Soil Erosion and Control

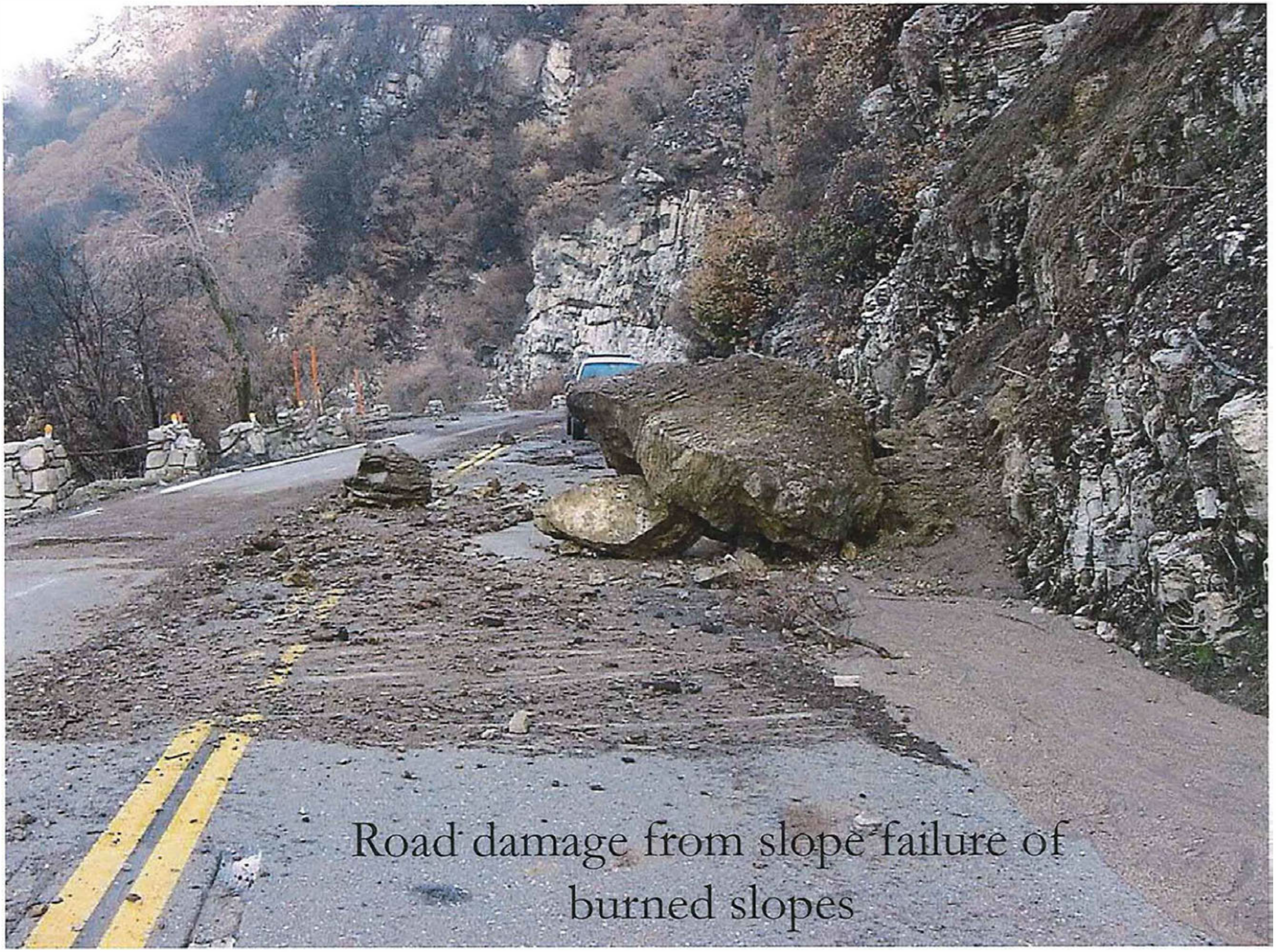
Soil Erosion

- Most destructive worldwide soil phenomenon
  - Water, plant nutrients, soil are lost
  - Soil loss in USA about 5 billion metric tons/year
    - 2/3 lost by water erosion
    - 1/3 lost by wind erosion
  - Majority of erosion occurs on most productive agricultural land
  - Responsible for sedimentation of water bodies

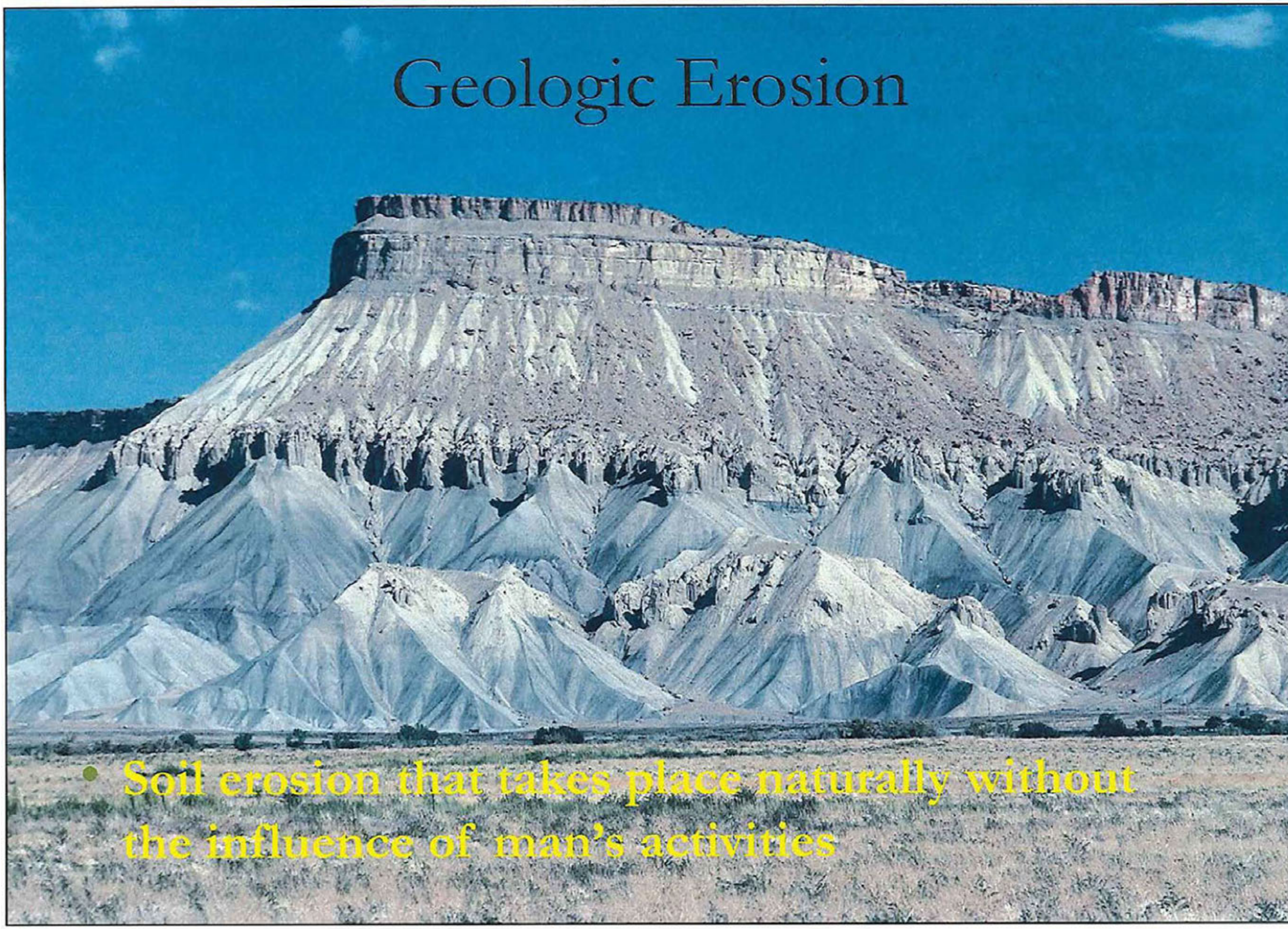
Soil Erosion

- Essentially a natural process accelerated by man's activities
  - Occurs incessantly but majority of erosion occurs in relatively few discrete events
  - Accelerated erosion: when erosion rate exceeds normal rate
    - Caused by water
    - Important for agricultural lands


Waterman Canyon Debris Flow

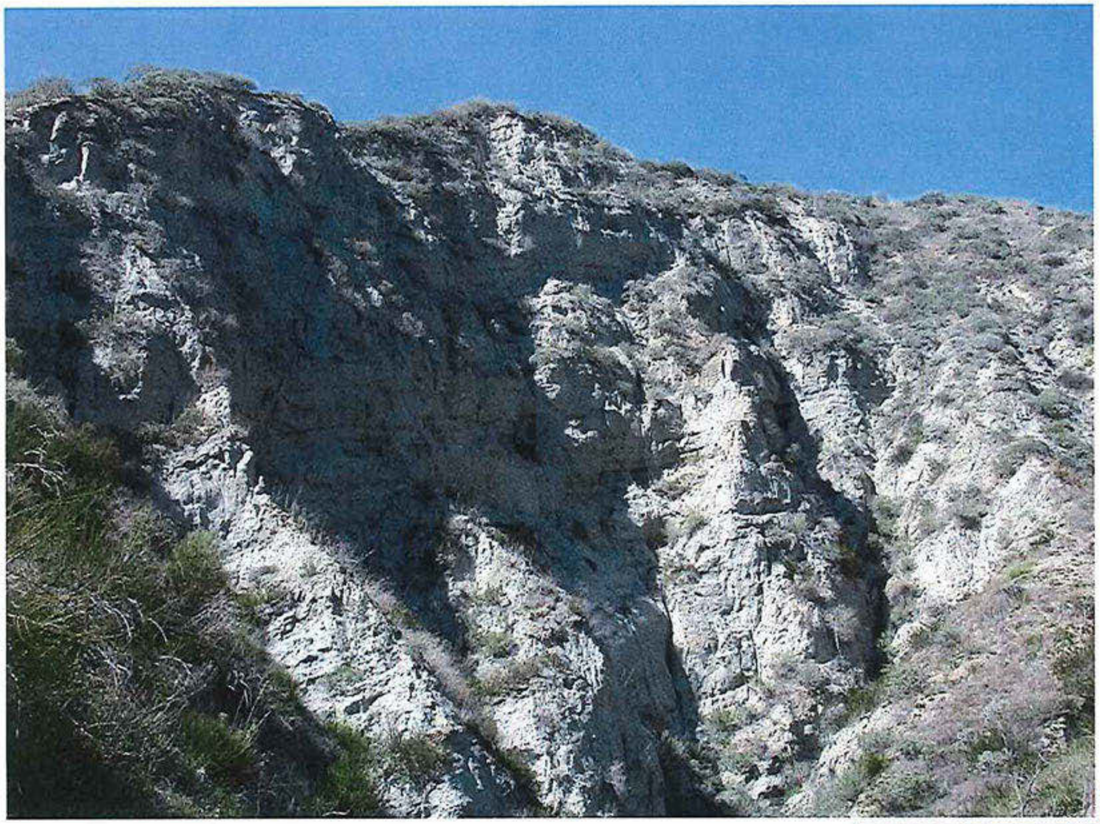


Road damage from slope failure of burned slopes


Geologic Erosion
Soil erosion that takes place naturally without the influence of man's activities

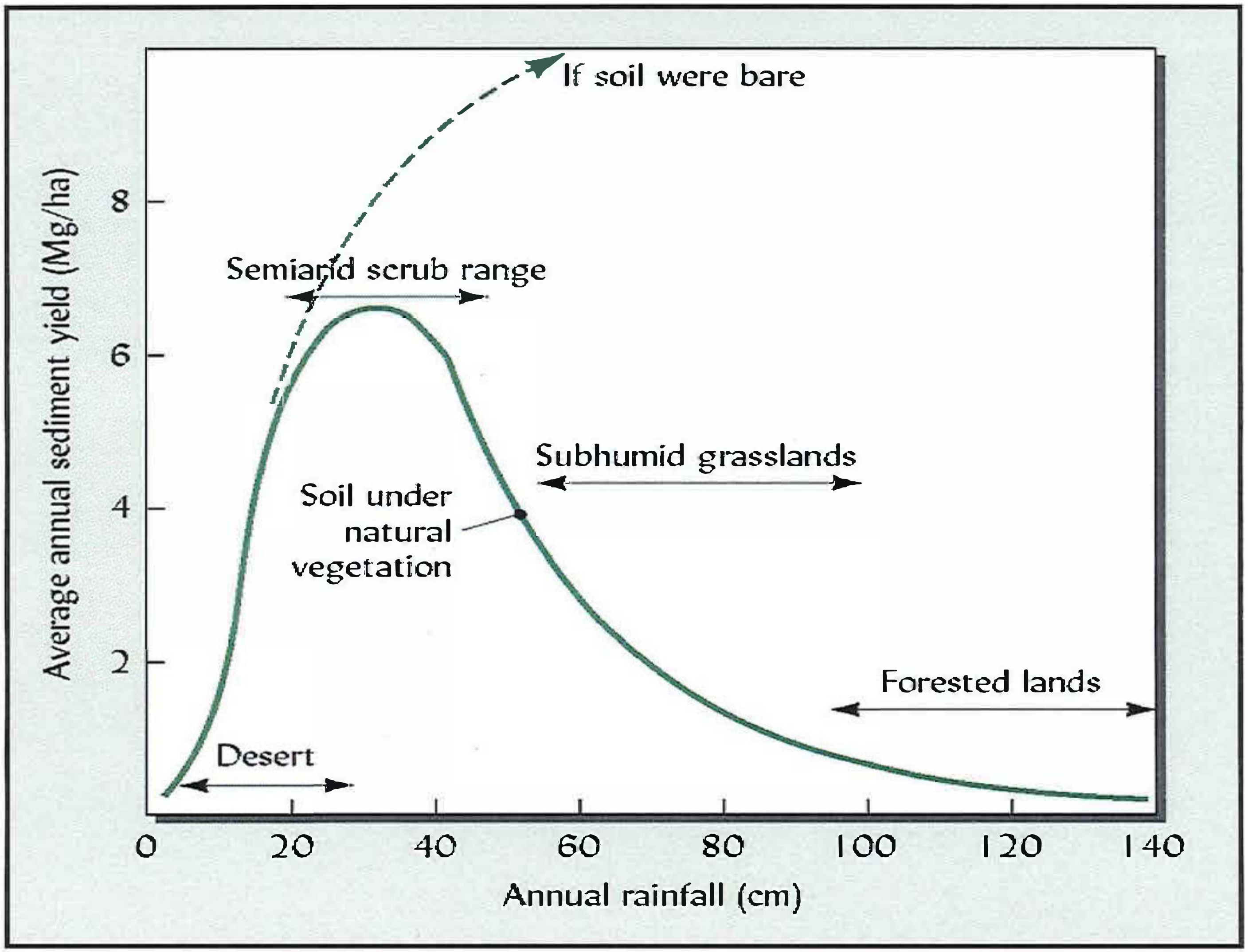
Geologic Erosion

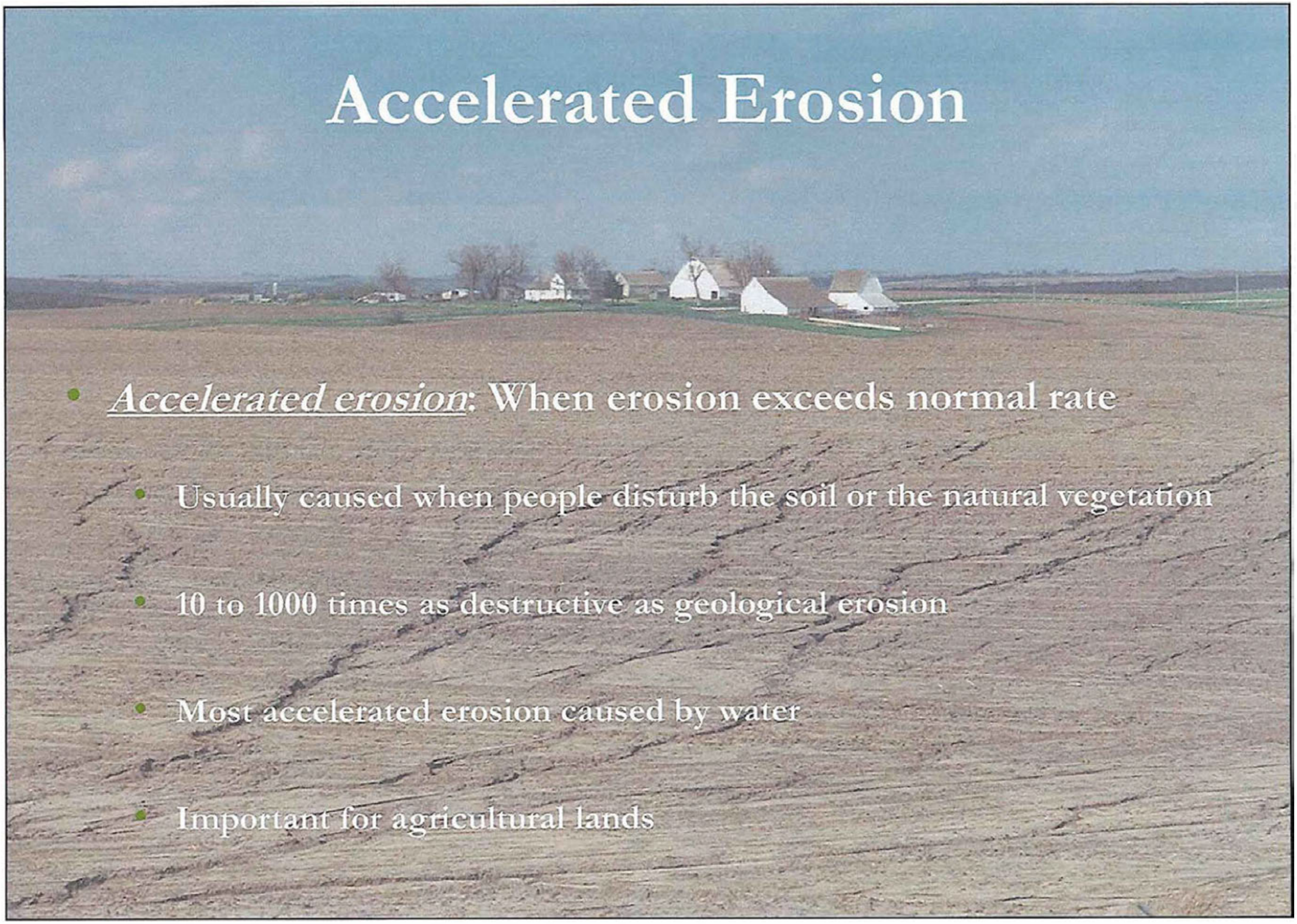
- Natural leveling process, wearing down hills and mountains and filling valleys and lakes
  - Usually new soil forms faster than old soil is lost
  - Rates of geologic erosion affected by rainfall amount and type of material being eroded



Weakly consolidated sandstone

Generalized relationship between annual rainfall and soil loss from geologic erosion by water





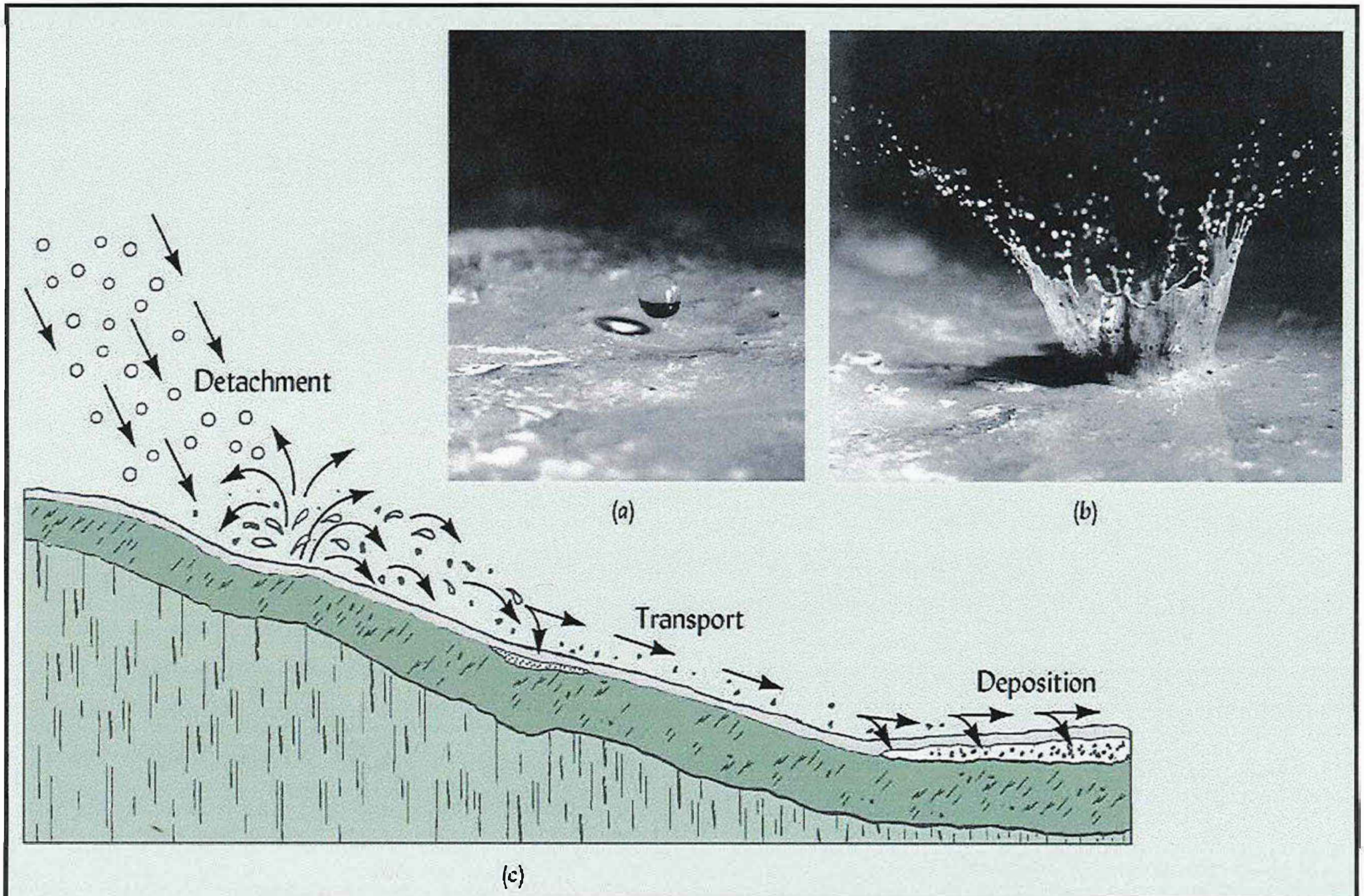
Accelerated Erosion

- ***Accelerated erosion***: When erosion exceeds normal rate
  - Usually caused when people disturb the soil or the natural vegetation
  - 10 to 1000 times as destructive as geological erosion
  - Most accelerated erosion caused by water
  - Important for agricultural lands

Mechanics of Water Erosion

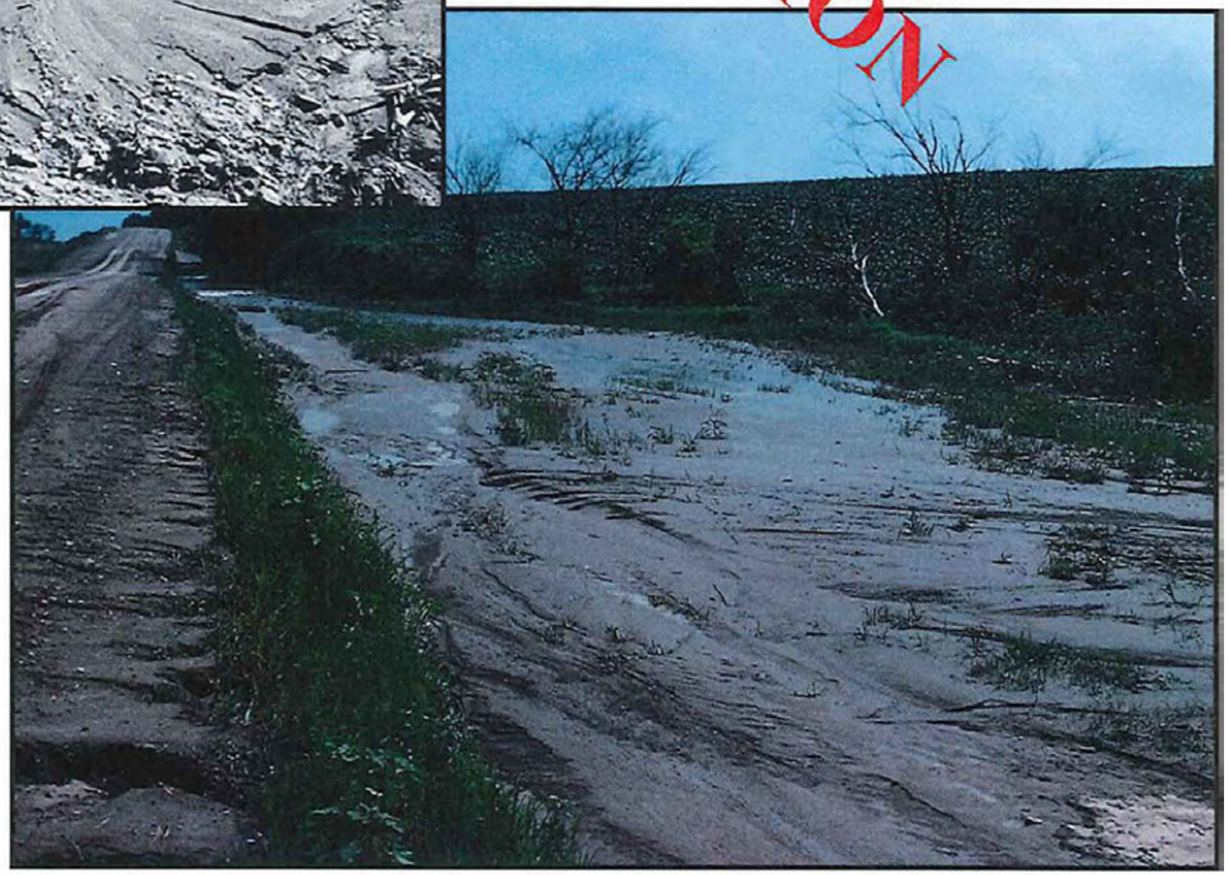
- Water erosion involves three processes
  - <u>Detachment</u> of soil particles from soil mass
    - By raindrops, freezing/thawing, running water
  - <u>Transport</u> of the detached particles
    - Mostly by runoff water
      - Floating, rolling, dragging and/or splashing action
  - <u>Deposition</u> of the detached particles
    - Settling of transported particles

Three Step Process of Water Erosion



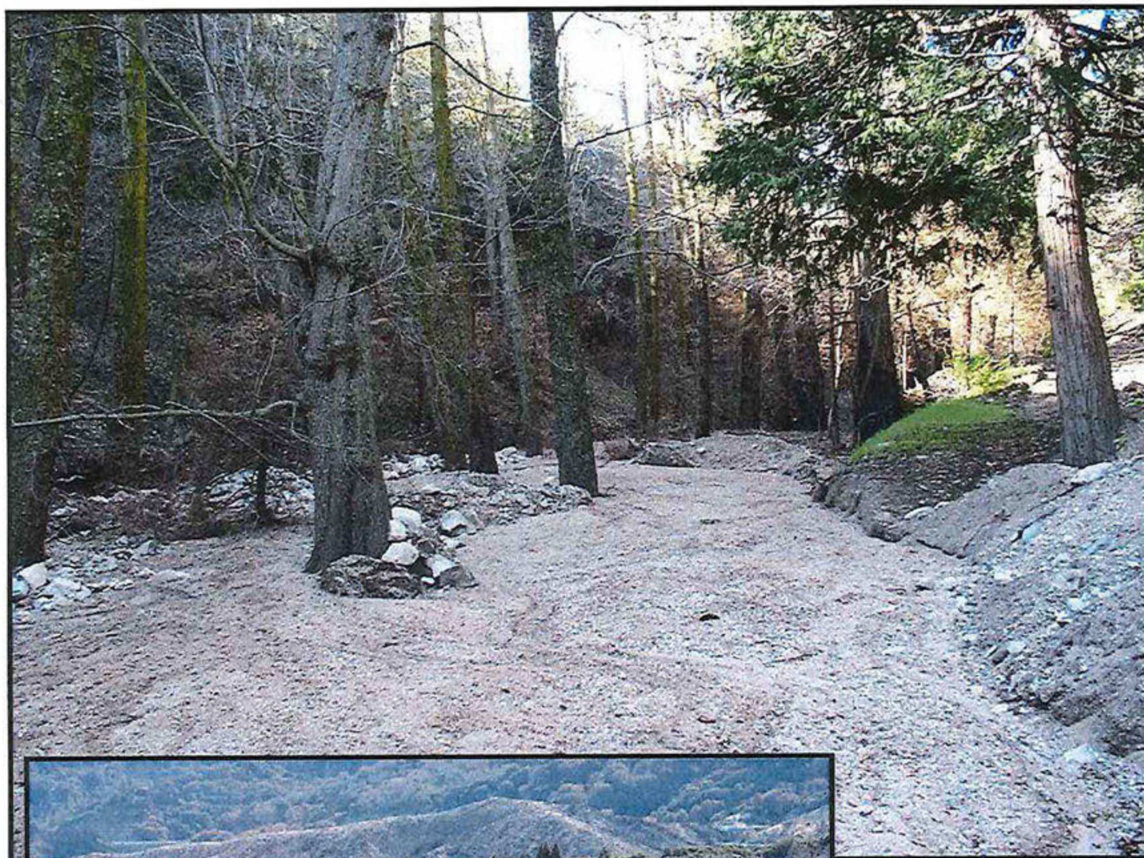

TRANSPORT

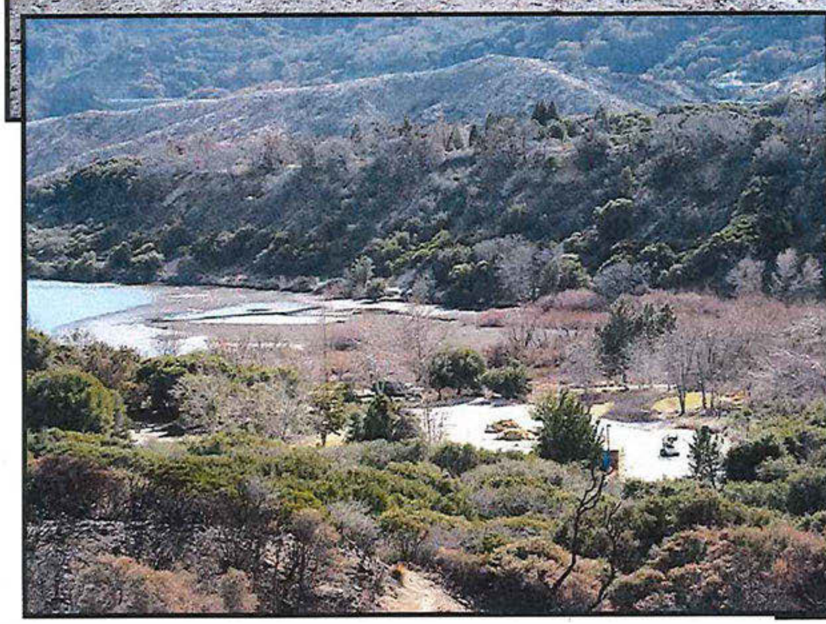
DEPOSITION



Debris fills narrow drainageways off steep slopes

Sediment fills in waterways, ditches, lakes





Influence of Raindrop Impact on Water Erosion

1) Detaches soil particles

2) Destroys granulation (aggregation)

3) Can cause transport of soil by its splash

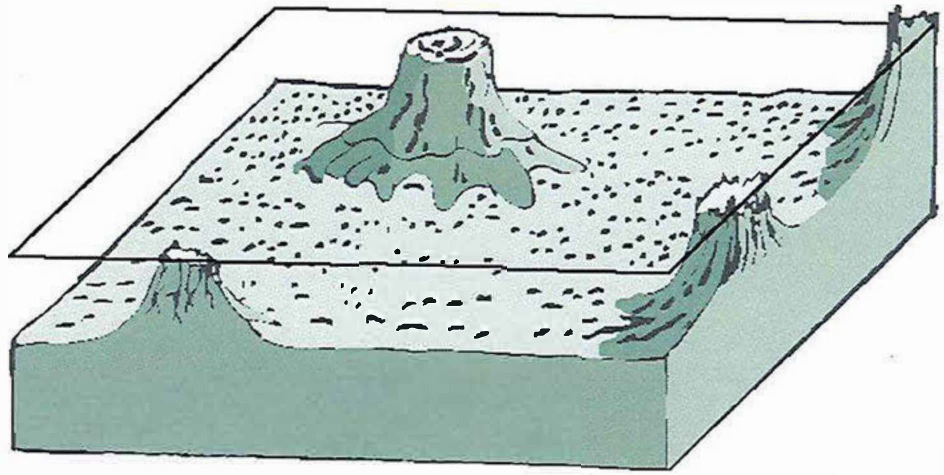
Influence of Raindrop Impact on Water Erosion

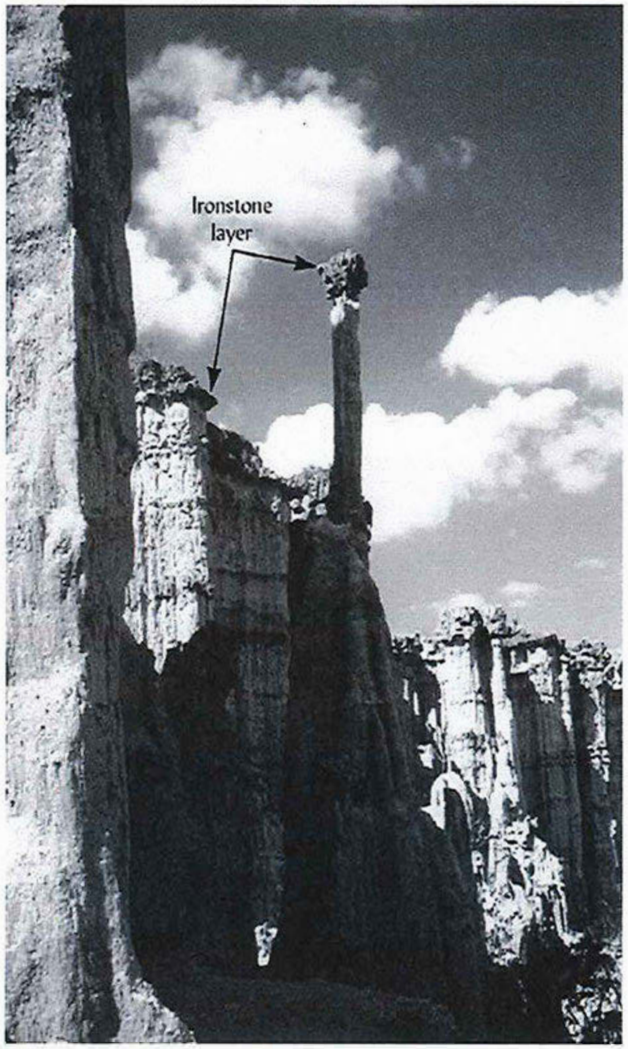
- Most erosion initiated by impact of raindrops, not by running water
    - Raindrops can seal some soils resulting in reduced infiltration, quick saturation
        - Silty soils and salt affected soils very susceptible
        - Runoff can carry detached particles farther

Types of Water Erosion

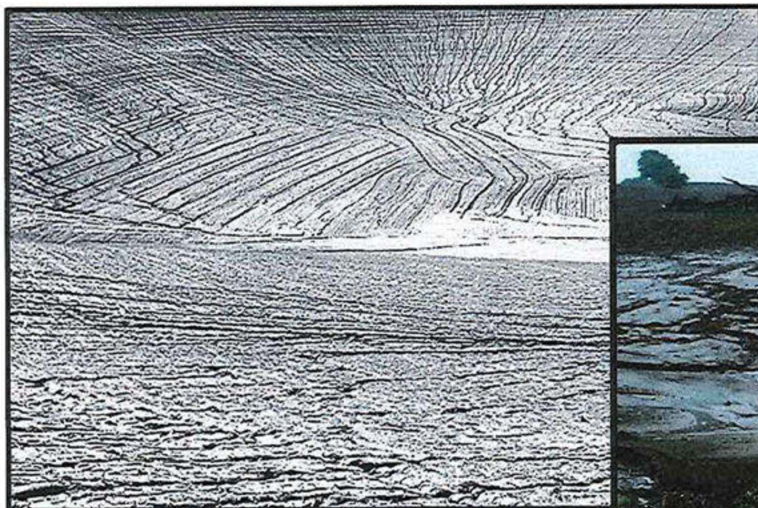
- Sheet erosion: removes soil evenly from the surface of the land
- Rill erosion: miniature channels formed, often accompanies sheet erosion
- Gully erosion: heavy concentrations of runoff
  - Produces large deep channels that cut back from their head
  - Looks worst, but more soil lost by sheet and rill erosion

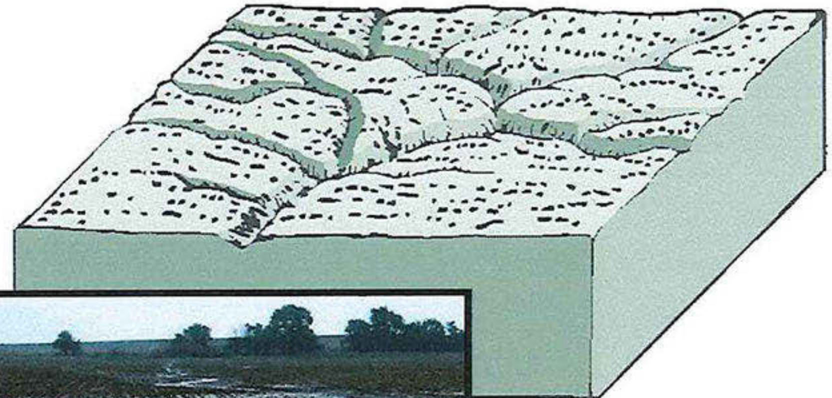
Sheet Erosion

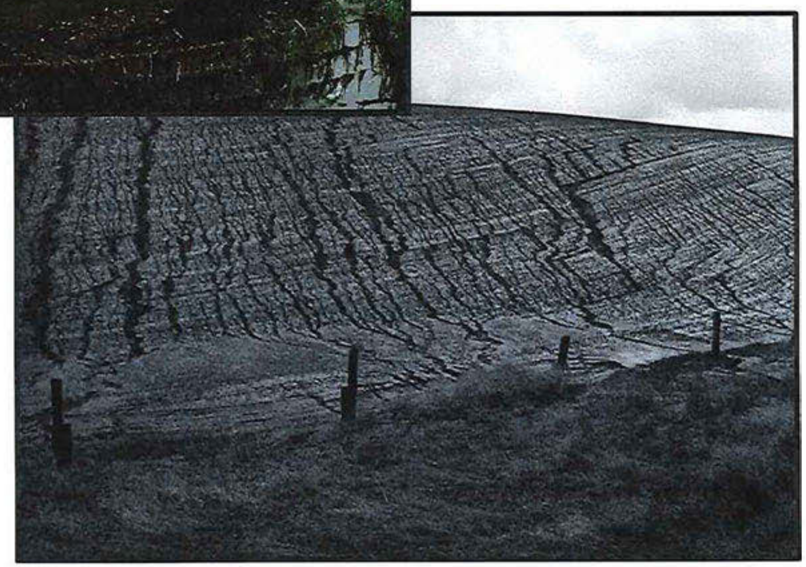




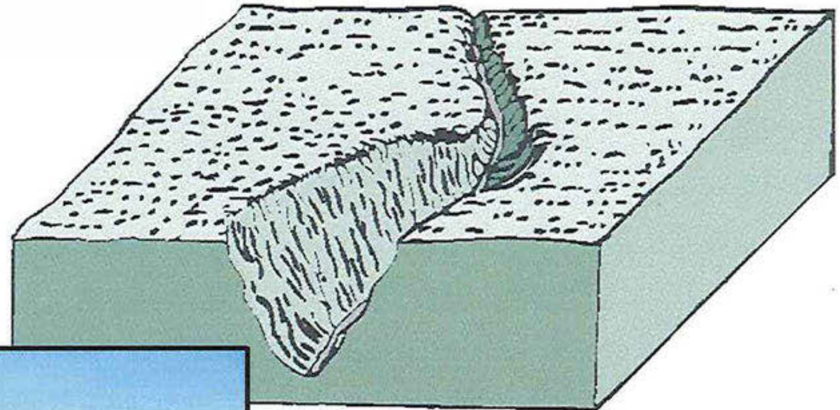
Rill Erosion



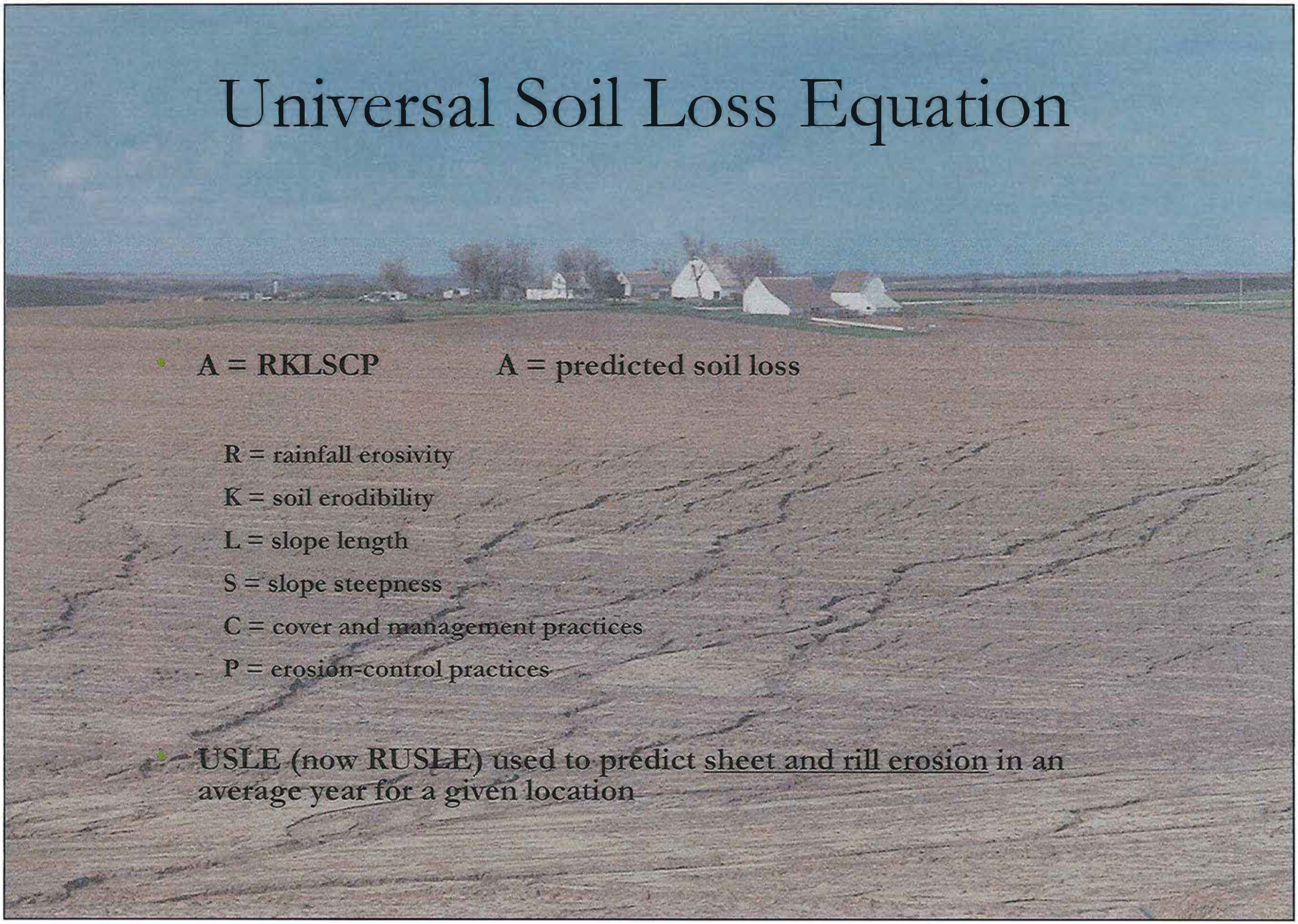




Gully Erosion



Debris flow cuts new gully



Universal Soil Loss Equation

- A = RKLSCP A = predicted soil loss

  R = rainfall erosivity

  K = soil erodibility

  L = slope length

  S = slope steepness

  C = cover and management practices

  P = erosion-control practices

- USLE (now RUSLE) used to predict <u>sheet and rill erosion</u> in an average year for a given location

Factors Affecting Water Erosion

- ***Rainfall erosivity factor R***
  - Evaluates the total rainfall and intensity and seasonal distribution of rain
    - Intensity more important than total rainfall
    - Little erosion occurs if rainfall comes in gentle showers

Factors Affecting Water Erosion

- *Soil erodibility factor K*
  - Indicates a soil's inherent susceptibility to erosion *(higher K = more erosive potential)*
- Most important soil characteristics influencing erodibility are *infiltration capacity* and *structural stability*
  - High infiltration means less runoff
    - Texture, organic matter content and type of clay mineral are important
  - Structural stability resists beating action of raindrops

Factors Affecting Water Erosion

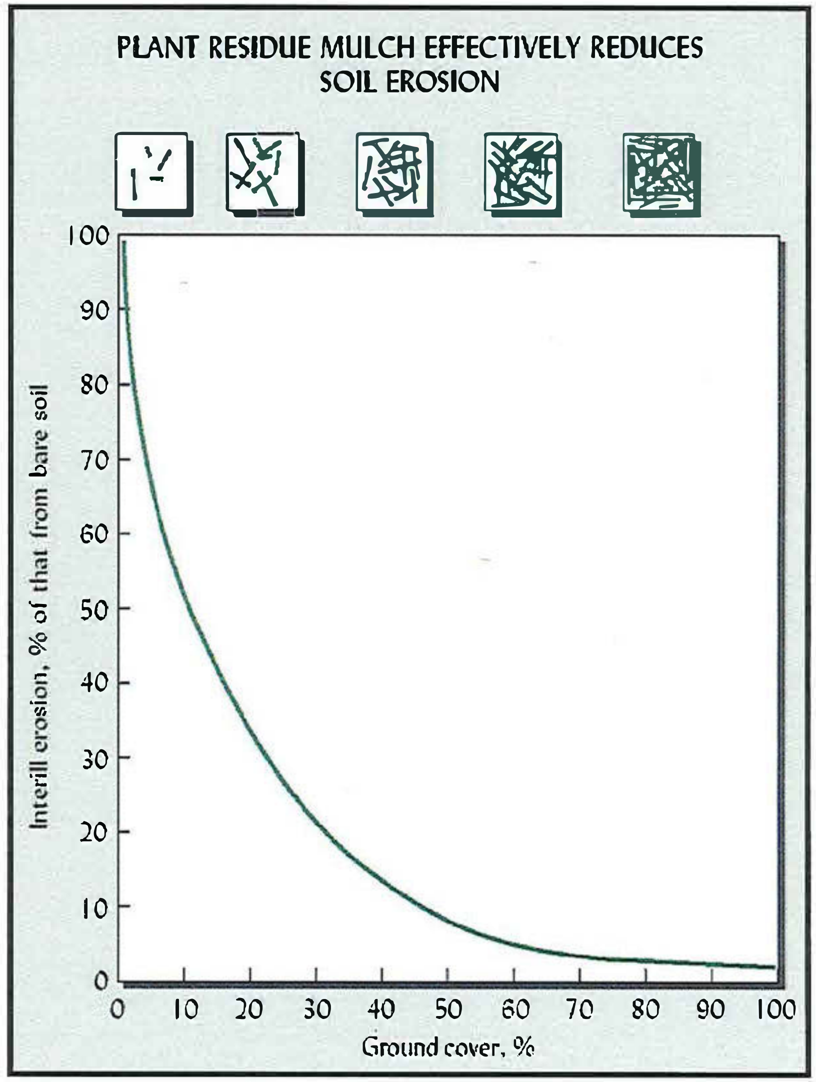
- Soil characteristics influencing infiltration and structural stability
  - Texture
    - Resistance to crusting
    - Silty soils are most susceptible
  - Type and amount of 2:1 clay minerals
    - Degree of shrinking and swelling tendency
  - Organic matter content
    - Increased OM results in increased structural stability

Factors Affecting Water Erosion

- Site characteristics
  - Topography (determines the L and S factors)
    - Steeper the slope, greater the erosion potential
      - More water will run off, higher speed of runoff water
    - Length of slope
      - Longer slopes allow more source for runoff water
  - Drainage
    - Terraces, waterways can change steepness and length of slope
      - Reduces velocity and source area of runoff water

Factors Affecting Water Erosion

- Cover and management (factor C)
  - Vegetative cover and cropping systems affect runoff and erosion
    - Undisturbed forest and dense grass provide best soil protection
    - Row crops offer least soil protection
    - Leaving residue from previous crop or planting a cover crop can reduce soil erosion



Contour strip cropping with grassed waterways

Factors Affecting Water Erosion

- Support practices (factor P)
  - Physical structures or other steps aimed at guiding and slowing the flow of runoff water
    - Vegetative barriers used to create terraces or waterways
    - Contour tillage
    - Constructed terraces or contour ridges
    - Strip cropping

  - Combinations of above practices to change steepness and length of slope and reduce velocity and source area for runoff water (influences the L and S factors)

Ridges constructed on contour must be of sufficient height to hold back water from heavy rain

Soil Erosion By Water

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Soil Conservation Service

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Department of
Agriculture

**Soil
Conservation
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Soil Erosion By Water

Foreword

Erosion is the wearing away of the soil by water, wind, and other forces. Soil erosion is at once the greatest threat to the Nation's soil productivity and the largest source of pollutants in our waterways.

