mulch, especially gravel or sewage sludge, has been questioned (24).

Figure 50.—Areas of Potential Saline Seep Development, Northern Great Plains Region



SOURCE: Office of Technology Assessment, *Impacts of Technology on U.S. Cropland and Rangeland Productivity* (Washington, D.C.: U.S. Government Printing Office, 1982)

Plant-Barrier Systems

Growing plants can be used to conserve soil and water that might otherwise be lost because of the drying effects of wind. The types of plants used as barriers vary; historically, rows of trees and shrubs (shelterbelts) have been used, More recently, research has focused on incorporating single and double rows of' relatively low-growing vegetation (e.g., wheatgrass, sorghum, or corn) within a field to catch snow, reduce windspeed near the soil surface, reduce evaporation from wet soil, and control wind erosion.

Plant-barrier systems are used mainly in semiarid dryland farming areas that rely on snow to supply soil water. The barriers are especially useful in conserving snow during the second winter of a fallow period. The subsequent increase in soil water can boost crop production and may be sufficient to permit annual cropping.

Limited research indicates that plant barriers can also be applied to rangeland. Grass strips planted between low-growing sagebrush vegetation increased onsite snow retention and contributed to increased soil water and improved site productivity (30).

Plant barriers also have other benefits. Tree barriers provide protection from wind erosion and are pleasing esthetically. Annual vegetative barriers and shelterbelts also can provide cover and food for wildlife.

Although plant barriers are an effective way to conserve snowfall, several considerations may restrict their adoption. First, it is sometimes physically difficult to get water into frozen soil once the snow begins to melt. In the northern part of the Great Plains, for example, soils freeze deep and "hard." Moreover, these soils

Photo credit: USDA-Soil Conservation Service

This farmstead windbreak includes a variety of plants, both trees and shrubs. Besides conserving snowfall, the windbreaks protect against wind erosion, provide wildlife with food and cover, and are esthetically pleasing

Photo credit: USDA-Soil Conservation Service

Tall wheatgrass barriers control wind erosion and trap snow to increase stored soil water. Tall wheatgrass barriers reach an average height of 4 ft and snow accumulates relatively uniformly across the interval between barriers are often wet when they freeze. As a result, storage efficiency of the soil is often low and serious erosion and water loss problems can occur. Occasional midwinter warm periods have a similar effect, In these areas, tillage operations may be needed to roughen the soil surface to trap snow and snowmelt water and to allow water movement into the frozen soil.

Other constraints on adoption of plant-barrier systems include:

- accelerated wind erosion if plants are not spaced properly;
- buildup of crop pests—e.g., weeds and insects—and difficulty in control;
- loss of some cropland;
- disease problems in some areas, especially in northern Washington and southeastern Idaho, where snow mold can develop and affect winter wheat;
- soil-water use by noncrop plants;
- uneven grain ripening (especially where annual barriers are planted) unless barriers are spaced properly to ensure uniform snow distribution; and
- soil compaction where annual barriers force tillage operations in the same direction and on the same path.

Modification of Plant Canopies

To reduce the amount of evaporation that occurs early in the growing season, two approaches have been developed to allow for earlier canopy closure: increased plant density and modified plant spacing. These measures are especially effective in reducing evaporation losses in areas of frequent rainfall early in the growing season or of frequent irrigations that are required because of soil texture and depth. Modifications in plant canopies can also reduce wind velocities near the soil surface and lessen evaporation losses. Such practices can result in a slight increase in yield because of the higher plant populations.

Widespread application of these systems is hindered by two considerations. First, under high water-stress situations, close-growing crops may suffer yield reductions. Second, if tall and short varieties are combined in a field to reduce wind velocity, height difference may become insignificant when plants are water-stressed (10).

Changing Soil Properties

INTRODUCTION

Besides mineral and organic constituents, soils include a living component that consists of a diverse population of micro-organisms such as bacteria, fungi, algae, and protozoa; small invertebrate animals such as earthworms, ants, and termites; larger vertebrate animals like snakes, moles, gophers; and birds, such as burrowing owls. This diversity in animal and plant life accounts for the varied role the living component plays in soil and plant processes. For example, some micro-organisms cause plant disease. More importantly, however, they decompose dead plants and animals, recycle plant nutrients, and play a critical part in forming the humus that binds minute soil particles into larger aggregates. Humus aids in water infiltration and retention and plant-root development. Soil animals may also assist in improving water relationships by mixing the soil profile and by breaking up hard subsurface layers.

Amendments* added to soil can affect soil and water relationships. For example, chemical fertilizers appear to stimulate plant root growth and aid soil-water extraction. Chemical soil conditioner materials (other than conventional fertilizers) that are added to soils to change them physically, chemically, or biologically, imitate the action of living organisms and increase the amount of water retained in soils. Plastic sheeting or gravel can be buried within sandy soils to assist in retaining water for plant growth.

ASSESSMENT

The potential for changing soil properties to improve soil-water retention by using biologi-

*Substances that aid plant growth indirectly by improving the condition of the soil.

cal organisms or other amendments is unclear and more research is needed. These technologies seem to have some application on small areas with special problems, but, generally, questions about their longevity, effectiveness under different climates and variable field conditions, economics of use, and other possible effects have not been resolved.

Mycorrhizae

Mycorrhizal fungi are beneficial soil microorganisms that form symbiotic associations with the fine feeder roots of plants, By colonizing the plant root, the fungi receive an energy source, nutrients, and other plant chemicals from the host, Generally, the plant benefits from improved uptake of mineral nutrients (particularly phosphorus) and water. Ninety-eight percent of all plant species form mycorrhizal associations and most require symbiosis for maximum growth and survival (12).

Mycorrhizal fungi may play an important part in agricultural production in arid and semiarid regions. Research shows that plants colonized by these fungi seem more tolerant of dry conditions, have increased resistance to the toxic effects of salts, and have improved tolerance to numerous root pathogens (e.g., 14, 19,27). Also, mycorrhizae have been shown to improve the growth and survival of plants introduced into arid and semiarid lands by 20 to 200 percent (e.g., 1,7). The mechanisms that underlie these effects are not understood fully. Improved mineral nutrition of the host is thought to be a dominant influence, but osmotic and hormonal adjustments to infection may also be involved.

