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4 Soil Conservation

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Dryland agriculture, although inherently less productive than irrigated agriculture or other rainfed agriculture where precipitation is more reliable, provides for the production of a significant portion of the food and fiber products for the world's human population. Many animals also receive their food materials from plants grown under dryland conditions, often in close association with the production of dryland crops. Emphasis on dryland crop production is increasing in some regions because the water supply for irrigated crop production is limited or decreasing. Contributing to this emphasis on dryland crop production is the increasing competition for water among agricultural, urban, industrial, and recreational users (Unger and Howell, 1999).

As for other types of agriculture, dryland agriculture depends on the thin layer of topsoil that covers much of the earth (Kleinhenz and Bierman, 2001). Because soil formation is extremely slow, it is imperative that available soil resources be conserved for current productive uses and for future food and fiber production for an ever-increasing world population. Soil conservation involves the prevention of soil movement (or translocation) due to the forces of wind and water, which are natural forces causing erosion. A type of human-influenced soil movement is tillage erosion, which is a serious problem under some conditions.

In this chapter, we discuss the processes and consequences of wind, water, and tillage erosion, and the principles, practices, and techniques for keeping soil in place, along with selected examples for dryland regions showing the benefits of various control practices. We also identify some areas of research that could lead to improved practices or techniques for conserving soil resources under dryland conditions.

EROSION PROCESSES

Although we will focus on soil conservation under dryland conditions, the erosion processes and principles for controlling erosion under dryland conditions are generally similar to those applicable to more humid or irrigated conditions. One difference between erosion under dryland as compared with other conditions is that wind erosion poses a potentially greater problem than water erosion under dryland conditions. An anomaly regarding water erosion is that it often is more severe under dryland conditions than under more humid conditions, even though total precipitation is lower in dryland regions. Reasons for the anomaly include generally less soil cover due to limited plant growth under dryland conditions and high rainfall intensities, which frequently is the case in dry regions (Hoogmoed, 1999; Sterk, 1997).

Wind Erosion

Wind erosion may occur when wind that exceeds the threshold velocity required to initiate soil movement passes over nonprotected soil surfaces (Greeley and Iverson, 1985). Most soils can be protected under usual wind conditions. With high wind velocities, however, even rocks several centimeters in diameter can be dislodged and moved across the surface (Batt and Peabody, 1999).

Historical evidence of the magnitude of soil movement due to wind erosion is documented by unique landscape features such as yardangs, ventifacts, pedestal rocks, lag deposits, hammadas, regs, and ergs (Thornbury, 1957), and deep loess deposits on every continent (Dregne, 1983). While the movements from a given area are unfortunate, the resultant loess deposits are valuable soil parent materials at the receiving area (Drees et al., 1993). In addition to damaging the source area, dust in the airstream degrades air quality during transport to the deposition area. As particles are eroded from the soil surface, they abrade nonerodible particles, soil crusts, or growing plants. The net effect is destruction of crops, a gradual increase in percentage of coarser particles, lowered water holding capacity (Meng et al., 1987), and reduced nutrient holding capacity of the soil. Diminished water and nutrient holding capacity decrease crop yields, reduce crop residue production, and thereby increase susceptibility of soil to wind erosion.

Soil aggregates and particles can be transported as surface creep, saltation, or suspension (Sterk, 1997). Surface creep is the rolling of large soil materials across the surface, but the materials do not enter the airstream. Slightly smaller particles may be injected into the wind stream to a height of several centimeters. Because these saltating materials are too large to be transported great distances by the wind, they return to the surface at a tangential velocity that can dislodge additional surface aggregates or particles, or abrade nonerodible aggregates into erodible particles (Zobeck, 1991). The smallest particles may be injected into the wind stream (Chen and Fryrear, 1996). Because of turbulence in natural winds, the suspended materials rise to heights of several kilometers and can be transported hundreds or thousands of kilometers before being deposited on the soil surface or in water (Gillette and Chen, 1999; Sterk et al., 1996).

The total amount of materials transported in each mode by wind varies, depending on surface conditions, particle shape and density, and wind speed or turbulence. According to Chepil and Woodruff (1963), the amount is 5 to 25% as surface creep and 50 to 75% as saltation. Chepil (1957) reported 3 to 40% as suspension. Once the transport capacity of the wind has been reached, no additional material can be added to the wind stream. A small amount of suspended material may be added as the depth of the dust cloud increases, but this does not add significantly to the total mass load.