Water causes about two-thirds of the erosion on our agricultural land. This booklet was written for anyone interested in knowing how water erosion happens and why we must get erosion under control.

Nearly all erosion control is the work of farmers, ranchers, and other land users who voluntarily conserve the soil. Why do they control erosion? They do so because they know that erosion control is an investment that safeguards the land's productivity and can boost profits . . . because erosion control cuts flood damage . . . and because it fosters clear streams and abundant wildlife.

To help land users control erosion, the Soil Conservation Service (SCS) of the U.S. Department of Agriculture offers technical assistance through local conservation districts. SCS also helps people solve many other natural resource problems on farms and in urban areas.

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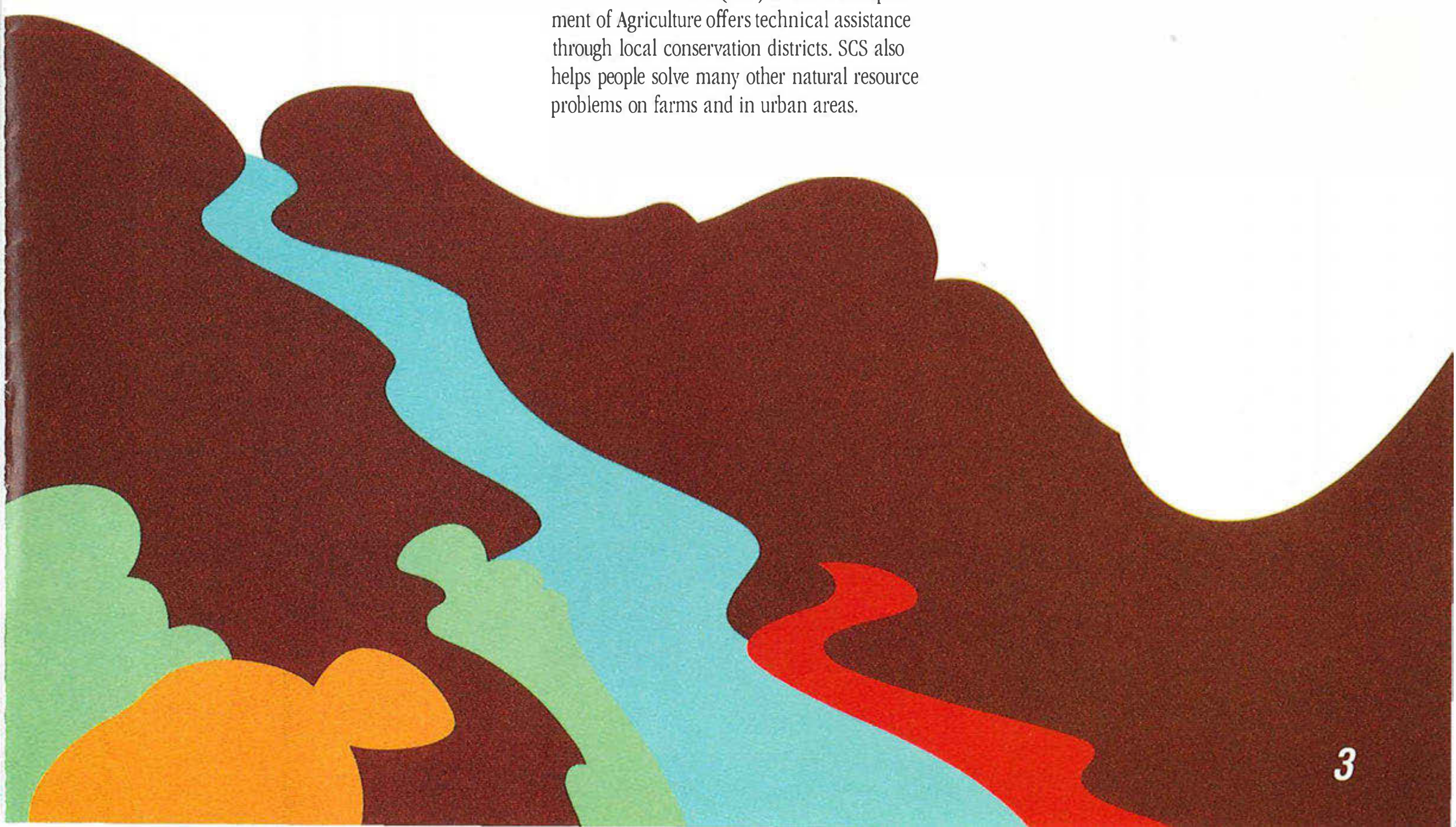


Why control erosion?

On and off the farm, the annual price tag for erosion damage in the United States is estimated to be in the billions of dollars. But the full cost of erosion is unknown. For example, there is no estimate of the effects of sediment and associated pollutants on human health.

On one-fourth of the Nation's cropland, soil erosion by water exceeds the rate considered to be allowable. On this land, soil productivity cannot be economically sustained unless erosion is reduced.

Figure 1. *Onfarm damage from erosion.*

Erosion increases the cost of farming. This increase contributes to lower profits for farmers and higher food prices for consumers. Onfarm damage from erosion includes lower yields of crops or forage, higher fertilizer requirements, more difficult tillage, and higher bills for farm maintenance (fig. 1).

Sediment from eroding areas clogs rivers and decreases reservoir capacity, thereby restricting navigation, reducing recreation and scenic value, and increasing the hazard and severity of flooding.

Sediment, along with accompanying plant nutrients and pesticides, can destroy fish and wildlife habitat and pollute water supplies.

You help pay the bill for erosion damage. But do you feel its effects directly? Not usually, especially if you live in an urban area. Out in farm country, however, ask a farmer about that abandoned, gullied field: "Did erosion do that?" Ask the rancher who over a lifetime has seen lush grassland reduced to scrub and gullies by overgrazing that allowed excessive erosion. Ask the fisherman who no longer bothers to toss a line into a lake now choked by algae and mud. Ask the public official who uses tax dollars to remove sediment from road ditches, to dredge sediment from rivers and reservoirs, and to remove harmful chemicals from the water supply.

Ask these and other people about the damage erosion can cause . . . and then ask yourself whether you should make erosion control *your* business.

How erosion became a national problem

Our soil erosion problems began in colonial times. Erosion on colonial farms was often severe because farmers did not adapt European farming methods to the different climate in North America. In England, for example, much of the rain falls as relatively low-intensity or small raindrops during long storms. But in North America, most rain falls as large drops in intense storms.

Another reason for erosion was economics. Rather than invest in their soil by rotating crops and adding manure, many farmers grew the same cash crop every year until the soil was depleted of nutrients and organic matter. Then they farmed somewhere else. After all, land was cheap and plentiful.

The development of farm tractors began in the early 1900's, enabling a farmer to produce crops on many more acres in much less time.

Later, during the 1930's, economic depression left millions of Americans unemployed. Many banks, factories, and other businesses failed. Thousands of farmers went broke because of scarce credit, poor markets, recurring drought – and severe erosion.

Across the Dust Bowl, an area that centers on the Oklahoma Panhandle, soil eroded by strong winds repeatedly blackened the sky. In the Midwest and Southeast, decades of poor management had led to severe erosion damage on millions of acres of farmland.

Erosion had become a major threat to the recovery of the Nation's economy. In this atmosphere of crisis, the Congress in 1933 established the Soil Erosion Service, which in turn established demonstration projects to show farmers how to control soil erosion. In 1935, Congress transferred the agency to the United States Department of Agriculture (USDA), renamed it the Soil Conservation Service, and increased its duties to include technical help to farmers. Erosion control had become a public as well as private responsibility.

Figure 2. *A very old and stable landscape.*

"When our fore-Fathers settled here . . . the Land being new they depended upon the Natural Fertility of the Ground . . . and when they had worn out one piece they cleared another. . . ." (fig. 2)

–Jared Eliot, Connecticut minister, doctor, and farmer, 1748

Because farmers needed local help in planning and applying conservation, soil conservation districts were formed. By the late 1940's, nearly every acre of privately owned land in the Nation was part of a conservation district. These districts are local units of State government and have primary responsibility for local conservation programs. Districts provide help directly to land users, and they are the main conduit for conservation assistance from State and Federal government.

USDA provides most of this assistance; an increasing amount of help is being given by State and local governments.

Much of the technology for conservation help was developed in SCS or resulted from research by land grant universities and USDA's Agricultural Research Service. Some conservation work is eligible for cost-sharing by USDA's Agricultural Stabilization and Conservation Service. And SCS also works closely with USDA's Forest Service, the Bureau of Land Management in the Department of the Interior, the U.S. Environmental Protection Agency, and other Federal, State, and local agencies.

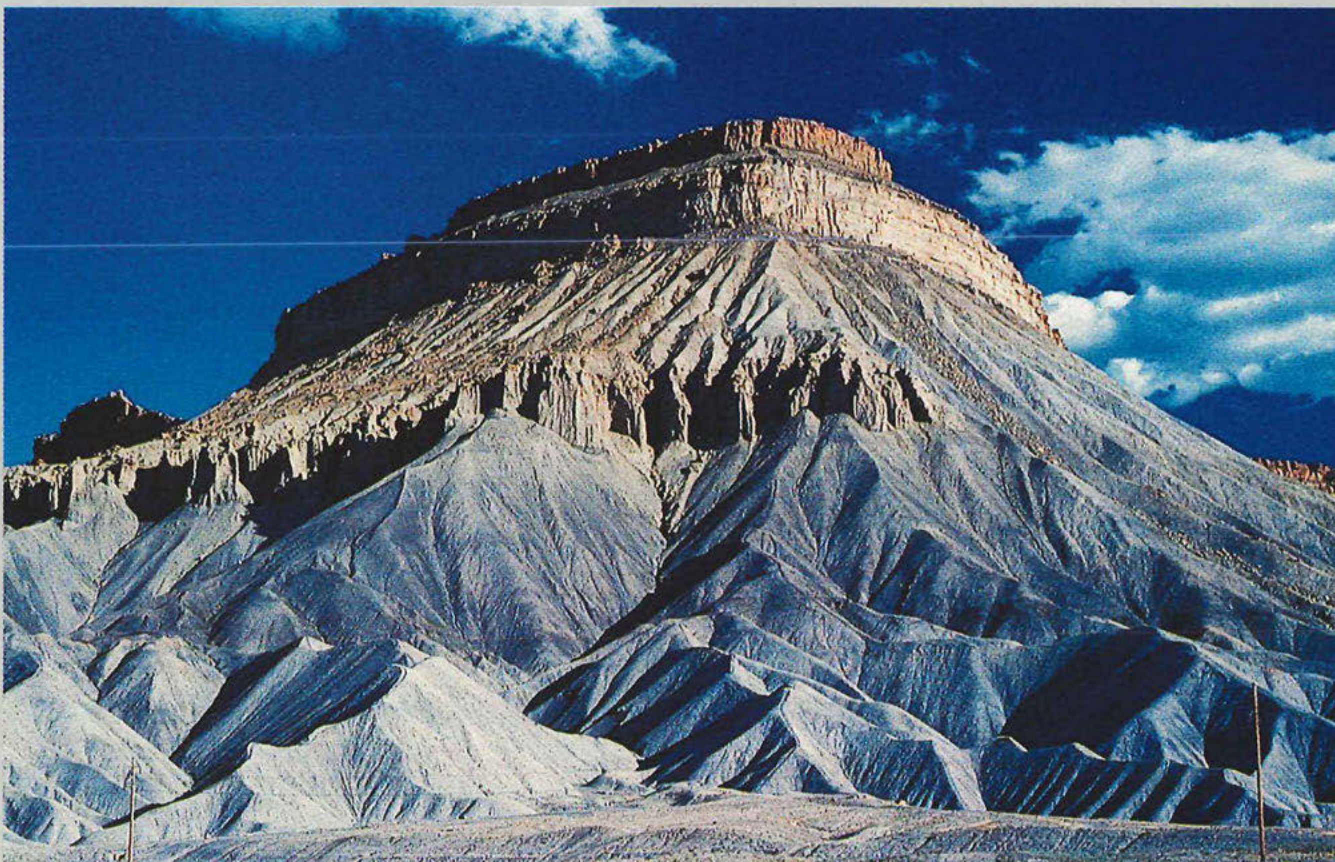


Figure 3. *An example of geologic erosion.*

Geologic erosion

Geologic erosion is the wearing away of the Earth's surface by the forces of water and wind. It occurs in an environment largely unaffected by the activities of people. Geologic erosion usually occurs very slowly.

For example, in humid climates that support forests or grasslands, vegetation holds the soil in place. New soil forms continuously, offsetting all or part of the slow geologic erosion.

In arid climates such as the Southwest, the plant cover is thin and fragile in many areas. Over thousands of years, erosion by rare but torrential storms has left behind towering mesas, sheer canyons, and natural stone sculptures (fig. 3).

Geologic erosion can also occur as landslides. Landslides generally result from inherent geologic instability, but they can be triggered – and their consequences made worse – by drilling, digging, or farming in areas of unstable soils.

Accelerated erosion

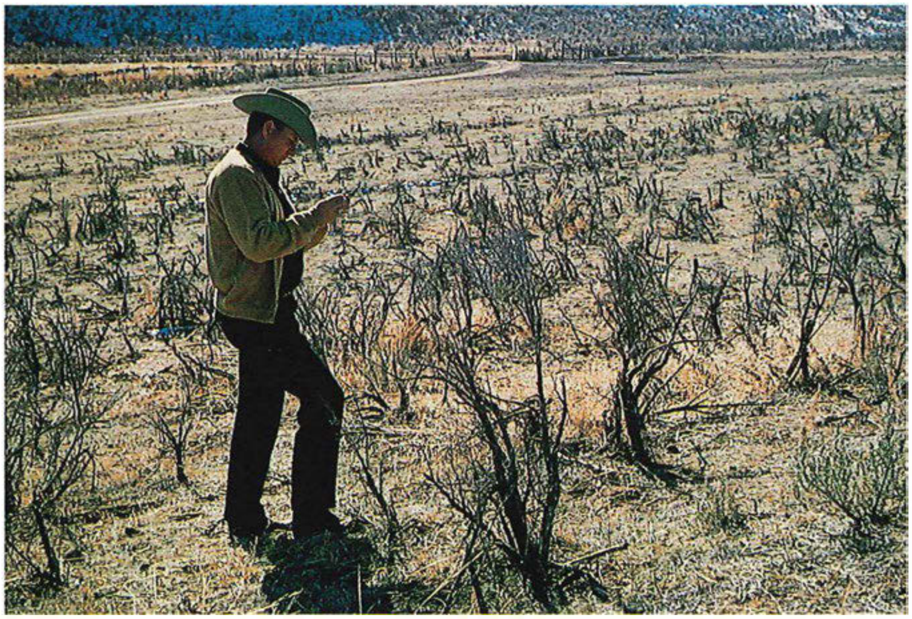


Figure 4. *The effect of overgrazing.*

Figure 5. *Poorly managed woodland.*

Without geologic erosion the Earth would be a far different place in which to live. River valleys, for example, are fertile because of eons of **geologic erosion** (see box, p. 6) from the highlands. And many marine fisheries depend on nutrient-rich sediments entering the ocean at the mouths of rivers. But farming and other activities can endanger these and other resources by speeding erosion far past its natural geologic rate.

Erosion that results from humans disturbing the soil is **accelerated erosion.** For example, when farmers clear native woodland or meadow to grow cultivated crops, soil is exposed to the erosive forces of water and wind.

When livestock repeatedly overgraze range and pasture, soil productivity eventually decreases (fig. 4). Less desirable plant species replace the more palatable, nutritive species preferred by foraging animals. With less protection from the plant cover, the soil is more readily washed away.

Figure 6. *An example of bench leveling to prevent erosion in an urban area.*

When a forest is stripped of its trees, when logging roads and skid trails are poorly designed or located, or when harvested trees aren't replaced with saplings, sediment from increased erosion pollutes streams and erosion delays the recovery of the forest (fig. 5).

When land is bulldozed for urban development and runoff and erosion are not controlled, sediment and flooding can damage property and pollute waterways (fig. 6).

Major types of erosion by water

In **splash erosion,** raindrops break the bonds between soil particles and splash them a short distance (fig. 7). These particles are then much more vulnerable to erosion by water flowing over the surface.

When rain falls faster than the soil can absorb it, water begins to collect and flow over the ground surface. **Sheet erosion** can begin when this surface water begins to carry along particles that were detached by raindrops.

Surface flow soon establishes paths. If the soil is unprotected, some of these paths become rills, small eroding channels. In **rill erosion,** water flowing through rills readily detaches soil from their sides and bottoms (fig. 8). As it moves further downslope, flow in rills becomes more erosive, causing the rills to enlarge and join with others.

The topography of many landscapes is such that water tends to collect in a few major waterways before leaving the fields. **Concentrated-flow erosion** is erosion by water flowing in channels that may range from a large rill to a small gully. Rills are erased by tillage, but channels eroded by concentrated flow tend to reform in the same location each year. If allowed to continue, erosion by concentrated flow can form a gully.

Gully erosion is difficult to control. In a gully, soil is rapidly removed by water gushing over the "headcut" (the uphill end) of the gully, water scouring the gully's bottom, and water removing soil material that has slumped from the gully's sidewalls. The slope at the headcut is nearly vertical, causing the runoff flowing over it to be highly erosive so that the gully advances upslope (fig. 9).

In any given place, the processes of splash, sheet, rill, concentrated-flow, and gully erosion may all be active and account for considerable soil loss. Or erosion may be chiefly by only one or two of these processes.

Mass erosion or **slumping** occurs where a hillside becomes so saturated by water that large areas of soil slide or creep downhill. Gullies can form rapidly in these slide areas.

Figure 7. *Splash erosion.*

Figure 8. *Rill erosion.*

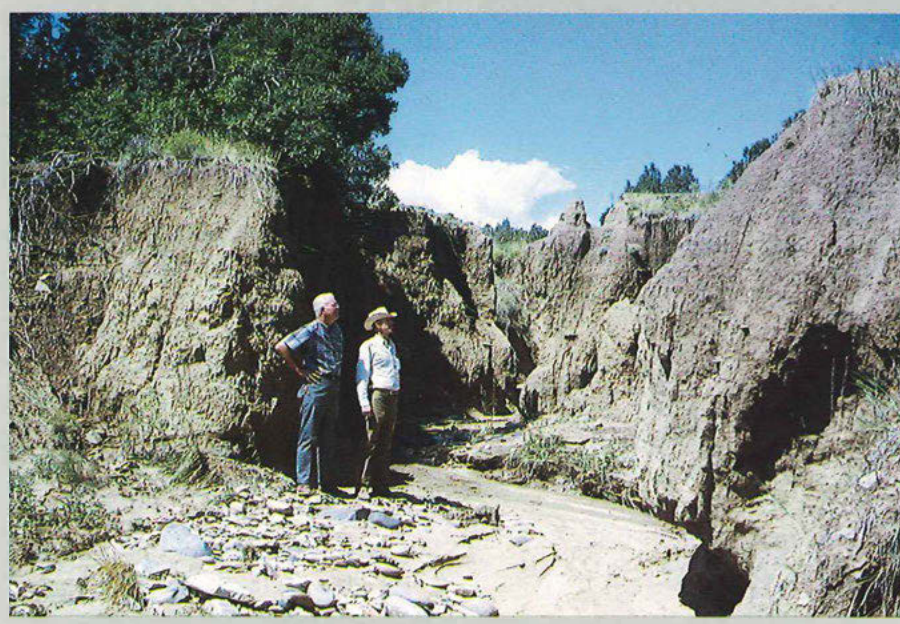


Figure 9. *Gully erosion.*

How water erodes soil

All types of erosion by water (see box, p. 8) occur in a three-part process. First, the erosive force of raindrops or flowing water breaks the natural physical and chemical bonds between soil particles. Then, surface flow carries particles downslope. Where the erosive energy of the water decreases – for example, at the bottom of a hill – some particles are deposited as sediment.

Erosive water may begin as raindrops, as surface runoff from rainstorms or melting snow, or as water from an irrigation system. Erosive water also includes the flow in a natural or artificial channel or water that saturates a steep hillside and erodes it through mass slumping.

Most soil movement on farmland occurs through a combination of sheet and rill erosion caused mainly by rainfall and its associated surface runoff.

Water erosion may move tons of soil per acre during one storm, or it may move less than a ton per acre over several decades. The surface runoff may carry particles only a few feet downslope, or it may carry them thousands of miles to the ocean. Erosion rates depend mainly on the characteristics of three interacting factors:

1. The erosive potential of rainstorms,
2. The protection provided by ground cover, and
3. The resistance of the soil to erosion.

The forces and energy that cause erosion are in impacting waterdrops from rainfall and sprinkle irrigation, and in runoff water from rainfall, snowmelt, and irrigation. Plant canopy and ground cover reduce these forces and the erosivity of the water. Soil properties determine the resistance of soil particles to the erosive energy that remains.

The aims of erosion-control practices are to reduce erosive energy or increase the soil's resistance, or both. This is simple in theory, but erosion at any given site may be affected by more than a dozen major interacting characteristics that affect erosivity, ground cover, and soil resistance. The major relationships must be known before erosion control can be planned.

Rainfall

In general, rainfall is most erosive when the most intensive rains coincide with the time when the soil is bare and its resistance to erosion is lowest.

> "[O]ne of the surest causes of washing [is] the almost perpetual recurrence of ploughed crops, either corn or cotton, by the clean tillage of which the land is kept always in the condition the best adapted to its being washed off by rains."
>
> *– Edmund Ruffin, Virginia farmer and pioneer conservationist, 1843*

East of the Rocky Mountains, this period usually is spring and early summer, when most fields have been recently tilled; the fields have not yet been planted or the crop cover is just beginning to develop. In much of the Northwest, especially where the land is left bare over the winter, the critical period is late winter and early spring. At this time, the rains often fall on thawing soil that is easily eroded. In most of the Southwest, heavy storms are infrequent but often very erosive. In the Far West the rainy season is generally November through February, when land may be bare after the previous fall harvest. In Hawaii and in U.S. possessions in the Caribbean area, rainfall can be much more erosive than on the North American mainland. Maximum precipitation occurs from October to May in Hawaii, and in May and September in the Caribbean area.

Major characteristics that determine the erosive potential of rainstorms include size and velocity of the raindrops and, most importantly, the frequency, intensity, and duration of storms. Other conditions being equal, erosion is greater with large drops than with small ones, with a storm accompanied by wind than a storm in still air, and with a 1-inch storm lasting 24 hours than a 1-inch storm lasting 1 hour.

The erosive characteristics of irrigation water depend on the type of irrigation system and the rate and amount of water application. Irrigation by open furrows or channels is generally more erosive than sprinkler, drip, or subsurface irrigation systems.

Ground cover

Living plants, plant residue, and bits of rock on the surface of the soil intercept falling raindrops and absorb some erosive energy before the drops reach the soil. This ground cover also slows the flow of water across the surface and increases the rate at which water soaks into the soil. Good management of plant residue reduces the area of bare soil and the time when it is bare. The effectiveness of ground cover depends on many factors:

- The percentage of the soil area covered by rock, living plants, or residue;
- The density and height of the plant canopy;
- The capacity of the plants to intercept water through leaves, stems, and roots;
- The extent to which the soil beneath the plant canopy is exposed to the surface flow of water;
- The amount of plant residue – decaying leaves, stalks, and other plant litter – on the soil surface;
- The stage of plant growth; and
- The cropping sequence.

Ground cover is, then, the first line of defense against erosion by water. As a practical matter, however, it is impossible to eliminate all erosive energy before it strikes the soil. The second line of defense is to increase the soil's resistance to erosion.

Soil formation

Every soil has a history that affects its vulnerability to erosion. Soil forms through weathering and other processes that act on "parent material" – bedrock or other geologic material. Climate affects the rate of weathering, rates of geologic erosion and deposition of parent material, soil water content, and soil temperature. Relief – the configuration of the land surface – affects slope and drainage patterns on the landscape. Organisms – plants, animals, and micro-organisms – affect soil development chiefly by mixing soil material and adding organic matter. Over time – hundreds, thousands, even millions of years – climate, relief, and organisms form unique soils from the raw parent material.

Nearly all soils develop a series of different layers. In most undisturbed soils, the major layers are called the **surface** or **topsoil,** the **subsoil,** and the **underlying** or **parent material** (fig. 10). The content of organic matter is almost always highest in the surface layer, very low in the subsoil, and nearly absent below that.

By measuring the properties of each soil layer and by observing how various soils respond to use and management and to laboratory tests, researchers can estimate a soil's erodibility.

Figure 10. *A soil profile.*

Soil

Conservation planners need a thorough understanding of the soils at a site before they can develop a conservation plan. Four properties, mainly, determine a soil's erodibility:

- Texture,
- Slope,
- Structure, and
- Organic matter content.

Of the four, **texture** is generally the most important. It refers to the proportions of particles of sand, silt, and clay in a soil. Water moves detached clay particles more readily than particles of silt or sand, but clay particle bonds are generally stronger than those of silt and sand, so soils with a high content of clay may be quite resistant to erosion. More closely related to erodibility is the content of silt and sand – that is, particles with a diameter between 0.004 and 0.00008 of an inch. Texture is one inherent property of soil that is impractical to change.

Slope, like texture, is a "given" on the natural landscape. As slope steepness increases, so does the erosivity of runoff. The runoff then exerts more force on soil particles, breaking their bonds more readily and carrying them farther before deposition.

The longer water flows along a slope before reaching a major waterway, the greater is the potential for erosion.

In an undisturbed landscape, each major layer of most soils develops a unique, fairly stable **soil structure.** Soil particles are clustered in aggregates held together by physical and chemical bonds. The aggregates in turn form clumps called peds. Peds of a given undisturbed soil have a consistent appearance and size range, but intensive use of a soil can alter the natural soil structure (fig. 11).

Shape, size, and arrangement of aggregates determine the pathways of infiltrating water and the volume of air space between aggregates. The more air space a soil has, the more room it has for infiltrating water. Reduced infiltration capacity is often the major reason for declining yield on an eroding soil. In turn, reduced infiltration leads to more runoff – and more erosion.

Land use practices can strengthen or weaken aggregate bonds and can increase or decrease the size of the aggregates. Strong bonds and large aggregates provide more resistance to erosion than weak bonds and small aggregates.

Excessive tillage tends to break down peds and aggregates, lowering the erosion resistance of soil particles and the volume of air space in the soil. In most soils, structure can be improved by reducing the frequency and depth of tillage, avoiding tillage when the soil is wet, and increasing the soil's content of organic matter.

Organic matter is the decomposed remains of plants and animals. Plentiful organic matter helps soil fertility, water infiltration and storage, and soil structure. Increasing the content of organic matter is a principal means of improving soils that have been damaged by erosion; it is a very slow process.

Figure 11. *A ped.*

When European colonists cleared southeastern forests to grow crops, yields were high at first because of the large amounts of plant nutrients supplied by organic matter in the soil. In many areas, cotton, tobacco, or other cash crops were grown year after year without intervals of soil-building crops such as alfalfa. As a result, erosion increased, nutrients and organic matter became depleted, yields decreased, and crop failure became more likely, until abandonment of the land was the only remaining option.

Today, continuous row crops can contribute to soil erosion and nutrient depletion unless adequate management practices are used, including a crop rotation that restores organic matter.

Crops can be grown in soils that are low in organic matter. Generally, however, tillage is more difficult and expensive, more fertilizer is needed, and yields are lower.

Erosion and soil productivity

Researchers, conservationists, and farmers know that erosion can rob the soil of its productivity. But they also know that erosion does not simply penalize yield by some fixed number of bushels per ton of soil loss.

A rule of thumb is that 1 inch of topsoil takes about 30 years to form from subsoil material. Subsoil forms from the parent material even more slowly. Since 1 inch of soil from 1 acre weighs about 150 tons, many conservationists believe that erosion should be held at or below 5 tons per acre per year on most deep soils. At this rate, it would take 33 years to lose that 1 inch of soil; therefore, soil is being formed nearly as fast as it is lost.

Over the years, the Soil Conservation Service has established **soil loss tolerance** (T) levels. These T levels indicate the maximum average annual erosion rate consistent with sustaining the soil's long-term productivity and with avoiding such problems as severe rilling, gullying, and nutrient losses.

For many years, SCS erosion-control planning with land users has focused on the goal of reducing average annual erosion to T. The T level, however, does not consider other damage from erosion, such as water pollution from sediment and associated nutrients and pesticides.

In some parts of the country, loss of productivity caused by erosion is easy to see – in stunted crops, low yields, bare spots, crops buried by mud, and gullies chewing into productive fields. But measuring the actual damage on specific soils can be very difficult. Besides erosion, crop yields are affected by many other physical, chemical, climatic, management, and soil factors.

Many questions have to be answered to obtain a meaningful estimate of erosion's effect on the productivity of a particular field, including the following:

- Can the farmer afford the cost of replacing losses of organic matter and of the major nutrients nitrogen, phosphorus, and potassium?
- Does the crop need other nutrients such as zinc, which are lost with eroded soil?
- Does plentiful and frequent rainfall offset the eroded soil's loss of water-holding capacity, or does arid climate make this problem even worse?
- Is the depth to bedrock only 24 inches – or more than 200 inches?
- Does the subsoil resemble the topsoil except for having a lower percentage of organic matter? Or is the subsoil more clayey or acid than the topsoil?
- Is the farmer growing continuous cotton, corn, or soybeans – or using a crop rotation that includes 1 or more years of soil-building cover crops?
- In a field with both eroded and uneroded areas, is the farmer overfertilizing the uneroded areas as a result of trying to maintain production in the eroded areas?

In recent years, conservationists have developed computer programs or models of the erosion process and its effects. These models account for the interaction of many time- and space-dependent factors that affect erosion or crop production.

An example of such models is EPIC (Erosion-Productivity Impact Calculator), which was developed by the scientists in USDA's Agricultural Research Service with help from universities and SCS conservationists. EPIC incorporates data on soils, hydrology, weather, crops, and management activities such as tillage and fertilization. The model can estimate erosion rates and the change in crop yield over time in response to erosion. Results from EPIC and other models can be used to estimate the cost of erosion and to help farmers improve their management of the land.

However we estimate the cost of erosion for productivity, we are left with the knowledge that technology has not developed a large-scale replacement for soil as a medium for growing crops.

Lost productivity

Erosion damage to soil productivity takes many forms. Some of the most common are the following:

- With the loss of topsoil, the soil has a lower capacity to hold and store water for use by plants. The soil is more vulnerable to drought.
- Erosion results in the loss of organic matter and of plant nutrients that are already present in the soil or are applied in chemical fertilizers. Some nutrients are lost because they are attached to eroded soil particles; water-soluble nutrients are lost in surface runoff.
- Uncontrolled runoff and deposits of sediment can damage the seedbed and seedlings.
- In many soils, layers with unfavorable properties are brought nearer to the surface and eventually exposed as the topsoil erodes. Such properties can include low organic matter content, high clay content, reduced availability of phosphorus, and root-limiting layers or bedrock.
- Erosion tends to make a field more variable, with rilled, gullied, and other eroded areas alternating with uneroded areas and areas where eroded soil has been deposited. One typical result is that some areas get too much fertilizer while others don't get enough.
- Gullied areas are not only useless for crop production or grazing but also can make the entire field unusable or extremely difficult to farm with modern-day equipment.

Offsite damage from water erosion

Figure 12a. *A natural stream.*

Runoff from the land carries sediment, fertilizers, and pesticides into streams, lakes, and other bodies of water (figs. 12a and b). The full damage caused by these pollutants is unknown, and much of the damage cannot be expressed in dollars. Evidence suggests, however, that the off-farm damage caused by water erosion exceeds the onfarm damage to soil productivity and farming operations. Research by the Conservation Foundation[1] estimates that sediment and related pollutants may cause $6 billion in damage each year. Of this, cropland-related pollutants are held responsible for more than $2 billion.

Figure 12b. *A damaged stream.*

[1] Estimates are from *Eroding Soils: The Off-Farm Impacts* (1985, Edwin H. Clark II, Jennifer A. Haverkamp, and William Chapman, The Conservation Foundation: Washington, DC, 252 p.).

Some of the sediment carried from farm fields is deposited in nearby drainage or irrigation ditches (figs. 13a and b). As a result, the ditches must be cleaned out more frequently. Farther away, sediment deposits build up in rivers and harbors, causing difficulties for navigation. Millions of tax dollars are spent every year to dredge these deposits.

When sediment enters streams and reservoirs, it reduces their capacity to hold flood flows. As a result, flooding is more likely and the damage it causes will be worse.

The cost of building and maintaining reservoirs and dams is increased because of the need to store sediment from erosion occurring upstream in the watersheds feeding the reservoirs.

Sediment can destroy fish spawning areas. Nutrients entering waterways with the sediment contribute to algae growth that can block sunlight, endangering aquatic plants and the organisms dependent on them. When the algae die and decay, they consume dissolved oxygen, threatening fish and other aquatic organisms. Algae also clog the filters that treatment plants use to remove contaminants from water (fig. 14).

Long-term accumulations of sediment, nutrients, and pesticides have damaged vital marine resources such as the Chesapeake Bay.

Erosion and associated chemical pollutants in the runoff stimulate weed growth and siltation that affect use of the Nation's waters for boating, fishing, and swimming. They can also make water unfit for drinking, adding millions of dollars annually to the cost of water treatment.

Figure 13a. *An example of sediment damage.*

Figure 13b. *An example of protection against sediment.*

"The clear stream, not as yet choked by the earth washed from cultivated high land, and rarely obstructed, flowed in a deep and meandering channel [through the bottom lands] * * * When the neighboring higher lands . . . were cleared and cultivated and their soil and even the sub-soil in many cases were washing down with every heavy rain, then commenced the ruin of both the natural beauty of the bottoms and much of their available value for cultivation."

— Edmund Ruffin, 1855

Figure 14. *Eutrophication.*

Erosion control — whose job is it?

Most erosion problems can be economically solved by using proven technology and methods that are available today.

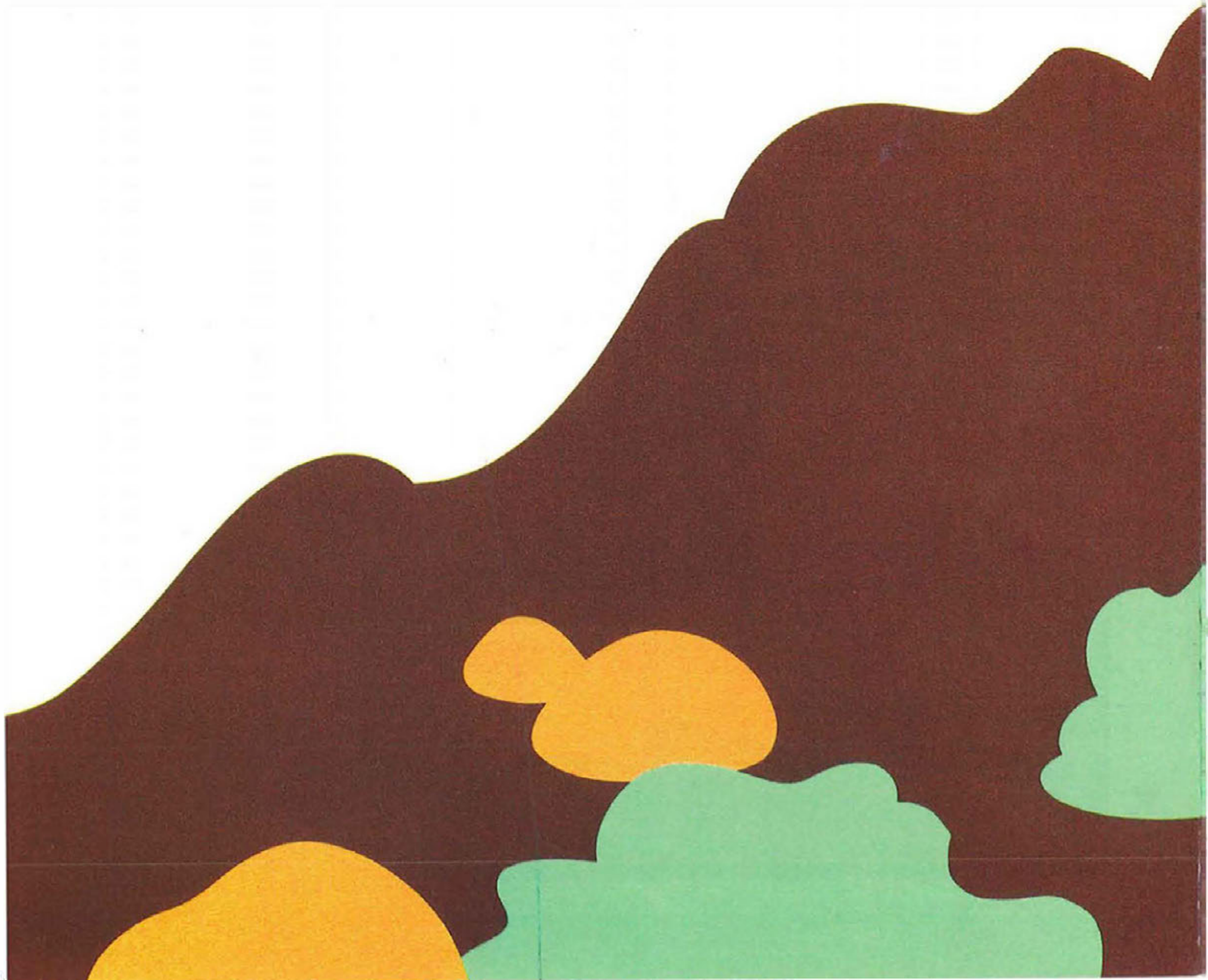
If you are a farmer or rancher, contact the conservation district or local SCS office to find out whether you have an erosion problem and to get direct technical help and, in some instances, financial help in solving erosion and other conservation problems on your land (fig. 15).

Is there an erosion or other natural-resource problem in your rural or urban community? Contact the conservation district or SCS for information on what is being done about it and on how you can help (fig. 16). SCS offices are listed in municipal telephone directories under "United States Government, Department of Agriculture, Soil Conservation Service."

All programs and assistance of the Soil Conservation Service are available without regard to race, color, religion, sex, age, marital status, handicap, or national origin.