Potentially, two important applications of mycorrhizal inocula exist. The first involves rebuilding depleted populations of mycorrhizal fungi in soils that have been disturbed by soil erosion, surface mining, fire, fumigation, or long-term cropping with nonmycorrhizal species. Plants grown on such soils are frequently stunted and may benefit from mycorrhizal inoculations, The second application is associated with transplanted horticultural crops. Mycorrhizal inoculation can reduce transplant injury and increase growth and establishment of some nursery crops (4,21).

Despite their potential utility, commercialization and use of mycorrhizal inoculants are limited at present. Major obstacles include problems in development of commercial culture systems for inoculum production, risks associated with inocula that may carry disease, lack of efficient field inoculation techniques, lack of guidelines for predicting costs and benefits of inoculations, and the need for identification of superior and versatile fungal strains.

Harvester Ants and Termites

Western harvester ants and termites are regarded as pests of economic importance on many Western range sites. They frequently denude an area of existing vegetation through forage and mound activities.

Limited research indicates that dry matter yields in the area around ant colonies and termite mounds are much higher than in adjacent areas (3,28). Researchers speculate that vegetation removal by the ants and termites increases soil water in the mound area and its border. In addition, ant and termite activity may be beneficial to the physical and chemical character of the soil and may increase infiltration and soil-water storage.

The potential for this technology is unknown. Most range managers view these insects more as a detriment than a benefit to rangeland, Their future use appears restricted to small, local sites.

Soil Conditioners

Soil conditioners, also known as soil amendments and soil additives, are materials other than conventional fertilizers that are added to soils to change them physically, chemically, or biologically to improve productivity. In the arid and semiarid regions, most attention has focused on the use of these substances to increase the amount of water retained in soils that have low water-retention capacities.

Some chemical amendments, such as water-holding starch copolymers ("super-slurpers," H-SPAN) have shown a tendency to increase water retention in sandy soils, Naturally occurring zeolite minerals have also been used to increase soil water-holding capacity.

Widespread use of chemical conditioners has been hampered by many scientific, economic, and legal considerations. Generally, research is lacking on their application. Zeolites have not attracted widespread attention from agricultural researchers in the United States. Use of expensive soil conditioners is limited to special soil conditions and to high-value crops. Finally, because of unfavorable experience with chemical soil conditioners in the past, some States have taken legal action to require scientifically acceptable evidence for efficacy before these products are offered for sale within the State.

Supplementing Soil-Water Supplies

The primary purpose of irrigation is to supply water to crops during periods of water shortage, The practice lessens some seasonal risks associated with farming, allows production in areas that could not produce most crops otherwise, and gives producers greater flexibility in selecting crops to be grown. Also, irrigation can boost crop yields.

Irrigated agriculture plays a significant role in modifying natural resources. Some of these

Box S.-Irrigation and Soil Erosion

Many people assume that soil erosion in the arid and semiarid region is limited to overgrazed rangeland and dryland agriculture. Irrigated lands are considered to be free of this hazard. For example, the Soil Conservation Service's (SCS) 1977 National Resources Inventory estimated that erosion on irrigated row crops averaged approximately 3 tons/acre/yr. The national average on all cropland was about 7 tons/acre/yr. (Soil conservationists generally recommend that soil losses not exceed 5 tons/acre/yr.)

Some irrigated lands do have little erosion. For example, surface irrigation in an enclosed basin (basin irrigation) usually results in no net soil loss to the fie1d and minimal soil transfer within the basin. Often, however, erosion in other types of surface systems and on sloping lands are much higher. A study by SCS in Idaho (Hazleton Butte Watershed) found that on fields with slopes of O to 4 percent and under furrow irrigation, erosion averaged 8 tons/acre/yr. Winter erosion added another 15 tons/acre/yr.

One of the reasons that soil erosion on irrigated land has been discounted is that it is hard to measure. Erosion depends on soil, slope, climate, and agricultural management, including the type and management of the irrigation system (e.g., length of run, set time, and number of sets in a field). Furthermore, within a single field, soil loss can vary from irrigation to irrigation. For example, early season irrigations can be more erosive than later irrigations because the furrows are unstable and susceptible to the erosive force of water. Another factor that makes erosion difficult to measure is that under some types of irrigation, the process of soil erosion is fundamentally different from the process that occurs under rainfall. Because of these discrepancies, the usual method of estimating soil erosion on cropland (Universal Soil Loss Equation) is not accurate on irrigated lands.

A number of practices can be adopted to reduce erosion on irrigated land, and some erosion control methods are also water-conserving operations. Conversion from furrow irrigation to sprinkler irrigation, installation of sediment traps, or simpler operation such as planting a filter strip of grain across the top or bottom of a furrow-irrigated field, or reducing the amount of water running through the furrow once it has been wetted, can cut erosion lossses. If weeds can be controlled, conservation tillage on irrigated lands is another possible option. If soil savings can be combined with improved profitability—higher crop yields or lower operating costs--farmers will be more likely to adopt these practices.

SOURCE: Excerpted from: Neil Sampson, "Soil Erosion and Irrigation," paper prepared for the American Farmland Trust Study on Soil Conservation Issues, Mar. 1, 1983, effects—depleted water supplies, altered streamflow conditions, and degraded water quality—have been discussed in other chapters. A major problem affecting irrigated soils is salinity, although soil erosion and nutrient content of irrigated crops are concerns as well (e.g., 22,26).

Soil salinity is often associated with irrigated agriculture although nonirrigated lands can also be affected. * Salinity is a special hazard in the Western States; van Schilfgaarde (32) estimates that 25 to 35 percent of the irrigated cropland in the region is affected by high levels of salinity and that the problem is growing. Furthermore, the costs of damage to both farmers and municipal and industrial users are enormous. The Bureau of Reclamation, for example, has estimated that the annual cost of damage in the Colorado River Basin is $100 million and will escalate to $237 million per year in 2000 (in constant 1981 dollars) (2). The process of salinization is considered in this section because excessive salt concentrations can interfere with plant-water uptake. Under these conditions, a plant can show signs of water stress even though the soil is wet and crop yields can be lowered.

Soil salinization can occur in two ways—either insufficient irrigation water is applied or drainage is inadequate. In the first case, as irrigation proceeds and water (containing salt) is added to the soil, pure water evaporates or is transpired by plants, and salts remain in the soil. Soil weathering, accelerated by irrigation, also contributes salts to the soil solution. Unless these salts are periodically flushed by rain or by excess application of irrigation water, the salt content of the soil will gradually increase and soil salinization will occur. In the second case, where drainage is inadequate, salinization occurs as repeated irrigations raise the ground water table and capillary rise carries water close to the soil surface where it evaporates, leaving a salt residue.