When technology advances permitted collection of materials transported by wind (Fryrear, 1986), the need arose to scientifically describe the significance of these resultant data on the wind erosion process (Fryrear and Saleh, 1996). When mass samples are collected at several heights above the soil surface, the vertical distribution of the material can be mathematically described (Fryrear and Saleh, 1993; Vories and Fryrear, 1991). An integration of the resulting equations provides the total mass being transported at that point. Assuming the total mass is eroded from the upwind eroding surface, the average soil loss can be determined by dividing total mass by the upwind length of the eroding field.

Major natural factors affecting wind erosion are the prevailing climatic and soil conditions. Wind erosion usually is considered a problem for dryland regions where precipitation is limited and winds exceed the threshold velocity needed to cause detachment and movement of soil particles. Generally, dry, sandy soils are most prone to wind erosion, but other bare soils may also erode under some conditions (Troeh et al., 1991). Medium- and fine-textured soils often become highly erodible after freezing and thawing, causing the disintegration of surface materials into particles susceptible to movement by wind.

Water Erosion

Water erosion involves three types of soil movement. These are detachment of individual particles from the soil mass, transport of detached particles across the surface, and deposition of transported particles as they fall out of suspension at the new site (Troeh et al., 1991). Water erosion occurs when raindrops strike unprotected (bare) soil surfaces or when runoff water flows across erodible and unprotected soils at a rate sufficiently rapid to entrain soil. The main types of water erosion are gully, rill, sheet, splash, and streambank.

Gully erosion is the result of concentrated flow of accumulated water in narrow channels. The flowing water removes soil from channels to depths usually greater than about 0.3 m (as distinguished from rill erosion) (SSSA, 1997). Although not necessarily resulting in the greatest soil movement, gully erosion generally is the most obvious type. Severe gully erosion on steeply sloping land has limited agricultural significance because such land usually is not suitable for crop production (Hudson, 1981).

Rill erosion results in numerous small channels caused by intermittent water flow during or immediately after a rain or when snow melt occurs. Rills usually are several centimeters deep with relatively-steep sides, occur most frequently on recently-tilled land, and do not interfere with and can be eliminated by normal cultural operations (SSSA, 1997).

Sheet erosion is the removal of a fairly uniform, thin layer of soil from the land caused by raindrop splash or water flowing across the surface. Raindrops provide most of the energy for detaching soil particles and over-surface flow is the primary transport mechanism (Troeh et al., 1991). Soil movement due to sheet erosion sometimes is difficult to detect, but total movement from a given tract of land may exceed that resulting from gully or rill erosion.

Splash erosion is the loosening and splattering of small soil particles caused by impacting raindrops on a wet soil surface. The distance to which the particles are moved by the splash is relatively small, and the particles may or may not be removed when runoff occurs. The raindrop, however, is a complete erosive agent within itself and little or no water erosion occurs when soil surfaces are protected by ample cover (Hudson, 1981). In fact, raindrop impact usually is the force that initiates most water erosion.

Streambank erosion is the scouring of soil materials and cutting of streambanks by water flowing in streams. Areas impacted by streambank erosion usually are relatively small, but soils of those areas often are highly productive, thereby resulting in significant productivity losses (Troeh et al., 1991).

Major natural factors influencing water erosion are climate, soil properties, and landscape characteristics. The primary climatic factors are the energy associated with falling raindrops and rainstorm amount and intensity, and the added influence of wind on raindrop energy. Intense rainstorms, which sometimes result in major portions of the annual precipitation in dryland regions, frequently cause severe water erosion. Such storms, when accompanied by high velocity winds, can be especially damaging to unprotected soils.

Soil properties influencing water erosion include texture, structure, and profile characteristics. Sandy soils erode easily, but the sand grains readily settle from water and are carried relatively short distances. In contrast, clay particles adhere to each other and are more difficult to detach. When detached, however, clay particles can be transported great distances in water. Besides the texture effects, soil structure factors influencing water erosion are aggregation, type of clay mineral, organic matter content, and cementing agents in the soil (Troeh et al., 1991). Distance to dense or impermeable horizons in the soil profile can have a major effect on the potential for water erosion. When such horizons are present, water infiltration may be limited, which results in greater runoff water and, hence, potentially greater erosion.

The main landscape feature affecting water erosion is surface slope. The potential for erosion is slight where the slope is low, but steadily increases with slope increases under most conditions. In Shaanxi Province, China, runoff across the surface was the dominant factor causing erosion for slopes up to 28°. On greater slopes, gravitational soil movement became the prime form of erosion (Cao and Coote, 1993).