Figure 15. *A district conservationist helping a farmer.*

Figure 16. *Environmental education at work.*

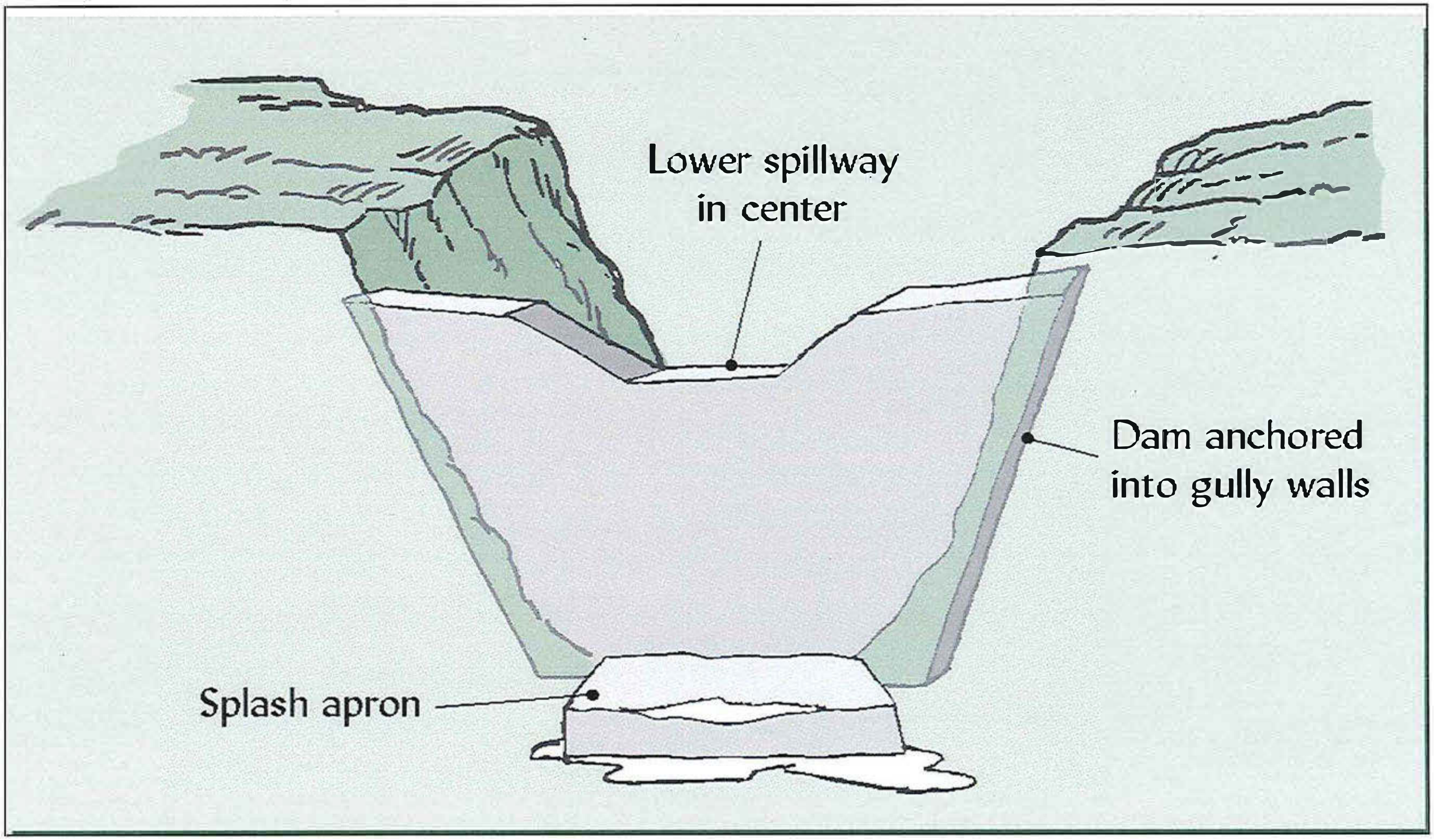


Controlling Water Erosion

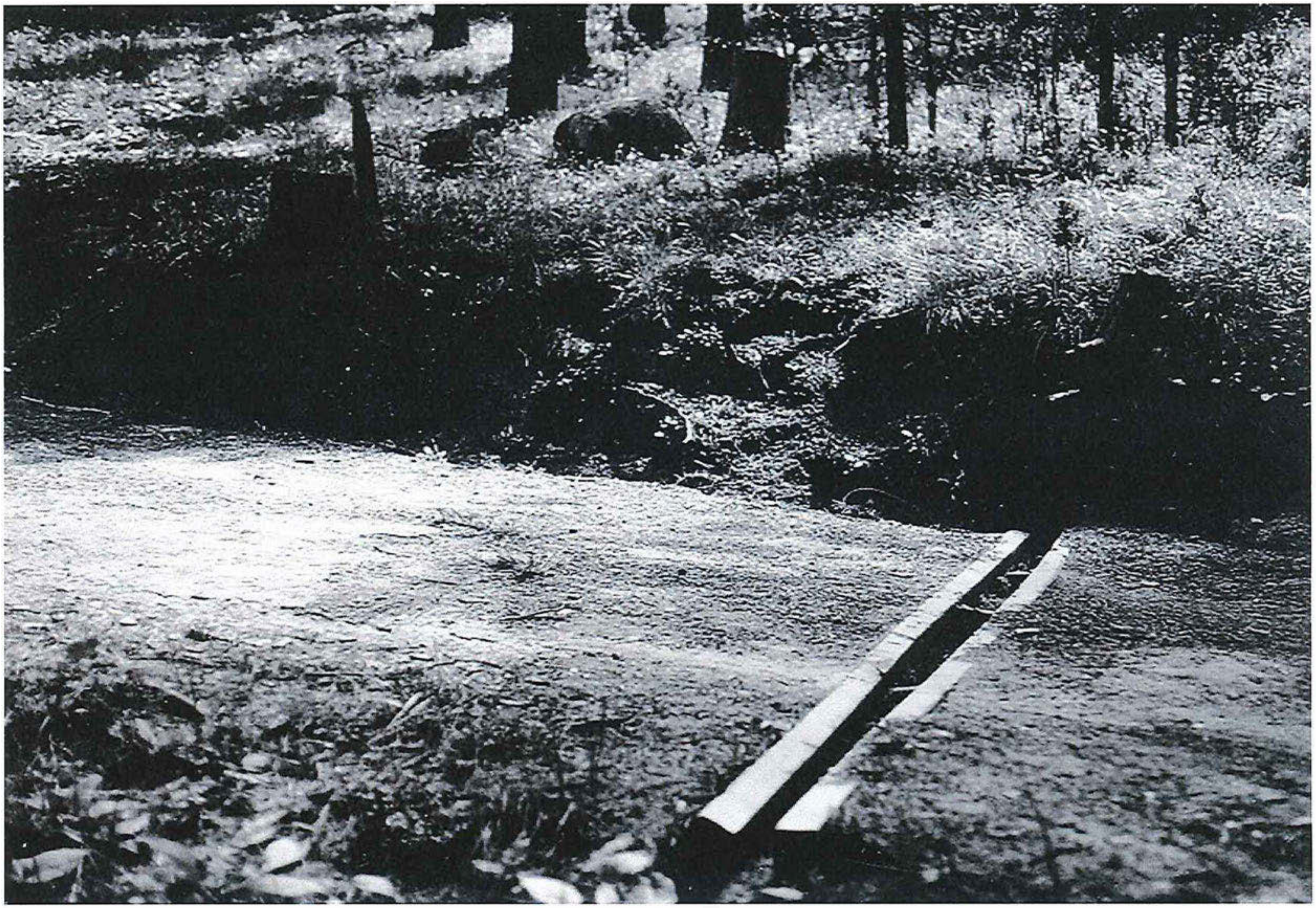
- Encourage maximum infiltration of precipitation
  - Provide vegetative cover and management structures to reduce velocity of runoff water
    - Terracing, strip cropping, good ground cover crops
- Keep sediment load in runoff low
  - Management practices used to reduce velocity and volume of runoff water
- Direct concentrated runoff into waterways or channels where it can be controlled

Erosion Control Structures and Practices

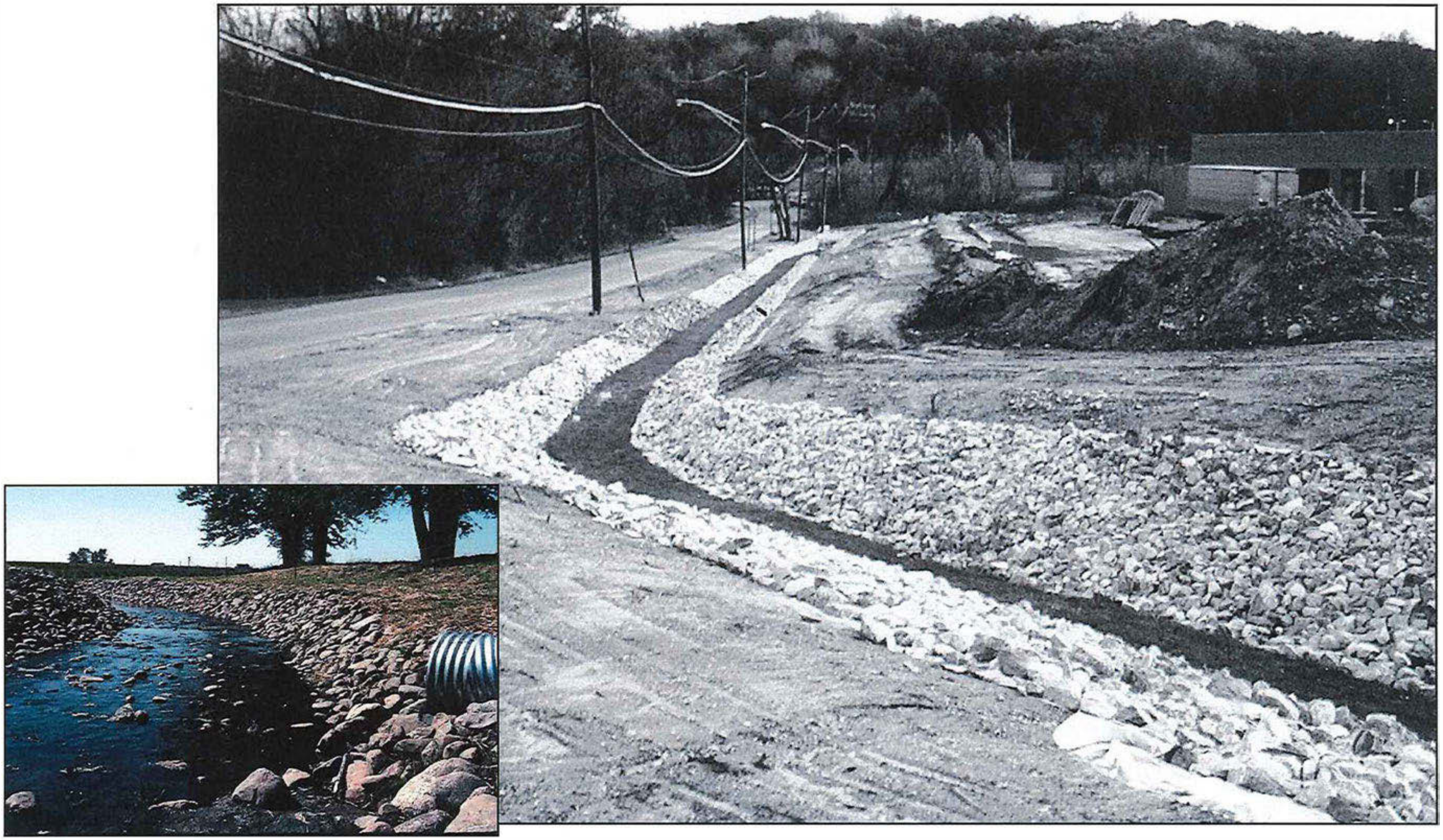
A check dam slows gully erosion by reducing slope length and slowing velocity of runoff water



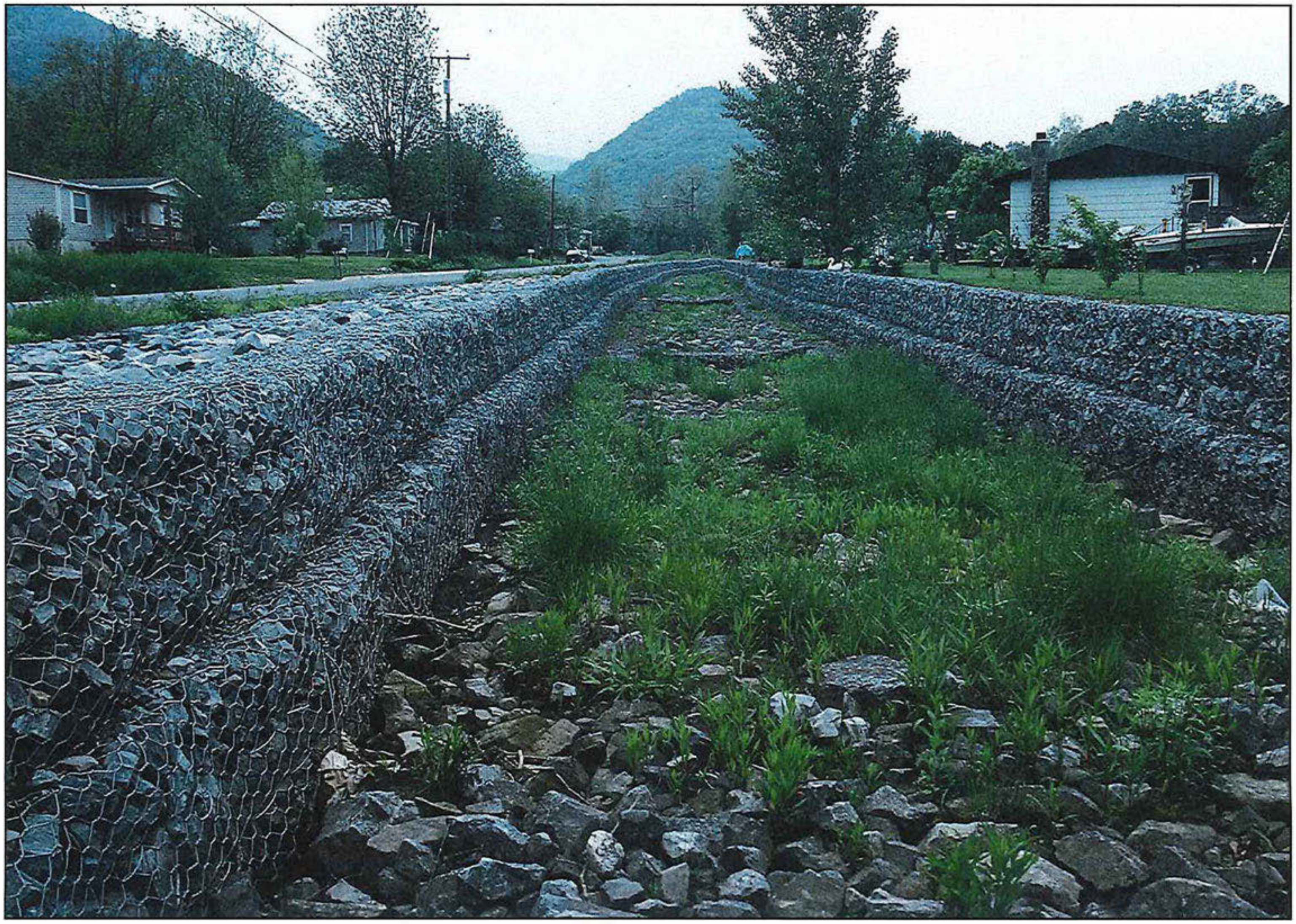
Open-top culvert on a logging road designed to lead runoff water off the road

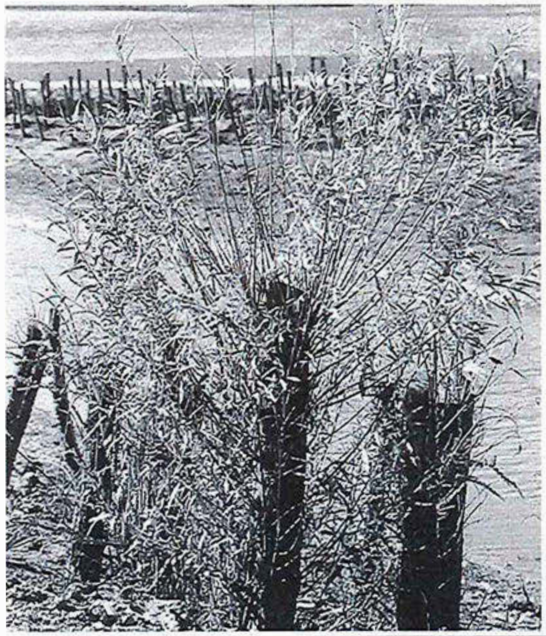


Grass-lined channel bottom with riprap (rock) sides to prevent gully erosion, reduce soil loss and direct runoff



Gabions form artificial channel bank. Use of large rocks in channel bottom slows water velocity as do the check dams visible in photo





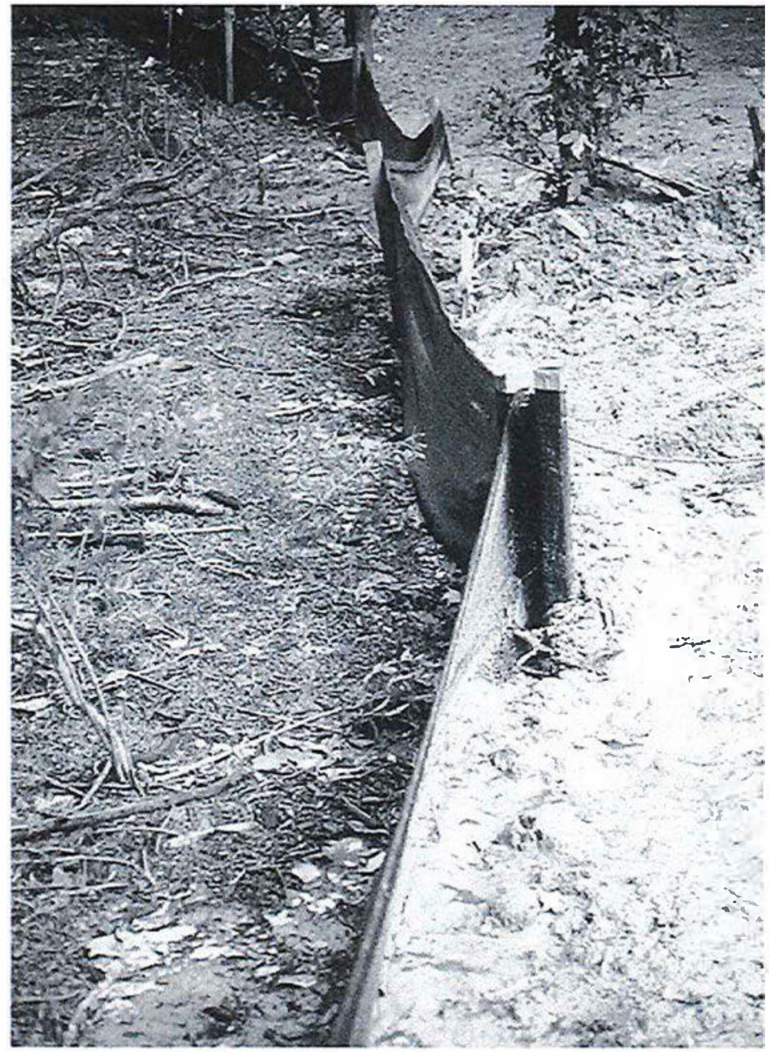
Bioengineering ("live stake technique") to stabilize a stream bank from eroding utilizing live willow branches pounded into soil

Deflection bars used to prevent stream bank erosion. Water velocity is dramatically slowed on outside curves where erosion is greatest.

Trash rack protecting culvert from plugging by debris.

Straw bales filter sediment and reduce flow velocity of water

Silt fence will remove sediment from runoff water



Another use for a silt fence: catching sediment at the upper part of the slope after a burn. Has been effective at controlling erosion in conjunction with seeding with grass.

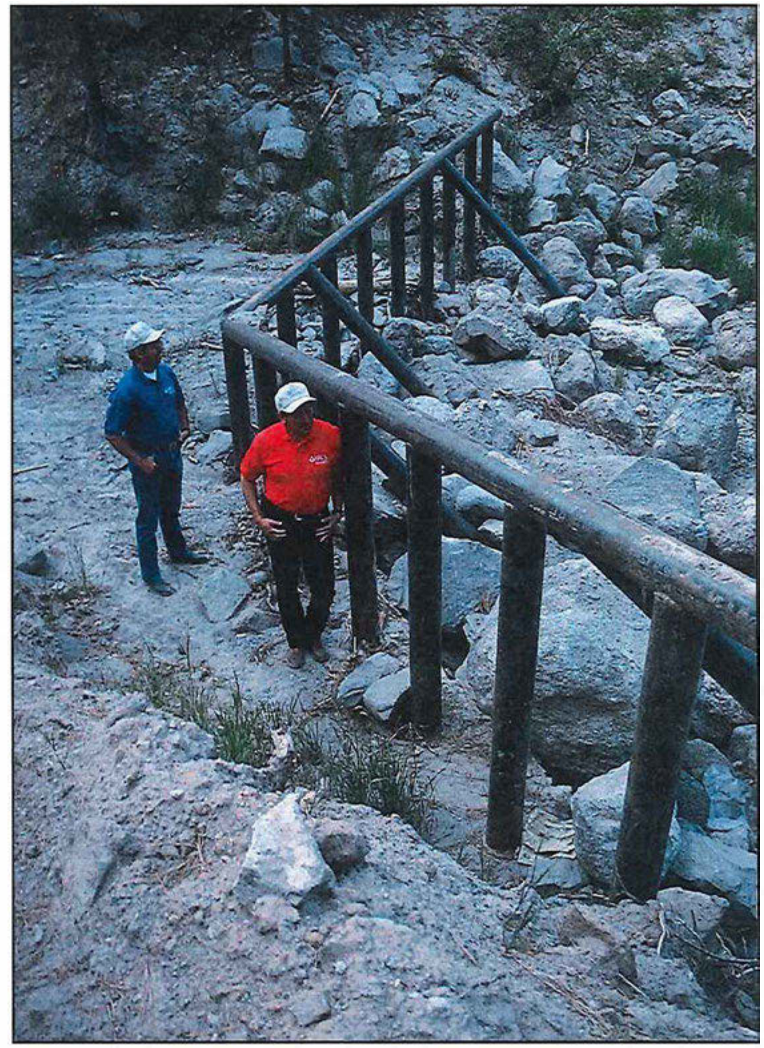
Retention and sedimentation ponds constructed at lowest elevation of a site collect excess runoff and sediment load

Straw wattles used to break up slope length and steepness. Water velocity is slowed and sediment is trapped quickly.

Reseeding burned or cleared areas with quick-growing grass to prevent erosion

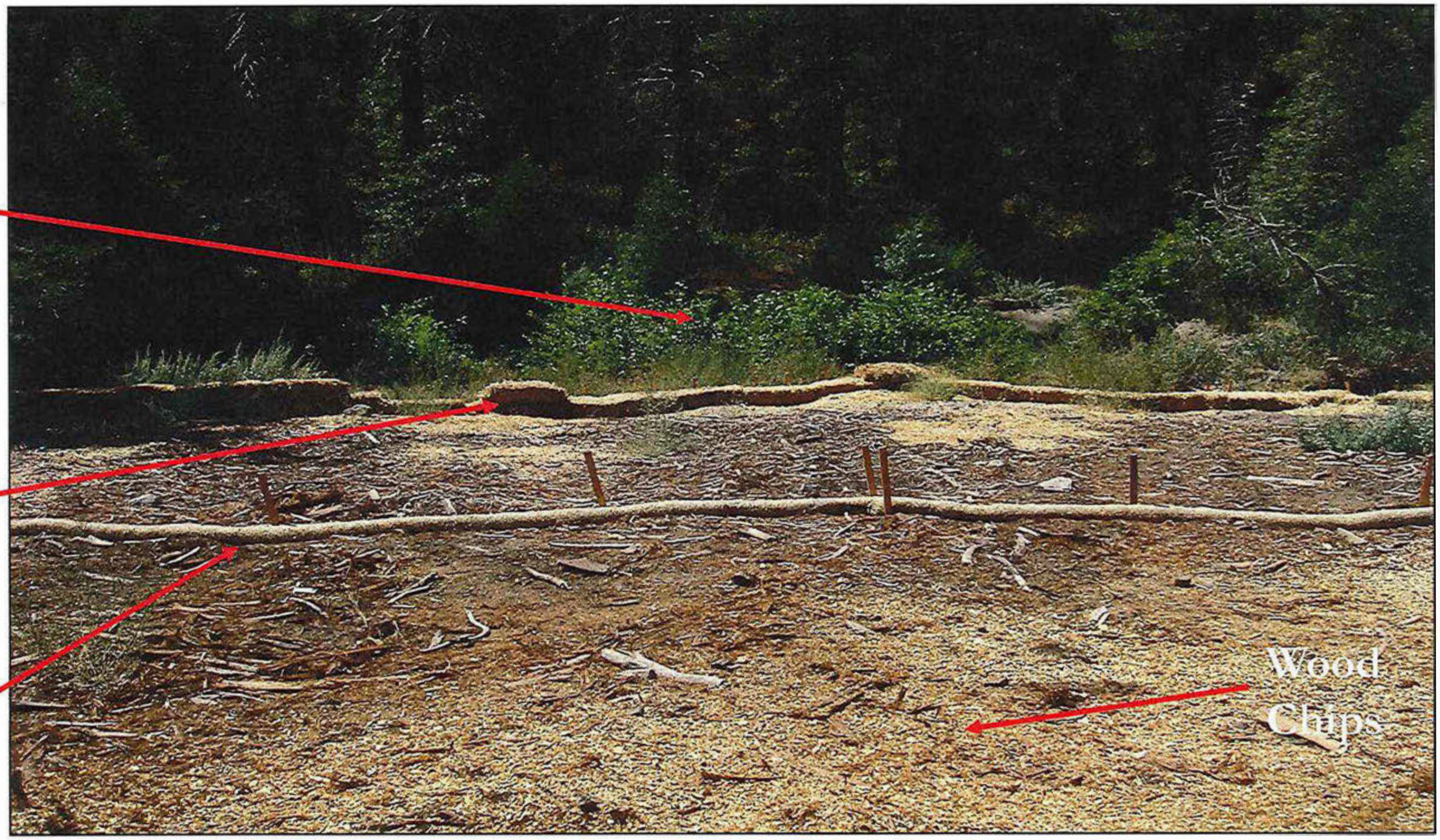
Rip-rap armoring the contact point between slope and stream bed to prevent erosion and possible slope failure by cutting action of water.

Rock catcher anchored in stream bed keeps large debris upslope



Straw matting used to stabilize stream bank used as crossing by vehicles

Straw matting: straw blanket enclosed in a plastic netting. Will not wash away as wood chips might in a water course.



Landing site where logging helicopter dropped logs and heavy equipment moved and processed the logs. Notice the use of several measures to protect the creek from sediment influx. Straw wattles and straw bales keep sediment from moving into the creek while wood chips applied to the site break up raindrop impact.

Jute netting is effective on steeper slopes when specific areas need to be protected. Disperses force of raindrop impact, protects the soil from moving.

Rolling Dip

A rolling dip crossing an access road. This water diversion structure is a wide trench that goes across a road at about a 20 degree angle with a low angle of entry and exit to allow easy vehicle passage.

Water bar and a layer of wood chips on a skid trail.

A water bar is a water diversion structure for a road that is more difficult to cross by vehicles. The CDF definition of a water bar is a trench 6 inches wide by 6 inches deep with a berm of dirt 6 inches high on the downhill side. The trench goes across the road at about a 20 degree angle.

Slash packing uses small diameter brush and trees packed down by heavy equipment in place of wood chips to control erosion.

Wind Erosion

- Most common in arid and semi-arid regions
  - Deserts
  - Dry weather phenomenon, stimulated by moisture deficiency
  - Crops blown away, covered by soil, or left with roots exposed
  - In TX, CO, MT, NM wind erosion causes more damage ($) than water erosion
  - Wind damage may be as great at site of deposition as at site of removal

Plant covered by blowing sand

Sand accumulation along fence line

Wind Erosion

- Wind erosion can occur in humid areas
  - **Sand dune movement on beaches**
  - **Sandy soils under cultivation**
  - **High organic matter soils under cultivation**
    - Drying and cultivation produces a fine, highly erodible surface layer

Processes of Wind Erosion

- Detachment of particles
  - The lifting and abrasive action of wind dislodges soil particles from clods
  - As more particles picked up, abrasive power is increased
    - More particles become detached
- Transportation of particles
    - Several methods of transportation

Processes of Wind Erosion

- Transport of detached soil particles
  - Saltation: 50-70% of movement
    - Medium-sized particles bounce along soil surface striking and dislodging other particles
      - Particles remain close to ground, too heavy to be windborne
  - Soil creep: 5-25% of movement
    - Rolling along of particles by wind along soil surface
  - Suspension: ~15% of movement
    - Particles of fine sand size and smaller are carried in air

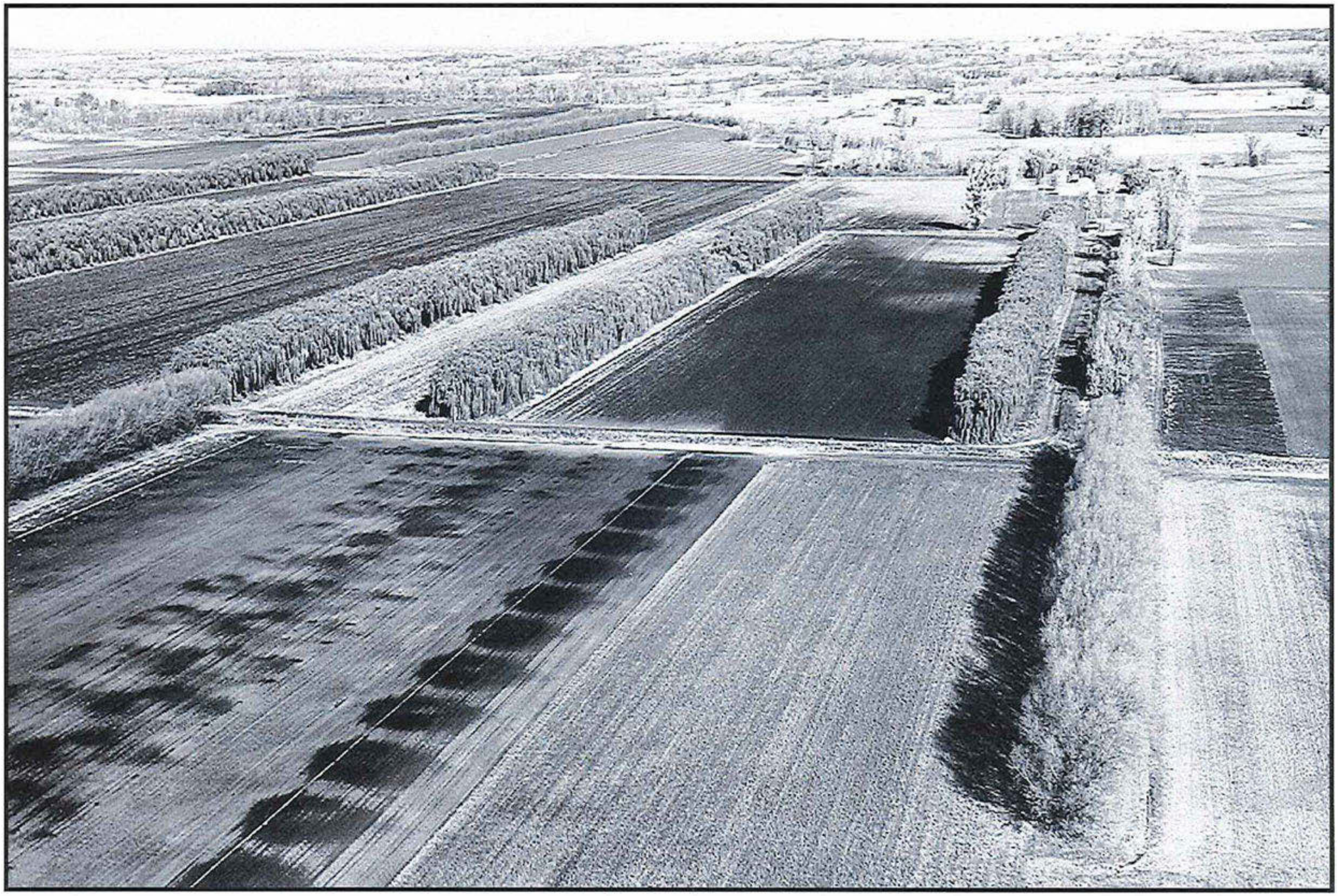
Factors Affecting Wind Erosion

- Condition of soil surface
  - Roughness is desirable
    - Leave clods, stubble on surface
- Wind intensity
  - Increased soil movement proportional to increased wind velocity
- Length of unimpeded path
  - Increased soil movement proportional to length of unimpeded path

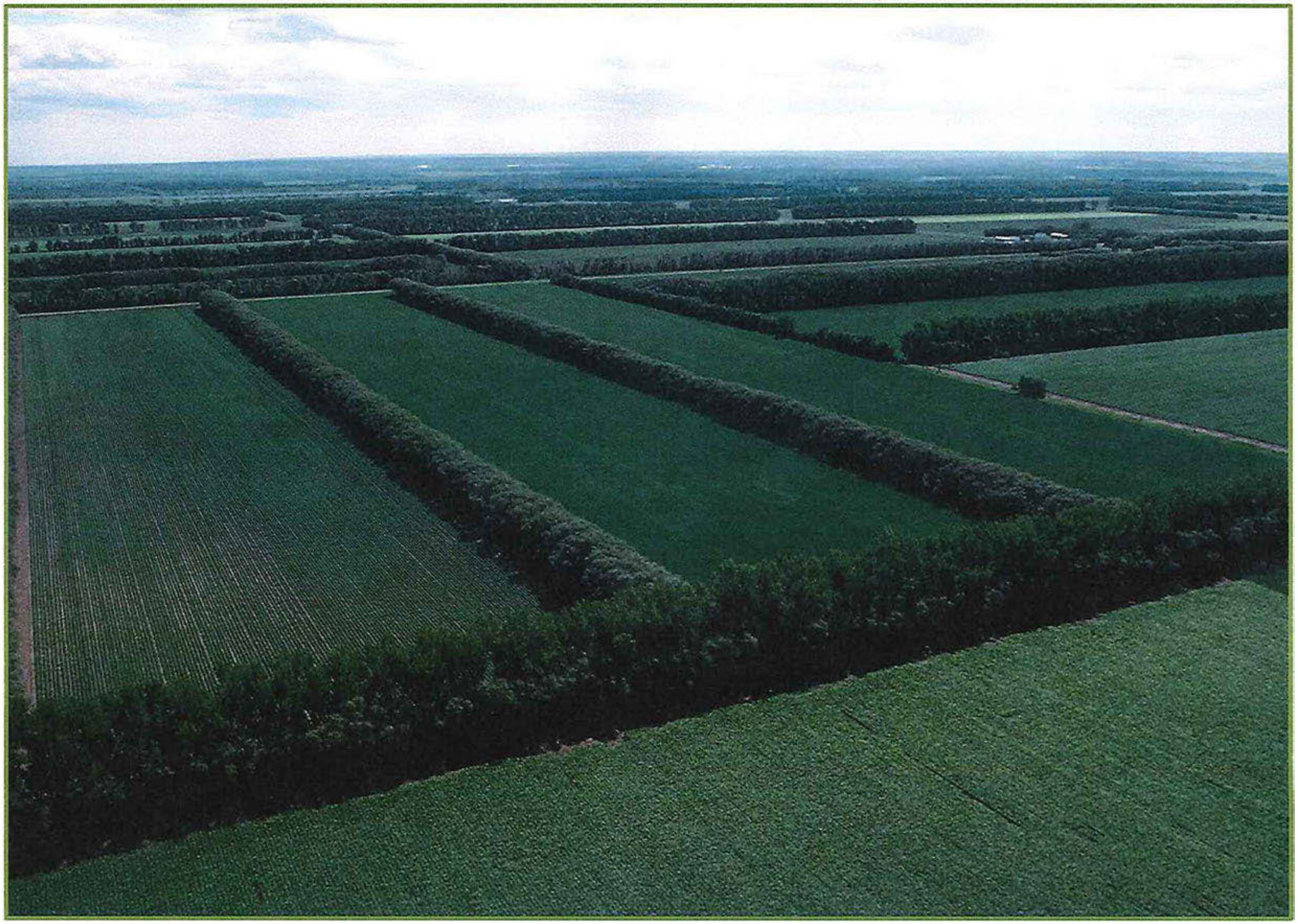
Managing Wind Erosion

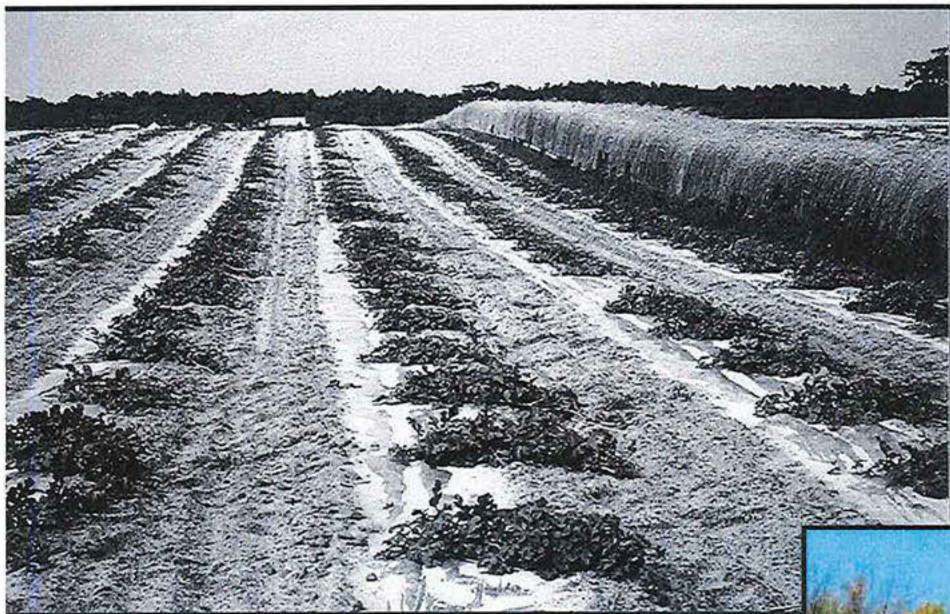
- Soil moisture
    - Increasing moisture increases the velocity of wind necessary to detach particles
- Tillage
    - Tillage practices which leave large clods and vegetative residue are desirable
        - Timing important, need moisture in the soil to form clods
- Barriers
    - Shelter belts, windbreaks, certain grass species, fences planted perpendicular to prevailing wind direction to reduce wind velocity and trap particles.

Rows of trees planted perpendicular to wind direction to slow wind velocity and reduce erosion potential

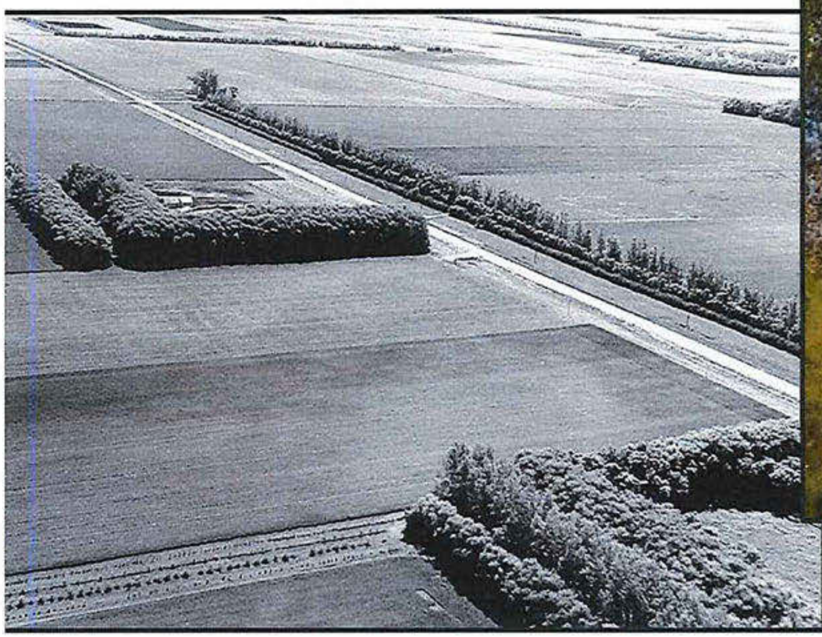


Windbreaks Protecting Fields



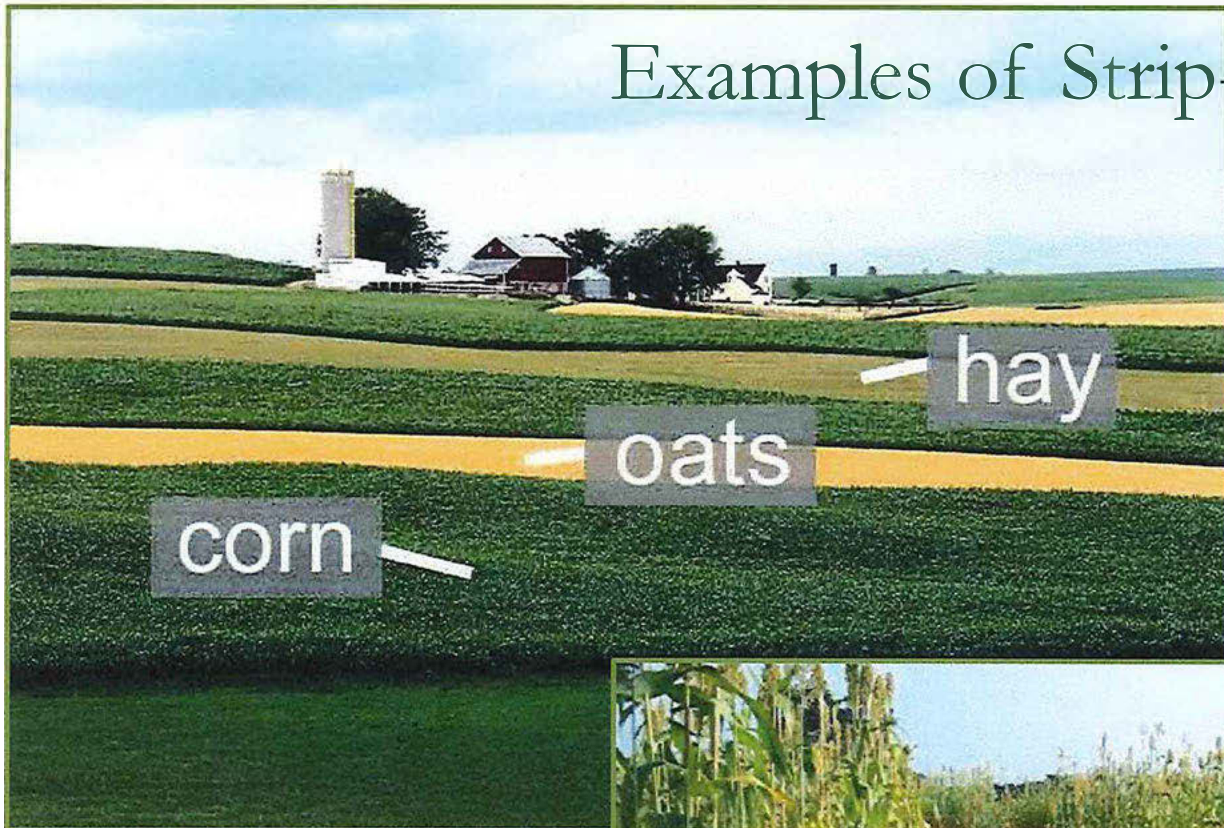


Strips of rye grass act as miniature windbreaks for watermelon crop



Shrubs and trees acting as windbreaks

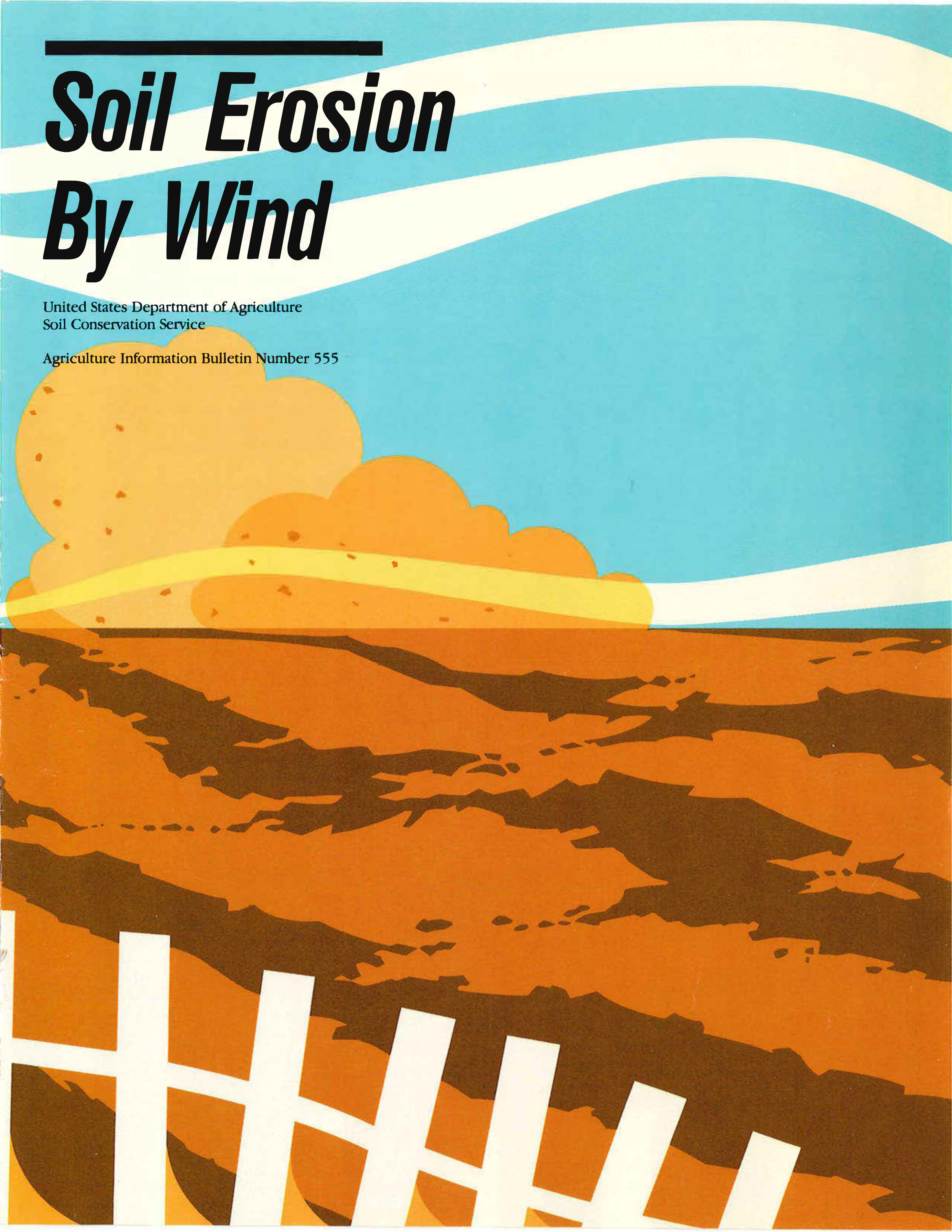
Examples of Strip-cropping



Soil Erosion By Wind

United States Department of Agriculture
Soil Conservation Service

Agriculture Information Bulletin Number 555



United States
Department of
Agriculture

Soil
Conservation
Service

Preface

Accelerated soil erosion by wind is the most dramatic form of soil erosion. It was the dust storms of the 1930's that focused national attention on the problem of soil erosion.