*In salinization, a soil accumulates sufficient soluble salts to impair its productivity. These salts mostly consist of various proportions of the cations (positively charged ions) sodium, calcium, and magnesium, and the anions (negatively charged ions) chloride and sulfate.

Photo credit: USDA-Soil Conservation Service

In California's Imperial Valley, soil-salinity levels on irrigated land pose a major limitation to crop production. This alfalfa crop has been reduced severely by salt buildup

Leaching, whether by periodic flushing or adequate irrigation, can mitigate the effects of salinization, However, large water applications require adequate drainage (sometimes a network of drains must be installed across a salt-affect area) and often increases the salt concentrations for downstream users. If smaller quantities of water are used for leaching, a crop's tolerance to increased salinity in the lower part of the root zone must be considered and monitoring is necessary. As stressed by Rhoades (25):

> At present we do not have suitable inventories of soil salinity in this country nor do we have operational monitoring programs to follow the salinity status in our soils . . . The prop-

er operation of a viable, permanent irrigation agriculture that is also efficient in water use requires periodic information on the salinity levels and distributions present within the root-zones of the soils of irrigation projects. Only then can the adequacy, effectiveness, and efficiency of the projects' operations be validly assessed with respect to salt balance.

Other management methods to cope with soil salinity include precise land leveling of fields to enable flood, rather than furrow, irrigation so that infiltration is more uniform and dissolved salts are transported below the root to the drainage system with a minimum of applied water. Where land leveling is impractical, sprinkler irrigation may be needed. In both cases, irrigation must be scheduled with smaller quantities of water at each irrigation and at more frequent intervals to maintain downward movement of salts and favorable growing conditions for the plant, especially during germination and seedling stages.

Onfarm salinity management is costly and many farmers may not have the capital necessary for such practices. One estimate placed the cost for a sprinkler irrigation setup at about $500 per acre. Precision land leveling was estimated at $50 to $100 per acre [15).

Defining Irrigation Terms

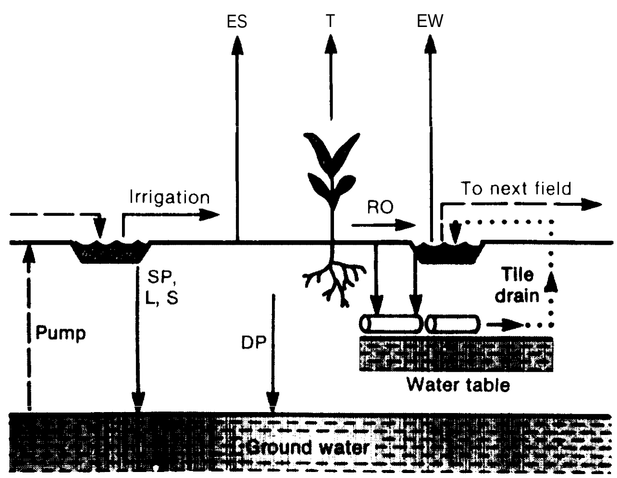
Farmers are encouraged often to "save" irrigation water, but this term and its effects on the individual and on total water supplies are sometimes unclear. First, this section defines some of the terms associated with irrigation water management and then discusses how onfarm water conservation affects an individual irrigator and regional water supplies.

Technologies that affect irrigation practices are often discussed in terms of their "onfarm irrigation efficiency, " defined as the ratio, or percentage, of the volume of water stored in the soil root zone and used by the crop to the volume of water delivered t. the farm (31). Onfarm irrigation efficiency characterizes the onfarm distribution system and the field-application system.

After irrigation water is applied, water that does not become a part of soil moisture supplies in one field (this component includes seepage, surface runoff, and deep percolation) remains part of an area's total water supply and is usually available for reuse downstream, although pumping may be required and water quality may be changed significantly. These losses are termed "recoverable." Losses that result from evaporation from open water, and from the soil surface, transpiration, and flows to saline sinks are called "irrecoverable" since they are lost except through the course of the hydrologic cycle or costly desalination operations (fig. 51).

Surface runoff and deep percolation can be curtailed in several ways, resulting in higher onfarm irrigation efficiencies. In most cases, however, a roughly equal reduction in return flows occurs, and a small net water savings is realized (fig. 52) (9).

Figure 51 .—Water Destinations in a Cropped Field



Key

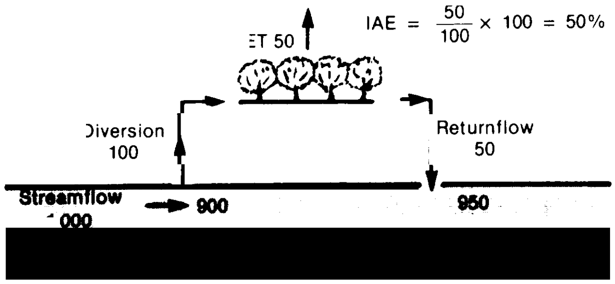
Recoverable losses.
S—Seepage
L—Leakage
SP-Operational spills
RO-Surface runoff
DP-Deep percolation

Irrecoverable losses:
EW-Evaporation from open water
ES-Evaporation from soil
T—Transportation

SOURCE David C. Davenport and Robert M. Hagen, *Agricultural Water Conservation in California, With Emphasis on the San Joaquin Valley*, Technical Report, Department of Land, Air and Water Resources, University of California, Davis, 1982

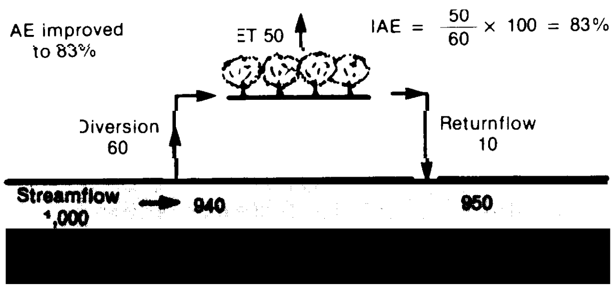
Figure 52.— Effects of Agricultural Water Conservation on Streamflow

A.