Tillage Erosion

Tillage erosion is soil movement in agricultural fields due to the direct action of tillage. It results in an increase in soil variability and an overall decrease in soil productivity, except possibly on deep soils where surface modification (reduction in slope) might improve productivity because there would be less runoff. Tillage erosion is directly related to landscape characteristics. Landscapes subject to tillage erosion are topographically complex or have a high number of field boundaries. Tillage erosion contributes to the evolution of landscape heterogeneity through creation of distinctive landforms such as lynchets, terraces, and field boundary steps, and through progressive, but relatively rapid, redistribution of soil from uplands to depressions. The resultant variability in soil properties has an important effect on crop production.

Evidence of tillage erosion commonly can be observed as the difference in soil color between hilltops and adjacent lower slope positions. The problem increases with increased tillage speed and depth, increased tillage tool size, and tillage of steeper and more undulating lands. When tillage is performed in the upslope direction, forward soil movement is less than when performed in the downslope direction. Net downslope soil displacement occurs when tillage direction is in the downslope direction as often as in the upslope direction.

Tillage erosion often is described in qualitative rather than quantitative terms, and evidence of mass downslope movement of soil by tillage has been observed for years. One frequently cited example is from the Palouse region of the U.S. Pacific Northwest (Papendick and Miller, 1977) where 3- to 4-m high soil banks have developed at fenceline positions on steep slopes. The fenceline represents a zone of zero soil flux due to tillage; that is, soil does not move through the fenceline. As soil is moved toward the fenceline from above and away from it from below, a field border develops. This soil accumulation and removal at field borders can be fairly rapid, leading to development of soil banks several meters high in a few decades when soil is consistently turned downslope during tillage.

CONSEQUENCES OF EROSION

Erosion, whether due to wind, water, or tillage, results in soil removal from some point of the land and its deposition at some other point on the land or its transport away from the land by wind or water. Removal and deposition of soil materials have a number of consequences with respect to agriculture under dryland as well as for other crop production conditions. Continued erosion results in soil degradation, which has serious implications regarding the potential for food and fiber production in the future (Dazhong, 1993; Elwell, 1985; Szabó, 1991; White, 1986).

Wind Erosion

Soil Removal

The most lasting impact of wind erosion is the subtle loss of soil productivity (Fryrear, 1981; Kaihura et al., 2000; Lyles, 1975; Michels, 1994). Productivity losses result from, for example, removal of the soil material, loss of plant nutrients and organic matter from the soil, and poorer water infiltration with less organic matter being present. Some crops are more sensitive to nutrient deficiencies than other crops; therefore, the tolerable soil loss (maximum annual soil loss rate that will permit economical crop productivity indefinitely; SCSA, 1982) will be a function of the crop being grown, climate of the region, and effective rooting depth of the crop. The design of good soil conservation practices that will sustain agricultural production in a region must consider the crop, climate, and soil depth.

Soil Sorting

During erosion, soil aggregates or particles are sorted according to size. Those larger than 0.84 mm are normally considered nonerodible (Chepil and Woodruff, 1963), while those smaller than 50 microns may be transported long distances in suspension. As wind erosion continues for many years, the fertile fine soil materials are removed, leaving the more sterile sand or rock fragments in place. Such sorting essentially results in a soil texture change.

Nutrient and Productivity Losses

Clay and organic materials retain most of the nutrients in a soil, thus having a strong influence on a soil's level of fertility. When these materials are removed due to erosion, major fertility decreases generally occur, thereby potentially resulting in crop productivity losses (Michels, 1994; Sterk et al., 1996). To establish the relationship between soil movement due to wind erosion and soil productivity losses requires controlled experiments covering more than 10 yr. Analysis of crop yields for the same management systems after many years may reflect the impact of erosion and loss of soil productivity, but the results may be confounded by changes in crop varieties, climatic patterns, or operators. Winter wheat (*Triticum aestivum* L.) yields in the U.S. Great Plains decreased 35 kg ha^{-1} yr^{-1} for the first 4 yr the land was cultivated and 7 kg ha^{-1} yr^{-1} for the next 21 yr (Stallings, 1957). In 13 western Kansas counties, wind erosion reduced wheat and sorghum (*Sorghum* sp.) yields 26 to 129 and 39 to 193 kg ha^{-1} yr^{-1}, respectively (Lyles, 1975). Thirty years of cotton (*Gossypium hirsutum* L.), grain sorghum [*Sorghum bicolor* (L.) Moench], and forage sorghum (*Sorghum* sp.) yield data from Big Spring, TX, were statistically normalized to remove climatic effects (Fryrear, 1981). During above-normal rainfall years, soil productivity was more important than rainfall in determining crop yield. In such semiarid region, however, water is the factor that limits crop yields most years.