Today, soil erosion by wind is quite visible and commands public attention. Lost topsoil decreases the land's productivity. In addition, dust in the air can cause automobile accidents, kill young agricultural crops, and damage public facilities such as roads.

April 1989

Soil Erosion By Wind

This bulletin details the scope of erosion by wind in the United States, describes the conditions that allow erosion, and shows how hundreds of thousands of landowners and land users are controlling erosion by wind.

As serious as soil erosion by wind is, more than twice as much topsoil is eroded in the United States by water. For information on erosion by water, ask your local office of the U.S. Department of Agriculture's Soil Conservation Service for the companion brochure "Soil Erosion By Water" (Agriculture Information Bulletin Number 513).

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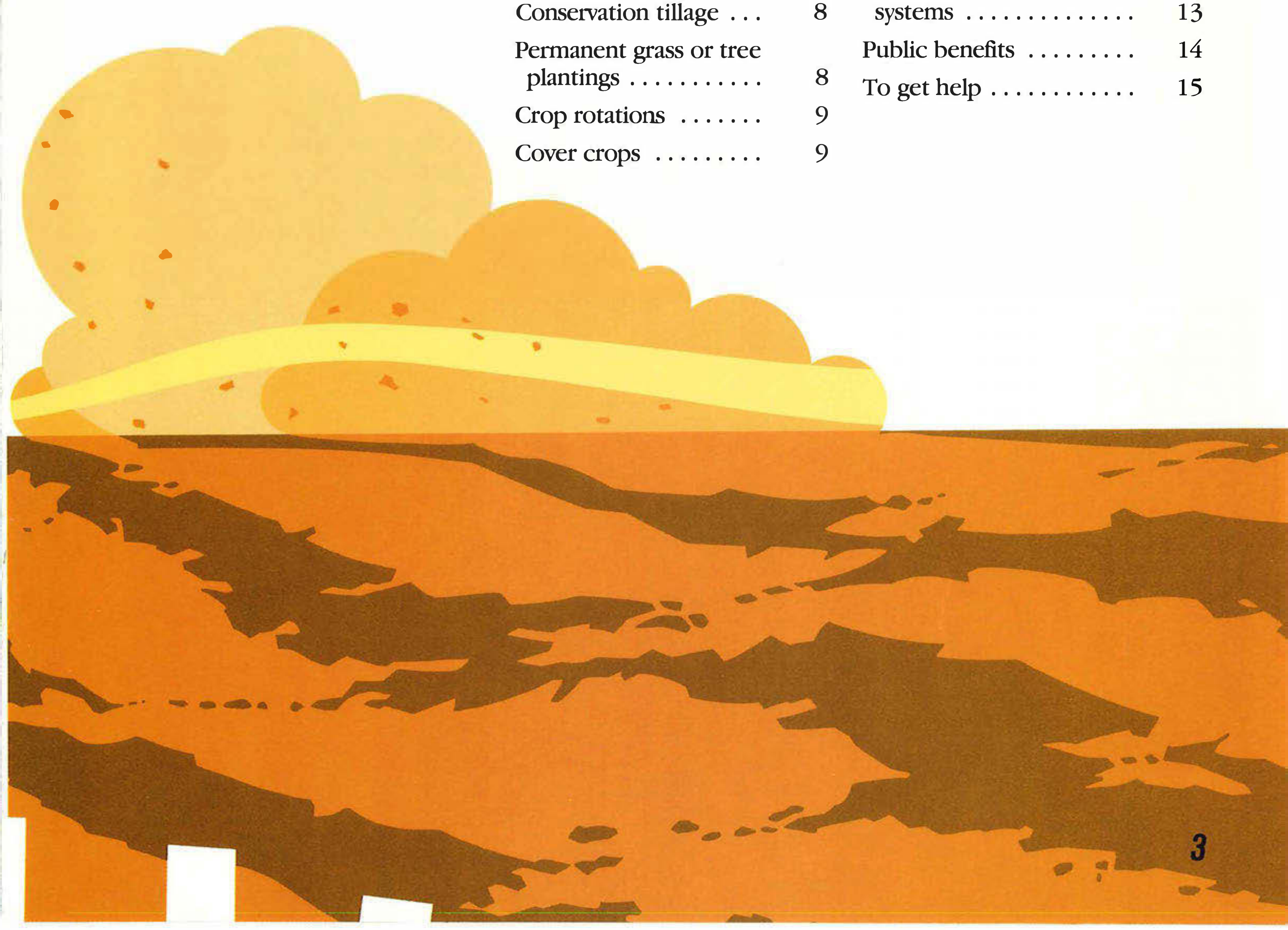


The Dust Bowl

Tragically, at the time the United States was experiencing the Great Depression, several years of severe drought struck the Great Plains States. Without moisture, grasses and plants that normally held the soil in place withered and died. Both the Southern Plains area, centered around the Oklahoma Panhandle, and the time period became known as the Dust Bowl (fig. 1).

Left unprotected, the topsoil was lifted by strong winds thousands of feet into the air. Blowing soil was everywhere on those hot, dry days of the 1930's. "Black blizzards," as they were called, would blind people as a snowstorm would. Fences, farm machinery, railroad lines, and buildings were left mired in great dunes of windblown soil (fig. 2).

The widespread damage caused by dust storms brought national attention to the problem of soil erosion and led to the establishment of a national agency with erosion control responsibility in 1935. The Soil Conservation Service (SCS), the technical soil conservation agency in the U.S. Department of Agriculture (USDA), now has about 3,000 local offices across the country.

Figure 1. *A dust cloud approaches a small town in Oklahoma.*

"This particular dust storm blotted out the sun over the Nation's capital . . . I suspect that when people along the seaboard of the Eastern United States began to taste fresh soil from the plains 2,000 miles away, many of them realized for the first time that somewhere something had gone wrong with the land."

—Hugh Hammond Bennett on the May 12, 1934, dust storm

Extent of erosion by wind

Few regions of the United States are entirely safe from wind erosion. Wherever the soil surface is loose and dry, vegetation sparse or absent, and the wind sufficiently strong, soil erosion will occur unless control measures are applied. Erosion by wind in the United States is generally most severe in the Great Plains. Other major regions affected are the Columbia River plains, some parts of the Southwest and the Colorado Basin, the muck and sandy areas of the Great Lakes region, and the sands of the Gulf, Pacific, and Atlantic seaboards (fig. 3).

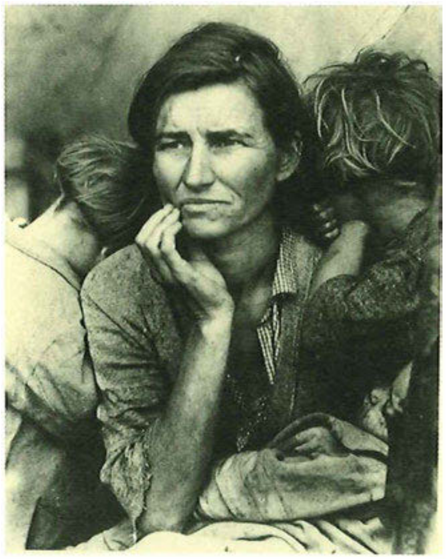


Figure 2. *The Dust Bowl and drought devastated some farm families in the early 1930's.*

In some areas, the main problem caused by wind erosion is crop damage. Some crops, including many vegetables and specialty crops, are especially vulnerable to damage by blowing soil. Even low rates of wind erosion may cause short-term economic loss in areas where these crops are grown.

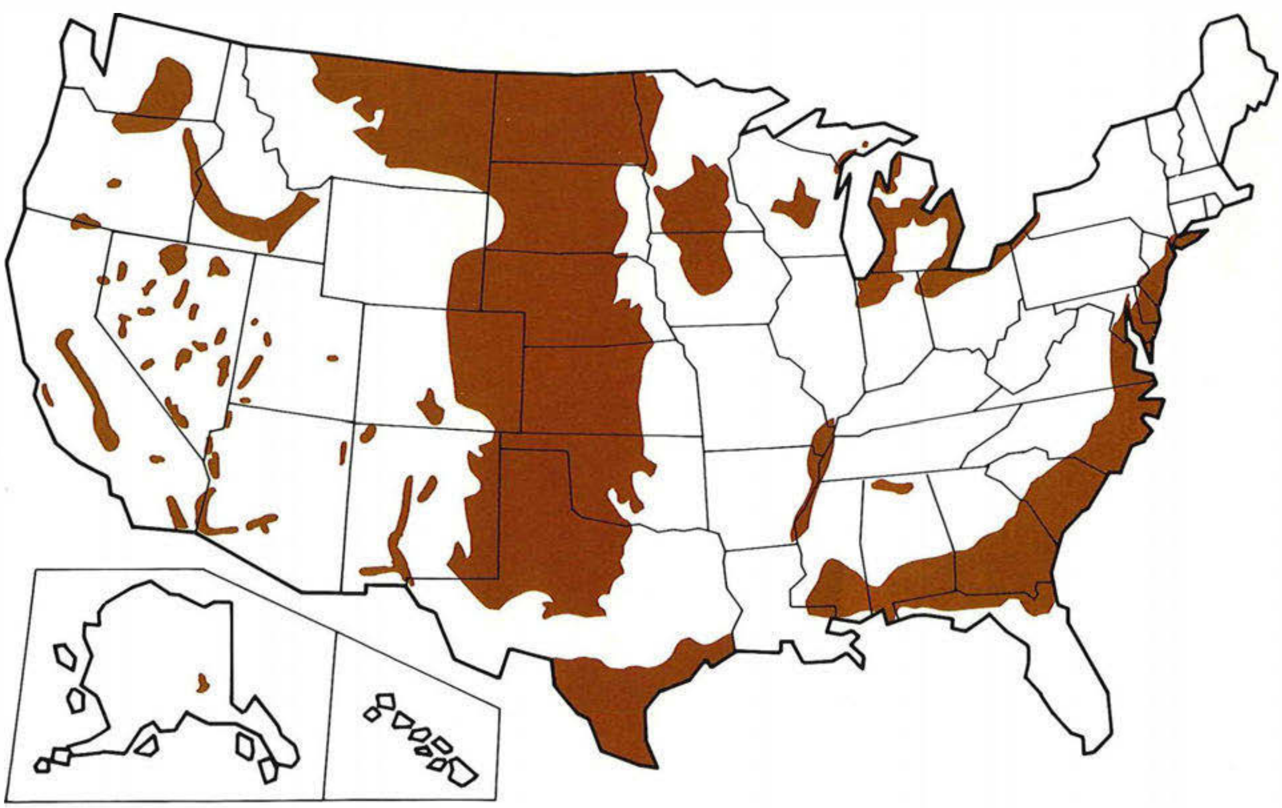


Figure 3. *This map shows cropland areas of the United States that have the highest potential for wind erosion.*

How wind erodes the soil

Understanding how wind moves soil helps in deciding how to reduce erosion (fig. 4). For instance, the dust high in the air is what most people notice. While this "dirty air" contains particles of the most valuable portions of the topsoil—organic matter and clay—it also contains only a small percentage of the soil moved by wind erosion. Most of the soil movement is within a foot of the ground (fig. 5). Under field conditions, soil begins to move when the wind velocity reaches about 13 miles per hour (mph) at 1 foot above the ground surface. Depending on their size and the strength of the wind, soil particles move in three different ways (fig. 6).

Figure 4. *Any soil that is loose, dry, bare, and smooth is a candidate to be blown by the wind. If that soil is also unprotected for some distance, it will erode under windy conditions.*

Figure 5. *Most soil movement is within a foot of the ground.*

Saltation

Fine and medium sand-sized particles move mainly by saltation. They are lifted only a short distance into the air and then fall back to the ground to dislodge more soil. Referred to as the "bouncing particles," they are lifted off the ground at a 50- to 90-degree angle and travel a distance of 10 to 15 times the height they are lifted. The spinning action and forward/downward movement of these particles give them extra power to dislodge other soil particles when they hit the ground and to break down large clods into smaller soil aggregates that can be carried by the wind. Saltation also destroys stable surface crusts, creating a more erodible condition. It accounts for 50 to 80 percent of the total soil movement. The width of the field is important because the amount of soil moved increases downwind (fig. 7).

"Windblown soil is one landowner's loss—and the community's burden."

Suspension

Suspension refers to the process by which very fine soil particles are lifted from the surface by the impact of saltation, carried high into the air, and remain suspended in air for long distances. This "dust" can be blown hundreds of miles. The diameter of suspended soil particles is only about one-eighth the thickness of a dime or less. Although they account for only a small part of the total soil moved by wind, these small particles are the most fertile part of the eroded soils.

Surface creep

Surface creep is the movement of larger (sand-sized) soil particles along the surface of the soil. These particles are loosened by the impact of saltating particles, but they are too large to be lifted off the ground in most winds. They move along the soil surface in a rolling motion. Surface creep can account for up to 25 percent of the soil moved by wind.

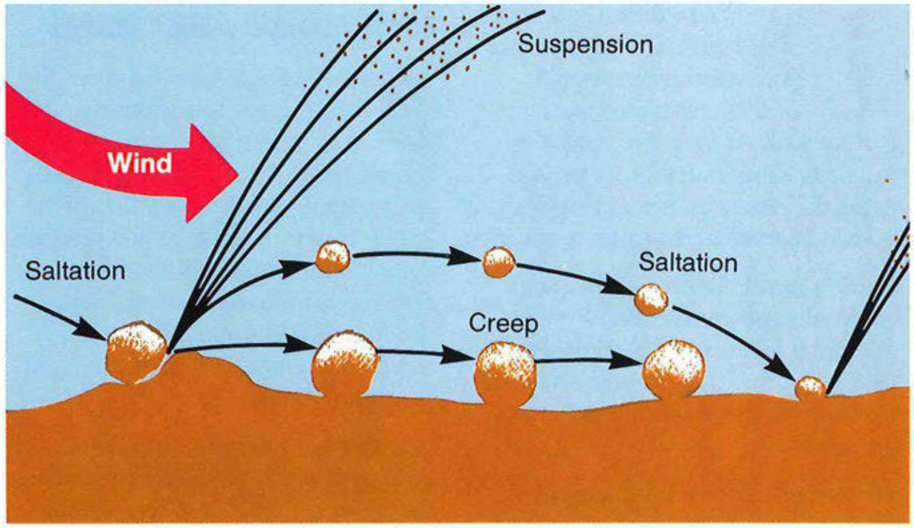


Figure 6. *Saltation, the bouncing action of eroding soil particles near the ground surface, accounts for most of the soil movement by wind. The impact of saltating particles dislodges finer particles into suspension and sets coarser particles into motion as surface creep.*

Figure 7. *Soil moved as saltation and surface creep is deposited in a road ditch in Iowa.*

Reduce wind erosion—cover the ground

To a certain extent, the amount of soil erosion that will occur from wind is predictable. Factors considered are climate, how easily a certain type of soil blows, the roughness of the soil ridge, the distance across a field with no wind barrier, and vegetative cover.

Farmers can do little to control soil erodibility and climate. But they can manage ridge roughness, the width of field strips, the distance between wind barriers, and the amount of cover on the soil.

The first principle in wind erosion control is to cover the soil. Vegetative cover slows the wind at ground level, protects soil particles from being detached, and traps other blowing soil. The cover may be in the form of living plants or the residues from a previous crop. Among the ways to reduce erosion with cover are management of crop residues, permanent grass plantings, crop rotations, and cover crops.

Crop residue management

Because the greatest wind erosion hazard often occurs during seasons in which no crops are grown, protection of the soil depends on managing the dead residues of the previous crop. A well-planned program of residue management begins when the crop is harvested, and includes actions to keep as much residue as possible on the surface as a protective mulch.

The less the soil and the previous crop's residue are disturbed, the better the erosion control will be. Standing stubble gives better protection against wind erosion than residues flattened by tillage or shredding, and it is best not to disturb residues until planting time. Avoid fall tillage.

Conservation tillage

Conservation tillage is any tilling and planting system that leaves enough crop residue on the soil

Figure 9. *Grass and legume crops are rotated with row crops in Iowa.*

surface to significantly reduce soil erosion (fig. 10). Conservation tillage systems range from no-till, where soil is undisturbed before planting and only a narrow slot is made to insert the crop seed into the ground at planting, to mulch till, where the entire soil surface is disturbed by tillage before planting, using implements that keep a high percentage of crop residues on the surface.

Permanent grass or tree plantings

Covering an area with healthy grasses or trees will stop erosion by wind. This option may be best on severely eroding areas that are not suitable for crops. Well-managed pastures, rangelands, woodlands, and wildlife plantings offer the best possible erosion control (fig. 8).

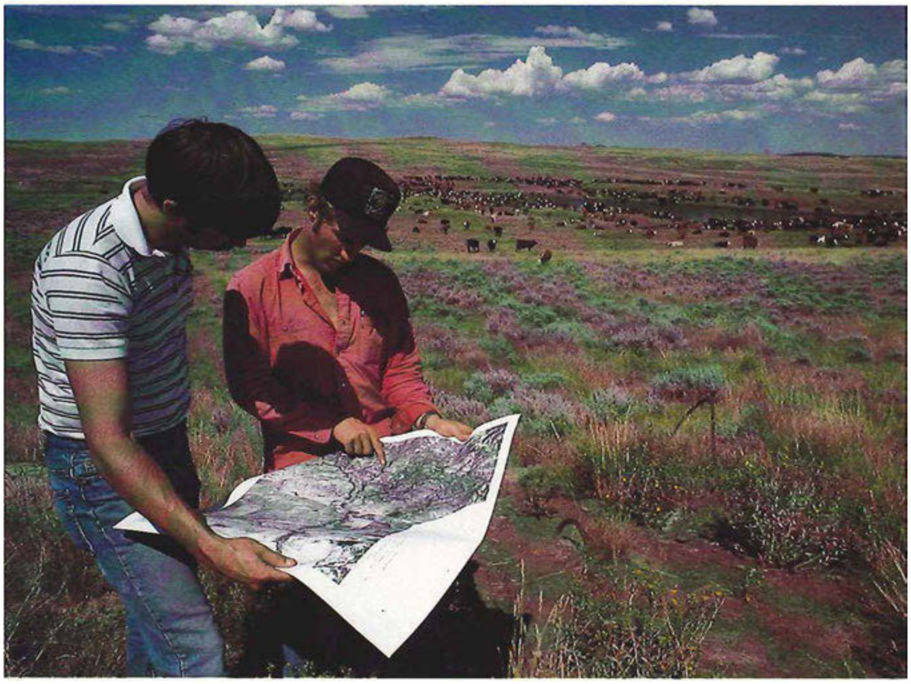


Figure 8. *Well-managed rangeland protects highly erosive soil in Wyoming.*

Figure 10. *Wheat residues are left on the soil surface to protect an Oklahoma crop field.*

Q: When is the best time to plant a tree?
A: Twenty years ago.

Q: When is the second best time?
A: Today.

Crop rotations

Planting a grass or legume in a crop rotation helps build soil nutrients (fig. 9). Erosion by wind will be controlled during the years the land is in grass rather than row crops. Close growing crops such as small grains, which produce high amounts of crop residue, have good potential to help control wind erosion.

Cover crops

In many areas, severe wind erosion occurs after one crop is harvested and before the next begins to grow. Planting a protective cover crop during this period is another option for controlling wind erosion.

Reduce wind erosion—slow the wind

Wind barriers

One of the most permanent wind erosion control methods is the wind barrier (fig. 11). Besides their soil-saving benefits, these barriers save moisture and prevent wind damage to plants, thereby increasing crop yields. A wind barrier will generally protect the soil downwind for a distance of 10 times the height of the barrier. That distance may vary depending on the density of the barrier—a moderately dense barrier is effective over greater distances.

Field windbreaks

Planting windbreaks at right angles to prevailing winds will reduce wind speed several times the height of the windbreak downwind (fig. 12). Choose species that are adapted to the soil and climate, compatible with adjacent crops, and have few pest problems. The most desirable plants for windbreaks are tall, narrow-crowned species with a density of 40 to 80 percent. Usually, a single or double row of trees is used to serve as the backbone of a wind erosion control system. Spacing between windbreaks can vary depending on height and density of the windbreak, soil type, crops grown, and tillage practices used.

In dry areas, a drip irrigation system has proved successful in establishing windbreaks (fig. 13). Drip irrigation applies water slowly only to the trees, making the best possible use of water.

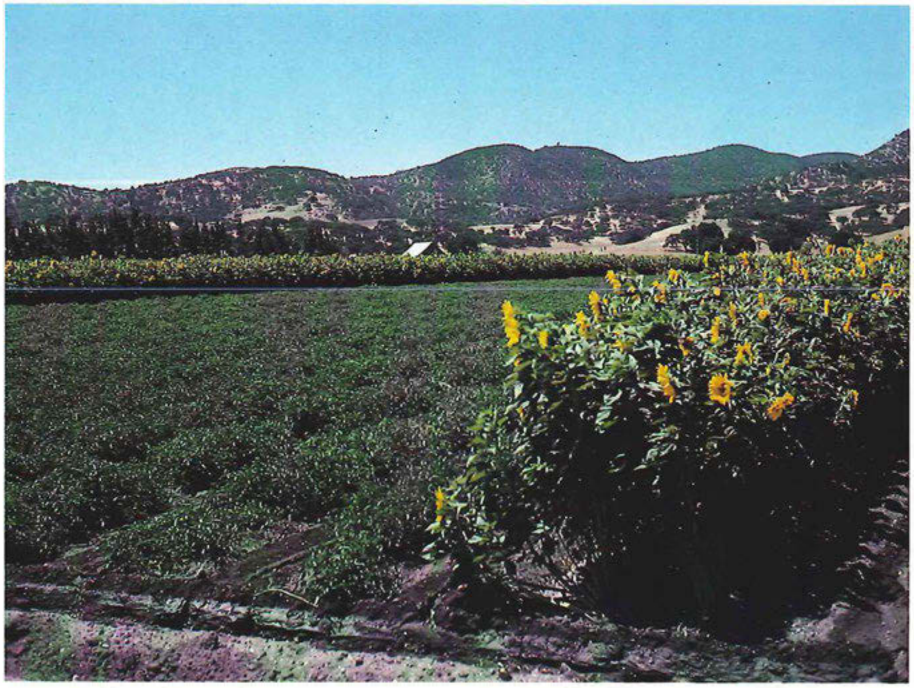


Figure 11. *Annually planted sunflower barriers protect specialty crops in California.*

Figure 12. *A field windbreak in Nebraska slows the wind.*

Figure 13. *Drip irrigation is a successful, economical way to water new windbreaks.*

Figure 14. *Perennial grass barriers protect cucumbers growing in South Carolina.*

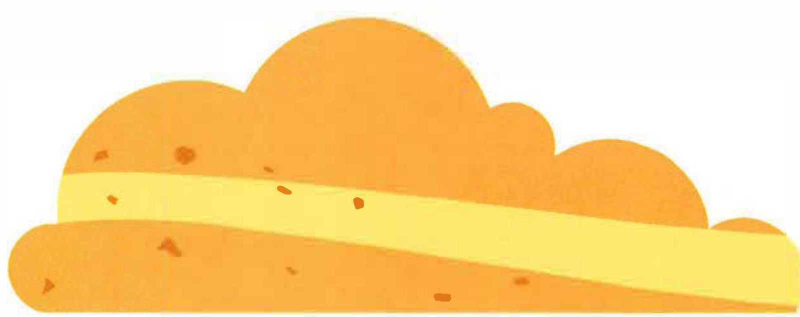
Perennial grass barriers

Strips of perennial grasses interspersed through a crop field can make excellent, inexpensive wind barriers (fig. 14). Since the purpose of a grass barrier is to protect the soil and the seedlings of spring-planted crop from the hazards of wind erosion, it is important to select a perennial grass that remains erect during winter.

The perennial grass selected for an effective wind barrier should create a stand at least 3 feet tall to alter the wind profile and have enough density to trap airborne particles. It should also be hardy enough to thrive under dryland conditions. Check with your local SCS office for species adapted to your locality.

Ridge roughness

It is important to consider row direction, crop row ridge height, and row spacing. Crop row ridges at right angles to prevailing winds absorb wind energy and also trap moving soil particles. Proper ridging, row spacing, and direction can cut wind erosion by as much as 50 percent.



Reduce wind erosion—consider field size

Field size is a critical element in wind erosion control because of the effect of "avalanching." Avalanching is the buildup in the amount of soil being moved by the wind. As the distance across bare soil increases, wind erosion becomes more severe. Any vegetation planted to break up long expanses of bare soil helps reduce the buildup of blowing soil near the surface.

Areas stabilized by vegetation prevent soil particles from being dislodged, and also trap saltation and surface creep from upwind. Smaller fields help stabilize an area against wind erosion by reducing the length and width of an unprotected area of soil. In addition to windbreaks, grass barriers, and fence rows, there are two major methods used to reduce field size.

Stripcropping

Stripcropping is the practice of alternating equal-width strips of row crop or fallow with strips of wind-resistant crops (fig. 15). This practice offers the benefits of crop rotation as well as soil protection. As with other control systems, stripcropping is most effective if the strips are at right angles to the prevailing winds.

Figure 15. *A wind stripcropping system in Montana.*

Buffer strips

This practice is much like stripcropping, except buffer strips are not likely to be as wide as the grass, legume, or small grain strips in a conventional stripcropping system. Buffer strips should be at least 12-feet wide, and wider if needed to stop and hold blowing soil. Perennial grass or annual wind-resistant crops such as small grain or sorghum may be used (fig. 16).

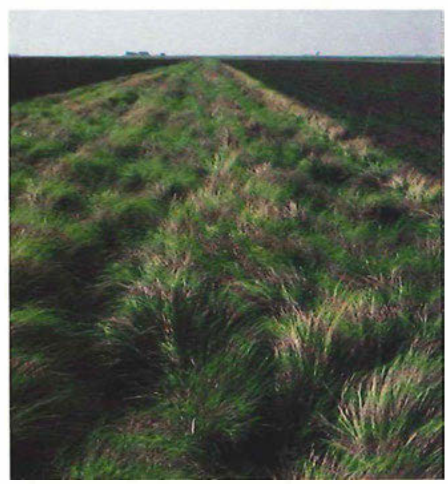


Figure 16. *Buffer strips of weeping lovegrass protect a cottonfield in Texas.*

Wind erosion control systems

To control wind erosion, it is best to think in terms of a systems approach that looks at all options. For instance, using a conservation tillage system supports the protection provided by windbreaks or grass strips and allows for wider spacing of these practices. Or, grass buffer strips or perennial grass barriers can provide protection while slower growing windbreaks are becoming established. The systems approach looks at the combination of practices that fit a farm or ranch operation (fig. 17).

If you own or operate a farm or ranch and would like help in planning a conservation system to control wind erosion, contact the SCS office nearest you. SCS conservationists consider your entire farming or ranching operation as they discuss your alternatives for controlling wind erosion. They also offer suggestions on how different components of your intended system could be designed to improve water quality, establish wildlife habitat, and offer other benefits you may be striving to achieve. The conservation planning assistance from SCS should help you get the broadest range of benefits from a complete wind erosion control system.

Figure 17. *A combination of wind barriers and ground cover protects soil.*

Public benefits

Many of the benefits a landowner or land user receives from controlling wind erosion are also public benefits (fig. 18). For instance, if a landowner or land user keeps soil in place on his or her farm or ranch, that soil will not be a problem for someone else.

If soil is allowed to blow across highways, it can cause accidents just like blowing snow. Controlling wind erosion means cleaner air. "Fugitive" dust in the air affects homes, health, public facilities, and everyday living.

While control of soil erosion is the primary benefit of erosion control measures, there are several secondary advantages. Wind barriers reduce snow blowing and drifting, keeping snow on the fields where moisture is needed rather than on the roads (fig. 19). The barriers can also provide shelter—in some cases the only nearby shelter—for wildlife (fig. 20). These same tree, grass, or shrub plantings help beautify the countryside—a benefit for the public as well as for the landowner or land user. Keeping soil in place also means less sediment in lakes and streams.

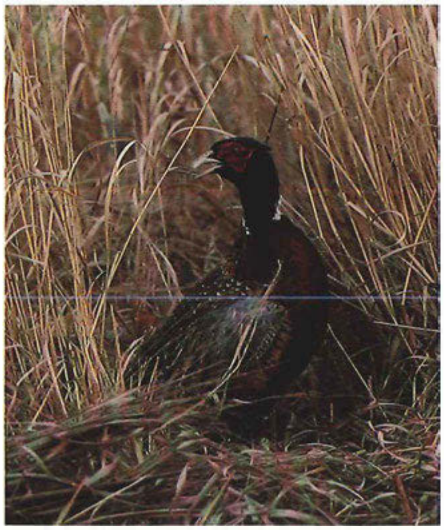


Figure 20. *Switchgrass gives pheasants excellent habitat in Iowa.*

Figure 18. *Trees and shrubs planted in windbreaks in a subdivision in North Dakota make an interesting pattern on the land.*

Figure 19. *A living snowfence in Colorado beautifies the landscape and will stop blowing snow.*

To get help

Technical help in solving soil erosion problems is available in your locality. There are more than 3,000 local conservation districts and SCS offices across the United States (fig. 21).

Figure 21. *You can get help controlling erosion by visiting an SCS office near you.*

Figure 22. *SCS makes an onsite visit in South Dakota to help with a resource problem.*

SCS and local conservation district offices have information on soil types, predicted wind and water erosion levels, explanations of conservation options, detailed advice on planning and establishing conservation measures such as drip irrigation, and much more. This technical help is available at no charge (fig. 22). Additionally, information and, in some cases, financial help are available from other local, State, or Federal government agencies, including State forestry departments and the Cooperative Extension Service.

Local SCS offices are listed in municipal telephone directories under "United States Government, Department of Agriculture, Soil Conservation Service."

All programs and services of the U.S. Department of Agriculture, Soil Conservation Service, are offered on a nondiscriminatory basis without regard to race, color, national origin, religion, sex, age, marital status, or handicap.

how to control SOIL BLOWING

U.S. DEPARTMENT OF AGRICULTURE

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CONTENTS

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HOW TO CONTROL SOIL BLOWING

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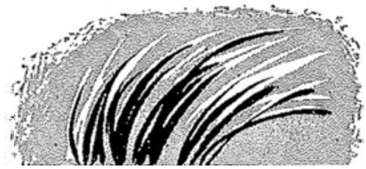

Depletion of vegetative cover on the land is the basic cause of soil erosion by wind or water. Little erosion occurs under natural conditions. Restoring the vegetative cover comparable to natural conditions would appear to be the logical solution for erosion control. However, man must till the soil to produce crops, graze the land to produce livestock, and cut trees to supply other needs. All these practices tend to deplete the vegetative cover on the land.

The most serious damage from wind-blown soil particles in some regions is the sorting of soil material. Wind erosion gradually removes silt, clay, and organic matter from the surface soils. The remaining materials may be sandy and are infertile; the sand often piles up in dunes and presents a serious threat to better surrounding lands. As recorded in history, huge agricultural areas in different parts of the world have been seriously damaged in this manner.

Soil blowing causes other damage. Crops are often destroyed by abrasion of wind-blown soil particles. Insects and weed seeds are blown far and wide with drifted soil, to infest clean fields. Mounds of accumulated soil may smother grass, shrubs, and trees. Drifting soil often buries and ruins fences, hedges, and shelterbelts. Drifted soil sometimes blocks entrances to farmsteads and makes the buildings unsuitable for living quarters.

During duststorms, traffic is sometimes held up on roads and traffic accidents are common. Duststorms are disagreeable and sometimes unbearable to farmers and their families. Farm animals suffer and sometimes die from dust suffocation. People in villages, towns, and cities also suffer some inconveniences from duststorms.

Consequently, in areas susceptible to soil blowing, great care is required to raise crops and livestock and to conserve the soil.

PRIMARY CAUSES AND REMEDIES OF SOIL BLOWING

Soil erosion is caused by a *strong wind* blowing in the *direction* that gives the greatest distance across a *large* and *unprotected* field with a *smooth* and *bare* surface and a *loose*, *dry*, and *finely granulated* soil.

Conversely, nine general ways can reduce or eliminate soil blowing: Keep the soil *firm* and *moist;* create soil aggregates or clods *large* and *stable* enough so they cannot be moved or abraded by wind; *roughen* the surface to trap and protect the fine soil particles; *cover* with and preferably maintain vegetation or

[1] Deceased.

[2] The information reported in this bulletin was made possible by research conducted in cooperation with the Kansas Agricultural Experiment Station.

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vegetative residue on the land; *narrow* the width of fields and arrange the broad sides of the fields at *right angles* to the prevailing direction of wind; and reduce the velocity of wind near the ground by using *barriers* placed along the path of the wind.

SOIL AND SOIL BLOWING PROCESSES THAT AFFECT CONTROL MEASURES

Rain, compaction by implements and livestock, and soil micro-organisms tend to cement eroded soil particles together into larger, nonerodible aggregates. On the other hand, repeated wetting and drying, and especially freezing and thawing of the soil, tend to soften and disintegrate the surface crust and aggregates and to increase soil blowing. Because of these two counteracting processes, maximum degree of soil consolidation and aggregation occurs usually below a depth of 3 to 4 inches.

Bringing clods to the surface only controls wind erosion temporarily, because clods at the surface readily weather down to erodible particles. For a permanent method of wind erosion control, the soil surface must be covered by living plants or by dead vegetation continuously replenished.

Decomposing vegetative matter produces cementing materials that bind the soil particles together to form water-stable soil aggregates large enough to resist wind erosion. On the other hand, decomposed organic matter—that is, the products of decomposition that normally give the soil a black color—produces fine soil granules that increase wind erosion. As a result, a mulch should be added to the soil to maintain sufficient vegetative matter above the surface to protect the soil from wind erosion. Thus, vegetative cover, and not organic matter in the soil, is needed to control soil blowing.

Soil blowing begins when the most erodible particles range in size from very fine to medium sand. These sizes are moved by wind in jumps known as *saltation.* The jumping particles cause fine dust to be blown far through the atmosphere. The saltating particles also cause the coarser grains to roll and slide along the surface of the ground. Farmers should not allow the soil to become finely granulated —a condition most susceptible to movement by saltation.

The impacts of grains in saltation tend to break up the surface crust and clods into fine fragments that, in turn, are moved by the wind. This breakup is called *abrasion.* The sandier the soil, the more susceptible it is to abrasion.

The rate of soil flow is zero at the windward edge of an eroding field, but the rate increases with distance to leeward until it reaches the maximum that a given wind can carry. The increase in soil flow with the distance downwind is called *soil avalanching.* The larger the proportion of erodible fractions in the soil and the more the surface crust and clods are susceptible to abrasion from jumping particles, the greater is the rate of soil avalanching. For these soils, the fields should be narrow enough to slow the rate of soil movement to a tolerable limit.

The finer soil fractions are moved by wind faster than the coarser ones. This causes *sorting* of the soil materials. Fine dust, including much of the organic matter, is moved far and wide. Particles moved in saltation usually form dunes or drifts, whereas the coarser particles that roll along the surface form gravels and sands.

CONTROL MEASURES

Permanent methods include those soil conservation practices that will ordinarily control soil blowing for years. These practices include stubble mulching, cover crops, stripcropping, and crop rotations; proper choice and use of tillage, planting, and harvesting implements; wind barriers, shelterbelts, and regrassing and reforestation. Farmers may need to adopt all these permanent wind erosion practices, but sometimes they may have to fall back on emergency methods when a period of severe climatic conditions may cause poor crops.

Emergency methods include tillage to bring clods to the surface, furrowing, and placement of temporary barriers at intervals across the field. The term "preventive methods" describe these methods better, but "emergency methods" is so well-rooted in present-day vocabulary, it is used here.

STUBBLE MULCHING

Stubble mulching—the practice of maintaining crop residues at the ground surface—offers good protection from soil blowing. The degree of protection depends on the quantity and quality of the residue and planting and cropping practices used with stubble mulching.

It is impossible to estimate the quantity of crop residue required to control soil blowing unless all the major factors that affect soil blowing are known. For instance, the more susceptible the soil is to movement by wind, the more residue is required to prevent blowing. Large block fields require more residue than narrow fields or fields protected by windbreaks and shelterbelts. Arid areas need more residue than humid areas, and areas of high winds require more cover than those of low winds.

Pound for pound, fine residue gives more protection to the soil than coarse material, if the fine residue is equally distributed and anchored. Residue in a vertical position shelters the soil better than that in a leaning position and much better than residue in a flattened position. Long or tall-crop residue is more effective than short residue.

To reduce soil loss to an insignificant quantity for large open fields in the average semiarid region during the windy season—which usually is in the spring:

♦ A silt loam soil with 25 percent nonerodible fractions needs 750 pounds of 12-inch high standing and uniformly distributed wheat stubble or 1,500 pounds of 12-inch flattened wheat stubble per acre.

♦ A loamy sand with 25 percent nonerodible fractions needs 1,750 pounds of the standing stubble or 3,500 pounds of flattened wheat stubble per acre.

♦ If sorghum is substituted for wheat in the above examples, double the quantity of sorghum stubble.

To provide the quantity of stubble needed above, much more stubble should be left on the field after harvest. Some residue decomposes during the fall and winter.

Crops on extremely erodible sandy lands seldom supply enough cover to prevent soil blowing. Some farmers have found that the best remedy is to return such lands to permanent grass, shrubs, or trees, despite possible immediate lower income.

COVER CROPS

Although not planted specifically as a cover crop, winter wheat planted in late summer or early fall gives excellent to fair protection during the critical wind erosion period the following spring. The combination of a good stubble mulch from the preceding crop and of fall growth made by the wheat effectively controls soil blowing. If

PN-1109

Winter wheat planted with semideep furrow drill in rows 12 inches apart gives an effective cover crop. It provided about 700 pounds per acre of dry matter above the surface. Although this sandy loam soil is highly susceptible to wind erosion, little soil removal took place under an exceedingly dry and windy spring.

the wheat fails to germinate or to make sufficient cover in the fall, severe blowing may occur unless the land is protected with residue from a previous crop. If there is not enough crop residue at planting time, roughening the land and making it as cloddy as possible are temporary expedients against soil blowing. A semideep furrow drill is usually effective in establishing a rough surface until the wheat covers the ground.

If moisture is sufficient, some farmers plant cover crops of spring wheat, oats, or barley on summer fallow in late summer to prevent soil blowing. If the cover crop makes sufficient growth, it can be pastured. This system, used effectively in some northern areas, protects the soil during the following spring period of high winds before a spring crop is planted. Moisture used by these cover crops is often replaced by snow trapped by the vegetation.

In severe cases of soil blowing in the Great Plains, planting sorghum in summer provides a protective cover for the critical spring erosion period. This crop is often left unharvested.

STRIPCROPPING

For wind erosion control, crop strips are straight and run as nearly as possible at right angles to the prevailing winds; for water erosion control, crop strips follow as much as possible the contour of the land. The relative severity of the two types of erosion determines which system to use. However, to control soil blowing, even contour stripcropping is better than large block farming.

Stripcropping does not require any change in cropping practices, nor does it remove any land from cultivation. The field is subdivided into alternate strips of erosion-resistant crops and erosion-susceptible crops or fallow. Stripcropping requires adequate quantities of crop residues as an additional protection against wind erosion.

Erosion-resistant crops are small grains and other crops seeded closely that cover the ground rapidly. Erosion-susceptible crops are cotton, tobacco, sugar beets, peas, beans, potatoes, peanuts, asparagus, and most truck crops. Corn and sorghum are intermediate in their resistance to wind erosion.

Stripcropping controls soil blowing by reducing soil avalanching, which increases with width of the eroding field. The rate of soil avalanching varies directly with the erodibility tendency of the soil. Therefore, the width of the strips is determined by the kind of soil in the field. For instance, in western Kansas strips with a 1-foot high stubble of erosion-resistant crops on their windward sides should have the following average width of crop strips for—

Soil:	*Width of strips (feet)*
Sand	20
Loamy sand	25
Granulated clay	80
Sandy loam	100
Silty clay	150
Loam	250
Silt loam	280
Clay loam	350
Silty clay loam	430

PN-1110

Wheat and sorghum strips, 254 feet wide, are rotated with 254-foot strips of sorghum and fallow, then with wheat and fallow on this loam soil. Proper residue management has given adequate protection from wind erosion on this farm.

The width of the strip would be either narrower or wider in areas where wind velocity is higher or lower than that of western Kansas in spring.

Such topographic features as irregularity, length, degree, and exposure of slope in relation to prevailing winds influence the effectiveness of crop strips. These features and the soil type determine the design for a stripcropping system. Standard farm machinery does not work efficiently on strips narrower than about 50 feet. On those fields that require strips narrower than 50 feet, consider growing erosion-resistant crops continuously or seeding the field to a permanent cover.

CROP ROTATIONS AND FALLOWING

Most farmers in dryland areas subject to soil blowing follow rotations of wheat and fallow, wheat-wheat-fallow, and wheat-sorghum-fallow. These rotations are readily adapted to stripcropping. Other rotations that are longer and include grasses and legumes also work well in a stripcropping system.

The greatest damage from soil blowing is on fallow. However, in regions of low rainfall, fallow is essential to store moisture in the soil for the next crop. Fallow may not increase total crop yields.

On some lands that are susceptible to soil blowing, a continuous system of cropping has been substituted for fallowing. Continuous cropping increases the hazard of crop failure, but a growing crop each year assures a more continuous cover and reduces erosion.

MACHINERY TO CONTROL SOIL BLOWING

Tillage machinery and tillage practices can either aggravate or alleviate the soil blowing problem. Machines that tend to pulverize the soil or to diminish the vegetative cover increase soil blowing. If crops are grown, however, weeds and vegetative cover must be destroyed. Nevertheless, at the time the growing cover is destroyed, machines can create a cloddy and rough surface to prevent blowing.