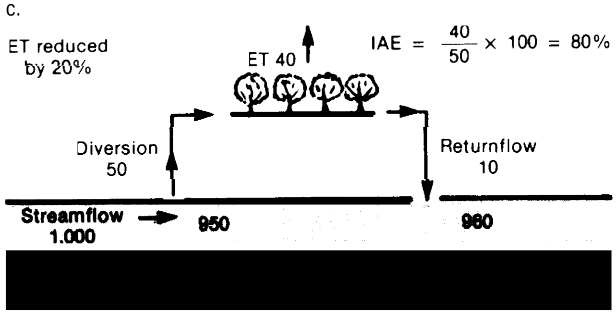
These illustrations show in a simplified way, the interrelations among water supply, gross demand, and return flows. In figure A, 100 units of water are diverted from a 1,000-unit supply of streamflow. 50 of the 100 units are lost as evapotranspiration (resulting in an onfarm irrigation efficiency of 500/0). 50 units are returned to the water source as return flow, thereby yielding a final streamflow of 950 units.

B.



In figure **B,** the farming area has improved its irrigation efficiency to 830/0. Still meeting crop needs for water of 50 units, only 60 units of **water (instead of 100 units)** need to be diverted. Streamflow is reduced to 940 units between points of diversion and outflow and 10 units are returned to the source. Final streamflow remains at 950 units.

C.



In figure C, the evapotranspiration requirements of the agricultural area are reduced from 50 units to 40 units. Because ET is smaller, less water diversion is needed (50 units instead of 60 units). The smaller diversion results in a streamflow of 950 units between the points of diversion and return flow; final streamflow is 960 units (instead of the 950 units in the other examples).

(ET = Evapotransplratlon IAE = Irrlgatton Appllcatlon Efflclency)

SOURCE David C Davenport and Robert M Hagen, *Agricultural Wafer Conservation in California, With Emphasis on the San Joaquin Valley,* technical report, Department of Land, Air and Water Resources, University of California, Davis, 1982

Reduction in irrecoverable losses are generally harder to achieve but can result in a reduction in net water consumption. Evaporation losses, for example, can be reduced most easily by preventing unnecessary wetting and exposure of the soil surface. In many areas, the effort required to reduce evaporation is not worthwhile in relation to the amount of water saved. Furthermore, a reduction in evaporation losses can increase temperatures and reduce humidities at the surface and result in greater transpiration losses. Crop transpiration losses are especially difficult to control. Producers can decrease crop acreage and thereby curtail total transpiration losses, grow crops that mature in a shorter time, or use antitranspirants but these measures are usually not economically feasible for most producers.

To assess the effect of irrigation water conservation on total water supplies, a study by the Soil Conservation Service looked at several irrigation water conservation measures, both on and off the farm, and evaluated their potential for reducing irrigation water demands in the 17 Western States (31). With no increase in either irrigated acreage or volume of water provided to water-short areas, improved irrigation efficiencies reduced irrigation diversions by over 30 million acre-ft. However, the water that was available for reallocation was estimated at only 3.3 million acre-ft.

Other than saving some quantity of water, onfarm water conservation efforts have both benefits and negative consequences for an individual and for a wider area. Advantages of reducing recoverable losses include energy savings by reduced pumping requirements, plant-nutrient savings by reducing leaching losses, less nutrient pollution and salt emission to surface and ground water, fewer plant disease and weed problems, less standing water from runoff where mosquitoes could breed, and increased instream flows in sections of rivers where water diversions are reduced. The disadvantage of reducing recoverable water losses is that less water is available for leaching salts from the soil, ground water recharge, and wildlife habitat.

Advantages for reducing irrecoverable losses include reduced draft requirements for both surface and ground water, energy savings from lowered pumping requirements, increased streamflow, additional water for other agricultural and municipal and industrial uses, and improved quality of subsurface water. Reduced crop yields and the physical requirements needed to implement measures to reduce evapotranspiration losses are major disadvantages.

Finally, physical, social, legal, and economic factors often hinder adoption of practices that could improve onfarm irrigation efficiencies. These include:

- onfarm physical conditions that cannot be alleviated easily (e. g., sandy soils that have low retention capacities);
- difficulties in identifying practices that reduce irrigation efficiencies because of current measurement techniques and services;
- relative insignificance of water losses to an individual if water is inexpensive or cannot be used if saved;
- questions over costs of practices relative to benefits derived from application;
- feasibility of integrating new practices into existing farm management practices; and
- legal uncertainties regarding whether the farmer can use the water "saved" (see ch. V).

The following sections discuss various modifications to existing irrigation systems and possible irrigation strategies that individuals can use to "stretch" their water supplies.

Supplying Full Water Needs to Plants

INTRODUCTION

Traditionally, irrigation systems are designed and operated to supply full water needs to plants so that yields are not limited by water shortages and yields are maximized per unit area irrigated. The crop root zone, the depth of soil where crop roots are actively growing (usually 1.5 to 6 ft deep), provides a reservoir for storing water until it is needed for plant growth. Water that infiltrates the soil but exceeds its storage capacity will percolate below the roots and will enter the ground water.

ASSESSMENT

In irrigated areas of the West, three major types of irrigation systems are used to apply water. The most widespread type is gravity or surface flow, followed by sprinkler irrigation, and drip or microirrigation (table 55). A fourth type, subsurface irrigation, is used less frequently, Each system is best suited to specific soil, topography, crop, climatic, and economic conditions. For example, surface methods are generally the least expensive type of irrigation, in capital required for application, but they require larger flow rates to operate efficiently than do sprinkler or drip methods. If less efficient, surface methods require larger gross applications of water than do sprinkler or drip irrigation. Sprinkler methods are well suited to steep or rolling lands but often require substantial investments in equipment. Drip irrigation is appropriate for orchard and horticultural crops but less suited to row crops like corn or cotton. It also requires large capital investments,

Technically, most irrigation systems have similar field application efficiencies. However, actual application efficiencies vary considerably and range from less than 40 percent in areas where management and site conditions

Table 55.—irrigation Methods, 17 Western States, 1981

State	Type of irrigation (in percent)		
	Surface	Sprinkler	Drip
Arizona	93,6	6.0	0.4
California	77,0	20.0	4.0
Colorado	78.0	22.0	—
Idaho	73.0	27.0	—
Kansas	63.0	37.0	—
Montana	92.0	8.0	—
Nebraska	57,0	43.0	—
Nevada	95.0	5.0	—
New Mexico	87.9	12,0	0.1
North Dakota	23.0	77.0	—
Oklahoma	48.9	51.0	0.1
Oregon	46.9	53.0	0.1
South Dakota	13.0	87.0	—
Texas	72.7	27.0	0.3
Utah	77,9	22.0	0.1
Washington	28,8	71.0	0.2
Wyoming	90.0	10.0	—

SOURCE" Marvin Jensen, *Overview-Irrigation in U S Arid and Semiarid Lands,* OTA commissioned paper, 1982 (Original source *Irrigation* Journal, December 1981) are poor to over 80 percent in a well-managed system under good field conditions (fig. 53). Reasons for low onfarm irrigation efficiencies are outlined in table 56.