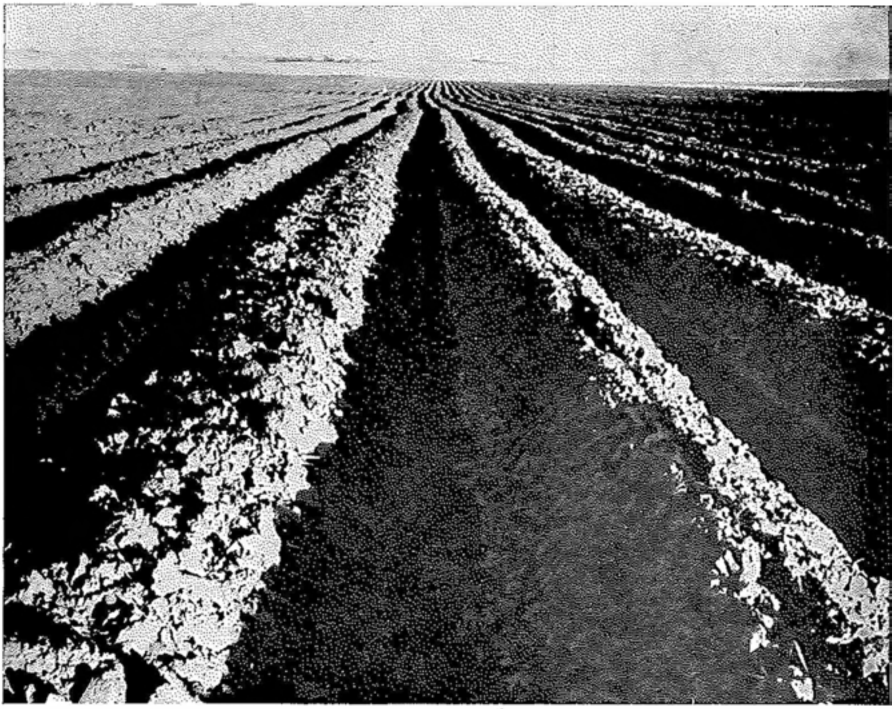
Farmers should choose implements suited to conditions of a specific area and use them properly. They can choose tillage machinery that (1) turns a layer of soil over; (2) mixes or stirs the surface soil; or (3) cuts underneath the surface but neither mixes nor turns the soil layer.

Implements That Turn the Soil Over—*Moldboard* and *disk plows* are limited to humid and subhumid areas and to irrigated and special-problem soils. Plowing buries crop residues needed to control erosion. It is also a relatively expensive operation.

In some wind erosion areas, however, plows are used to turn under green manures, to produce a cloddy surface on soils denuded of residues, to kill certain types of weeds, or to bring up clayey materials on soils that have been sorted by wind.

Implements That Mix the Soil—The *lister* is a combination of furrow opener and planter. It provides good protection against soil blowing because it leaves the land ridged and rough. In dryland areas the lister is used for planting sorghum, for contour tillage to conserve soil moisture, to channel irrigation water to crops, or as an emergency tillage tool to control soil blowing.

The *single*, *offset*, or *tandem disk harrows* tend to chop and partly bury the residue and pulverize and loosen the soil. These implements smooth the surface, break up large clods on plowed land, and destroy weeds if not too large. Do not use disk harrows to cultivate smooth,



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A 14-inch lister did a good job of ridging and throwing up clods here to resist wind erosion.

bare soils where soil blowing is a hazard.

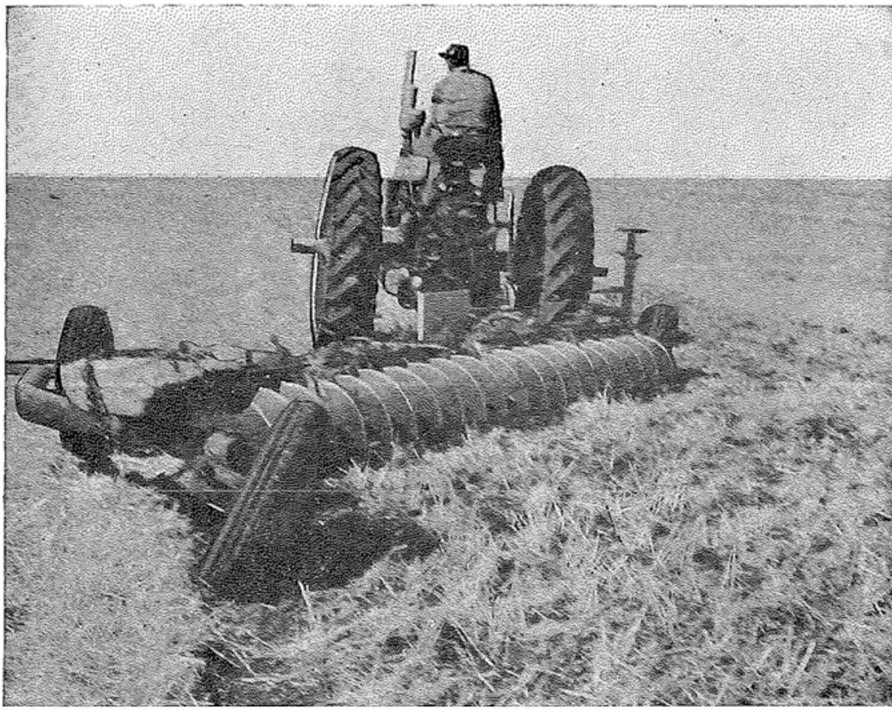
Where soil blowing is a hazard, the *spring-tooth harrow* is somewhat better than the *spike-tooth harrow*. The spring-tooth harrow penetrates deeper, brings some clods to the surface, causes some ridging, and is more able to destroy small weeds than the spike-tooth harrow. Neither implement can operate in heavy residues. As a rule, use other implements in areas subject to soil blowing.

The *duckfoot cultivator* cultivates fallow, prepares the seedbed, and, to a limited extent, roughens and brings clods to the surface to stop soil blowing. This implement destroys weeds effectively if the residues are not too heavy to prohibit close spacing of the shovel shanks.

Chisel-type tools, available in a variety of designs, break up hard soil to permit better intake of rainfall. If the chisels penetrate deep enough to bring up compacted clods and to roughen the surface, these implements will control soil blowing. Chisels do not destroy weeds effectively.

The *one-way disk* is an excellent implement for working in heavy residues and for destroying weeds. The first disking maintains approximately 50 percent of the residue on the surface. The one-way disk buries too much residue and leaves the soil susceptible to blowing if residues are meager. Many farmers use the one-way disk only for heavy residues and for the initial tillage of stubbleland.

Rotary hoes and *skew treaders* spread bunched residue and pack the soil to form better seedbeds.



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After harvest the heavy wheat stubble in this field was one-way disked to destroy weeds and put soil in condition to absorb moisture. Sufficient residue is left on the surface to protect the soil from wind erosion.

These implements tend to pulverize the soil regardless of residue quantity.

Implements That Cut Below the Surface—*Subsurface tillage implements* undercut land with a minimum disturbance of surface residues. They may maintain 80 to 90 percent of the residue on the surface after a single operation. However, these implements do not bring many clods to the surface to prevent soil blowing.

Subsurface tillage implements are equipped with either straight or V-shaped blades or rods. The V-blades are more extensively used and are 1 to 7 feet wide. Blade implements differ from the duckfoot cultivator in that the blades are wider and the shanks are fewer and longer for better clearance of residue.

Rod weeders destroy weeds, create a good seedbed, and maintain residues on top. On some rod weeders narrow duckfoot shovels or chisels are placed ahead of the rod. This added equipment undercuts hard ground.

Planting Machinery—To prevent soil blowing, use special planters to maintain land with a rough, cloddy, and residue-covered surface. Deep-furrow disk and shovels drills, with 12- to 14-inch spacing, are capable of going through heavy residues without clogging. Moreover, they place the seed at a depth where moisture is sufficient to permit germination. Use single- and double-disk drills only where residues are light.

PN–1113

For stubble mulching, this rod weeder with small duckfoot sweeps in front of the rod left 80 percent of the wheat stubble, mostly standing above the surface.

SOIL BLOWING AND WEED CONTROL

Improper or frequent cultivation to kill weeds and the volunteer crop increases the hazard from soil blowing. However, to conserve soil moisture and maintain crop yields, choose a time and use an implement that will destroy all existing growth, preferably in one operation. At the same time, leave the soil surface rough and leave some residue to prevent soil blowing. The soil condition and the amount and kind of crop residue determine the type of implement to use.

Some weed growth may control soil blowing. Little moisture is lost if the weeds are not more than 2 or 3 inches high before they are destroyed by tillage. If the season is inducive to soil blowing or the soil is highly erodible, delay tillage until planting time or until conditions are more favorable for erosion control.

In some areas annual weeds are killed by frost. If the land is not seeded in the fall, kill the perennial weeds in the spring rather than in fall.

Where grasses and legumes are grown successfully in crop rotations, both weeds and soil blowing are much easier to control.

SOIL BLOWING AND INSECT CONTROL

Insects and mites—such as the hessian fly, greenbugs, aphids and curl mites that carry wheat streak mosaic — maintain themselves chiefly on volunteer wheat from harvest until the next wheat crop is planted in the fall. Destroying the volunteer wheat with implements that leave the residues on the surface will control these insects and will prevent soil blowing as well.

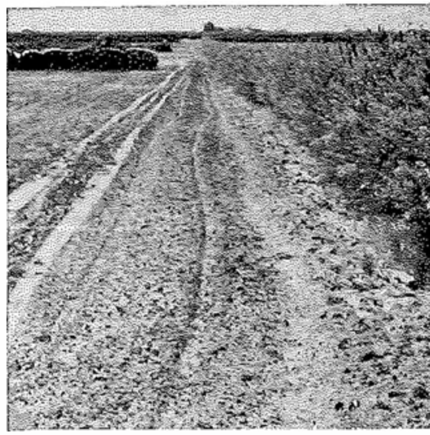
Some insects that feed primarily on wheat will not attack other crops. Planting wheat in rotation with other crops or with fallow will reduce infestations of hessian fly, wheat strawworm, wheat white grub, and wheat stem sawfly. To control soil blowing, stripcrop with crops resistant to wheat insects where fallow is necessary.

Stripcropping presents difficulties in controlling lesser migratory grasshoppers (*Melanoplus mexicanus*) in winter wheat regions. The grasshoppers move from stubble strips into edges of wheat strips in the fall and consume the young plants. Spray margins of stubble strips and roadsides with aldrin, chlordane, heptachlor, or toxaphene before the new wheat is up. If heavy grasshopper outbreaks are impending, substitute sorghum or other spring crops for winter wheat. In late fall or early spring, fallow strips can be listed to prevent any soil blowing that might occur.

Wheat curl mites and greenbugs that transmit wheat streak mosaic may infest early plantings of winter wheat. Do not plant wheat early when the mosaic was prevalent the previous year. Delayed seedings, however, may cause serious soil blowing where residue cover is inadequate. Under such conditions, adopt stripcropping as a permanent measure.

WINDBREAKS, SHELTERBELTS, AND OTHER BARRIERS

Any barrier, such as soil ridge, stubble crop, hedge, or tree windbreak or shelterbelt, in rows and at intervals at right angles to the direction of the prevailing wind, reduces the surface wind velocity and soil blowing. In many areas barriers not only control soil blowing but also trap snow and reduce evaporation and transpiration.



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A shelterbelt traps snow and protects the soil from wind for some distance away from the belt. It is indispensable to farm homes.

The effectiveness of any barrier depends on such factors as wind velocity and direction and on barrier shape, width, and porosity. When the wind blows at right angles to an average tree shelterbelt, wind velocity is reduced 70 to 80 percent near the belt. At a distance equal to 20 times the height of the belt, the velocity is reduced by 20 percent, and at a distance equal to 30 to 40 belt-heights leeward of the belt, no reduction in velocity occurs. The higher the average wind velocity, the closer the belts or other barriers should be spaced to protect the soil from blowing. If the wind velocity is 40 miles per hour at a 50-foot height and the barrier is 25 feet high, space the barriers 250 feet apart, or 10 times the height of the barrier—to protect bare and extremely erodible sandy soils. For less erodible soils with some crop residue and for lower wind velocity, space barriers farther apart.

EMERGENCY TILLAGE

If vegetative cover becomes depleted, emergency tillage will be necessary. Emergency tillage should be used as a last resort, after such methods as stubble mulching, cover crops, stripcropping, crop rotations, regular tillage practices, and windbreaks and other barriers have failed. The purpose of emergency tillage is to create a rough, cloddy soil surface that will resist the force of the wind. This measure is only temporary, as clods readily disintegrate.

Use emergency tillage before soil blowing starts rather than after. Soil becomes rapidly more erodible under abrasion of moving soil particles and requires more drastic measures to prevent it from further erosion.

Measures for Soil Types—Sandy soils are by far the most difficult to hold with emergency tillage. Few clods are obtained, no matter what the depth or what tool is used. At best, any emergency measure in sand will be rather short-lived; it is far better to keep such soils permanently covered with vegetation. If, however, tillage is required, work the entire area with a lister at sufficient depth to produce a rough surface. As soon as possible, farmers should allow a vegetative cover provided by nature to take over rather than continue to till and keep the surface rough. There is more danger of erosion from too much tillage of sandy soils than with no tillage.

Fine- and medium-textured soils respond more readily to emergency tillage than the sands. Use chisels to produce a rough, cloddy surface, and chisel the whole field rather than at intervals across the field.

Tillage Practices—Listers with either 8- or 14-inch bottoms, narrow and heavy-duty chisels, and duckfoot and wide-spade shovel culti-

PN-1115

A chisel-point cultivator (chisel) does a good job of bringing clods to the surface on fine-textured, compacted soils. The chisel is not effective on loose sandy soils.

vators are effective implements for emergency tillage. The seriousness of the possible erosion hazard, soil texture, and cropping system determine the choice of implement and the method to use.

Emergency tillage must be at right angles to the prevailing winds. Till deep enough to bring compact clods to the surface—usually 3 to 6 inches. If soil blowing is expected to be serious, till not only on individual fields but large areas. Use a 14-inch lister with 42-inch spacing or an 8-inch lister spaced 20 to 24 inches. If soil blowing is expected to be moderate, tillage of individual fields with chisels or cultivators will be sufficient. For most types of chisels, a 24-inch spacing provides good protection. Intermediate speeds of cultivation—3.5 to 4.0 miles per hour—provide the most effective surfaces.

A crop also determines the choice of emergency tillage methods. Often a wheat crop may be too sparse to hold against erosive winds, yet a partial crop may be salvaged. In this case, till the entire field with a chisel with the points spaced 54 inches apart.

RECLAIMING DRIFTING SANDS AND SAND DUNES

Drifting sands and sand dunes are much more difficult to stabilize than cultivated soils and constitute a special reclamation problem. These areas are usually very rough and hummocky. Leveling sand dunes prior to reclaiming the land usually increases the difficulty of stabilizing the sand.

Dune sands are easiest to reclaim during periods when rainfall is most plentiful and wind velocity is lowest. Smooth out only the crests of the dunes with a dragpole or a bulldozer. Work the side of the field facing the prevailing direction of the wind first. To bring some clods to the surface use a deep-furrow cultivator where sand accumulation is shallow; use a lister for deeper sand accumulations. As a temporary cover, seed this stabilized land to broomcorn, sudangrass, or a small-grain crop such as rye.

On very deep sand accumulations, use mulches of straw, hay, brush, or other vegetative materials to anchor the sand. Add the mulch on the windward side first. Apply the mulch uniformly with a blower-type spreader or a converted manure spreader. Spread at least 1½ to 2 tons per acre of prairie hay or wheat straw or 3 to 4 tons of corn or sorghum fodder. To anchor the mulch, use a colter-type packer.

Plant suitable grasses, shrubs, or trees for permanent stabilization of temporarily reclaimed areas. The final objective is the establishment of native vegetation. Drill grass seed directly in the temporary cover or mulch. Broadcast the seed on rough land, even though the task may be tedious. At the time of seeding the grass, be sure that the temporary cover of weeds, whole plants, or stubble is dead, so that it will not compete with the grass seedlings for moisture.

Manage stabilized sand-dune land carefully. Cover trails and roads leading through loose sand with nonerodible material such as gravel. Do not build homes on sand. Guard grasslands, woodlands, or scrublands from fire, overgrazing, or excessive cutting of trees. Use stabilized dunes mostly for recreational purposes and limited pasture or woodland.

Local offices of the Soil Conservation Service, the Extension Service, State experiment station, or other agencies can supply information on the most suitable grasses, shrubs, or trees for reclaiming sand dunes in the area.

COMMUNITY EFFORT AND LEGISLATION

Although individual efforts are usually very effective in controlling soil blowing, the most successful results are obtained where groups of farmers promote community action against the problem. Soil blowing on one uncontrolled area can often spread to carefully managed farms and ruin them. Community action is often aided by State and Federal laws. Also, community laws often place the responsibility for soil-blowing damage done to neighbors' properties upon the owners of the land where the soil blowing originated, unless these owners have used control measures as prescribed by law.

TO CONTROL SOIL BLOWING—

- Keep a crop or stubble on land as much as possible.
- Stripcrop on soils that permit strips.
- Plant row crops at right angles to prevailing winds.
- Maintain high soil productivity with fertilizers and rotations.
- Use tillage machines that provide a rough and cloddy surface.
- Plant a permanent cover of native vegetation on sands and extremely erodible soils.
- Use emergency tillage before blowing starts if the methods above appear to have failed.
- Work together in the community to control wind erosion.

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Soil Quality Information Sheet

Soil Quality Resource Concerns: Sediment Deposition on Cropland

USDA Natural Resources Conservation Service **April 1996**

What is sediment deposition?

Sediment is solid material that is or has been transported from its site of origin by air, water, gravity, or ice to a field or low landscape position. Deposition occurs when the amount of sediment becomes greater than the carrying capacity of the force that is moving it.

How is soil quality affected?

Sediment can either improve or degrade the soils upon which it is deposited. The impact of sediment deposition depends on the characteristics of the original soil, rate of deposition, type of material, and depth of deposition.

Fine-grained soil particles deposited on sandy soils generally improve soil quality, but if coarser material is deposited on fine-textured soils there is a more delicate balance. Soil quality may improve over a short period, but coarser material generally results in degraded soil structure and physical characteristics and decreased fertility.

Deposits of infertile sand on a highly productive silt loam that is high in organic matter and nutrients can significantly decrease the quality of the silt loam. However, soil quality would change little if similar deposits occurred on a sandy soil that had a low content of organic matter, and low levels of nitrogen, phosphorus, and potash.

The rate of deposition also affects soil quality. If an inch of sand is deposited on a fertile soil every year for 16 years, the effects would be much less than if eight inches of sand were deposited in one year. Incremental deposits become incorporated with the surface layer and improve with organic matter accumulation.

How is sediment deposition identified?

Modern deposits of sediment have different physical characteristics than the older, buried soils upon which they were deposited. The buried soil is generally darker and more uniform in color. The sediment deposits are generally less dense, with a wider range in grain sizes. Sediment deposits often show distinct stratification or layering.

What can be done about sediment deposition?

Management response to sediment deposition is generally determined by the depth of deposition and the quality of the underlying soil. Generally, as the depth of sediment deposition increases, less mixing is possible.

Potential management practices include the one-time use of**:**

- **moldboard plowing,** which generally turns 6 to 8 inches of soil over but causes a minimum amount of mixing between the surface and subsurface layers.

- **chisel plowing,** which causes a greater degree of mixing but generally disturbs the soil to a shallower depth of only 4 to 6 inches.

- **deep chiseling,** which disturbs the soil to the greatest depth (12 to 24 inches) but generally results in a minimal amount of mixing.

The best method for addressing sedimentation is **prevention,** since soil quality generally decreases as the depth of sediment deposition increases.

Prevent soil erosion in upstream landscape positions by maintaining plant or crop residue cover, high infiltration rates, and minimal runoff.

Conservation practices on upstream watersheds reduce the risk of high volume flooding and damaging sediment deposition. Dikes, levees, and intercepting channels are used to provide local protection from some flooding and sediment deposition.

Relationships between the depth and type of sediment deposit and damage to soils on flood plains relative to crop yield are shown in the following table. An estimate of the amount of recovery and the length of time required are made with the assumption that the flooding was a one-time event and would not reoccur.

	Depth and Texture	**Damage Pct**	**Recovery Period Yrs**	**Damage Remaining After Recovery Pct**
4 - 8"	fine sand and silt coarse sand and silt	20	5	0
4 - 8"	medium sand coarse sand	40	10	10
8 - 12"	fine sand coarse sand	40	10	10
12 - 14"	coarse sand	60	20	30
12 - 24"	coarse sand and gravel	90	30	50

(from Technical Release No. 17, Geologic Investigations for Watershed Planning, USDA, SCS, 1966**)**

(Prepared by National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA)

Slaking

Slaking is the breakdown of large, air-dry soil aggregates (>2-5 mm) into smaller sized microaggregates (<0.25 mm) when they are suddenly immersed in water. Slaking occurs when aggregates are not strong enough to withstand internal stresses caused by rapid water uptake. Internal stresses result from differential swelling of clay particles, trapped and escaping air in soil pores, rapid release of heat during wetting, and the mechanical action of moving water.

In contrast to slaking, tests for aggregate stability measure how well soil withstands external destructive forces, such as the splashing impact of raindrops. Both poor aggregate stability and slaking result in detached soil particles that settle into pores, and cause surface sealing, reduced infiltration and plant available water, and increased runoff and erosion.

These photos were taken from fields near Davis, California. The soil contains clay with slight to moderate swelling potential. Left: Soil aggregates were collected from a field used to produce dry beans in rotation using organic management. Soil organic matter helps the aggregates resist slaking. Right: Soil aggregates collected from a conventional walnut operation are much less stable and burst apart when rapidly wetted. The walnut orchard is cultivated frequently, which destroys plant residue and prevents accumulation of organic matter.

Factors Affecting

Inherent - Slaking is affected by wetting rate, soil water content, soil texture, type of clay, and organic matter. Slaking is increased by fast wetting rates, particularly when soil is initially dry. Moist aggregates slake less readily than air-dry aggregates because they have already completed some or all of their swelling and some pores are already filled with water. The pressure of entrapped air is the primary factor for causing slaking of loamy soils, while clay is associated with slaking caused by soil swelling.

Slaking is influenced by the presence of smectitic clays, such as montmorillonite, that shrink when dry and swell when wet. Soil water forms part of the structure of these clays. Montmorillonite can swell 25 times more than kaolinite. The presence of even small quantities of smectites in kaolinitic soils can dramatically affect slaking, soil dispersion and surface sealing. Soils with high shrink-swell potential are common in the central region of the United States (see Figure 1).

Fast wetting of high clay soil increases the extent of differential swelling and volume of entrapped air in pore space that create internal stress and break aggregates apart. Compared to the effects of raindrop splash on external breakdown of soil aggregates, slaking plays the primary role in particle detachment and surface sealing of clay soils with otherwise stable structure.

Conversely, clay in association with organic matter acts as a cementing agent to bind soil particles together. Organic matter also influences the rate at which water is absorbed by soil and increases the soil's resistance to stress caused by wetting.

Dynamic - Soil organic matter promotes aggregate formation and stability of bound aggregates. Repeated tillage prevents accumulation or results in loss of organic matter and causes soil aggregates to breakdown into finer particles. Since loss of organic matter reduces aggregate stability, slaking increases as organic matter decreases.

Relationship to Soil Function

Slaking indicates the stability of soil aggregates, resistance to erosion and suggests how well soil can maintain its structure to provide water and air for plants and soil biota when it is rapidly wetted. Limited slaking suggests that organic matter is present in soil to help bind soil particles and microaggregates into larger, stable aggregates.

Problems with Poor Function

Slaked soil particles block soil pores, form a soil crust, reduce infiltration and water movement through soil, and increase runoff and erosion. Small aggregates produced by slaking settle together resulting in smaller pore spaces than where present with larger aggregates. Pore volume may be reduced and the ability of plants to use water stored in pore spaces may be altered.

Conservation practices that lead to slaking include:

- Conventional tillage methods that disturb soil and accelerate organic matter decomposition,
- Burning, harvesting or otherwise removing crop residues, and
- Using pesticides harmful to soil organisms that cycle organic matter and promote aggregation.

conventional till corn: low organic matter | perennial sod: high organic matter

Soil samples collected from 20 year old conventional till corn and perennial bluegrass sod systems were saturated with water and allowed to dry. Note the soil crusting in the low organic matter conventional till sample compared to the abundance of stable aggregates in the high organic matter perennial sod sample. Photo courtesy Ray R. Weil, University of Maryland.

Avoiding Slaking

Conservation tillage systems, such as no-till, reduce slaking by reducing soil disturbing activities that break aggregates apart and accelerate decomposition of organic matter. No-till and residue management lead to increased soil organic matter and improved aggregate stability and soil structure, particularly when cover crops or sod-based rotations provide an additional source of residue.

Conservation practices that minimize slaking include:

- Conservation Crop Rotation
- Cover Crops
- Prescribed Grazing
- Residue and Tillage management

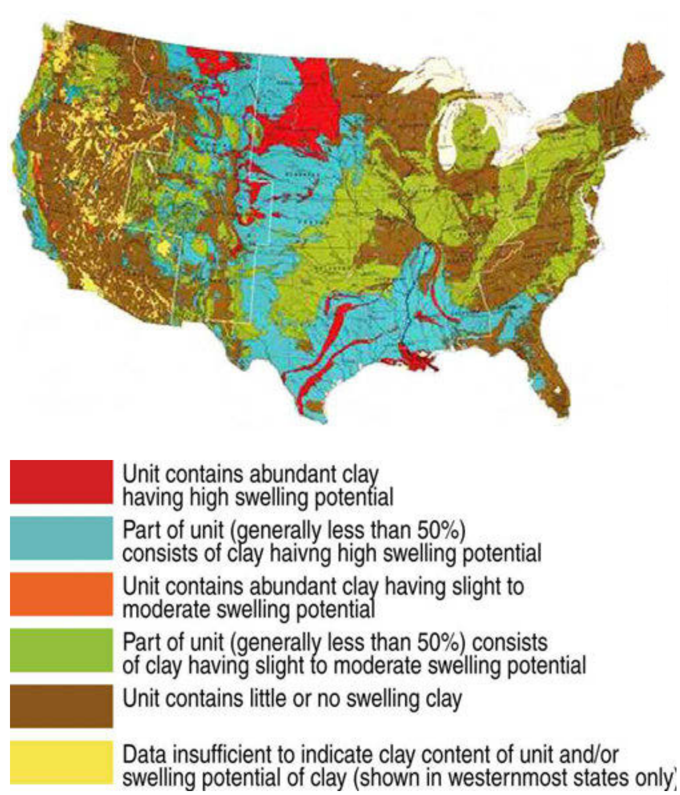

Figure 1. Map of the continental United States showing location of high swelling potential clay. Presence of shrink-swell clay contributes to soil slaking.

Measuring Slaking

The Slake or Soil Stability Test is described in the Soil Quality Test Kit Guide, Section I, Chapter 9, pp. 20 - 21. See Section II, Chapter 8, p. 72 for interpretation of results.

Reference: Herrick JE, Whitford WG, de Soyza AG, Van Zee JW, Havstad KM, Seybold CA, Walton M. 2001. Field soil aggregate stability kit for soil quality and rangeland health evaluations. Catena 44:27-35.

Specialized equipment, shortcuts, tips:

This test allows 18 samples to be evaluated in the field at one time using 2.5 cm diameter sieves, with 1.5 mm openings, fitted in holders made of PVC pipe.

Time needed: Approximately 10 minutes per batch

Soil Quality Indicators: Soil Crusts

USDA Natural Resources Conservation Service **April 1996**

Soil crusts are relatively thin, somewhat continuous layers of the soil surface that often restrict water movement, air entry, and seedling emergence from the soil. They generally are less than 2 inches thick and are massive.

Crusts are created by the breakdown of structural units by flowing water, or raindrops, or through freeze-thaw action. Soil crusts are generally only a temporary condition. Typically, the soil immediately below the surface layer is loose.

Why are soil crusts a concern?

Crusts reduce infiltration and increase runoff. Rainfall and sprinkler irrigation water impart a large amount of impact energy onto the soil surface. If the soil is not protected by a cover of growing plants, crop residue or other material, and if soil aggregates are weak, the energy can cause a soil crust to form.

If a crust forms, individual soil particles fill the pore space near the surface and prevent the water from entering (infiltrating) the soil. If the infiltration is limited, water accumulates and flows down slope, causing movement of soil particles. Thus water erosion is initiated.

Crusts restrict seedling emergence. The physical emergence of seedlings through a soil crust depends on the:

- thickness of the crust,
- strength of the crust,
- size of the broken crust pieces,
- water content, and
- type of plant species. Non-grass plant species, such as soybeans or alfalfa, exert less pressure under identical conditions than grasses such as corn.

Crusts reduce oxygen diffusion to seedlings. Seed germination depends on the diffusion of oxygen from the air through the soil. If soil crusts are wet, oxygen diffusion is reduced as much as 50 percent.

Crusts reduce surface water evaporation. The reflectance of a crusted surface is higher than that for an uncrusted surface. Higher reflectance results in less absorption of energy from the sun. This results in a cooler soil surface and decreases the rate of evaporation.

Crusts decrease water loss because less of their surface area is exposed to the air than a tilled soil. When crusts become dry, they become barriers to evaporation by retarding capillary movement of water to the soil surface.

Crusts affect wind erosion. Crusts increase wind erosion in those soils that have an appreciable amount of sand. Rainfall produces clean sand grains that are not attached to the soil surface. These clean sand grains are subject to movement by air along the smooth surface of the crust. The sand breaks down the crust as it moves across the soil surface. Cultivation to break the crust and increase the surface roughness reduces wind erosion on sandy soils.

For soils that have a small amount of sand, crusts protect the soil surface and generally decrease the hazard of wind erosion.

How do crusts form?

Soil crusts and associated cracks form by raindrop impact or freeze-thaw processes.

Raindrop impact breaks soil aggregates, moves clay downward a short distance leaving a concentration of sand and silt particles on the soil surface.

Raindrop-impact crusts break down to a granular condition in many soils that have a high shrink-swell potential and experience frequent wetting and drying cycles.

Freeze-thaw crusts are formed by the puddling effect as ice forms, melts, and reforms. The temperature and water regimes and parent material control freeze-thaw crust formation. These crusts are generally 3/8- to 5/8-inch thick, compared to 1/4-inch commonly for raindrop-impact crusts.

The size and behavior on wetting of cracks associated with raindrop-impact and freeze-thaw crust differ. Both extend to the base of the crust. The cracks in raindrop-impact crust are 1/4 inch wide. They close on wetting and hence are ineffective in increasing infiltration. The cracks in freeze-thaw crust are 1/4- to 3/4-inch wide. They do not close on wetting and hence increase infiltration.

How are soil crusts measured?

Soil crusts are characterized by their thickness and strength (air dry rupture resistance). Crust air dry rupture resistance can be measured by taking a dry piece about 1/2 inch on edge and applying a force on the edge until the crust breaks. In general, more force is required for crusts that are thick and have a high clay content. Other means of measurement, such as a penetrometer, may be used.

How can the problem be corrected?

- Maintain plant cover or crop residues on the soil surface to reduce the impact of raindrops.

- Adopt management practices that increase aggregate stability.

- Use practices that increase soil organic matter content or reduce concentrations of sodium ions.

- Use a rotary hoe or row cultivator to shatter crusts and thus increase seedling emergence and weed control.

- Employ sprinkler water to reduce restriction of seedling emergence.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA). Soil crust photo courtesy of University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources.

Soil Crusts

Left: Note the surface crust on this soil. The field was in tall fescue sod for 11 years. It was cleared and plowed using conventional tillage methods. Photo courtesy Bobby Brock, USDA NRCS (retired). Right: Collected from a no-till field in Georgia's Southern Piedmont, good structure and aggregation are evident in the soil on the right. The same soil formed a structural crust under conventional tillage. Note the sunlight reflectance of the crusted soil. Photo courtesy James E. Dean, USDA NRCS (retired).

Structural soil crusts are relatively thin, dense, somewhat continuous layers of non-aggregated soil particles on the surface of tilled and exposed soils. Structural crusts develop when a sealed-over soil surface dries out after rainfall or irrigation. Water droplets striking soil aggregates and water flowing across soil breaks aggregates into individual soil particles. Fine soil particles wash, settle into and block surface pores causing the soil surface to seal over and preventing water from soaking into the soil. As the muddy soil surface dries out, it crusts over.

Structural crusts range from a few tenths to as thick as two inches. A surface crust is much more compact, hard and brittle when dry than the soil immediately beneath it, which may be loose and friable. Crusts can be described by their strength, or air-dry rupture resistance.

Soil crusting is also associated with biological and chemical factors. A biological crust is a living community of lichen, cyanobacteria, algae, and moss growing on the soil surface that bind the soil together. A precipitated, chemical crust can develop on soils with high salt content.

Factors Affecting

Inherent - Soil crusting is related to soil texture, organic matter, and sodium content. Surface crusts are more common on fine-textured soils, such as silts, loams and clays. In combination with the splashing effect of raindrops, increased runoff and erosion of fine-textured soil increases the likelihood that a crust will develop. Crusts are usually thin and weak if present on coarse-textured, sandy soils.

Low organic matter results in poor soil structure, reduced pore space, and weak, unstable aggregates that fall apart when raindrops hit them. Rainfall and runoff disperses the soil into individual particles that clog soil pores and seal its surface with a soil crust.

Soils with high sodium content are more likely to develop surface crusts since these soils are more readily dispersed with rainfall and irrigation.

Dynamic - Management activities that deplete soil organic matter and leave soil bare, smooth and exposed to the direct impact of water droplets increase soil dispersion, surface sealing, runoff, erosion, and crusting. Excessive tillage tends to break up soil clods into smaller sizes more susceptible to breakdown, bury most plant residue, and accelerate decomposition of organic matter. Harvest methods that remove most or all of aboveground biomass also prevent or reduce organic matter buildup and protection of the soil surface. Until the crop and its protective canopy is established, residue removal also exposes soil to direct sunlight, which increases soil temperature and accelerates drying of the soil surface into a hard crust.

Relationship to Soil Function

A surface crust indicates poor infiltration, a problematical seedbed, and reduced air exchange between the soil and atmosphere. It can also indicate that a soil has a high sodium content that increases soil dispersion when it is wetted by rainfall or irrigation.

Problems with Poor Function

Because they are hard and relatively difficult to break, crusts restrict seedling emergence, especially in non-grass crops such as soybeans and alfalfa. Crusts can also reduce oxygen diffusion into the soil profile by as much as 50% if the soil crust is wet. Crust development soon after a crop is planted can result in such poor emergence that the crop might have to be replanted.

Surface sealing and crusts greatly reduce infiltration, and increase runoff and erosion. Increased runoff results in less water available in soil for plant growth.

The sunlight (and energy) reflectance of a surface crust is higher than that of a non-crusted soil, so soil temperature may be lower and surface evaporation reduced where a crust exists (see photo on reverse). This could negatively effect germination and development of healthy seedlings in cooler climates.

The relatively smooth surface of a crusted soil initially increases wind erosion of sandy soils. Loose sand particles blow across and abrade the smooth surface of the crust. Roughening of the surface crust eventually reduces wind erosion. For soils with a small amount of sand, hard crusts protect the soil surface from wind erosion.

Surface crusts can have other limited benefits. Crusts decrease water loss because less of their surface area is exposed to the air compared to a tilled, fluffy soil. In addition, a crust forms a barrier to evaporation of soil moisture. Reduced evaporation of soil moisture means more water remains in the soil for plant use.

Practices that lead to soil crusting include:

- Harvesting, burning, burying, or otherwise removing plant residues and mulches so as to leave the soil surface bare for an extended period of time, and
- Soil disturbing activities that destroy organic matter, soil structure and aggregation, and result in very smooth seedbeds.

Avoiding Soil Crusting

Practices reducing the development of soil crusts or minimizing their negative impacts include those that protect or increase soil structure and organic matter and provide protective vegetative or residue cover on the soil surface. No-till or reduced tillage of cropland is the best way to reduce or eliminate crust formation. If tillage is necessary, it should only be done to the minimum level required for good seed germination and emergence. Large seeded crops do not require the same degree of clod size reduction or as smooth of a seedbed as do small seeded crops. Residue intercepts the force of falling raindrops and is a source of organic matter. Organic matter stabilizes soil aggregates making them more resistant to the physical impact of raindrops. Improved aggregation results in lower bulk density and increased pore space, and improves infiltration and water movement through soil.

Improved infiltration and water movement through soil decreases surface ponding and runoff, and helps protect soil from erosion. Good soil structure and aggregate stability are vital to supporting healthy, vigorous plants. Healthy plants provide and conservation tillage methods manage surface and subsurface plant residues needed to increase organic matter while maintaining and improving aggregate stability and soil structure.

To reduce the incidence of surface crusting of soils high in sodium, irrigation water management prevents sodium accumulation at the surface, and gypsum (calcium sulfate) can be applied to promote flocculation and inhibit dispersion of soil particles.

It may be necessary to break a soil crust with a shallow, light tillage operation such as with a rotary hoe or row cultivator, preferably when the soil is still moist. Light tillage can increase seedling emergence and help control weeds. Irrigation water can also be used to help with seedling emergence.

Conservation practices that minimize the development of a soil crust include:

- Conservation Crop Rotation
- Cover Crop
- Residue and Tillage Management
- Salinity and Sodic Soil Management

Measuring Soil Crusting

Crust air-dry rupture resistance can be measured by taking a dry piece of the crust about ½ inch on edge and applying a force on the edge until the crust breaks. Generally, more force is required for crusts that are thick and have high clay content. A penetrometer to measure the penetration resistance of the crust can be used. Crust thickness can also be measured.

Reference: Soil Survey Division Staff. 1993. Soil survey manual. Soil Conservation Service. U.S. Department of Agriculture Handbook 18. Chapter 3, Part 8. [Online] http://soils.usda.gov/technical/manual/contents/chapter3d.html

Specialized equipment, shortcuts, tips:

A penetrometer may be needed to measure penetration resistance of a soil crust.

Time needed: 30 minutes

Soil Quality Information Sheet

Soil Quality Resource Concerns: Soil Erosion

USDA Natural Resources Conservation Service **April 1996**

What is erosion?

Wind or water erosion is the physical wearing of the earth's surface. Surface soil material is removed in the process.

Why should we be concerned?

Erosion removes topsoil, reduces levels of soil organic matter, and contributes to the breakdown of soil structure. This creates a less favorable environment for plant growth.

In soils that have restrictions to root growth, erosion decreases rooting depth, which decreases the amount of water, air, and nutrients available to plants.

Erosion removes surface soil, which often has the highest biological activity and greatest amount of soil organic matter. This causes a loss in nutrients and often creates a less favorable environment for plant growth.

Nutrients removed by erosion are no longer available to support plant growth onsite, but can accumulate in water where such problems as algal blooms and lake eutrophication may occur.

Deposition of eroded materials can obstruct roadways and fill drainage channels. Sediment can damage fish habitat and degrade water quality in streams, rivers, and lakes.

Blowing dust can affect human health and create public safety hazards.

What are some signs of erosion?

Wind erosion:

- dust clouds,
- soil accumulation along fencelines or snowbanks,
- a drifted appearance of the soil surface.

Water erosion:

- small rills and channels on the soil surface,
- soil deposited at the base of slopes,
- sediment in streams, lakes, and reservoirs,
- pedestals of soil supporting pebbles and plant material.

Water erosion is most obvious on steep, convex landscape positions. However, erosion is not always readily visible on cropland because farming operations may cover up its signs. Loss of only 1/32 of an inch can represent a 5 ton per acre soil loss.

Long-term soil erosion results in:

- persistent and large gullies,
- exposure of lighter colored subsoil at the surface,
- poorer plant growth.

How can soil erosion be measured?

Visual, physical, chemical, and biological indicators can be used to estimate soil surface stability or loss.

Visual indicators

- comparisons of aerial photographs taken over time,
- presence of moss and algae (crypotogams) crusts in desert or arid soils,
- changes in soil horizon thickness,
- deposition of soil at field boundaries.

Physical indicators

- measurements of aggregate stability,
- increasing depth of channels and gullies.

Chemical indicators

- decreases in soil organic matter content,
- increases in calcium carbonate content at the surface, provided greater content exists in subsurface layers,
- changes in cation-exchange capacity (CEC).

Biological indicators

- decreased microbial biomass,
- lower rate of respiration,
- slower decomposition of plant residues.

What causes the problem?

Water erosion

- lack of protection against raindrop impact,
- decreased aggregate stability,
- long and steep slopes,
- intense rainfall or irrigation events when plant or residue cover is at a minimum,
- decreased infiltration by compaction or other means.

Mechanical erosion

- removal by harvest of root crops,
- tillage and cultivation practices that move soil downslope.

Wind erosion

- exposed surface soil during critical periods of the year,
- occurrence of wind velocities that are sufficient to lift individual soil particles,
- long, unsheltered, smooth soil surfaces.

How can soil erosion be avoided?

Soil erosion can be avoided by:

- maintaining a protective cover on the soil,
- creating a barrier to the erosive agent,
- modifying the landscape to control runoff amounts and rates.

Specific practices to avoid water erosion:

- growing forage crops in rotation or as permanent cover,
- growing winter cover crops
- interseeding,
- protecting the surface with crop residue,
- shortening the length and steepness of slopes,
- increasing water infiltration rates,
- improving aggregate stability.

Specific practices to avoid wind erosion:

- maintaining a cover of plants or residue,
- planting shelterbelts,
- stripcropping,
- increase surface roughness,
- cultivating on the contour,
- maintaining soil aggregates at a size less likely to be carried by wind.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA)

SOIL QUALITY-AGRONOMY
Technical Note No.7

Effects of Soil Erosion on Soil Productivity and Soil Quality

United States
Department of
Agriculture

Natural
Resources
Conservation
Service

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Technical
Note No.7

August, 1998

This is the seventh note in a series of Soil Quality-Agronomy technical notes on the effects of land management on soil quality. This information is general and covers broad application.

Soil erosion has long been considered detrimental soil productivity. It is the basis for soil loss tolerance values. Considerable loss in productivity is likely to occur on most soils if they erode for several centuries at present soil loss tolerance levels (2). Erosion-caused losses of productivity on cropland and pastureland in the United States approach $27 billion with an additional $17 billion for off-site environmental costs (1). Worldwide costs for erosion-caused losses and environmental off-site damages are estimated at $400 billion per year (1).

Soil formation is a very slow process. As a result, most soils cannot renew their eroded surface while erosion continues to degrade the soil. The development of a favorable rooting zone by the weathering of parent rock is much slower than development of the surface horizon. One estimate of this renewal rate is 0.5 ton per acre per year for unconsolidated parent materials and much less for consolidated materials (3). These very slow renewal rates support the philosophy that any soil erosion is too much.

Several studies illustrate the negative impact of soil erosion on cropland productivity. In Indiana three studies compared crop growth on slightly eroded and severely eroded phases of three soils. Corn yields on severely eroded soils were 9% to 34% lower than those on slightly eroded soils. Soybean yields were 14% to 29% lower (Table 1).

Table 1. Corn and soybean yield loss in severely eroded soils compared to slightly eroded soils in three studies in Indiana.

	Three-year study (4)	**Six-year study (5)**	**Ten-year study (6)**
Corn	- 16% to - 34%	- 15%	- 9% to - 18%
Soybeans	- 14% to - 29%	- 24%	- 17% to 24%

What are some of the possible reasons that soil erosion degrades soil and results in lower crop yields? Loss of organic matter, resulting from erosion and tillage, is one of the primary causes for reduction in crop yields. As organic matter decreases, soil aggregate stability, the soil's ability to hold moisture, and the cation exchange capacity decline.

In the Indiana study (4), levels of organic matter and phosphorus were lower and clay content was generally higher in the upper six inches (15 cm) of the severely eroded compared to the slightly eroded soil (Table 2). In addition, measurements made in 1982 showed that the potential plant-available water declined as much as 50 to 75 percent in the severely eroded phase compared to the slightly eroded phase (Table 3).

Table 2. Average values for content of clay, organic matter, and P in the upper six inches of three erosion phases of Corwin, Miami, and Morley soils in Indiana in 1981.

Soil and erosion phase	Clay	Organic Matter	Phosphorus
	--------------%	---------------	lbs/acre
Corwin			
Slight	20.8[ab]	3.03[a]	61.6[a]
Moderate	19.6[a]	2.51[b]	60.8[a]
Severe	23.0[b]	1.86	40.7[a]
Miami			
Slight	15.4[a]	1.89[a]	95.0[a]
Moderate	18.1[b]	1.64[ab]	86.2[a]
Severe	22.1[c]	1.51[b]	68.2[a]
Morley			
Slight	18.6[a]	1.91[a]	81.2[a]
Moderate	23.0[b]	1.76[ab]	66.3[ab]
Severe	28.4[c]	1.60[b]	50.4[b]

Table 3. Total potential plant-available water in the soil profile for Corwin, Miami, and Morley soils for selected sites in Indiana in 1982.