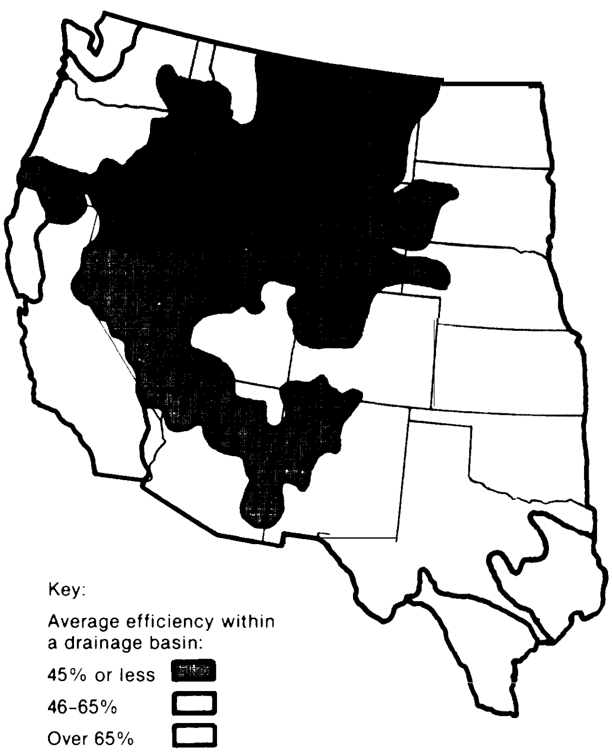
Surface Irrigation

Surface irrigation refers to irrigation methods where the soil surface serves both as the channel to distribute the water over the field and the control for water entry (fig. 54). Gravity provides the energy needed to distribute the water. Surface irrigation may be further subdivided into: 1) flooding, and 2) furrow irrigation.

Numerous modifications to existing surface irrigation operations can be made by irrigators to reduce evaporation and deep percolation losses and runoff. These include:

- manipulation of the length of time water is applied (set time), irrigation stream size, irrigation frequency, and the distance over which water is applied (length of run);
- land smoothing or leveling; ditch lining; surge flow (a method of water application);
- automation; and
- system replacement.

Figure 53.—Onfarm Irrigation Efficiencies, 17 Western States



SOURCE. U S Department of Agriculture, Soil *and Water Resources Conservation Act, 1980* Appraisal, pt. II, 1981

Table 56.—Factors Reducing Onfarm Irrigation Efficiency

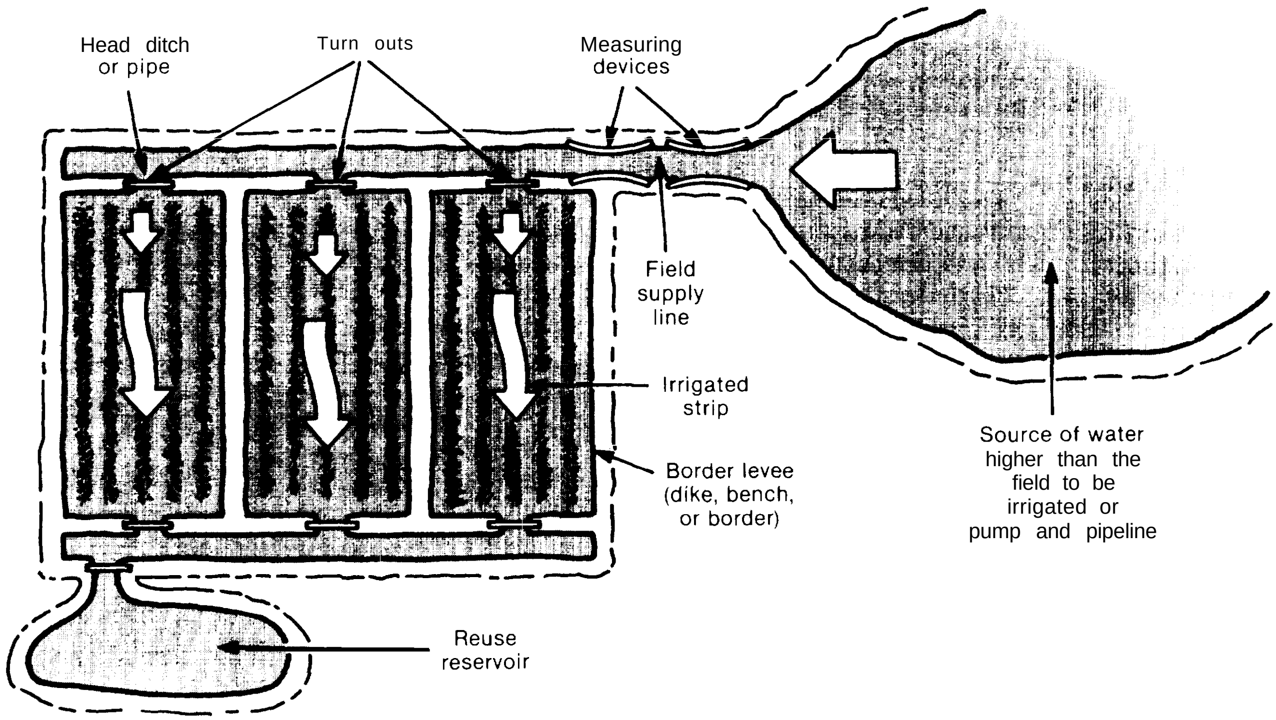
1. Delivery system:
   - Inadequate water-measurement devices
   - Unlined ditches
   - Improper location or alinement of ditches
   - Obsolete systems
   - Inflexible delivery schedule
2. Field application system:
   - Improper land shaping
   - Improper relationships of slopes, length of run, border widths, discharge rates
   - Improper design of sprinkler or drip system (pumping capacity, pressure, nozzle sizes)
   - Method of application not suited to soils or slopes
3. Ineffective water management:
   - Improper timing of irrigations
   - Incorrect application amounts
   - Improper scheduling of water
   - Excessive use of inexpensive water to save labor cost

SOURCE: U.S. Interagency Task Force, *Irrigation Water use and* **Management,** USDI, USDA, EPA (Washington, D. C.: U.S. Government Printing Office, 1979),

In recent years, several developments have occurred that may further improve onfarm efficiency of surface systems. Mathematical models have been developed to simulate and predict interactions between soil, water, and crops during irrigation (18). These models may help decrease the random nature of surface irrigation design and operation and allow for more effective and timely water application. At present, models require further refinement before they are used widely because of the extensive variability in site conditions across the arid and semiarid region (e.g., soild infiltration rates, weather, and crop consideration).

Another important modification to surface irrigation has been use of a tailwater-reuse system, which consists of a reservoir at the lower side of a field to collect excess irrigation water. A pump then delivers recovered water back to a field. Tailwater-reuse systems allow application of large quantities of irrigation water (with accompanying runoff), reduce de-

Figure 54.—Surface-Irrigation System



SOURCE J Howard Turner and Carl L Anderson Planning for an Irrigation System (Athens, Ga American Association for vocational Instructional Materials 1980).

Photo credit: USDA-Soil Conservation Service

Potatoes grow in furrow irrigation rows

mand for energy because pumping lift is less from a tailwater reservoir than from deep wells, and prevent damage to adjacent property by irrigation tailwater. However, irrigators who use a tailwater system lose land from crop production, and water that has been pumped through the system two or more times is lower in quality than the first time through the field.

Laser-controlled land leveling has increased the size of fields that can be irrigated using basin irrigation (a type of system consisting of a level area enclosed by earthen border ridges), Where soils are uniform, the combination of large flows with precision leveling can boost application efficiencies. Expansion of level basin irrigation over extensive areas of the

West is limited, however, by the availability of high-volume, instantaneous water flows and by potential problems with surface drainage in areas with substantial rainfall. The disadvantages associated with land leveling are a problem also.

Sprinkler Irrigation

Sprinkler irrigation is the application of water to the soil surface in the form of a spray, somewhat as rain. Many different types of sprinkler systems exist; in the United States, center-pivot systems represent the major sprinkler irrigation method (fig. 55).

With proper design and under correct management, sprinkler irrigation systems have a minimal amount of deep percolation and runoff loss. The primary practices available to an irrigator to minimize these losses further are design changes or changes in operating procedures. For example, sprinkler spacings, operating pressures, and set times may be changed, or additional use of automated equipment to control the system may be employed.

Energy conservation has received considerable attention in recent years and poses a special problem in continuously moving systems (center-pivot or lateral move). Reducing pressure while saving energy tends to lower irrigation efficiency because more water is applied and more runoff occurs. Modified-tillage practices, for example, basin tillage, can be incorporated into the farming program to reduce these runoff losses. Another practice is the placement of water application devices below the crop canopy. Low-energy precision application systems apply water directly to the irrigation furrow at low pressure through drop tubes as the sprinkler continuously moves through the field. Thus, runoff and spray evaporation are minimized (20).

Drip Irrigation

Drip, or microirrigation, is the frequent, slow application of water to the soil near the roots of a plant in sufficient amounts to meet its needs (fig. 56). The technology was introduced in the Western United States in the early 1970's; since then, its use has expanded to approximately 494,000 acres in 1980 (16). Drip irrigation is used primarily on high-value crops such as avocados, citrus fruits, strawberries, tomatoes, vineyards, and deciduous orchards, but has also been adapted to other types of crop production. Among the advantages of its use are:

- enhanced water control;
- lower seedling mortality;
- greater uniformity of plants, bushes, or trees;
- fuel savings;
- increased flexibility in the use of fertilizers;
- fewer weed problems;
- overall yield increases; and
- erosion control.

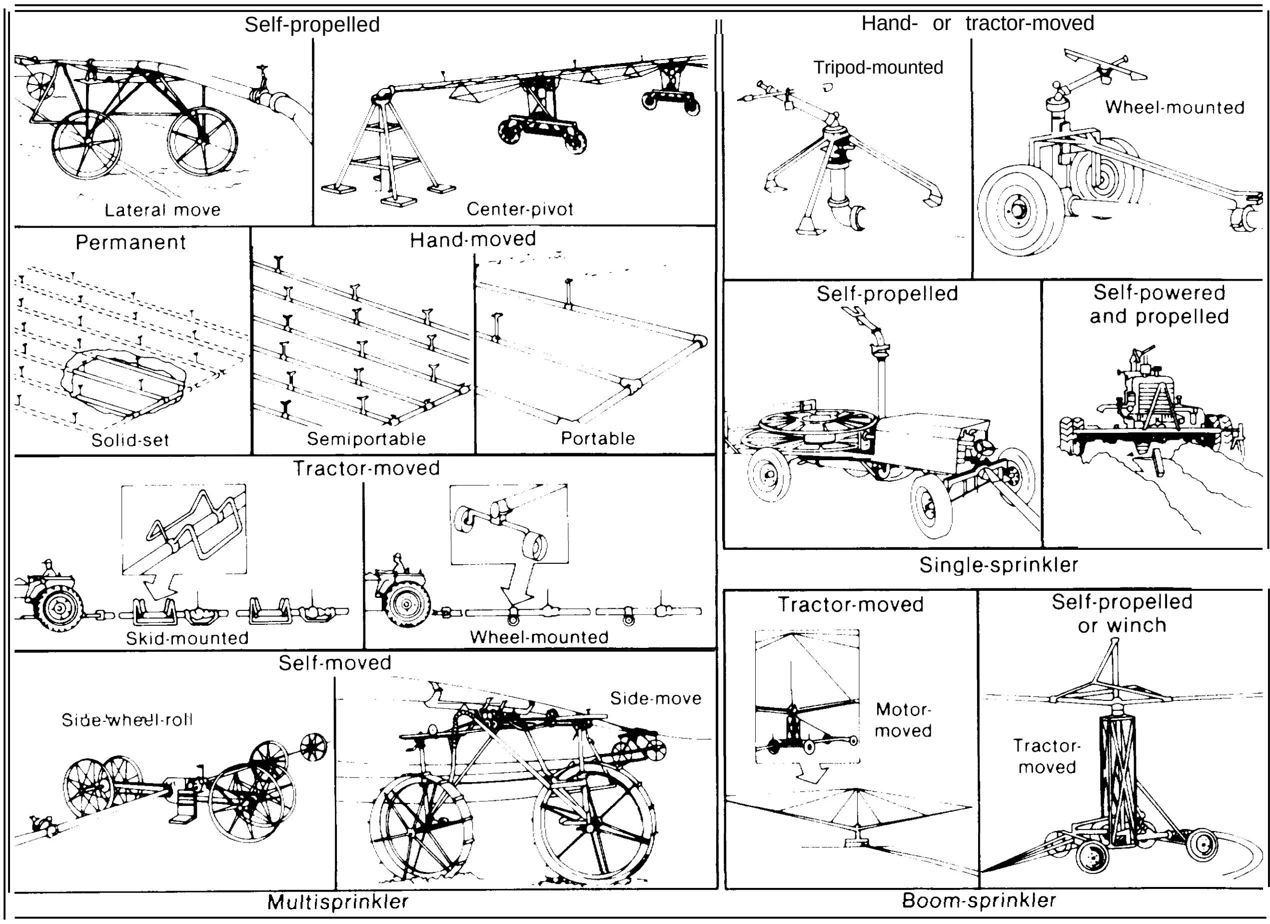
In theory, drip irrigation can increase irrigation efficiencies by reducing evaporation and deep percolation losses because a small amount of water is applied to a small portion of the soil surface. Actual water savings with a drip irrigation system, when compared to conventional surface or sprinkler irrigation, depends on such factors as irrigation frequency and crop. * In irrigation of row crops or crops with a nearly full cover, the water savings from reduced evaporation may be less. Drip irrigation with micro sprinklers ** may increase evaporation losses when compared with conventional drip systems because more of the surface is wetted.