	Plant-Available Water (%)		
Erosion Phase	**Corwin**	**Miami**	**Morley**
Slight	12.92	16.10	7.38
Moderate	9.77	11.47	6.21
Severe	6.63	4.76	3.62

These results are not unique to Indiana. Studies from across the Midwest have measured significantly lower yields on eroded soils (Table 4). Changes in available water holding capacity, topsoil depth, percent clay, and percent organic matter were common explanations for the reduced yield.

Precipitation is also a significant factor in determining the effect of erosion on productivity. With adequate moisture, some researchers saw no yield difference between severely and slightly eroded soils (See IL results in Table 4). The impact of erosion on productivity also depends on the soil type and the shape, aspect, and position of the slope.

Table 4. Results of erosion/productivity studies across the Midwest.

			Limitation on Crop Production					
State	Erosion Class	% Yield Change from Baseline Condition	Decreased AWHC	Lower pH	Increased Bulk Density	Increased % Clay	Decreased Organic Matter	Decreased Rooting Volume
IL	SEVERE	0						
IN	MOD	-5	X			X		
	SEVERE	-15	X			X	X	X
IA	MOD	-7					X	X
	SEVERE	-16	X				X	
MI	MOD	-11		X				
MN	MOD	-3	X				X	
MO	SEVERE [1]	-22						
NE	MOD	-7	X		X	X		
	SEVERE	-9	X		X	X		
ND	SEVERE	-20		X	X	X	X	
SD	MOD	-4		X		X		X
	SEVERE	-16	X	X	X			X
WI	MOD	-8	X					
	SEVERE	-6	X					

[1]Constructed soils were used

In summary, soil erosion can have a significant, negative impact on crop yields, especially in years when weather conditions are unfavorable. As soil erosion continues, the soil is further degraded. Poor soil quality is reflected in decreases in organic matter, aggregate stability, phosphorus levels, and potential plant-available water. The net result is a decrease in soil productivity. Although these studies considered only erosion by water, similar soil degradation and productivity losses can occur as a result of wind erosion.

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Soil Quality Information Sheet

Soil Quality Resource Concerns: Hydrophobicity

USDA Natural Resources Conservation Service **June 2000**

What are hydrophobic soils?

Soils that repel water are considered hydrophobic. A thin layer of soil at or below the mineral soil surface can become hydrophobic after intense heating. The hydrophobic layer is the result of a waxy substance that is derived from plant material burned during a hot fire. The waxy substance penetrates into the soil as a gas and solidifies after it cools, forming a waxy coating around soil particles. The layer appears similar to non-hydrophobic layers.

Plant leaves, twigs, branches, and needles form a layer of litter and duff on the forest floor and under chaparral and shrubs. During the interval between one fire and another, hydrophobic substances accumulate in this layer. During an intense fire, these substances move into the mineral soil. Some soil fungi excrete substances that make the litter and surface layer repel water.

Why is hydrophobicity important?

Fire-induced water repellency can affect soil and the watershed.

- Hydrophobic soils repel water, reducing the amount of water infiltration.
- Decreased infiltration into the soil results in damaging flows in stream channels.
- Erosion increases with greater amounts of runoff, and much of the fertile topsoil layer is lost.
- Increased runoff carries large amounts of sediment that can spread over lower lying areas, clog stream channels, and lower water quality.
- Depending on the intensity of the fire, hydrophobic layers can persist for a number of years, especially if they are relatively thick. A smaller amount of water will penetrate the soil and be available for plant growth.

What affects the development of hydrophobic layers?

Not all wildfires create a water-repellent layer. Four factors commonly influence the formation of this layer. These include:

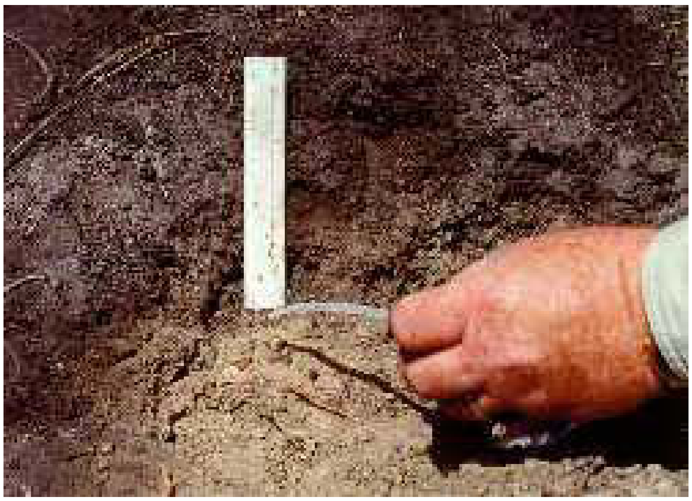
- A thick layer of plant litter prior to the fire
- High-intensity surface and crown fires
- Prolonged periods of intense heat
- Coarse textured soils

Very high temperatures are required to produce the gas that penetrates the soil and forms a hydrophobic layer. The gas is forced into the soil by the heat of the fire. Soils that have large pores, such as sandy soils, are more susceptible to the formation of hydrophobic layers because they transmit heat more readily than heavy textured soils, such as clay. The coarse textured soils also have larger pores that allow deeper penetration of the gas.

The hydrophobic layer is generally ½ inch to 3 inches beneath the soil surface and is commonly as much as 1 inch thick. Some hydrophobic layers are a few inches thick. The continuity and thickness of the layer vary across the landscape. The more continuous the layer, the greater the reduction in infiltration.

How are these layers detected?

Scrape away the ash layer and expose the mineral soil surface. Place a drop of water on air-dry soil and wait 1 minute. If the water beads, the soil layer is hydrophobic. The upper few inches of the soil commonly are not hydrophobic. In these cases, it is necessary to scrape away a layer of soil ½ to 1 inch thick and repeat the test to find the upper boundary of the water-repellent layer. Once a water-repellent layer is found, continue to scrape additional layers of soil, repeating the water drop test on each layer until a non-hydrophobic layer is reached. This procedure will indicate the thickness of the hydrophobic layer.



Considerations for rehabilitation

The amount of vegetative cover, woody material, soil texture, soil crusting, surface rocks, and slope of the land should be considered in any rehabilitation work. The combination of these factors along with the extent and thickness of the hydrophobic layer determine the likelihood of increased runoff, overland flow, erosion, and sedimentation.

Thicker layers will persist for more than a year and will continue to have an impact on infiltration as well as plant growth. Plant roots, soil micro-organisms, and soil fauna break down the hydrophobic layer. The reduction in water infiltration decreases the amount of water available for the plant growth and soil biological activity that break down the hydrophobic layer.

Treatment

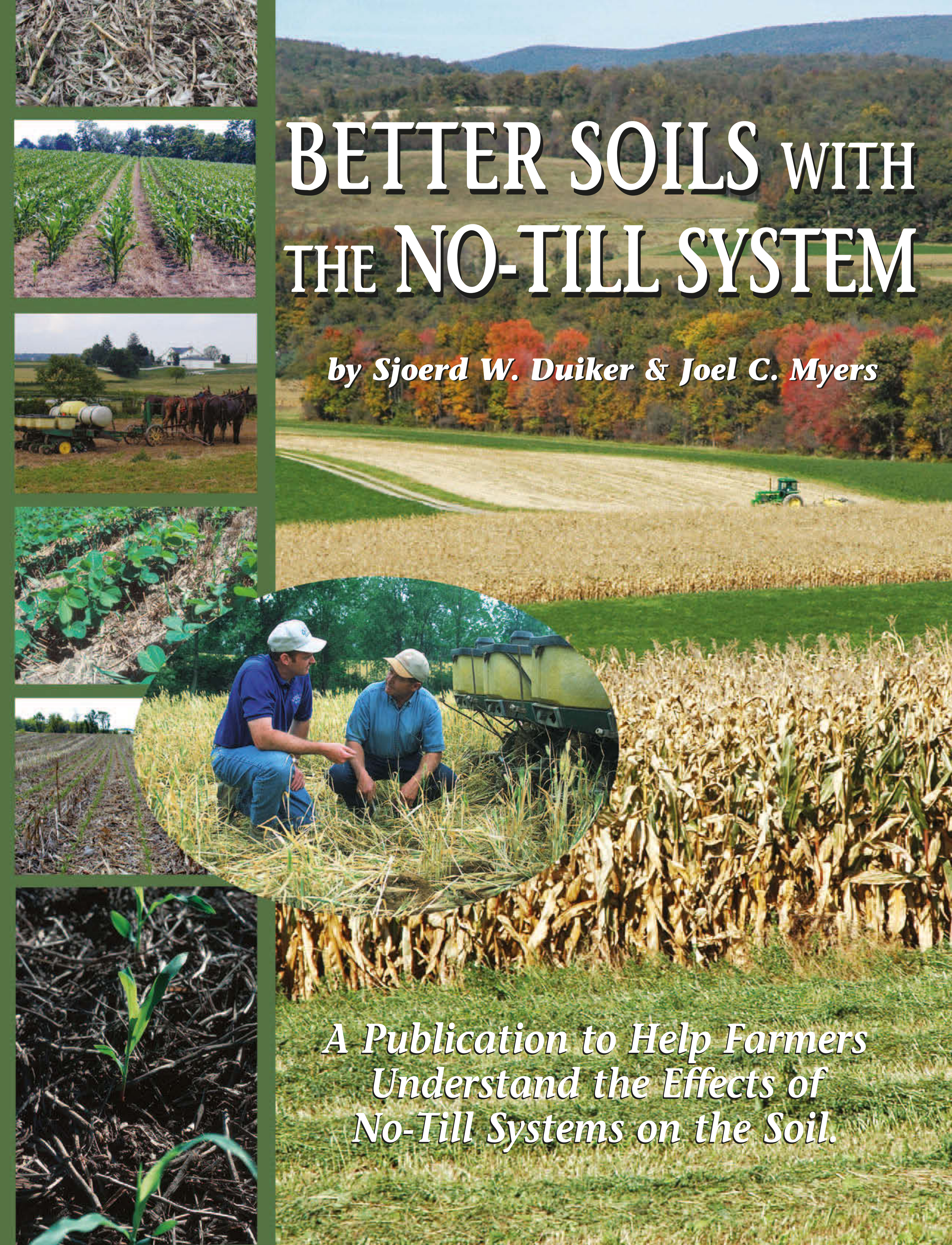
- Place fallen logs across the slope to slow runoff water and intercept sediment.
- On level or gentle slopes, rake or hoe the upper few inches of the soil to break up the water-repellant layer and thus allow water to penetrate the soil for seed germination and root growth.
- On gentle and steep slopes, scatter straw mulch to protect the soil from erosion. Anchor the straw to hold it in place.
- Other practices that control erosion and reduce runoff include seeding, straw bale check dams, and silt fences.

(Prepared by the USDA NRCS Soil Quality Institute)

For more information on soil quality: http://soils.usda.gov/sqi/

BETTER SOILS WITH THE NO-TILL SYSTEM

by Sjoerd W. Duiker & Joel C. Myers



A Publication to Help Farmers Understand the Effects of No-Till Systems on the Soil.

AUTHORS

Sjoerd Duiker and Joel Myers are known throughout
the Northeastern United States as staunch supporters of no-till farming.

Sjoerd Duiker, Ph.D. is an assistant professor of soil management at the Pennsylvania State University. Sjoerd has both research and extension responsibilities in his position in the Department of Crops and Soils at Penn State University. Much of his time is devoted to the impact of no-till on soil quality management. His specialization focuses on the effects of soil management practices on soil properties and processes. He has extensive experience working in the Netherlands, Spain, Africa and the United States. Sjoerd has actively supported no-till throughout Pennsylvania and the northeast and successfully started no-till programs and field days with the Amish in Lancaster County, Pennsylvania. He has actively supported the regional no-till groups in Pennsylvania and made presentations relating to no-till systems at many producer meetings.

Joel Myers is the State Agronomist for the USDA Natural Resources Conservation Service in Pennsylvania. He has promoted no-till through his support of field days, no-till programs and other programs in Pennsylvania. He integrates the principles of no-till into numerous training sessions he conducts. His personal farm experience with complete no-till systems has enabled him to discuss the practical aspects of no-till with producers, agency personnel and others. Joel has spoken several times at the National No-Till Conference. He has been a member of the Mid Atlantic No-Till Conference for over 20 years and has supported and helped start three regional no-till groups in Pennsylvania. He has also been working with researchers and equipment representatives to address the issues of managing manure in no-till systems.

For more information on No-Till in your county contact your local conservation district, NRCS office, Extension agent or the Pennsylvania No-Till Alliance.

The Pennsylvania No-Till Alliance seeks to bring together farmers and others interested in improving soil quality and crop production through the promotion of no-till agricultural systems within the Commonwealth. The main goal of the Alliance is to serve as a network for farmers interested in no-till practices as well as to provide the most recent resources available regarding no-till research, technology and funding. The Alliance will promote the development of strong relationships between producers, private sector, agencies and research institutions in Pennsylvania.

Participation in the Alliance is open to no-till farmers and those supporting no-till agriculture in the private sector. In addition, legislative and governmental agencies provide support and technical guidance as needed.

The successful formation of the PA No-Till Alliance has been the result of a great collaborative effort, and will continue to be mainly a producer-driven organization. Partnering groups/agencies that have been providing support for the effort include:

- USDA/Natural Resources Conservation Service
- Pennsylvania Department of Agriculture
- State Conservation Commission
- Pennsylvania Department of Environmental Protection
- Penn State College of Agricultural Sciences
- Penn State Cooperative Extension
- PA Association of RC&D Councils
- Chesapeake Bay Foundation
- Pennsylvania Farm Bureau
- PennAg Industries Association

For additional information or to join the PA No-Till Alliance, contact Susan Parry at the Capital Resource Conservation and Development Area Council office at (717) 948-6633, or email susan.parry@pa.usda.gov

BETTER SOILS WITH THE NO-TILL SYSTEM

CONTENTS

INTRODUCTION

SOIL IS IMPORTANT

Soil is Important for Crops and Life

Most people do not recognize the important role soil plays in our lives. Soil is a very thin mantle or layer between rock or unconsolidated material in the atmosphere. Because it is such a thin layer, soil is also very fragile and can be easily damaged or even destroyed.

FIGURE 1. The top 1-2" of the soil determines many soil quality properties that impact production and the environment.

Soil thrives with life … if all is well. It provides many critical ecosystem functions that are necessary for life on Planet Earth. A productive agriculture depends on healthy soil. The soil guarantees that nutrients are made available in sufficient amounts during a plant's life cycle. Soil holds water and makes it available to plants so they don't wilt during dry weather. Water is filtered as it percolates or moves through soil. The soil releases water slowly to the surface and subsurface water systems and thus acts as an important flow regulator.

Soil is nature's recycling system, where waste products and dead bodies of organisms are decomposed and their components made available for re-use. Soil is the habitat of a myriad of living

FIGURE 2. Soil erosion, the number one cause of soil degradation.

organisms. Because soil is so important, we, as human beings, need to insure that we are good stewards of this valuable resource.

SOIL IS AT RISK

While soil is a resource that can re-create itself, it is a very slow process. Unfortunately, our nation's soils have been and continue to be degraded at an alarming rate. Soil erosion is still the number one cause of soil degradation. Other causes of soil degradation include: soil compaction, soil acidification, soil pollution, and salinization. Dramatic increases in the use of no-till systems by American farmers have led to many benefits, including reductions in erosion, and savings of time, labor, fuel, and machinery. Between 1990 and 2000, no-till farming acreage rose from 16 million acres to 52 million acres, an increase of 300 percent. Now that some fields have been under no-till production systems for many years, farmers and researchers have begun to notice additional benefits including changes in soil physical, chemical, and biological properties. The most notable of these benefits include increases in organic matter and improved water infiltration. Improved water infiltration can lead to more efficient use of rainfall, increasing yields when rainfall is in short supply.

TABLE 1. Soil loss by erosion in the U.S.

	Cultivated cropland	Uncultivated cropland	CRP land	Pasture land
	SOIL LOSS (TONS PER ACRE)			
1982	4.4	0.7	-	1.1
1987	4.0	0.7	2.0	1.0
1992	3.5	0.6	0.6	1.0
1997	3.1	0.7	0.4	0.9

USDA National Resources Inventory, 1997

Although conservation practices have brought about improvement, the average soil erosion rate on U.S. cropland is still 3.1 tons/acre (Table 1). The erosion rate is often greater than the soil formation rate. As an example, **the average soil erosion rate in Pennsylvania was 5.1 tons/acre in 1997, whereas the tolerable soil loss level is 3-4 tons /acre per year for most of the soils of this state.** With the average loss of 5.1 tons/acre, you can see that the tolerable soil loss level was far exceeded on many fields. That means that our current rate of erosion is a threat to the future productivity of the soil.

Soil erosion removes the best portion of the soil—the part that contains most of the plant nutrients and soil organic matter. In many cases, the topsoil has more favorable soil texture for crop growth than the subsoil. When the topsoil is gone, the farmer is left with less productive subsoil. In addition, eroded soil becomes an environmental threat; polluting streams, lakes, and estuaries. In Pennsylvania, sediment is still the number one pollutant of streams and other bodies of water.

TILLAGE, MAJOR CAUSE OF EROSION

The process of planting, growing and harvesting brings about a certain amount of expected erosion that is considered acceptable to bring a crop to the table. The tolerable soil loss level is called "T" by soil conservationists. The major soil management practice that causes soil erosion is tillage, the process of preparing a field for seeding. Erosion due to tillage can be kept in check through methods such as contour farming, contour stripcropping, conservation buffers, grassed waterways, terraces and diversions to meet soil loss tolerance levels.

You will find that soil can still move within a field—for example, in a strip cropping system where sediment from unprotected soil is trapped by a down-slope strip with high residue or permanent cover. In fact, average soil loss on this entire field or system may be at, or below T, where it exceeds T on the tilled strips. But, if soil can be kept covered, erosion can be stopped before it starts and T can be met on the entire field every year.

The way to dramatically reduce soil erosion is the **no-till systems approach. This method keeps the soil covered with crop residue, reduces soil disturbance to almost zero, and attempts to maximize the number of days in the year when living roots grow in the soil.**

FIGURE 3. Soil tillage is the major cause of soil erosion.

Farmers and researchers have demonstrated that there are many other benefits to the no-till system besides soil savings. For example, a farmer can save significant amounts of time not working the fields prior to planting. That can result in more timely planting as well as increased acreage that can be managed with the same equipment and labor force. The efficiency of field operations will also increase because the farmer can often meet soil conservation requirements in a no-till system without adding as many conservation practices. Finally, the costs of producing a crop are decreased by excluding tillage machinery expenses.

Soil will improve over time in a no-till system through increased organic matter. Soil structure and water infiltration will improve in a no-till system through the slow, but continuous decomposition of crop residue and roots and the high activity of living organisms creating a permanent macro-pore system in the soil. Due to this high biological activity in no-till, soil compaction can be minimized. Finally, there are other environmental benefits of a no-till system that extend beyond the farm—cleaner air and streams and increased groundwater recharge.

THE USE OF CONSERVATION TILLAGE IN THE U.S.

In the 1970s, many researchers believed that by the year 2000, most cropland in the United States would be farmed without tillage. That prediction has not come true, although there

FIGURE 4. Ten Benefits of a No-Till Systems Approach

- Erosion control
- Higher infiltration
- Lower evaporation
- Organic matter conservation
- Improved soil structure
- Higher biological activity
- More earthworms
- Reduced total phosphorus losses
- Lower labor needs per acre
- Higher efficiency of farm operations

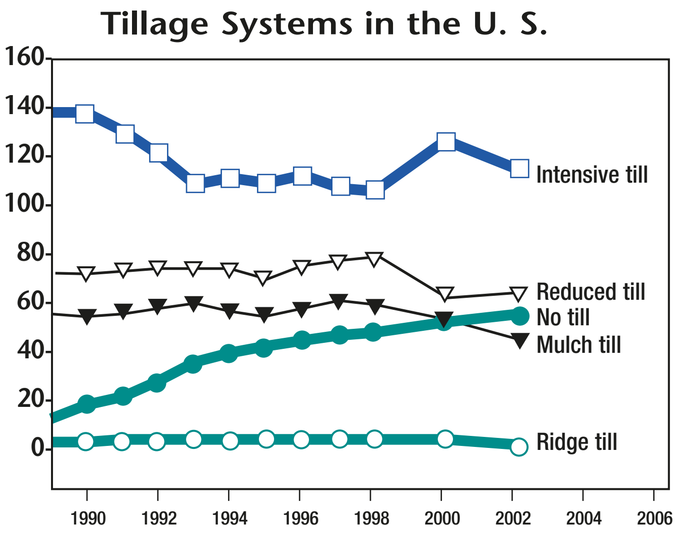


FIGURE 5. No-till is used on a growing amount of acreage in the U.S.

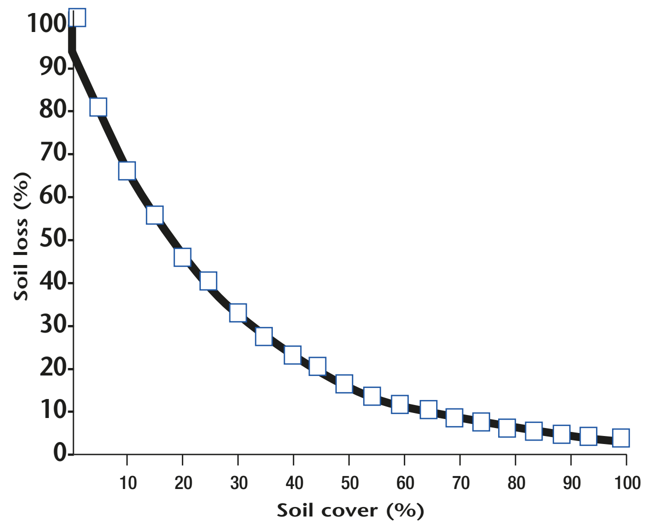


FIGURE 6. Residue cover – relative soil loss relationship. With 30% residue cover, soil loss is reduced 70%.

FIGURE 7. No-till leaves crop residue at the soil surface and reduces soil erosion dramatically.

has been a steady increase in the acreage of no-till (Figure 5). The Conservation Technology Information Center summarizes data collected by USDA-NRCS, Conservation Districts and Cooperative Extension.

Two broad categories of tillage systems are recognized: conservation tillage, which includes all tillage systems that leave more than 30% crop residue cover after planting; and conventional tillage, which leaves less than 30% crop residue cover after planting. **A 30% residue cover limit has been set because significant soil erosion reduction is achieved only when more than this amount is present (Figure 6).**

Conservation tillage includes no-till, mulch-till, and ridge-till. No-till is defined for the survey as conservation tillage acreage where no tillage is done from harvest to planting. It may include very limited in-season tillage for weed control. No-till includes in-row tillage systems such as zone- and strip-till that disturb less than 30% of the soil surface. In 2002, almost 20% of planted acres in the U.S. were no-tilled. Mulch-till includes all other tillage systems which leave more than 30% crop residue cover on the soil surface at planting. It was practiced on 16% of planted acres in 2002. Ridge-till was practiced on 1%. This brings the total percentage of conservation tillage to 36%. Reduced tillage leaves 15-30% residue after planting and was practiced on 23% of planted acres, while intensive tillage (<15% residue cover after planting) represented 41% of planted acres in 2002. Conventional tillage is still practiced on 63% of U.S. cropland.

These statistics hide many important details about changes in tillage systems in the U.S. For instance, across the U.S., more and more farmers use the chisel or disk plow for primary tillage instead of the moldboard plow. However, because they often leave less than 15% crop residue cover after planting, their tillage is still considered intensive because residue cover is the primary determinant of soil erosion. On the other hand, **the use of a continuous no-till system seems to be limited** to a fraction of the no-till acres. Instead, the rotation of no-till with tillage is more common. In the Midwest, many farmers plant soybeans without tillage but corn with tillage in their corn-soybean rotation. There is increasing recognition that many soil quality benefits are linked to the continuous use of a no-till system.

SOIL EROSION

WHEN TO BE READY

Soil erosion depends on many factors: the erosivity of rainfall (mostly related to the intensity and duration of rainstorms), the erodibility of soils, the length and steepness of slopes, and management practices. Although average annual soil loss rates are used for the design of conservation practices, it is important to remember that most erosion is caused by infrequent, heavy rainstorms. Long-term erosion data is available from a few places to verify this.

One site is the USDA-North Appalachian Experimental Watershed in Coshocton, Ohio. This station, established during the Great Depression to develop better farming methods for sloping land, provides a wealth of historical soil erosion data. Observations from 7 watersheds on the station showed that in a 25-year period, most erosion was caused by only 5 rain storms out of a total of almost 4,000. In fact, 75% of the soil erosion was caused by 0.1% of the total number of rainstorms.

To minimize soil erosion, it is necessary to be ready for the big, rare rainfall event at all times. Because of that, we **recommend maximum erosion protection at all times.** It is not

FIGURE 8. Runoff from no-till field on the left and conventional tilled field on the right from plots at Milan Experimental Station, Milan, Tennessee. The clear water from the no-till side of the field is transporting significantly less topsoil, nutrients, and pesticides.

enough to have erosion protection 95% of the time because the rainstorm that causes massive erosion might just occur in that 5% time window that the soil is not protected.

TYPES OF EROSION

There are four different kinds of erosion: sheet, rill, gully and streambank erosion. Only the first three occur on farmland. Sheet erosion is the washing of a uniform sheet of soil from the soil surface. Rill erosion occurs when small parallel rivulets start to form in the field. When these rivulets begin to concentrate, they form gullies. Most soil is lost due to sheet and rill erosion, although these are the least visible forms of soil erosion.

Sheet erosion represents the beginning of the erosion process. If sheet erosion can be stopped, the soil erosion problem is 'nipped in the bud.' Sheet erosion is primarily caused by the effect of raindrops hitting the soil surface. If soil is protected against raindrop impact by crop residue, little sheet erosion takes place. **Therefore, the key to erosion control is to keep the soil covered.**

FIGURE 9. The impact of large raindrops is the major cause of sheet erosion.

It is important to remember that not all rainstorms are equally erosive. Gentle, drizzling rains cause very little erosion in contrast to heavy rainstorms. Raindrops from gentle storms are smaller and fall more slowly than raindrops from heavy storms. The energy of the raindrops is a function of their velocity and their mass, in other words, their speed and size. The kinetic energy of large raindrops is much greater that that of small drops. When those large drops hit the soil surface, they act as small bombs that dislodge soil particles from the soil matrix. **Convective rainstorms (heavy thunderstorms) are frequent in spring or summer in the U.S. These storms are the most erosive so soil cover is especially important during these periods of the year.**

Figure 10. The purpose of conservation tillage is to keep crop residue at the soil surface.

Once soil is dislodged from its matrix, it can be easily carried away. With shallow runoff, raindrops act as stirring rods that keep the eroded soil in suspension. This makes it possible for a shallow flow to transport soil that would normally settle out. More runoff occurs on bare soils than covered soils because small, dislodged soil particles settle out and form a seal that subsequently dries to become a crust. Infiltration or absorption decreases rapidly once a seal or crust is formed.

If the velocity and size of the raindrops can be reduced, sheet erosion will be minimal. This was most vividly illustrated in an experiment with two types of plots—both were cultivated and bare, but one had mosquito gauze placed above it to break up the rain drops and reduce their velocity. When a heavy rain storm hit the two plots, the erosion on the plot with the gauze was 1/100 of the other plot. Again, keeping soil covered is the secret of soil conservation. The purpose of a no-till system is to keep soil covered.

DOES IT REALLY WORK?

How do these principles work in practice? At the North Appalachian Experimental Watershed, one watershed (9% slope) was in long-term no-till corn, where another watershed (6% slope) was moldboard plowed every year prior to corn planting. Because only the grain was harvested and all crop residue was left in the field, virtually 100% of the soil of the no-till watershed was covered all the time.

The most critical period for soil protection in the Northeastern United States is from April-July when most rain falls in high-intensity thunderstorms. When crops are planted using tillage, residue levels are low and therefore susceptible to erosion, as compared to no-till planted crops where residues are present to protect the soil.

FIGURE 11. Chisel plowing is between moldboard plowing and no-till. It does less soil inversion and leaves more residue cover than the moldboard.

During a 4-year period, the annual erosion rate from the no-till watershed was only 6 lbs/A, while it was 4750 lbs/A from the conventionally-tilled watershed. **The erosion from the conventionally tilled watershed was almost 700 times greater than that from the no-till watershed!** This shows the power of maximum-residue no-till.

In a follow-up study, chisel-plowing was compared with no-till in a corn-soybean rotation. Annual soil loss in the chisel plowed watersheds was a small–1100 lbs/A; but it was twice as much as that in the no-till watershed (500 lbs/A). **Chisel plowing is an intermediate practice for soil erosion control between moldboard plowing and no-till,** primarily because soil cover is considerably reduced with chisel plowing.

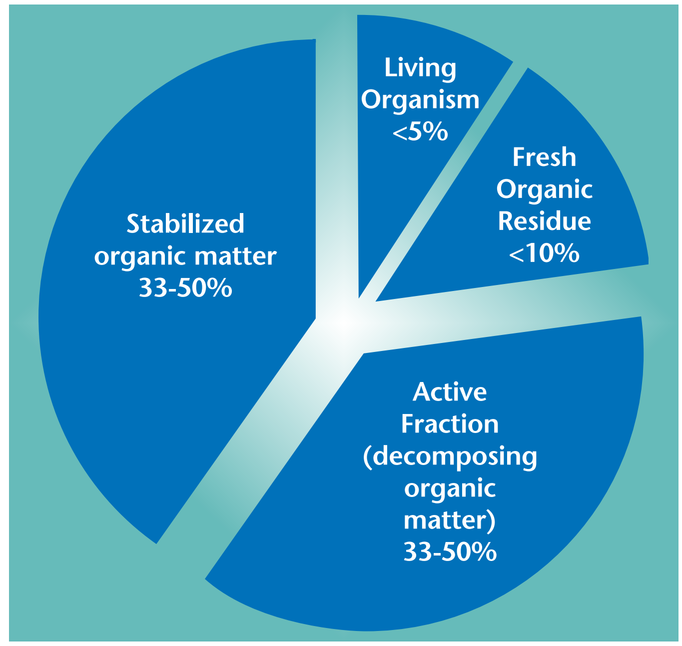


FIGURE 12. Different fractions of organic matter are: living organisms, fresh organic residue, and active and stabilized organic matter. Tillage causes young organic matter to oxidize more quickly leading to a decrease in organic matter content.

SOIL QUALITY

TILLAGE EFFECTS

The most important factor in determining soil quality is soil organic matter. The organic matter consists of living organisms, fresh organic residue, decomposing organic matter, and stabilized organic matter (Figure 12). Carbon makes up about 60% of total soil organic matter content. When the soil is opened up by tillage, large amounts of carbon dioxide are released in a matter of days (Figure 13). This results in reduced organic matter contents and explains why it is very difficult to build up organic matter contents with tillage.

Inversion tillage with the moldboard plow results in the greatest carbon dioxide losses. The deeper the depth of inversion tillage and the greater the volume of soil disturbed, the greater the losses of carbon dioxide. Long-term cropping studies have shown a steady decline in soil organic matter with conventional tillage. Lower losses have been recorded with non-inversion tillage such as chisel plowing. Because tilling a no-till field once can release much of the organic matter that has been previously preserved, **it is important to use no-till continuously within a no-till system.**

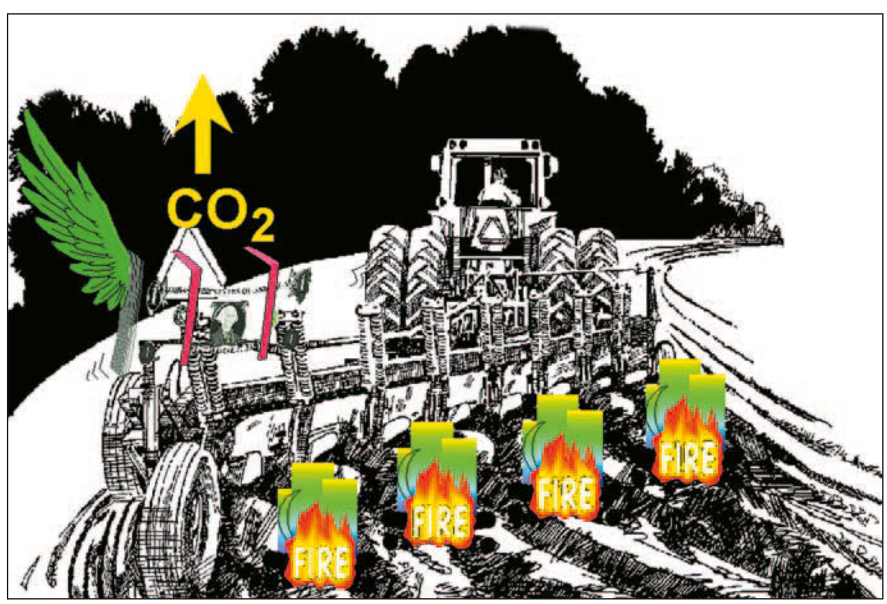


FIGURE 13. Intensive tillage results in the oxidation of organic matter and the release of massive quantities of carbon dioxide. This is like losing money out of your savings account of organic matter.

In a Minnesota study, five times more carbon was lost shortly after moldboard plowing than without tillage. The carbon lost in 19 days after plowing was more than what was present in the roots and straw of the preceding wheat crop. In a review of 20 long-term studies with moldboard plowing, the average loss of organic matter was 256 lbs/acre/yr. These studies were conducted with continuous corn or wheat and rotations of corn with soybeans and oats in Illinois, Oregon, and Missouri.

However, in 10 long-term no-till studies conducted in Ohio, Alabama, Georgia, Kentucky, Illinois, Minnesota and Nebraska, organic matter increased an average 953 lbs/acre/yr. These studies were with continuous corn or soybeans, and corn-soybean rotations. A summary of results with continuous corn or corn-soybean rotations from 4 Midwestern states (Figure 14) shows that approximately 400 lbs/acre/yr were lost with moldboard plowing, 200 lbs/acre/yr were gained with chisel plowing, and more than 1000 lbs/acre/yr were gained with continuous no-till.

WHERE YOU LIVE MATTERS

The potential for increases in soil organic matter is greater in the northern states than in the southern states. This is due to higher temperatures in the south, leading to the higher decomposition of organic matter which increases losses. In dry climates, the potential for organic matter build-up is also smaller because the crops grown produce little residue.

The amount of residue varies per crop. Corn and wheat, for example, return more residue to the soil than soybeans. This means the potential for increases in organic matter is greater with corn and wheat than with soybeans.

In a long-term study, the soil organic matter content was greatest with corn-wheat rotations, smaller with corn-wheat-soybeans-wheat, and smallest with soybeans-wheat.

COVER CROPS ARE IMPORTANT

Growing cover crops can increase organic matter beyond what is possible by simply leaving crop residue in the field. The potential and need for cover crops to build organic matter in the soil is greatest in the southern parts of the United States. Because of higher temperatures, organic matter oxidation is greater in the South. However, cover crop options as well as cover crop biomass production are also greater.

Pioneer research from the southeastern United States is showing the benefits of having actively growing crops in the field 365 days a year. The increased losses of organic matter from heat can be compensated for by combining cover crops and intensive cropping to produce increased residue. In colder regions, options are reduced due to freezing temperatures during part of the year, but there is work taking place to increase opportunities to maximize the time that crops or cover crops grow in the field.

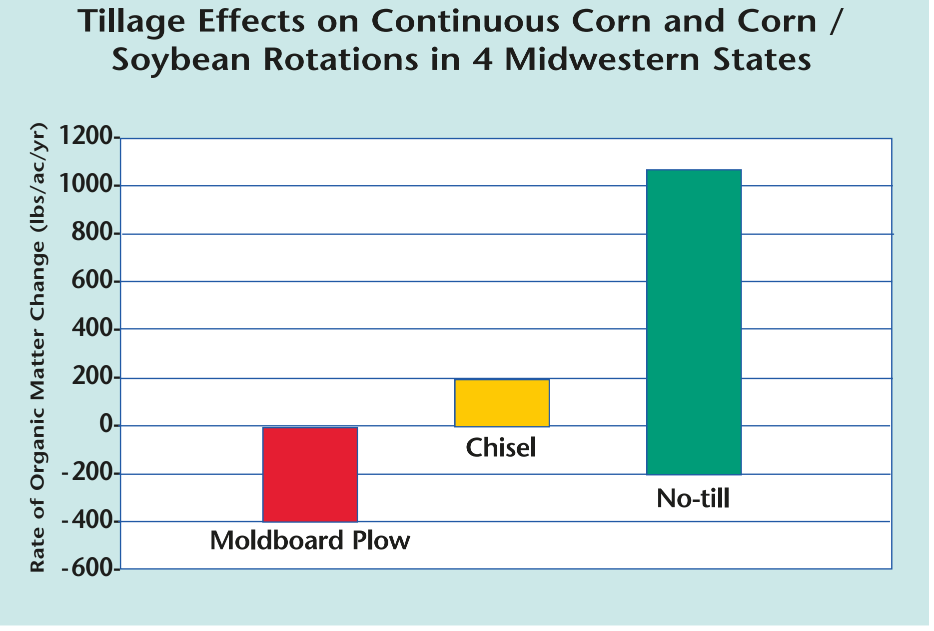


FIGURE 14. Tillage system effects on soil organic matter change recorded throughout long-term studies in 4 Midwestern States.

Nitrogen fertilization to provide optimal plant growth can also increase the rate of organic matter formation. The primary reason for this is the increased root and above-ground biomass production.

Besides increasing total soil organic matter content, no-till results in a different distribution of organic matter (Figure 16). Most organic matter is concentrated at the surface of the soil in no-till where it is mixed in the plow layer with tillage. The residue protects the soil from erosion, surface sealing and crusting. The increased surface organic matter content helps improve soil tilth and aggregate stability. In a conventional tillage situation, the reverse happens and a lack of residue cover exposes the soil to the elements. The result is sealing, crusting, and erosion. No-till has also been found to affect the stability of organic matter pools. The residence time of organic matter in no-till can increase by 10-15 years over conventional tillage.

SOIL STRUCTURE IMPROVEMENT

Over time, soil structure, also referred to as "soil tilth," will improve with no-till. One reason for this is the increased presence of fungal communities in no-till soils when compared with tilled soils (Figure 17). Tilled soils have more bacteria instead of fungi. Fungi form hair-like structures called "hyphae" which act like a net holding small aggregates together in larger units. Another reason for increased aggregation in no-till is the presence of old, partly decomposed roots from the previous

FIGURE 15. A cover crop can serve a multitude of functions, such as erosion protection, nitrogen fixation, additions of crop residue to build soil organic matter contents, and weed control.

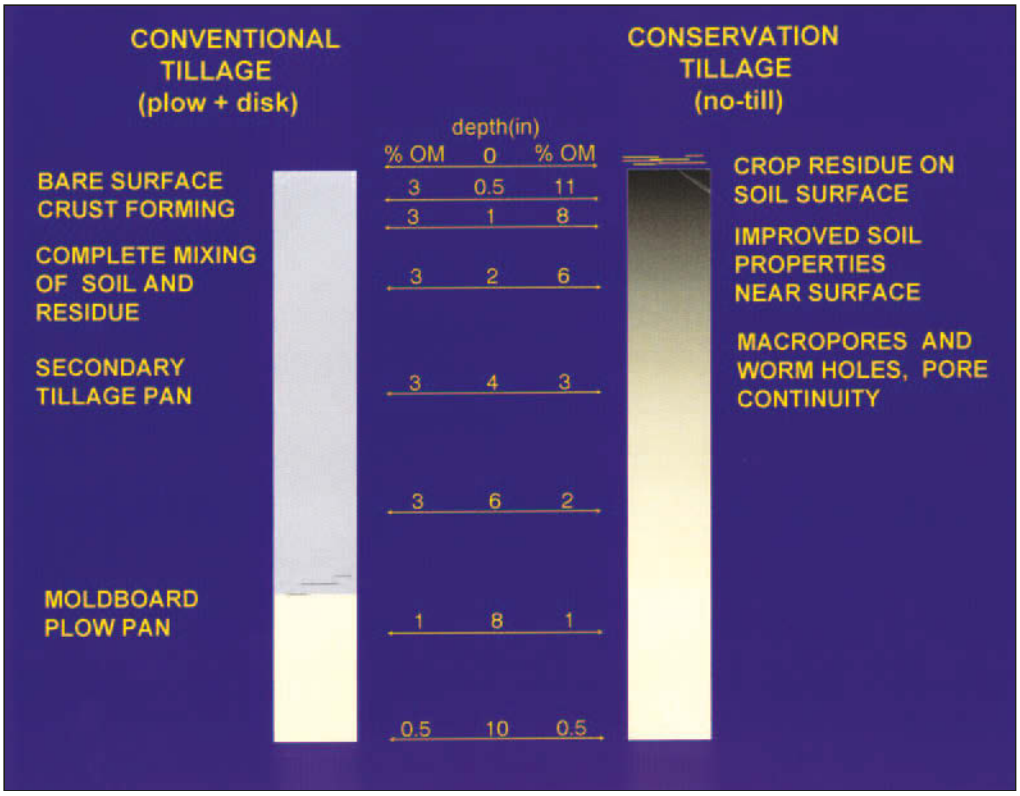


FIGURE 16. Soil organic matter will be concentrated near the surface of no-till soil where it is distributed throughout the plowed layer in moldboard plowed soil.

crops. Finally, the increased organic matter in no-till helps improve soil structure. Stable aggregates in no-till soil resist the sealing of soil surfaces which can cause crusting and water runoff.

Increased aggregation in no-till helps to increase water infiltration and the resistance of the soil to erosion. (Infiltration is the movement of water into and through the soil, feeding plant roots and working its way into groundwater systems.) Additionally, the aggregates enhance conditions for a desirable mix of air and water for good plant growth. They hold more water in place for crops to use.

CHECKING YOUR SOIL CONDITIONS

If you are interested in changes in total organic matter contents, it is important to sample to the same depth over a period of time. Follow state recommendations for the appropriate depth for soil fertility sampling. If soil fertility recommendations in your state are based on a sampling depth of 6 inches, it is important to use that sampling depth. With the increased popularity of continuous no-till, future recommendations may be based on shallower sampling depths. It is important to use the same method of determination to track changes in organic matter over a period of time. Methods vary so check which method is used by your lab and stick with that method to track change.

Soil organic matter content as determined by a lab is on a weight basis (For example, per cent or grams of organic matter per kilogram of soil). It may be more appropriate to compare soil organic matter content on a per acre basis. **To calculate soil organic matter content per acre, you need to know the bulk density of the soil or the weight of soil per unit volume.** Bulk density is usually expressed as metric tons per cubic meter. This becomes important when determining

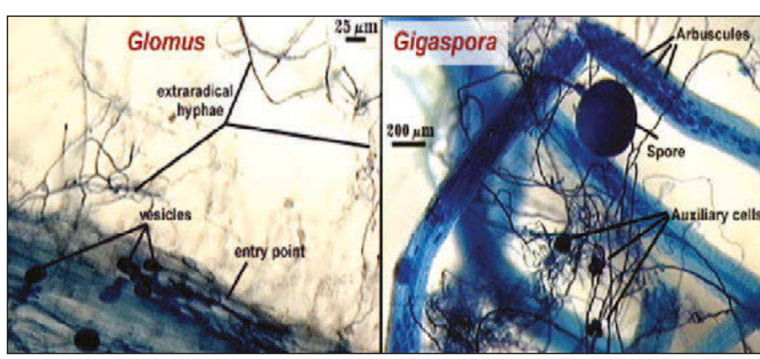


FIGURE 17. Residue is food for fungi and bacteria. The fungal hyphae and fine roots surround and stabilize soil aggregates. These aggregates don't easily fall apart with the action of rain or wind.

the effect of tillage systems on organic matter contents.

The bulk density of no-till soil is sometimes greater than that of conventionally tilled soil. In those cases, differences in organic matter content between the two systems are greater on a per-acre basis than on a weight basis. Much depends on the time of the sampling and the amount of time a soil has been in no-till. Shortly after tillage, a tilled soil is usually fluffy and has a lower bulk density than its no-till counterpart. However, at the end of the season, the difference in bulk density may be negligible because the tilled soil has settled. Increased organic matter contents in no-till may further reduce bulk density.

TABLE 2. A 4-year comparison of runoff and erosion on a no-till and moldboard plowed watershed at the North Appalachian Experimental Watershed.