Although the high irrigation efficiency associated with drip irrigation makes its use attractive, drip irrigation has some physical and economic limitations. Beyond the wetted zone, soil salinity may increase. Also, in most systems only a small portion of the soil is wet and plant roots tend to be confined to this area. If water delivery is stopped suddenly, severe plant stress can occur quickly. Large capital investments are required for plastic pipe, filtration

*The most favorable situation occurs with orchard crops in early growth stages where large areas of the surface is exposed and water is not needed in areas not yet explored by roots.

**Microsprinklers are smaller than conventional sprinkler heads but larger than standard drip emitters. Their use helps alleviate clogging hazards associated with emitters and have been tested in orchards to apply greater amounts of water than would be possible under conventional drip irrigation.

Figure 55.—Sprinkler Irrigation System



SOURCE" J. Howard Turner and Carl L Anderson, ***Planning for an** Irrigation System* (Athens, Ga. American Association for Vocational Instructional Materials, 1980)

Photo credit USDA-Soil Conservation Service

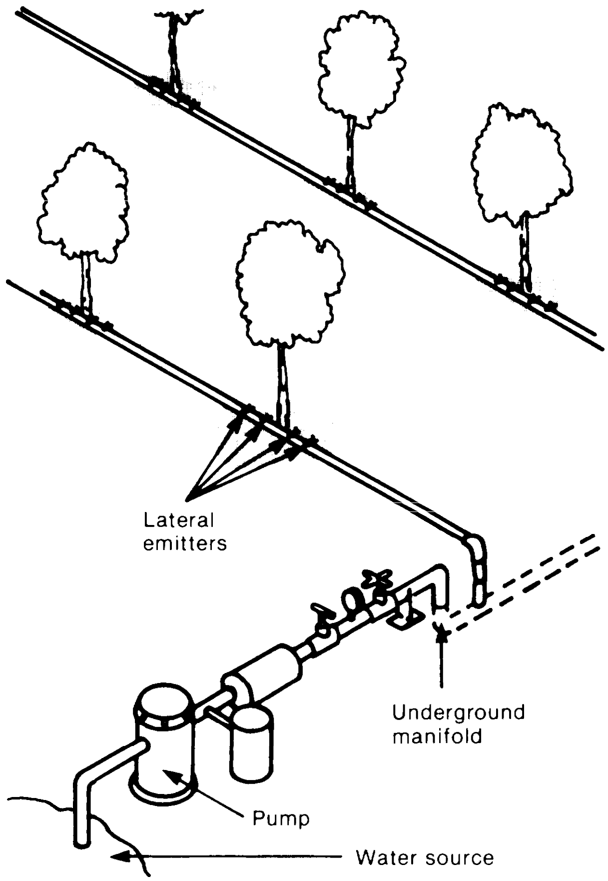
In a test field in California, private researchers are experimenting with the use of drip irrigation on furrowed cotton

equipment, and installation. Energy is required to pump water through the system, offsetting some of the energy savings compared to other irrigation systems. High maintenance is required. Water lines may be damaged by wildlife, insects, or soil-dwelling animals. Lines must be flushed periodically, and emitters may clog because of chemical buildup, silt, sludge, algae, slime, or roots. Emitters must be inspected frequently, and breakdowns in the system are sometimes not seen, especially where buried drip lines are used.

Subsurface Irrigation

Subsurface irrigation is accomplished by artificially raising the water table close to the soil

Figure 56.— Drip Irrigation Systems



Drip irrigation systems usually consist of a network of small-diameter plastic tubing along each row or between pairs of crop rows. Water is discharged through uniformly spaced small openings in the tubing or through emitters, nozzle-like devices that regulate water flow from lateral lines into the soil. Filtration equipment, provisions for fertilizer and pesticide injection, a fertilizer holding tank, and hardware to regulate water pressure are usually included as part of the system.

SOURCE J Howard Turner and Carl L Anderson Planning for an *Irrigation System* (Athens Ga American Association for Vocational Instructional Materials 1980)

surface. Water reaches the plant roots through capillary movement upward.

The advantages of subsurface irrigation include reduced evaporation, erosion control, and fuel and fertilizer savings. This method of irrigation also allows cultivation and other surface operations to be carried on without concern for the irrigation period.