YEAR	RAINFALL (inches)	RUNOFF (inches)		EROSION Lbs / A	
		NO-TILL	MOLDBOARD	NO-TILL	MOLDBOARD
1979	44	0.14	5.52	8	436
1980	46	0.19	12.47	15	8455
1981	42	0.00	5.60	1	7645
1982	35	0.00	4.46	0	2461
Average		**0.09**	**7.01**	**6**	**4748**

WATER IN THE SOIL

Many long-term no-till farmers have noted improvements in water infiltration or absorption in their fields. There are times during the same storm when no runoff occurs in no-till fields while adjacent tilled fields produce large amounts of water and sediment runoff. Similar observations have been made by researchers. At the North Appalachian Experimental Watershed, runoff from the no-till watershed was only a fraction of that of the moldboard plowed watershed (Table 2). Here we see the power of residue cover illustrated again. By breaking the impact of falling raindrops, soil sealing and crusting is reduced dramatically. Improved surface tilth also stimulates infiltration. **The channels created by soil organisms such as worms, soil insects and the decomposed plant roots that are found in the continuous no-till system increase water infiltration.** The residues on the soil surface act as small barriers, slowing runoff and giving water a greater opportunity to infiltrate.

FIGURE 18. Soil organic matter is conserved by using no-till, which results in better soil structure.

THE ROLE OF EARTHWORMS

Burrows of earthworms and soil insects have been discovered to be important in improving water infiltration. One earthworm species are nightcrawlers *(Lumbricus terrestris L).* They are surface feeders and construct vertical burrows. **In one study, up to 10.3% of simulated rainfall infiltrated through these burrows although they only occupied 0.3% of the horizontal area of the no-till field.** Tillage not only destroys the tops of the burrows, but more importantly destroys the habitat of the nightcrawlers. These earthworms need surface residue that they pull to the mouth of their burrow. If a soil is devoid of crop residue, nightcrawlers will be scarce or absent.

There are other earthworms that live in the surface of the soil. These earthworms are not as sensitive to tillage. They fill their burrows with casts as they go. These earthworms also have a positive influence on soil structure, which helps infiltration. In a study in Indiana, the number of earthworms (nightcrawlers and other species combined) was twice as high in continuous no-till fields as in moldboard plowed fields. In Missouri, up to 8 times more earthworms were counted in continuous no-till corn than in moldboard plowed corn.

FIGURE 19. Nightcrawlers live in vertical burrows that can extend 4-6 feet deep. Water can quickly infiltrate through these burrows. Nightcrawler excrements are called casts. Deposited at the soil surface, casts contain high contents of organic matter and nutrients. They form stable aggregates when dry.

CONTRADICTORY RESULTS

In some cases, tillage temporarily increases infiltration compared to no-till. Several explanations can be offered.

- Shortly after tillage, infiltration can be high because of increased surface roughness and high porosity. This increase is usually short lived. After heavy rainstorms hit the soil, surface clods start to break down, roughness decreases, and because of sealing and crusting, infiltration decreases. Despite the fact that total porosity may be lower in continuous no-till, infiltration may still be higher because of pore continuity, soil protection against the action of raindrops, better surface tilth, and surface residue that obstructs runoff. However, if a farmer causes compaction in no-till, infiltration can be negatively affected. Judicious use of “vertical tillage” may be justified in these conditions. Vertical tillage disturbs below the soil surface without a reduction of surface residue cover. The use of vertical tillage is recommended to maintain the benefits of maximum residue cover.
- Another reason infiltration is not always higher in no-till versus full tillage may be due to the methodology used in some research studies. In one review of 45 different studies, runoff with no-till was on average reduced only 14% compared with conventional tillage. In some studies, runoff was greatly reduced due to no-till, but in other studies, there was no reduction or even increased runoff with no-till. Many of these studies were rainfall simulation studies. In these studies, it is typical to prepare a site (preferably without a growing crop) and simulate a very heavy rainfall event for half an hour to an hour. The methodology often dictates that the rainfall is applied shortly after tillage when infiltration may still be

FIGURE 20. This table top rainfall simulator shows the dramatic differences in quantity and quality of runoff associated with high residue farming versus clean tillage. All trays received the same amount of simulated rainfall.

high. Little time is available for surface roughness to disappear as happens in a field situation.

In the field, runoff usually increases with time in tilled fields and decreases with time in no-till fields. Another peculiarity of these simulation studies is that the fields may not be in no-till for a long period of time. There has not been time for the macro-pore system to develop, or for surface soil tilth to improve. It is more realistic, therefore, to determine the effects of continuous no-till on infiltration in long-term field studies subject to natural rainfall where runoff is measured continuously.

Even if the infiltration of natural rainfall is measured over the full growing season in continuous no-till, there may be no measured improvement of infiltration. Two factors may help to explain the disparity: soil type and time in no-till. If soils have restrictive subsurface layers or are poorly drained, increased crop residue and organic matter at the surface cannot overcome a profile that is already full of water or has a restricted ability to transmit water to lower layers. These soils are not a good habitat for nightcrawlers and other earthworms, and will not benefit as much from

TABLE 3. Hydrologic soil group characteristics.

SOIL GROUP	SOIL GROUP CHARACTERISTICS
A	Soils having high infiltration rates, even when thoroughly wetted and consisting chiefly of deep, well to excessively-drained sands or gravels. These soils have a high rate of water transmission.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
D	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

TABLE 4. Summary of natural rainfall studies comparing water runoff with continuous no-till to conventional tillage (usually moldboard plow).

HYDROLOGIC SOIL GROUP	AVERAGE WATER RUNOFF IN NO-TILL AS % OF CONVENTIONAL TILL	CROPS	AVERAGE # YEARS IN NO-TILL	STATES
B	56%	Corn, soybean, cotton, rye, tobacco	5	IA, KY, MO, MD, NC, AL
C	67%	Corn, soybean, sorghum, cotton, tobacco, rye	6	OH, MS, NC
D	101%	Corn, soybean,	4	MO, MS, MD

their activity. **Soil hydrologic categorization is one way of grouping soils with respect to their potential to result in reduced runoff with no-till.** Hydrologic groups are mostly determined by soil texture and restrictive layers in the soil that slow water movement in the soil (Table 3).

Table 4 is a summary of runoff measured in various studies with natural rainfall. The studies have been grouped according to hydrologic soil group and the average number of years in no-till as indicated. The salient result of these studies is that runoff was dramatically reduced in continuous no-till fields on Group B and C but not on Group D soils. **It must be concluded that the runoff-reducing benefits of no-till will be greatest on coarse to medium textured soils that do not have an impeding layer or water table near the surface.**

Even on soils that have a moderate to fine texture or an impeding layer, no-till can still offer substantial runoff reduction as long as they are not too heavy and the impeding layer is not too close to the soil surface. Soils that are fine-textured have heavy swell/shrink clay or a restricted layer near the surface are not likely to show reduced runoff with no-till. It is interesting to note that the coarse to moderately textured soils also respond favorably to no-till crop production.

Clay soils are the most challenging for no-till. No-till crop yields are customarily higher or equal to those achieved with conventional tillage on Group A, B and C soils, but are often reduced on Group D soils. It may be necessary to make modifications to no-till equipment to improve crop yields and infiltration on Group D soils. Examples are in-row tillage techniques such as strip or zone-tillage that leave full residue cover between rows. Artificial drainage will also help to make these soils more suitable for no-till crop production. Crop rotation also becomes more important on these more challenging no-till soils.

When a farmer changes from plowing to no-tillage, the soil (and the farmer!) needs to adapt to the new management system. Organic matter content slowly increases and biological activity creates a new soil macro-pore system. This period may be associated with reduced yields in no-till until a new ecological equilibrium is achieved in the soil. There are some ways to get around this transition period.

If no-till annual crop production can be started immediately following a perennial grass or legume crop, the transition period can be reduced or eliminated. The perennial crop gives soil organisms the chance to develop a macro-pore system and improve soil tilth without tillage and with residue cover. The **extensive root systems and high root turnover of grasses will stimulate porosity and aggregate stability.** Taproots of some perennial legumes such as alfalfa will, upon death and decomposition, leave large vertical channels that help improve infiltration.

The benefits of starting no-till in a sod were illustrated in one study. Corn was established into sod with and without tillage. Water runoff occurred on the tilled plots when less than 1.5 inches of water was applied while no runoff occurred on the no-till plots even when 5.3 inches of water was applied. In another study in Kentucky, runoff was reduced 83% when planting no-till into a bluegrass sod as compared to conventional tillage, despite the fact that 5.2 inches of rain fell after tillage when infiltration is highest.

PESTICIDE EFFECTS ON WATER QUALITY

Reduced runoff with long-term, continuous no-till has many environmental advantages. However, some may comment that no-till is likely to pollute the natural environment due to a heavy reliance on chemical pesticides and a fear that those pesticides will end up in our surface and groundwater.

A decade ago, a review of the impact of conservation tillage (no-till, ridge till or mulch till) on pesticide runoff into surface water appeared in the Journal of Soil and Water Conservation. In the article, it was first concluded that total pesticide use in conservation tillage has not appreciably increased when compared with conventional tillage. Many people forget that even with conventional tillage, most farmers use herbicides for weed control and some insecticides and fungicides for insect and disease control. With the use of crop rotation, pesticide use in conventional tillage as well as no-till can be significantly reduced. **Crop rotation is an essential component of sustainable no-till systems.**

In no-till systems, a farmer will have to use a burndown herbicide application to eradicate any weeds or cover crops that are present at planting. After that, there is no need for different amounts of herbicide applied in no-tillage versus conventional tillage, although the types of herbicides may be different. Common burndown herbicides such as paraquat and glyphosate bind very tightly to soil particles and are mainly lost from fields associated with sediment.

Because erosion is dramatically reduced in no-till, and these herbicides are very quickly broken down by soil organisms into harmless compounds, the threat of surface water contamination is very small. What is more important, however, is that runoff is significantly reduced in no-till compared to conventional tillage. Because of this, the likelihood of the pesticides ending up in surface water is small (even those that do not bind to soil particles and are easily dissolved in runoff).

In a review of a large number of natural rainfall studies, the average herbicide loss in runoff from no-till and chisel plowed fields was 30% of that in moldboard plowed fields. The greatest threat of surface-applied herbicides leaving the field in runoff was if heavy rainfall occurred very soon after herbicide application. It should be noted that sometimes the concentration of herbicide in runoff was higher in no-till than conventional tillage, but because the total volume of runoff was small, total losses were significantly less with no-till. **In summary, it is justified to expect lower pesticide losses from no-till fields than from conventionally tilled fields because of smaller runoff and reduced erosion rates.**

SOIL COMPACTION

Some say soil compaction in no-till is less; some say it is more than with tillage. What to believe? It is first of all important to note that most soil compaction research has been done with conventional tillage, not with no-till. We know far less about soil compaction in no-till than in tillage systems. With increased adoption of no-till, however, more research is being initiated.

COMPACTION IS DIFFERENT IN NO-TILL

Compaction is caused by the movement or traffic of vehicles, livestock or humans over the surface of the soil. There are a few factors that change the effects of traffic in no-till fields compared to tilled fields. Over time, organic matter content in the surface soil increases with no-till. Soils with high organic matter content cannot be compressed as easily as those with low organic matter content. This means that compaction in the top 2 inches is not of great concern in long-term no-till. In addition, a firm no-till soil matrix with macropores for air and water movement can better support traffic without being compressed than a soft, tilled soil.

The higher biological activity in no-till soils also helps alleviate the effects of compaction. However, the soil under crop residue often stays wet longer than in clean tilled conditions. This makes it more likely the farmer will be in the field when soil conditions are really too wet for traffic in no-till.

In addition, no quick alleviation of compaction with tillage equipment takes place in no-till. Overall, research is suggesting that soil compaction can be a significant threat in no-till systems. In one study, extreme soil compaction of the complete soil surface to a depth of 12 inches reduced crop yields 98% compared to non-compacted long-term no-till fields. It was interesting that the following year, the yield in the compacted fields increased to 85% of that in the non-compacted plots. The recovery from soil compaction (without tillage) was attributed to high biological activity.

In another study, soil compaction due to heavy axle loads caused a 15-30% reduction in yield in a long-term no-till field. Soil compaction can increase soil density, and

FIGURE 21. Care has to be taken not to compact the soil in no-till. This can be achieved by avoiding traffic at suboptimal soil moisture conditions, using low tire pressure or tracks, and reducing axle load at least below 10 tons. Improving soil organic matter contents and stimulating soil biological activity make soil more resilient to compaction.

reduce porosity and infiltration in no-till soils. In a controlled traffic study in long-term no-till, infiltration was significantly reduced in wheel tracks compared to non-wheel tracks. In the non-trafficked area, the first inch of water took 2 min 15 sec to infiltrate and the second inch took 31 minutes. In a wheel track, the first inch took 7 minutes, whereas the second inch took more than 3 hours. This illustrates that soil compaction can significantly compromise soil quality in long-term no-till.

MINIMIZING AND ALLEVIATING COMPACTION IN NO-TILL

Farmers have some options to manage soil compaction in no-till. The very first principle is that soil compaction does not pose a significant threat if a farmer limits his traffic to dry soil conditions. It is only because field operations cannot always be tailored to soil moisture conditions that soil compaction becomes a threat. To limit soil compaction a farmer should limit his axle load to 10 tons (preferably 6 tons), and use flotation tires or tracks instead of road tires.

Another, even better solution is to use traffic lanes. By keeping all wheel traffic limited to permanent tracks, the areas between tracks will never be affected. If wide wheel spacing can be used, a limited area of the field will be impacted by traffic. The disadvantage of such an approach is that all heavy equipment has to be re-engineered to be on the same wheel spacing.

Research into using cover crops to alleviate soil compaction has not resulted in widely accepted solutions, although there are indications that cover crops with vigorous root systems or tap roots help loosen compacted soil.

A compromise of the no-till system may be to use vertical, in-row tillage techniques. There are different equipment options to alleviate soil compaction without disturbing surface residue cover. These 'vertical tillage tools' are consistent with the no-till system because they maintain surface residue cover. This method combines the benefits of mulch cover between rows with the compaction alleviation of tillage equipment in the row.

FIGURE 22. Manure injection limits ammonia losses and odor from liquid manure in no-till.

MANURE IN NO-TILL

PROS AND CONS OF MANURE IN NO-TILL

Many successful long-term no-tillers use surface-applied poultry and animal manure. Surface-applied manure serves:

1. as food for soil microbes, earthworms and night crawlers.
2. to enhance supplement surface residue, especially when solid manure and/or bedded pack manure is used.
3. as a source for soil organic matter.
4. to reduce the transition period for those just beginning no-till systems.

It should also be noted that surface application of manure reduces equipment costs for manure incorporation and saves time.

A disadvantage of the surface application of manure is the nitrogen loss due to ammonia volatilization that is likely to be higher compared to immediate incorporation into the soil.

It should be noted that when surface applied manure receives 0.5 inches rainfall or more, ammonia volatilization losses are the same as if manure had been incorporated. Early in the spring of the year when temperatures are generally cooler, the chances of rainfall occurring to reduce nitrogen losses is greater. Also, with cooler soil temperatures, nitrogen lost on a daily basis is reduced so rainfall several days after application will save more nitrogen than if manure is applied when temperatures are higher.

USE OF COVER CROPS

The use of cover crops becomes a very important consideration in the application of manure in terms of the uptake of nutrients, reduced runoff and increased infiltration and, in general, a reduction in soil erosion. Cover crops are essential to conserve nitrogen from fall-applied manure. The cover crop should be established using no till equipment, by airplane or helicopter, or by lightly incorporating during the process of manure handling as described earlier in this section.

EQUIPMENT BEING STUDIED

Research is currently underway to evaluate the use of minimal disturbance equipment such as rotary harrows, spiked rollers, and manure injectors to improve infiltration of liquid manure and to mix solid, semi solid or slurry manure with the upper several inches of the soil or place the manure under the soil surface. In all these instances, the key is to cause minimal impacts to the integrity of the soil in a no till system, which includes using no additional tillage equipment and retaining a high percentage of the surface residue which exists prior to the application of manure.

CONCLUSION

In a no-till systems approach, a producer aims to keep soil covered with crop residue, reduce soil disturbance to zero, and maximize the number of days with living roots in the soil. This system can lead to dramatically reduced erosion, increased soil quality, and improved water quality when compared with conventional tillage. It can help agricultural producers improve the efficiency and profitability of their operation and to improve their environmental stewardship. Society will benefit from the improved water and air quality that result from increased use of no-till systems.

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Page 12.	Figure 16.	*Better Soil Better Yields,* Conservation Techology Information Center (2002)
Page 12.	Figure 17.	Agricultural Research Service
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Page 15.	Figure 20.	USDA - Natural Resources Conservation Service

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"Better Soils with the No-Till System" is written to encourage farmers to obtain the benefits of reduced time spent tilling, increased moisture content in the soil, and healthy soil for growing crops from the micro- and macro-invertebrates that live within.

Many thanks to those farmers who have put these practices to work on their land and shared their successes. They are truly stewards of the land.

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PA6/05

Soil Quality Information Sheet

Rangeland Soil Quality—**Water Erosion**

USDA, Natural Resources Conservation Service **May 2001**

What is water erosion?

Water erosion is the detachment and removal of soil material by water. The process may be natural or accelerated by human activity. The rate of erosion may be very slow to very rapid, depending on the soil, the local landscape, and weather conditions.

Water erosion wears away the earth's surface. Sheet erosion is the more-or-less uniform removal of soil from the surface. Rill and gully erosion occurs when concentrated runoff cuts conspicuous channels into the soil. Deposition of the sediment removed by erosion is likely in any area where the velocity of running water is reduced—behind plants, litter, and rocks; in places where slope is reduced; or in streams, lakes, and reservoirs.

Why is erosion a concern?

Loss of topsoil changes the capacity of the soil to function and restricts its ability to sustain future uses.

Erosion removes or redistributes topsoil, the layer of soil with the greatest amount of organic matter, biological activity, and nutrients. The ability of a plant community to recover after topsoil is lost is restricted.

Erosion breaks down soil structure, exposing organic matter within soil aggregates to decomposition and loss. Degraded soil structure reduces the rate of water infiltration.

Erosion of nutrient-rich topsoil can cause a shift to less desirable plants, such as from grass to shrub species. In this process, soil organic matter and nutrients eroded from one area contribute to resource accumulation in another, such as the area around shrubs.

Erosion of shallow soils can decrease the thickness of the root zone and the amount of air, water, and nutrients available to plants.

The sediment removed by erosion can bury plants and roads; accumulate in streams, rivers, and reservoirs; and degrade water quality.

What causes water erosion?

Erosion is caused by the impact of raindrops on bare soil and by the power of running water on the soil surface. Natural erosion rates depend on inherent soil properties, slope, and climate, which together determine the ability of the site to support vegetation. Accelerated erosion occurs when the plant cover is depleted, the spaces between plants becomes larger, and soil structure is degraded by excessive disturbance or reduced inputs of organic matter. Compaction increases runoff and the risk of accelerated erosion. Runoff concentrated by poorly designed or maintained roads or trails can cause accelerated erosion on the adjacent slopes and in roadbeds.

Many vegetation and soil properties affect the risk of erosion. Each specific soil has its own natural erosion rate. A sandy or clayey texture generally is less erodible than loam or silt loam. Sandy soils that formed in material weathered from decomposed granitic rock, however, are highly erodible. Soils with rock fragments or biological crusts on the surface are protected from the impact of raindrops. Stable soil aggregates bound together by organic matter resist erosion, enhance infiltration, and result in less runoff. The amount of runoff and the power of water to erode and transport soil are greater on long, steep slopes. Bare soil between plants is most susceptible to erosion.

What are some indicators of erosion?

Erosion and the risk of erosion are difficult to measure directly. Other soil properties that affect erosion and can change with management, including soil surface stability, aggregate stability, infiltration, compaction, and content of organic matter, can be measured. Measuring these properties can shed light on the susceptibility of a site to erosion. Comparing visual observations along with quantitative measurements to the conditions indicated in the ecological site description or a reference area helps to provide information about soil surface stability, sedimentation, and soil loss.

The visual indicators used to identify past erosion include:

- bare soil;
- pedestaled plants or rocks;
- exposed roots;
- terracettes (benches of soil deposited behind obstacles);
- an increase in the number and connectivity of waterflow patterns between plants;
- soil deposition at slope changes;
- changes in thickness of topsoil;
- exposure of subsoil at the surface;
- rills, headcutting, and/or downcutting in gullies;
- sediment in streams, lakes, and reservoirs; and
- reduced plant growth.

When measured every few years, the following indicators can be used to predict where accelerated erosion is likely to occur in the future:

- an increase in the amount of bare ground or in the size or connectivity of bare patches,
- reduced soil aggregate and soil surface stability, and
- reduced water infiltration.

Management strategies that minimize water erosion

The risk of erosion and the potential for recovery after erosion must be considered in any management plan. The risk of erosion is increased by a fire frequency or intensity that is either greater or less than is expected for the site; by disturbances, such as heavy grazing; and by the establishment of weeds. Areas with fertile topsoil are most likely to recover after a disturbance. In areas where much of the topsoil is lost, the site may no longer be able to support the historic vegetation. Management strategies include:

- Maintain or increase the cover of plants or litter on the soil through the application of good rangeland management practices.
- Reduce soil surface disturbances, especially in arid areas.
- Increase the rate of water infiltration and improve soil aggregate stability by improving or maintaining the quality of the plant community.
- Minimize grazing and traffic when the soil is wet and thus prevent the reduced infiltration caused by compaction and physical crusting.
- Build water bars and direct waterflow from roads, trails, or vehicle tracks across the slope or into existing drainageways.
- Maintain road surfaces and drainageways.

For more information, check the following: http://soils.usda.gov/sqi **and** http://www.ftw.nrcs.usda.gov/glti

(Prepared by the Soil Quality Institute, Grazing Lands Technology Institute, and National Soil Survey Center, Natural Resources Conservation Service, USDA; the Jornada Experimental Range, Agricultural Research Service, USDA; and Bureau of Land Management, USDI)

Soil Quality Information Sheet

Rangeland Soil Quality—**Wind Erosion**

USDA, Natural Resources Conservation Service **May 2001**

What is wind erosion?

Wind erosion is the physical wearing of the earth's surface by wind. Wind erosion removes and redistributes soil. Small blowout areas may be associated with adjacent areas of deposition at the base of plants or behind obstacles, such as rocks, shrubs, fence rows, and roadbanks. In many cases the fine soil particles and organic matter are blown offsite or into the atmosphere as dust. Reducing the amount of bare ground by increasing the extent of vegetation, litter, and biological crusts reduces the risk of wind erosion.

Why is erosion a concern?

Loss of topsoil changes the capacity of the soil to function and restricts its ability to sustain future uses.

Erosion removes topsoil, the layer of soil with the greatest amount of organic matter, biological activity, and nutrients, creating a less favorable environment for plant growth.

Erosion breaks down soil structure, exposing organic matter within soil aggregates to decomposition and loss. Degraded soil structure reduces the rate of water infiltration.

Erosion of nutrient-rich topsoil can cause or accelerate a shift to less desirable plants, such as from grass to shrub species. In this process, soil organic matter and nutrients eroded from one area contribute to resource accumulation in another, such as the area around shrubs.

Erosion decreases soil depth and therefore the amount of air, water, and nutrients available for plant growth. This decrease can have a greater impact on shallow soils than on other soils.

Windblown dust affects animal and human health, creates public safety hazards, and degrades air quality.

Deposits of windblown soil can bury plants and fences and obstruct roadways.

What causes wind erosion?

Wind erosion can occur only when windspeed at the soil surface is sufficient to lift and transport soil particles. Moist soils and soils with stable aggregates or rock fragments are less likely to be eroded than other soils. Thick lichen crusts provide greater resistance to erosion than thin crusts. Sand moving across the soil surface wears away soil aggregates and thin crusts, causing more soil particles to become detached and to be blown away. A cover of plants disrupts the force of the wind.

Soils are more susceptible to wind erosion where disturbance exposes individual particles and soil aggregates to the wind. When physical or biological crusts are crushed or broken apart by such disturbances as heavy grazing, vehicle or foot traffic, and water erosion, particle movement begins at the lower windspeeds. The following conditions increase the susceptibility of the soil to wind erosion:

- crushed or broken soil surface crusts during windy periods;
- a reduction in the plant cover, biological crusts, and litter, resulting in bare soil;
- a decrease in the amount of organic matter in the soil, causing decreased aggregate stability; and
- long, unsheltered, smooth soil surfaces.

What are some indicators of wind erosion?

Erosion and the risk of erosion are difficult to measure directly. Other soil properties that affect erosion and can change with management, including soil surface stability, aggregate stability, and content of organic matter, can be measured. Measuring these properties can shed light on the susceptibility of a site to erosion. Comparing visual observations along with quantitative measurements to the conditions in the ecological site description or a reference area helps to provide information about soil surface stability and wind erosion.

The visual indicators used to identify past erosion include:

- bare soil,
- wind-scoured areas between plants,
- a drifted or rippled soil surface,
- loose sand on physical crusts,
- biological crusts buried by soil,
- pedestaled plants or rocks,
- exposed roots,
- soil deposition on the leeward side of plants and obstacles,
- litter movement to the leeward side of plants and obstacles,
- exposure of subsoil at the surface,
- reduced plant growth, and
- dust clouds.

When measured over time, the following indicators can be used to predict where accelerated erosion is likely to occur in the future:

- an increase in the amount of bare ground or in the size of bare patches,
- reduced soil surface stability, and
- a reduction in the amount of organic matter.

Management strategies that minimize wind erosion

The risk of erosion and the potential for recovery after erosion must be considered in any management plan. Disturbances, such as heavy grazing, fire that removes too much plant cover and litter, or vehicle and foot traffic, can increase the risk of wind erosion. Physical crusts protect the soil from wind erosion but can retard plant establishment. Areas with fertile topsoil are most likely to recover after a disturbance. Where much of the topsoil is lost, the site may no longer be able to support the historic vegetation. Management strategies include:

- Maintain or increase the protective cover of plants and litter on the soil through the application of good rangeland management practices.
- Reduce disturbances of physical and biological crusts, especially in arid areas.
- Maintain soil aggregate stability by improving or maintaining the quality of the plant community.

Lichen and cyanobacteria stabilize soil.

A physical crust protects soil.

For more information, check the following: http://soils.usda.gov/sqi **and** http://www.ftw.nrcs.usda.gov/glti

(Prepared by the Soil Quality Institute, Grazing Lands Technology Institute, and National Soil Survey Center, Natural Resources Conservation Service, USDA; the Jornada Experimental Range, Agricultural Research Service, USDA; and Bureau of Land Management, USDI)

SOIL PIPING
IN SOUTHEASTERN ARIZONA

By
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NOVEMBER 1949

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
REGION 6, ALBUQUERQUE, NEW MEXICO

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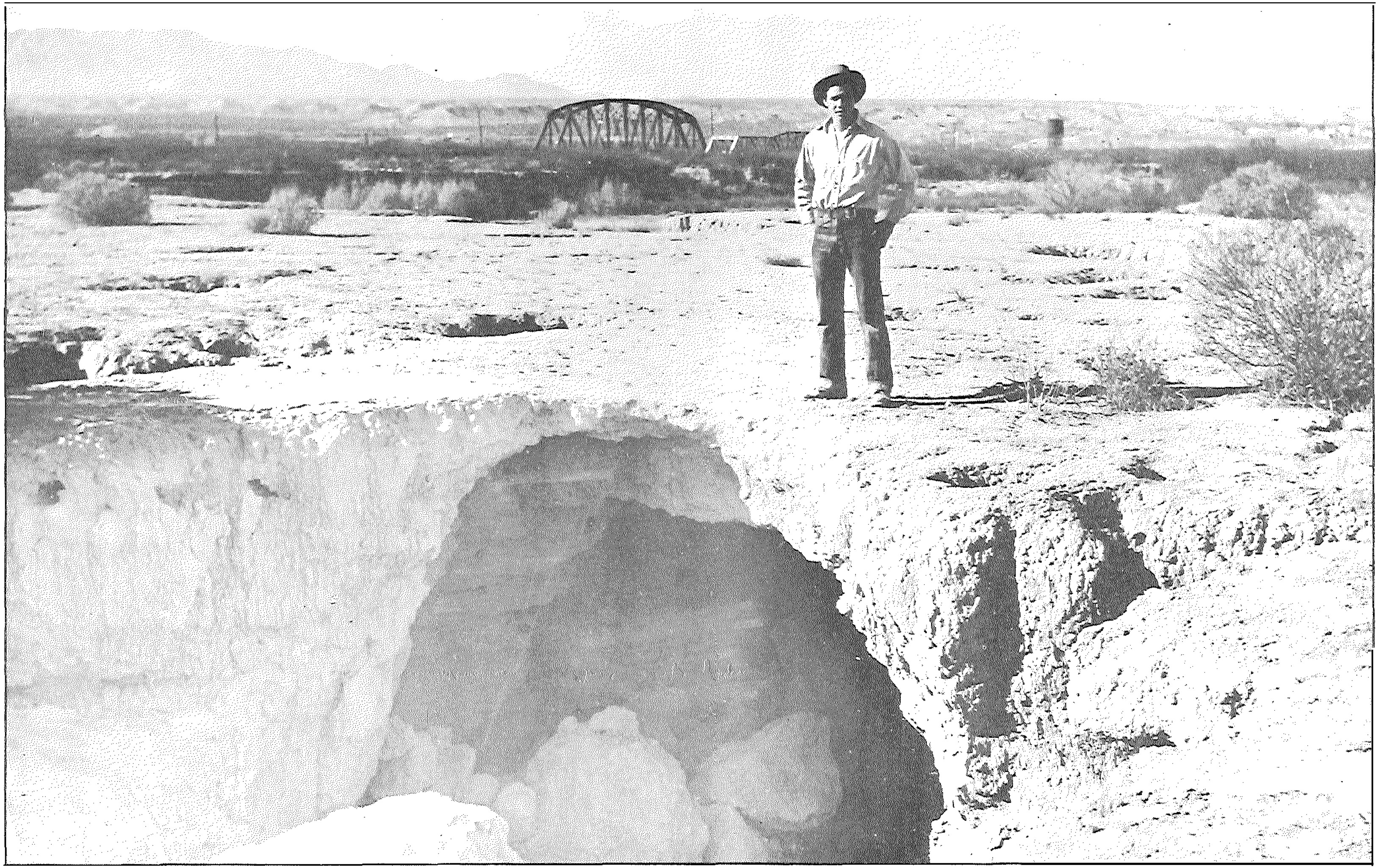

Destructive piping on an abandoned farm near Benson, Arizona.

Contents

Illustrations

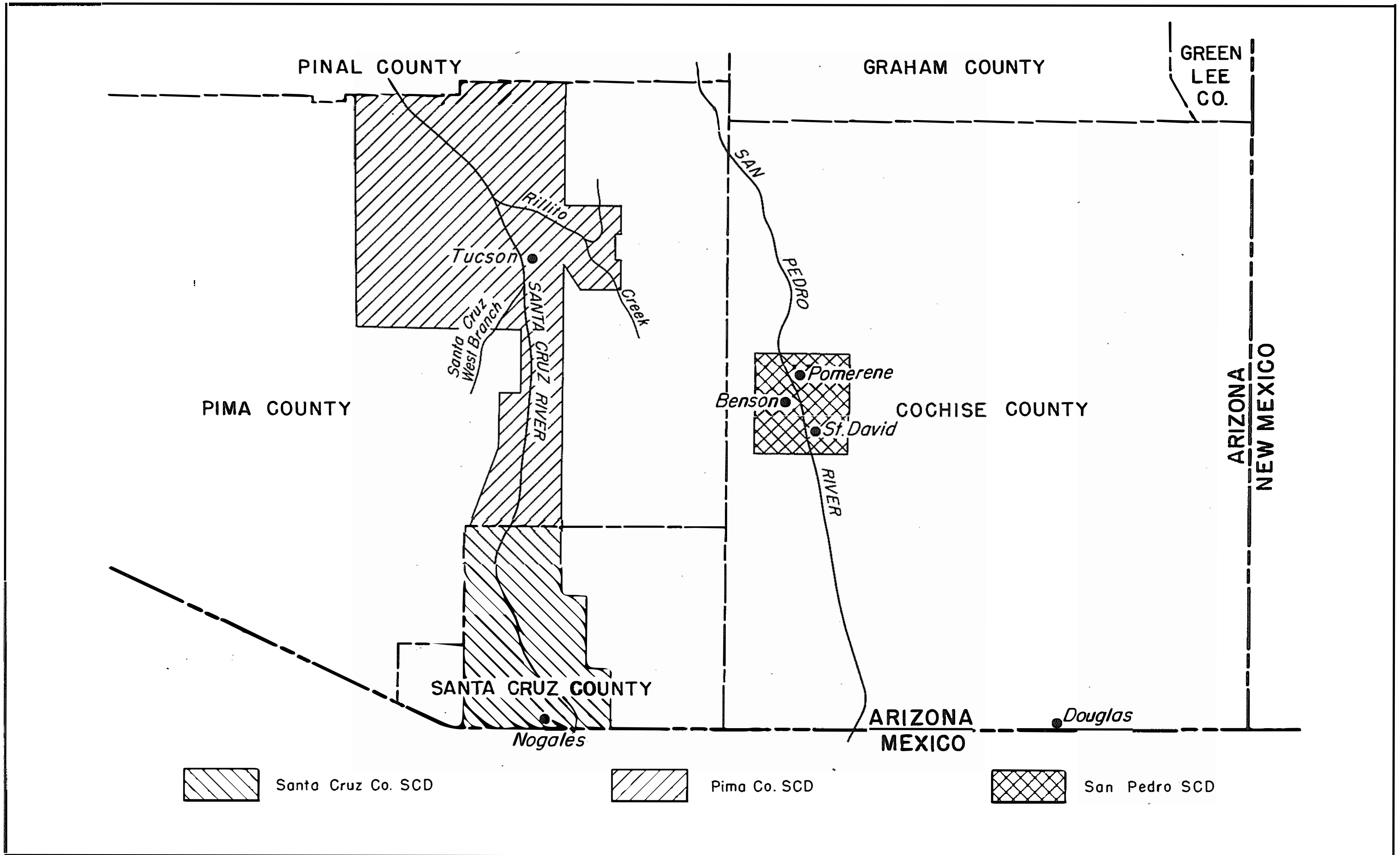

Figure 1. Sketch Map Showing Location of Counties, Soil Conservation Districts, Towns and Rivers Mentioned in the Report.

SOIL PIPING IN SOUTHEASTERN ARIZONA

Introduction

Farmers of the San Pedro, Pima County and Santa Cruz County Soil Conservation Districts often make inquiries relative to the cause and manner of handling that form of subsurface erosion known locally as "piping" or "tunneling." Many attempts to handle this peculiar erosion condition through generally approved conservation practices have proved ineffective, and numerous farmers have endeavored, some successfully, to apply their own ingenuity to the problem.

The problem of "piping" soils in this locality is an old one, but there was, at the time of this study, little information in the technical literature on the subject.

The object of this study is to obtain a better understanding of and more extensive information on the "piping" of soils. No attempt will be made to fully discuss the inherent physical and chemical characteristics of "piping" soils*, but attention will be given to those factors of soil cracking, land settling etc. which have been observed to precede or accompany pipe formation. It is hoped that these personal observations will add something to our knowledge of this form of erosion and will stimulate the development of practical and economical methods of handling this soil problem.

"Piping or Tunneling" and "Sinkholes"

"Piping or tunneling" is the descriptive name given to that form of accelerated erosion which results in subterranean voids and tunnels (see frontispiece). This type of erosion is common to highly dispersed ** alluvial soils.

"Sinkholes" result from a differential settlement of the land or from the collapsing or caving-in of subsurface tunnels and voids (Fig. 2).

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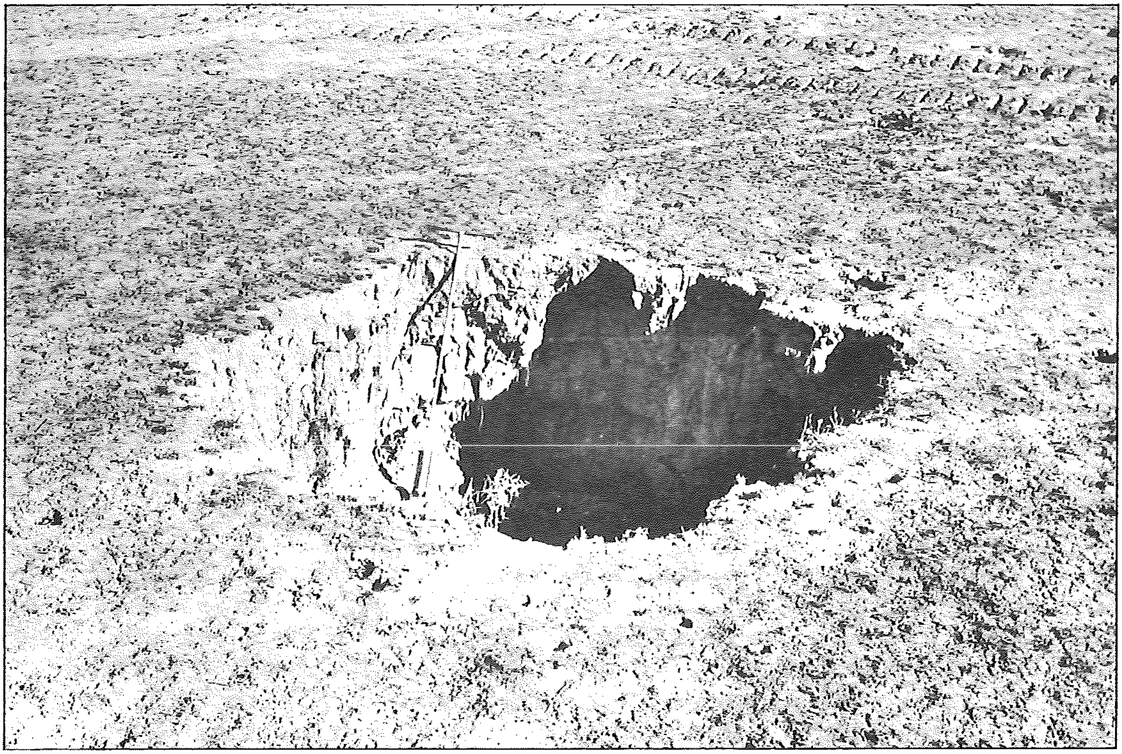
* A more complete study of the inherent factors associated with piping soils may be found in the following publication:
Fletcher, Joel and Carroll, Paul H., "Some Properties of Soils that are Subject to Piping in Southern Arizona", Soil Science Society of America Proceedings, 1948. (1)

** If a sample of very fine soil fraction is shaken in water, it passes into a state of suspension. The surface of each of the particles is the seat of a negative electrical charge. If the water is pure, no two particles come into contact because they carry like charges which repel each other. The sample is then said to be in a state of complete dispersion.



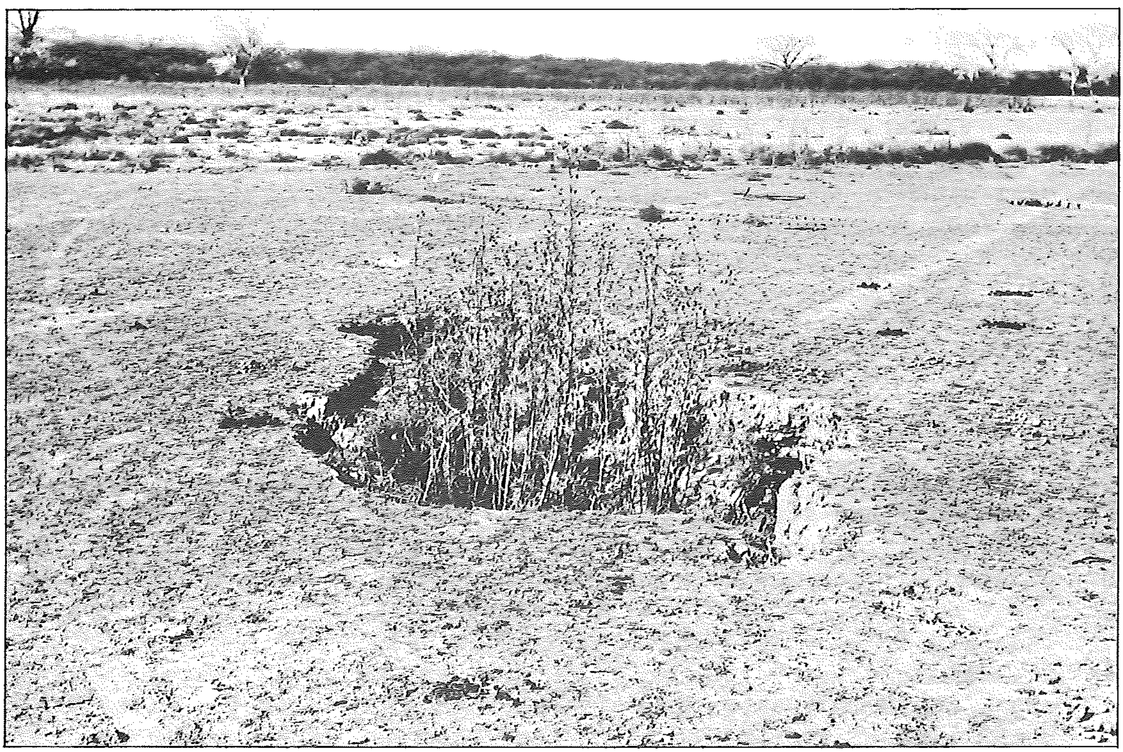


Figure 2. Sinkholes in the alluvial soil of the San Pedro River valley near Pomerene, Arizona.

Occurrence

Abundant visual evidence of the piping of soils is afforded in the alluvial deposits of the Southwest. Piping or tunneling and sinkholes have been observed in water-laid soils from New Mexico to California and from Utah to Old Mexico, but no one group has shown greater susceptibility to this form of accelerated erosion than have certain soil groups of the Santa Cruz and San Pedro River valleys.

Piping, in both early and advanced stages, has been observed in the valleys of the Tucson-Nogales and Benson areas. The Tucson-Nogales area includes the comparatively narrow alluvial valleys of the Santa Cruz River and its main tributary, Rillito Creek. Piping has also been noted in the lower courses of the nearby Pantano Wash, Canada del Oro and Aura Wash, and on the bordering narrow strips and intervening or adjacent areas of bench lands. In the Benson area, piping is limited to a part of the trough or plain of the San Pedro River.

Piping appears, in all cases, to be most pronounced in the uniformly fine-textured soils of the Gila and Pima series in the Pima and Santa Cruz County Soil Conservation Districts and in the Gila, Pima, Riggs, Curtis and San Pedro series* in the San Pedro Soil Conservation District. The eroded areas are usually limited to narrow strips adjacent to the stream channels in the valley part of the area, but excellent evidences of piping may be observed in places in old alluvial deposits as far as one mile from the present channel. In all instances, the soils are derived from water-laid deposits which have been altered through weathering and reworking by surface waters since deposition.

Formation

Piping, like other forms of accelerated erosion, may depend to a marked degree on the amount and intensity of rainfall, the slope of the land and its general topography, the size and shape of the watershed, the presence of channels in which water becomes concentrated, the type and amount of vegetative cover and the nature of the soil and subsoil. But piping, unlike other types of erosion, results in removal of the subsoil and substratum without necessarily eroding the surface soil. The surface soil in piping areas is generally composed of soil similar in texture to the immediate

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* Taken from U.S.D.A. survey reports of the Benson (2), Nogales (3), and Tucson (4) areas, Arizona.

subsurface layers. However, it is slightly higher in humus and mycelia which assist in stabilizing the surface against erosion. During the process of subsurface erosion, the more erodible subsoil and substratum are removed in water suspension; whereas, the more stable, less erodible surface soil remains firmly in place until it becomes undermined and can no longer support its own weight.

The formation of huge subterranean tunnels with unsupported roofs is possible only in soils with at least a trace of cohesion. The greater the cohesion, the wider are the spaces that can be bridged by the soil. In a general way, the cohesion of soils increases with decreasing grain size, and the danger of piping due to subsurface erosion increases with decreasing grain size.

Before piping can occur in any soil there must be provided an avenue of escape for the migrating soil particles. In some areas the soil is underlain at variable depths by highly porous, sandy or gravelly strata that permit a downward movement of the transported soil. Other piping areas are adjacent to deeply cut stream beds or gullies which permit a lateral movement and escape of the suspended soil particles. Soils known to be highly susceptible to piping may remain comparatively undisturbed for years if they are not provided with these paths of removal.