Certain physical conditions must be met to ensure the success of subsurface irrigation, and these limit its application. First, soils should permit rapid lateral and downward movement of water yet should be capable of lifting the moisture from the water table throughout a major portion of the root zone. Second, the topography of the land should be smooth, uniform, and approximately parallel to the water table to allow for even irrigation. Third, salinity control is necessary and often requires the use of auxiliary irrigation systems (surface or sprinkler) to leach salt that accumulates at the soil surface as water evaporates. Auxiliary irrigations may also be needed for seed germination and plant establishment.

Limited Use of Supplemental Water

INTRODUCTION

In recent years, in areas where water supplies have become scarce or where the price of water has increased, two concepts of irrigation management, distinct from full irrigation, have evolved. “Supplemental” irrigation manages precipitation and irrigation water together to supply full-crop water needs. In “deficit” irrigation, applied water or applied water combined with precipitation is less than the amount of water needed for maximum crop yield.

For limited irrigation to succeed, a management strategy is necessary that integrates crop selection, soil manipulation, and irrigation system management with available water and economic conditions. This plan is flexible and varies from year to year.

Crop Considerations

Limited irrigation normally requires a diversified cropping program. This program includes:

- relatively drought-resistant crops;
- deep-rooted crops or crops with dense root systems that can tap soil water or enhance infiltration;
- crop rotations to ensure that water is available during growth periods that are sensitive to water stress; and
- in areas of summer precipitation, cropping patterns that provide for a fallow period when rainfall can be stored.

Soil-Water Considerations

Tillage practices, water-storage facilities (e.g., tanks and ponds), and soil-water monitoring are key elements in limited irrigation. As discussed earlier in this chapter, many land-forming techniques can be used to improve infiltration and ensure that precipitation and irrigation water are retained onsite.

Auxiliary water-storage facilities can also be used to capture runoff for later use. Water can be pumped from the storage facility when crops need to be irrigated or when the soil can retain the water.

Another aspect of soil-water management is monitoring the extent of soil-water deficit. This practice can help a grower identify when irrigation is required.

Irrigation System Management

Effective limited irrigation requires that recoverable losses (e. g., deep percolation and runoff) are minimized and that water is available to the crop during critical growth periods. Recoverable water losses can be reduced by increasing onfarm distribution and application efficiencies (see previous discussion under full irrigation).

Application methods, suited to the irrigation system, can also be manipulated to distribute limited water over a greater land area. For surface irrigation systems, for example, these methods could include alternate furrow irrigation, which tends to reduce deep percolation and results in greater lateral movement of applied water in the soil, and alternate furrow irrigation plus basin tillage. This latter practice allows rainfall to be captured while irrigation is proceeding. With both sprinkler and surface methods, irrigators could practice skip-row planting which leaves a number of rows fallow to serve as a reservoir for soil water.

A second management practice for use in deficit irrigation is a limited irrigation-dryland system. In this system, a field is divided into three water-management sections, The upper half of the field is managed as fully irrigated. The next one-fourth is managed as a "tailwater runoff" section that uses runoff from the fully irrigated section. The lower one-fourth is managed as a dryland section. This system has been tested in the semiarid Texas High Plains region; limited research indicates that it has high irrigation water-use efficiency when compared to conventional irrigation (29).

Finally, the timing of irrigation water application is important. This requires that a knowledge of a crop's most sensitive growth period, If critical growth periods are known, irrigation water can be applied at that time to as large an area as possible, The irrigation is then terminated when plant-water stress on remaining unirrigated areas reaches a critical point and when the probable economic response to additional applied water would be mininal for the area already irrigated. A second irrigation begins on the area first irrigated and is normally continued until the economic contribution from irrigation declines or the crop reaches maturity (2).

ASSESSMENT

Limited irrigation has wide geographic potential. It could be applied in those irrigated areas where rainfall can supplement irrigation water or where drought-resistant crops are available, Currently, most limited irrigation is practiced in the southern Great Plains where high costs for pumping irrigation water are encouraging many farmers to shift from full irrigation to dryland farming. For these individuals, limited irrigation is one way to maintain higher crop production than possible with dryland farming while minimizing irrigation costs.

Economic and institutional considerations currently restrict extensive applications of limited irrigation to areas that face severe water shortages, Management requirements are high, and crop yields may decline when compared to a fully irrigated situation. Limited irrigation also requires precise and timely application of water; least expensive irrigation methods (e.g., surface irrigation) are often not suitable. The availability of large irrigation flows may limit the use of surface irrigation. Computerized instrumentation may be needed to monitor soil and crop and weather conditions and to control irrigation equipment, Institutionally, because this is a relatively recent development in irrigation-system management, many irrigation-system designers and extension personnel may not be able to provide appropriate information to producers who wish to change to a limited system.

Application of deficit irrigation is limited also by several technical considerations, First, standard procedures presently used to predict seasonal crop-water requirements and critical, water-sensitive growth periods (water production functions) are not accurate for more than one geographic area or crop, thus, results cannot be extrapolated across broad geographic areas or even from one field to another. Second, unless actual evapotranspiration and predicted evapotranspiration deficits are monitored closely and precisely, it is difficult for a producer to plan irrigation applications during water-stress periods. Monitoring programs are costly, however, and beyond the means of many individuals.

CONCLUSIONS

Many opportunities for improving soil-moisture conditions exist, both where precipitation is used to supply crop-water needs and where irrigation is practiced. Some of these technologies have been adopted by producers, but numerous barriers remain to their widespread application. First, many of these practices are effective under certain soil and/or climatic conditions. Where site conditions are not appropriate, application can yield little or no improvement in soil-water conditions. Second, some practices require large economic investments for equipment, fuel, and labor; application costs may outweigh their benefits in terms of higher farm or ranch profits. Third, the use of some technologies is hindered by Federal and State institutions, For example, mechanical land treatments on public rangelands by individuals are often prohibited; water saved by irrigators is often not available again for their use. Finally, some practices are difficult to incorporate into existing farm and ranch operations and may require new equipment or skills.

The extent of soil-water increase that can be expected with the adoption of a particular technology is difficult to quantify, given the wide variability in site conditions across the arid and semiarid region, For technologies that are used on irrigated land, data that assess the effects of widespread adoption on total water supplies are lacking. Similarly, information on economic and social consequences of adoption is generally not available.

Finally, soil salinization on irrigated lands and its associated effects on other natural resources may result in a reappraisal of the potential for dryland and rangeland agriculture in the Western United States. If a shift to limited irrigation or dryland or rangeland agriculture does occur, it may present Western agriulture with some new opportunities for production.

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