Though we are aware that piping in soils is made possible by the existence of escape avenues for the dispersed soil, we are not always certain of the manner in which these exits are formed. Soil conditions conducive to piping may result from one or more of several factors.

The type of piping with which we are most familiar begins with the burrowing action of gophers and other animals. Animal holes and burrows provide paths or openings through heavier-textured surface and subsoils to underlying strata of sand or gravel or extend laterally to adjacent streambeds or gullies (Fig. 3).

An excellent example of piping in which animal burrows have provided escape avenues into underlying gravel beds is afforded by soils of the old Santa Cruz West Branch near Tucson, Arizona (Fig. 4). These soils are made up of clay loams overlying thin strata of gravelly-sand. The formation of pipes in this area is unique among piping soils in that each time a pipe or tunnel reaches a certain stage in the erosion cycle, it tends to seal over and the erosion is brought to a halt. Actual piping begins when irrigation tailwater or overflow resulting from rainfall inundates the piping area, flows into the animal holes and drops rapidly into the sandy and gravelly substratum, taking with it considerable amounts of dispersed soil material. Due to the thinness of the gravelly-sandy layer, the amount of soil material it will accommodate is limited in amount. As soon as the porous layer is filled it will permit no further

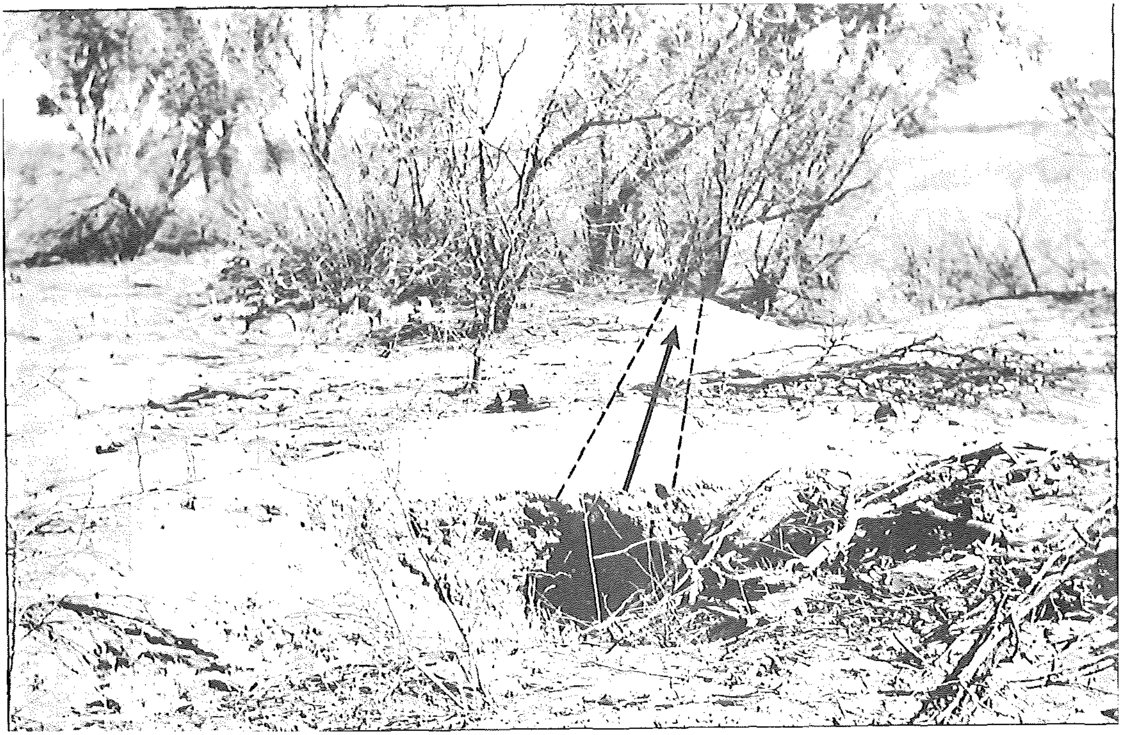

Figure 3. Entrance and exit of a pipe formed by the erosive action of irrigation waste-water flowing into an animal burrow.

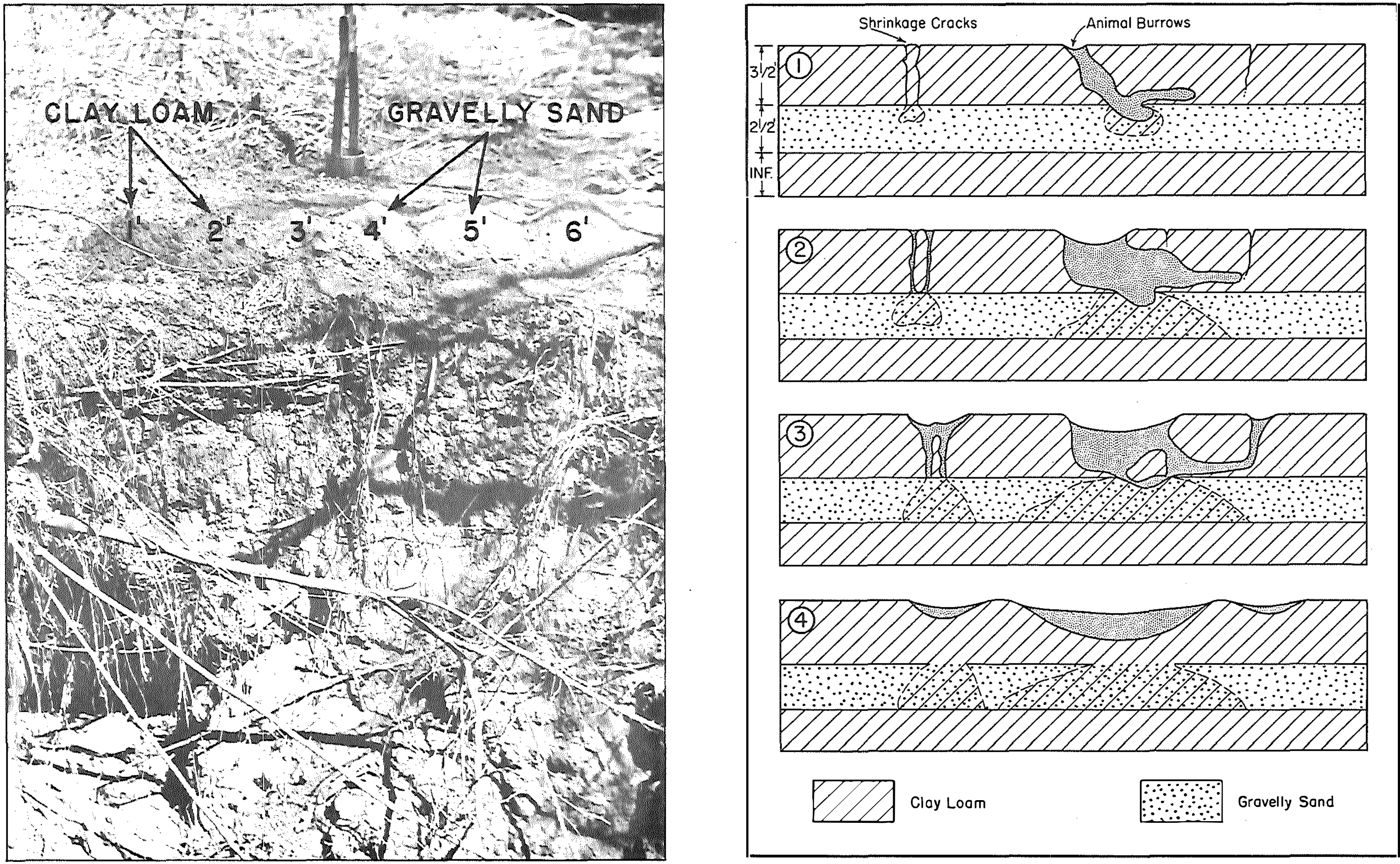

Figure 4. Soil piping in the flood plain area of the old Santa Cruz West Branch near Tucson, Arizona. Schematic drawing indicates how pipes complete an erosion cycle.

downward movement of the soil; thus, the piping is brought to a halt. Additional tailwater and rainfall will succeed only in sloughing off the walls of the pipe and creating a shallow depression in the land surface.

Another and more destructive type of piping resulting from animal holes may be observed along the high banks of the San Pedro River near Benson, Arizona (Fig. 5). Here, large areas of farms have been laid waste by piping through holes first dug by gophers. It has been observed throughout this area that where the most destructive piping occurs, channeling or impounding of surface water has been responsible for the greatly accelerated erosion. Ditches, furrows, dikes, etc. act as funnels to direct surface water into exposed gopher holes. The highly dispersed subsoil, taken into suspension by the free flowing water, is transported through the equally erodible substratum, through an outlet in the nearby embankment, and, finally, into the river. Soon the small gopher holes are converted into huge pipes or tunnels. Other gopher holes erode out to connect with the main tunnel (Fig. 6). With an increase in subsoil and substratum aeration caused by the holes and tunnels, there is a corresponding increase in the amount of shrinkage cracks in the soil profile and, subsequently, an increase in the amount of surface exposed to further water erosion.

In some areas the growth of alfalfa is thought to initiate piping and sinkholes. Growing alfalfa and other deep-rooted legumes for longer than three years has been said by local farmers to permit a too-rapid percolation of water. Decayed roots and root casts of deep-rooted plants provide paths whereby water and a suspension of finely divided soil may move downward or outward to an exit. Unless irrigated regularly, alfalfa may remove much of the moisture from the soil, and, if the soil is heavy in texture, large and extensive cracks are likely to occur (Figs. 7 & 8). As the shrinkage cracks are formed air is permitted to go deep into the subsoil and substratum and enhance still further drying and cracking of the deeper layers. The cracks in clay substrata are often sufficiently large and numerous in themselves to contain large amounts of washed in surface soil or subsoil, but if the cracks extend into underlying gravel beds or branch out laterally to gully or river banks, the amount of soil removed in increased manyfold.

Piping and sinkhole formation following a lowered water table has been observed in the alluvial soils of the Pomerene and St. David areas near Benson, Arizona. In earlier days before the lowering of the San Pedro River channel, the soils of the Pomerene and St. David vicinities had comparatively shallow water tables, and drainage of these areas was rather poor. At this time there was little or no damage to farms from piping or sinkholes. But within recent years an erosion cycle has commenced in which the channels of the San Pedro River and its tributaries have been lowered deeply into the valley alluvium. The lowering of the river channel has resulted in a

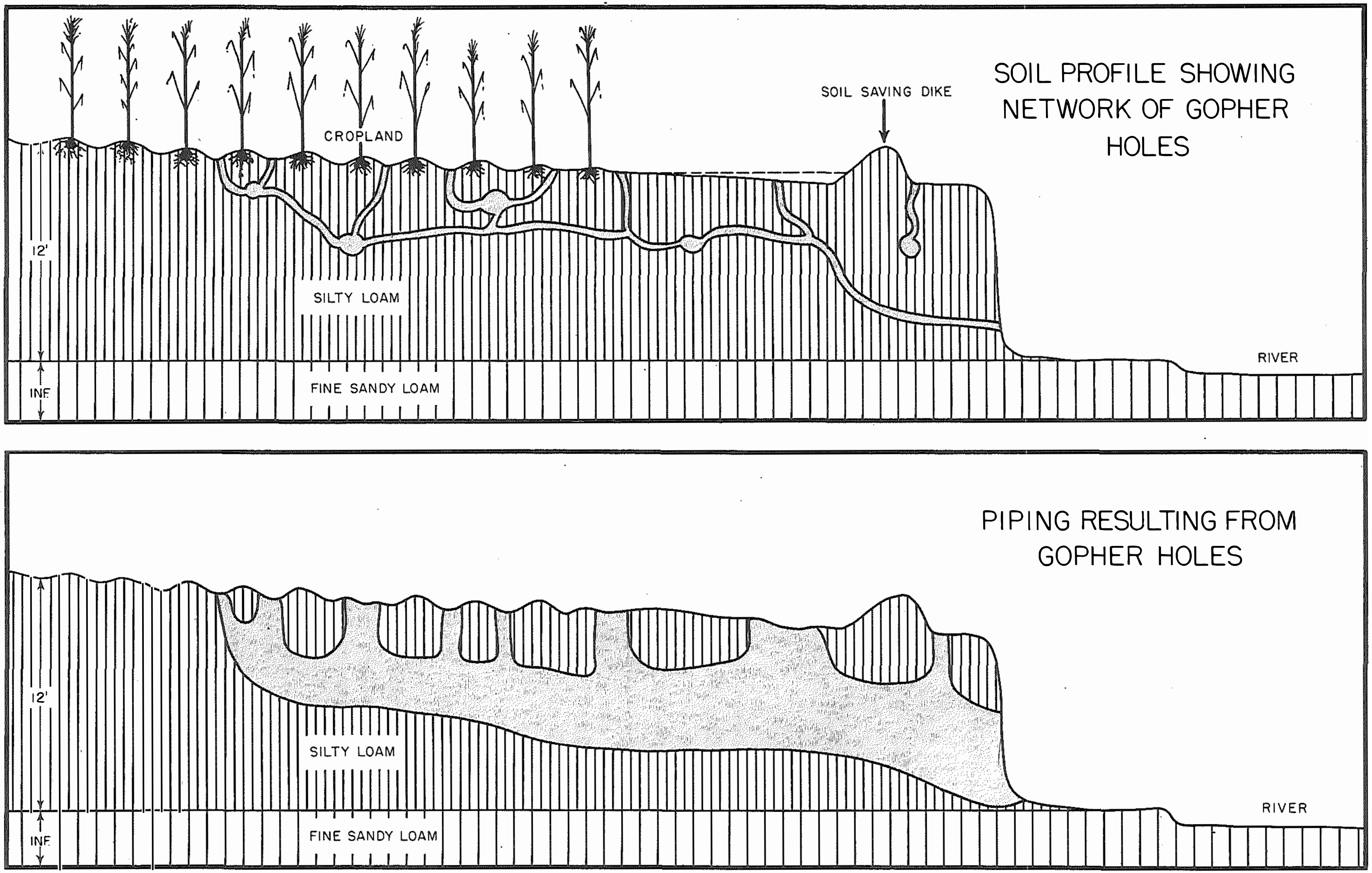

Figure 5. Schematic drawing of tunnel formation near the town of Benson, Arizona. See Frontispiece.

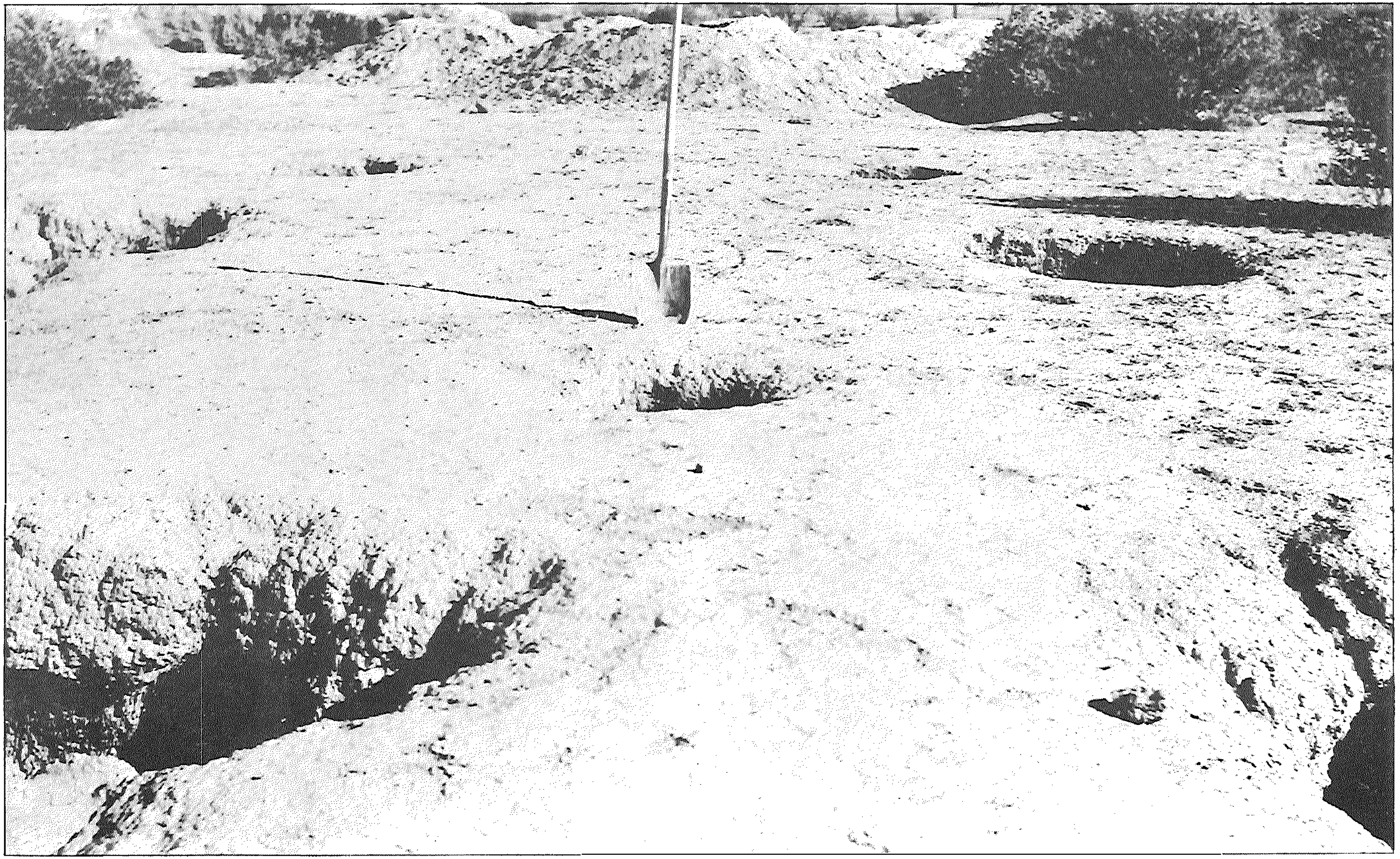

Figure 6. Subsurface erosion resulting from gopher holes. The above pipes connect with a near-by tunnel which empties into a river. See figure 5.

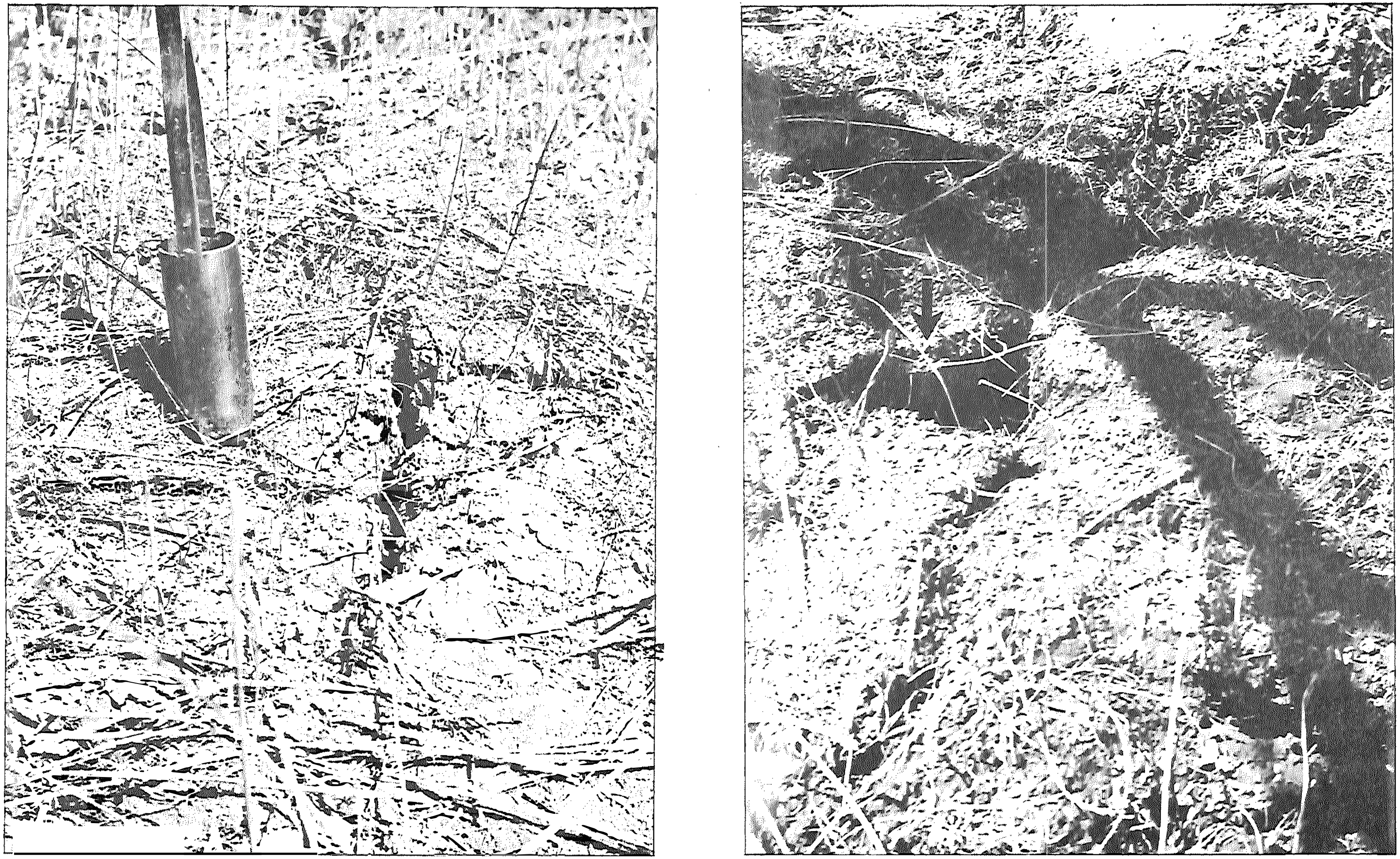

Figure 7. Deep shrinkage cracks in a heavy textured piping soil. Note in the picture to the right that the crack has begun to pipe.

Figure 8. Profile of a heavy textured piping soil. Note the network of deep shrinkage cracks.

simultaneous lowering of the local water table, and, in those areas underlain by thick strata of sand and gravel, piping and sink-holes have become increasingly evident. With the lowering of the water table there has been a resultant differential settling of the upper soil layers coincident with the formation of deep cracks through the soil profile (Fig. 9). By lowering of the water table the effective load on the lower soil layers is increased by an amount equal to the difference between the drained weight (solid and soil moisture combined) and the submerged weight of the entire mass of soil located between the original and the lowered water table.

The increase of the effective over-burden pressure produces a settlement of the soil layers. The amount of the settlement depends on the compressibility of the lower layers; the looser the soil material in the deeper substratum, the greater is the settlement.* Often the differential settlement of the ground is, in itself, sufficient to produce sinkholes, but very frequently the settlement simply creates deep cracks which extend from the soil surface down through the soil profile into a sandy or gravelly substratum (Figs. 10 & 11). Flooding of these areas permits water to flow into the cracks and initiate piping.

Farmers living near the towns of Pomerene and St. David give added substance to this theory by their statements that they have observed, in recent years, occasional cracks over their farms that measured from two inches to six feet in width and from five to five hundred feet in length. These fissures are referred to as "earth-quake cracks" because of the earth tremors that often accompany their formation. These fissures are not common to soils that are cracking as a result of drying out alone. Such a condition accounts for the chain-like formation of pipes which have been observed on many farms near the towns of Pomerene and St. David (Fig. 10).

It has been suggested that much of the piping along the San Pedro and Santa Cruz Rivers may be attributed to the erodibility of the more or less uniformly-textured, permeable soils which overlie impervious strata of denser soil materials. The downward movement of gravitational water is halted by the impermeable layer and a super-saturated soil is created. The free or gravitational water which can no longer move downward tends to flow laterally until it reaches an exit in a river or gully bank. The free water, under slight pressure, seeps from the embankment, carrying with it small particles in suspension. Soon, the soil begins to slough away, and a pipe is formed. Over a period of years, the hole or pipe may migrate back through the soil

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* Terzaghi, Karl and Peck, Ralph B., "Settlement Due to Lowering the Water Table", Soil Mechanics in Engineering Practice, p. 524, John Wiley and Sons, N. Y. 1948. (5)

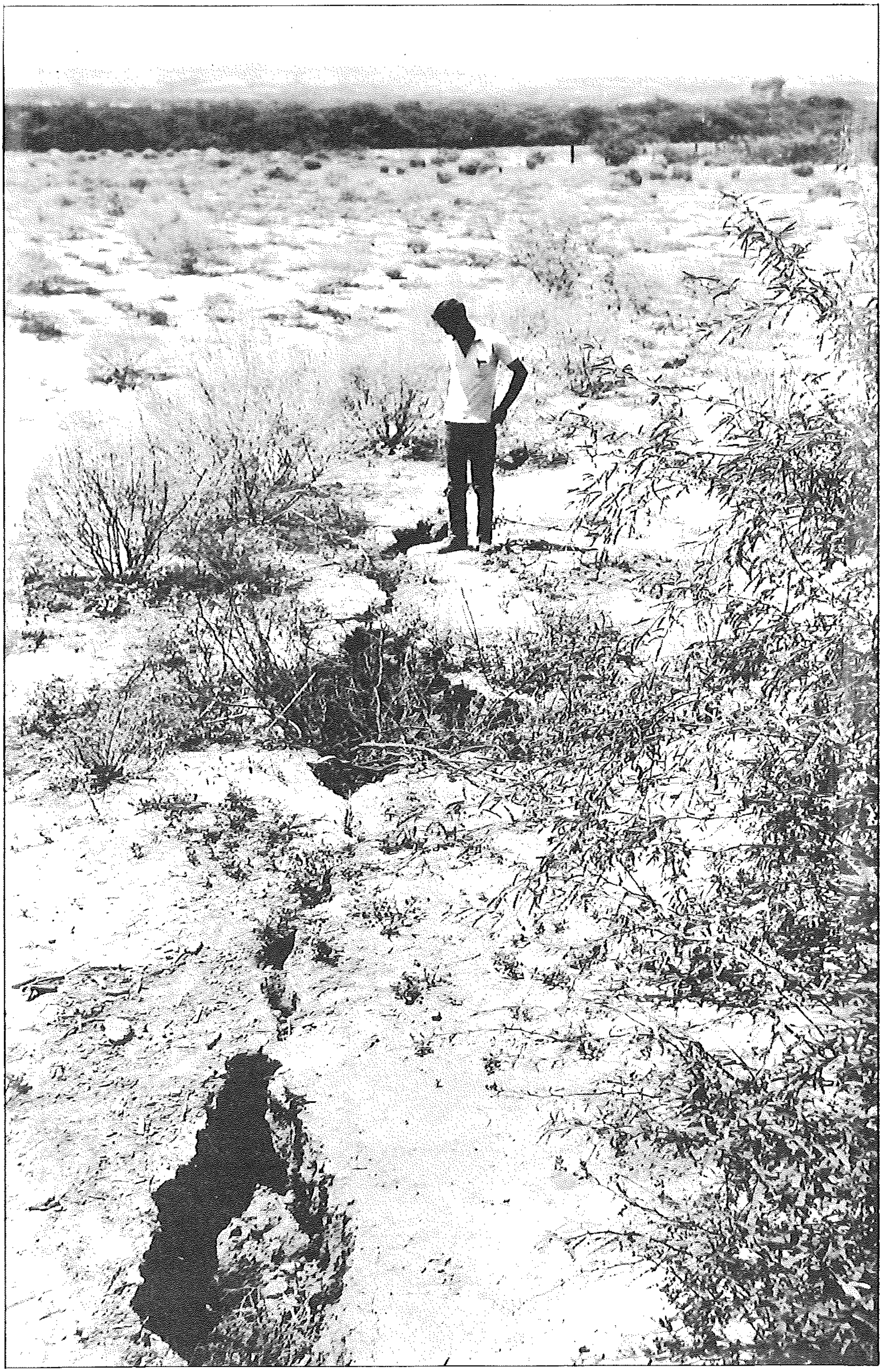


Figure 9. "Earthquake Crack" near St. David, Arizona. Crack has resulted from land settling. See Figure 10.

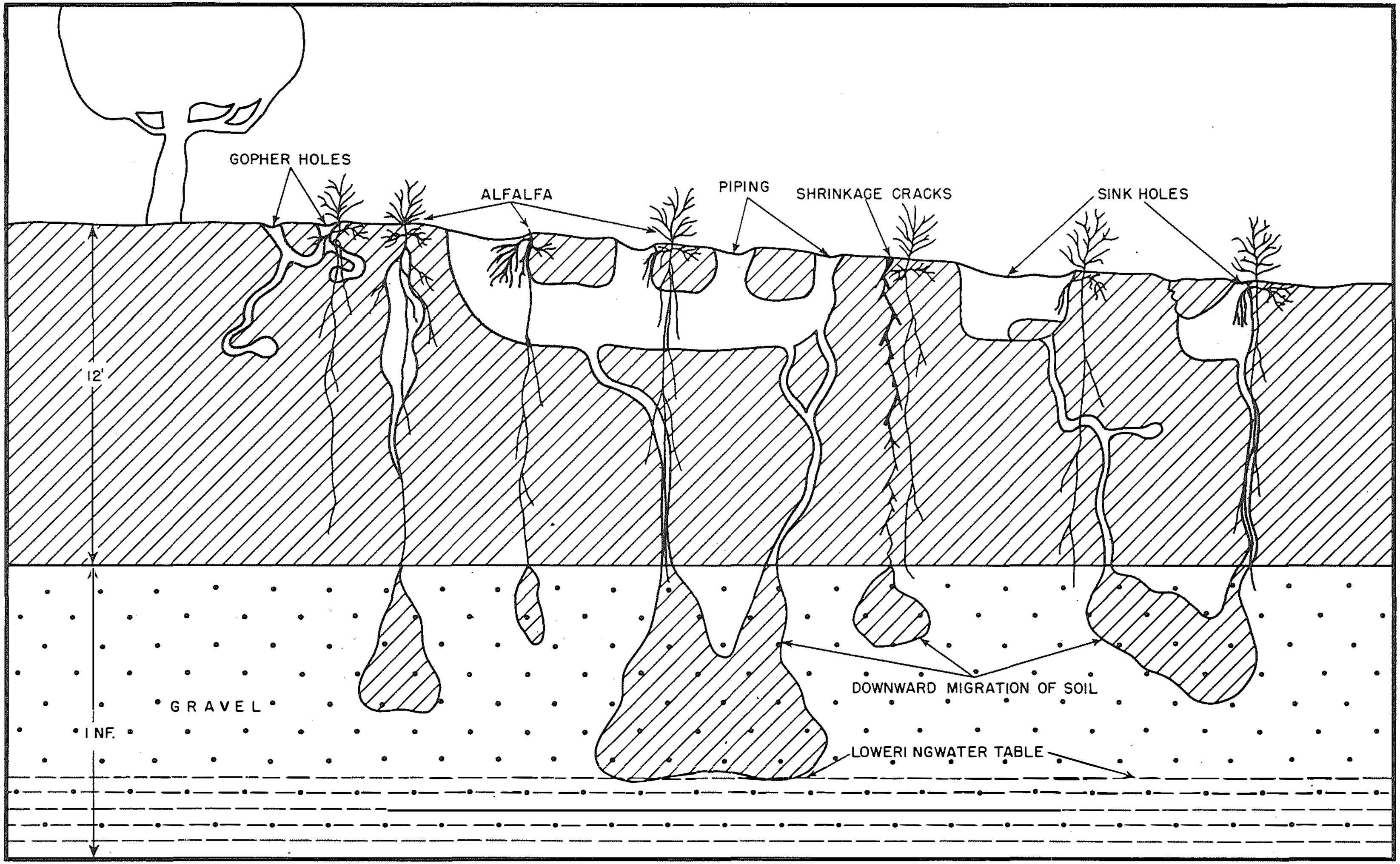
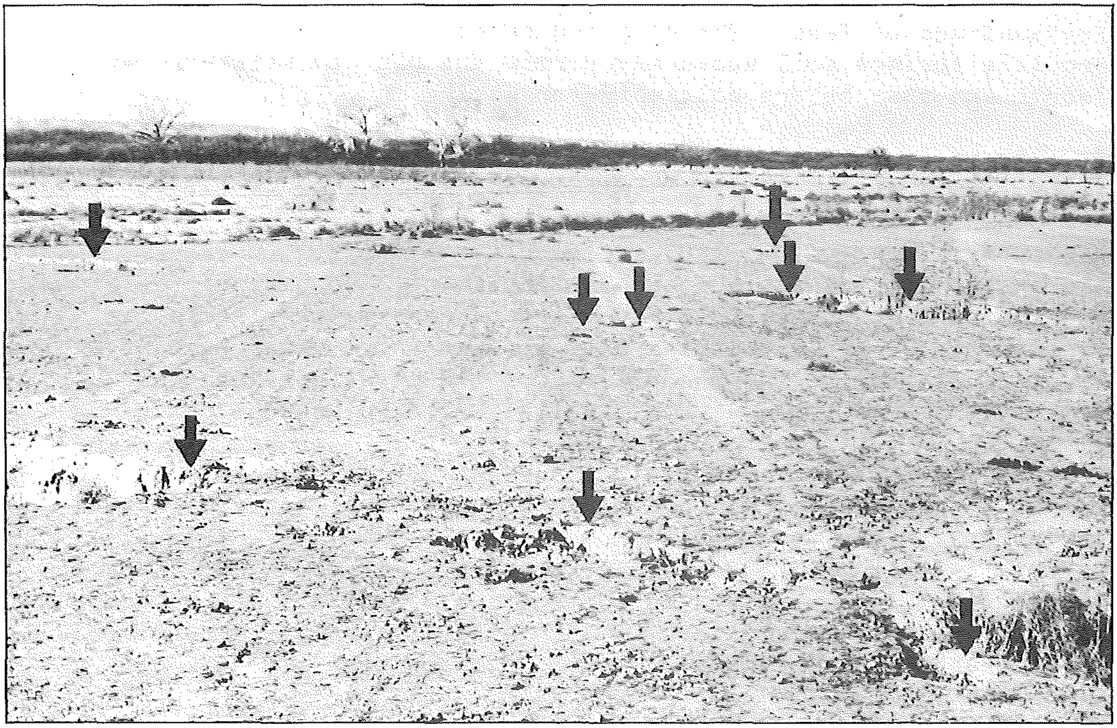


Figure 10. Schematic drawing of piping and sinkhole formation following a lowered water table. See figures 9 and 11.



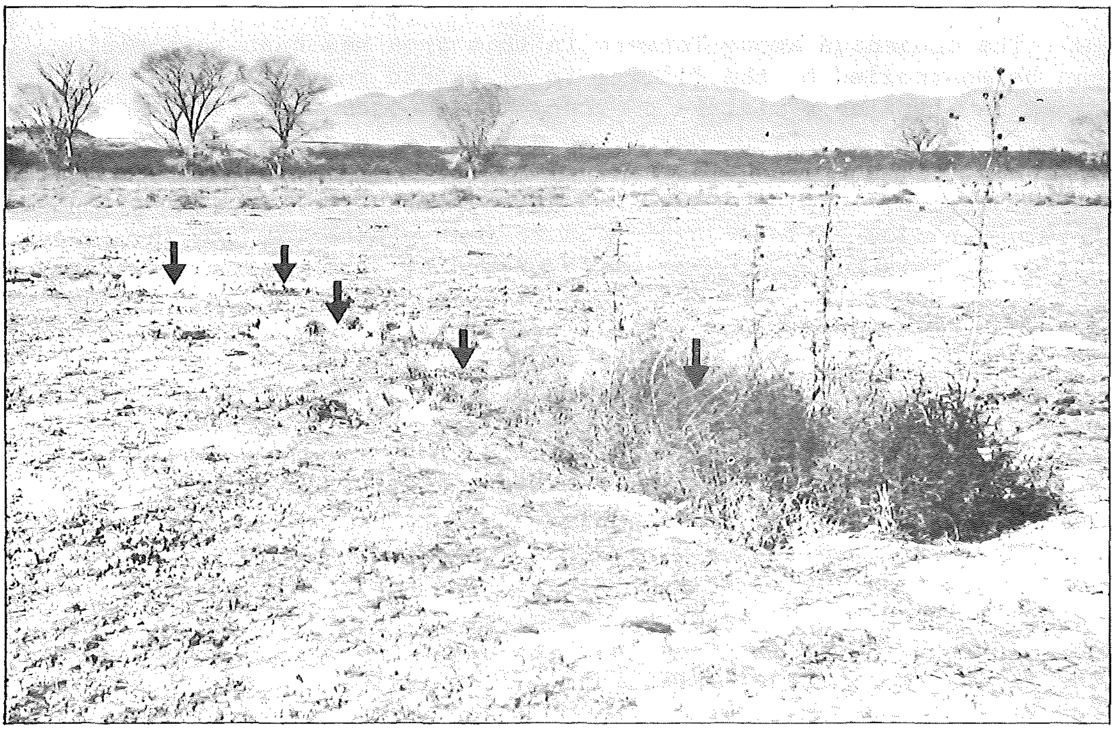


Figure 11. Soil piping resulting from land settling. The bottom picture shows a chain-like formation of sinkholes which have resulted from land settling cracks.

for hundreds of feet. The clay pan beneath and the more slowly erodible surface soil above may permit the pipe to attain great length and size before collapsing or caving in.

There is evidence that piping often occurs in medium- to heavy-textured alluvial soil lying immediately above a water table. Pipes have been observed to erode from river banks at a point level with the current river flow, and, as the river channel cuts deeper, there has appeared to be a simultaneous lowering of the base of the pipes. Within the past twenty to sixty years of stream lowering in the Pomerene area, pipes emptying into the San Pedro River have developed high vaulted roofs, but the outlets of the pipes have continued to remain on the same level with the lowering river channel (Fig. 12).

Though the formation of subterranean voids or pockets as a direct result of solution of soluble salts has not been observed in the area under survey it is not uncommon to the semi-arid Southwest. Soluble salts in the subsoil and substratum may be taken into solution by leaching water and moved to a lower horizon. The subsequent voids or pockets formed may, in turn, permit sizeable amounts of soil in upper layers to migrate downward in suspension.

Method of Handling Piping Soils

The consensus among farmers in this area has been that piping can be controlled by the filling in of eroded spots with undecomposed organic matter or a mixture of undecomposed organic matter and soil. This method of treatment may prove effective in eroded areas of most soils, but in a highly-dispersed piping soil the excessive permeability created by the loose undecomposed organic trash would still permit free water plus soil in suspension to find egress through the loose fill. In several areas where this method of control was attempted the soil around the original sinkholes and pipes eroded away, leaving trench-encircled heaps of organic trash.

Some farmers have attempted to control lateral piping by driving wood pilings into the earth at a point below the eroding areas, thus attempting to cut off the escape of the migrating soil. Others have driven sheet-iron plates into the subsoil to cut off the pipes, and still others have poured concrete dams along the lower end of their fields. One farmer near Pomerene dug a trench eight feet deep along the lower end of his field and maintained a vigilant watch to check the formation of new pipes. In all instances, it is obvious that the maintenance cost was high, and that, in many cases, the farmers were not only failing to control the cause of the trouble but were neglecting to apply the most economical or effective remedy.

It has been observed that those farmers who have successfully dealt with piping soils in these areas have learned that pipes,

Figure 12. Outlet of a high vaulted subsurface tunnel. Note that the base of the tunnel has eroded to a point level with the current flow.

sinkholes and earth fissures must first be "dozed out" with a tractor to remove all traces of the voids and tunnels. In some instances, tractors have been known to drop out of sight into these subterranean cavities, but work is not halted until all traces of active pipes and sinkholes have been removed. Afterwards, damp soil is shoved into the "dozed-out" areas and packed down. Compaction of the earth fill may be accomplished by the use of hand-tampers or by frequent passes of the pneumatic tires of the tractor. Uniform compaction of the fill is best obtained if the "dozed-out" areas have graded side slopes.

It has been noted, too, that a later building-up of the humus content of the soil surface is of primary importance in piping control. It not only acts as a deterrent to a too-rapid permeability, but it also binds the surface soil together, increases soil friability and lowers the amount of surface cracking. Farmers in southeastern Arizona are rapidly learning the value of plowing under straw, stubble and other organic trash as a measure in the prevention of piping.

It has been suggested by several farmers that deep-rooted legumes should be limited to not more than a two-year growth to prevent the formation of a too-deep tap root. Shallow rooted legumes have been mentioned as a substitute for alfalfa.

Extreme care in irrigation practices, including waste-water control, is another important factor in the prevention of piping. Farmers of the San Pedro River valley agree that where there is deep moisture penetration, piping may be kept under control. This is a logical conclusion in that if heavier-textured surface and subsoils are kept moist, shrinkage cracks and subsequent piping may be held to a minimum. In all areas, farmers are learning that a more efficient use and control of irrigation waste-water eliminates repeated inundations and subsequent erosion of soils susceptible to piping (Fig. 13). The majority of the farmers have learned that, if it is necessary to run tailwater, care should be taken to spread out the water to prevent its being channeled into piping areas.

Leveling of land to an irrigable grade and removal of channels of water concentration have been found to help alleviate subsurface erosion. If land is so leveled that irrigation water or surface run-off is prevented from being funneled into cracks, holes and burrows, the control or prevention of piping, in many instances, is simplified. If it becomes necessary to impound water on soil that is known to pipe care should be taken to seal off all soil cracks and openings. Evidences of the ability of these soils to hold water under such a practice is shown by the presence of numerous serviceable stock and storage tanks which stand near piping areas.

The majority of the farmers who cultivate land adjacent to the

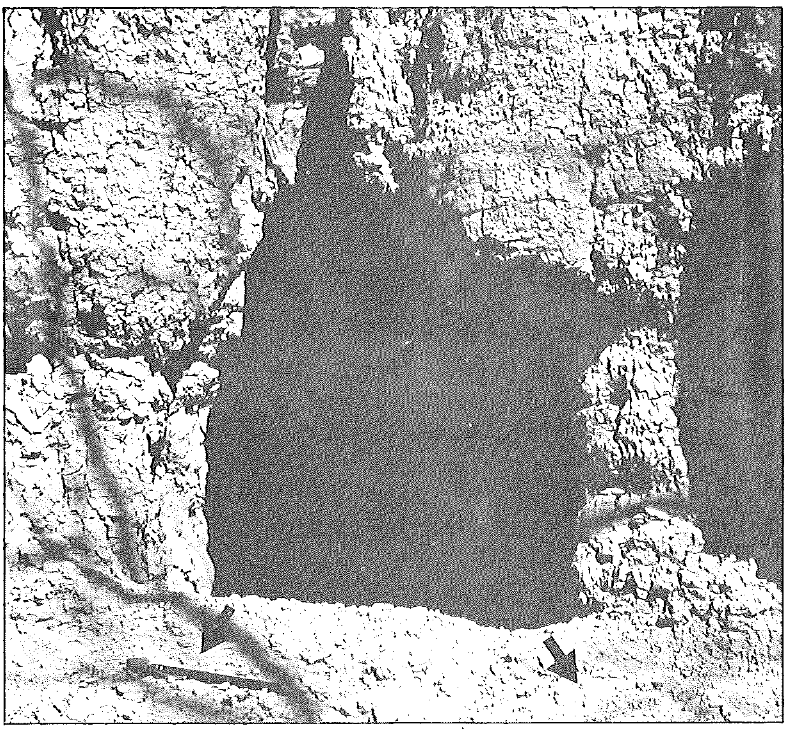


Figure 13. Piping resulting from the erosive action of enchanneled waste-water. The above pipes have eroded through seventy-five feet of subsoil to a nearby river channel.

high banks of the San Pedro River maintain buffer strips of native vegetation between the cultivated land and the deeply cut river bed. Every precaution is taken with irrigation waste-water and surface run-off to prevent overflows and possible introduction of piping into these areas.

There is no approved practice that will halt cracking resulting from land settling, but care can and should be taken to apply corrective measures to the fissures once they are observed.

An efficient program of rodent control on many farms has minimized and, in some instances, halted piping resulting from animal holes and burrows.

Summary

The subject matter of this report is based upon personal observations made of the erosional behavior of piping soils in the Santa Cruz and San Pedro River basins in southeastern Arizona. In this investigation, primary consideration has been given to factors which have been observed to initiate and accelerate subsurface erosion.

This paper deals specifically with the occurrence and formation of pipes and sinkholes in the Tucson-Nogales and Benson areas of Arizona and, in as brief and simple a way as possible, discusses methods employed by the farmers in these areas to prevent piping or to reclaim land that has already begun to pipe.

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