Plant Injury

At many erosion sites, wind velocity is higher than the threshold required to initiate soil movement. Whenever movement occurs, growing plants that are present can be damaged. The amount of damage and the potential crop yield loss depend on the crop species, plant age when damage occurs, soil movement amount, and wind velocity (Fryrear and Downes, 1975; Sterk, 1997).

Off-site Mechanical

Mechanical devices with moving parts may be damaged by wind-borne or -deposited soil materials. The damage may result from accumulation of fine dust within machines, abrasion of exposed surfaces, or malfunction of operating equipment. The cost of off-site damages may be several times the on-site cost (Piper, 1989; Piper and Huszer, 1989).

Abrasion of Surfaces

In addition to damaging plants, wind-blown soil particles also may abrade buildings, automobiles, and airplanes. The abrading particles destroy painted surfaces leaving bare metal exposed to rust. Exposed glass may be pitted, resulting in a frosted appearance.

Transport of Pesticides, Insects, Viruses, etc

Various pathogens attached to airborne soil particles (dust) have caused lung and respiratory problems (Pope et al., 1999) that have resulted in human fatalities. Dust also has led to accidents along roads and highways that resulted in fatalities. Dust transported and eventually deposited on watersheds may be a significant mechanism for introducing pesticides to surface waters (Hawthorne et al., 1996), may spread plant and animal diseases (Bout, 1987; Pimentel et al., 1995), and may contain pathogens that sometimes cause skin disorders (Troeh et al., 1991).

Sediment Deposition

Dust transported long distances generally causes no major damage where deposited. Saltating materials, however, do not move great distances, but often cause major problems where deposited. Such materials may bury fences, crops, and machinery; cover roads, highways, and railroads; settle in farmsteads, windbreaks, and shelterbelts; and seep into buildings. Many of these problems occurred during the "Dust Bowl" era in the U.S. Great Plains during the 1930s (Baumhardt, 2003). Off-site costs due to wind erosion greatly exceeded the on-site costs in a survey conducted in New Mexico (Huszar and Piper, 1986).

Water Erosion

Some consequences of water erosion are similar to those mentioned above for wind erosion with respect to soil movement and plant nutrient and crop productivity losses. Although the consequences are similar, the mechanisms may differ to some degree. Additional consequences of water erosion include the following:

Textural Change

Soil textural change is similar to soil sorting described above for wind erosion. Because detached fine soil particles are suspended and transported greater distances than coarse particles (sand grains), water erosion tends to make sandy soils sandier (Liu et al., 2000; Troeh et al., 1991). In fields where the entire surface soil layer is removed due to erosion, the new surface, which was the previous subsoil, often has a finer texture than the previous surface. Associated with complete removal of the surface layer often are plant nutrient imbalances, decreased plant growth, adverse soil structure conditions, tillage problems, water infiltration problems, and increased runoff, all of which can increase the potential for subsequent erosion.

Field Dissection

Fields being subjected to splash, sheet, or rill erosion can be farmed without major difficulty and crop productivity may not be greatly affected. However, when major gullies dissect a field, the available land area is reduced, production costs are increased, and total yields are decreased, which reduces net income for the producer.

Water Pollution

Sediments are the major pollutants in surface waters such as streams and reservoirs. When polluted, water in streams and reservoirs becomes less valuable or desirable for consumption and use by humans and animals, and for industrial, recreational, and fish and wildlife purposes (Baker, 2000). In addition, nutrients and pesticides dissolved in water or adhering to sediments contribute to the water pollution problem.

Sedimentation

In addition to the water pollution problems, sedimentation of low-lying areas may damage plants, buildings, and roads and highways, and reduce the capacity of stream channels to carry water, thereby increasing the potential for floods and reducing the value of streams for navigational purposes (Baker, 2000). Sedimentation also reduces the water storage capacity and useful life of lakes and reservoirs. Under extreme conditions, lakes or reservoirs may be completely filled with sediments. While sedimentation is generally undesirable, bottomland soils owe their high productivity to sediments derived from eroding upland soils. The productivity of bottomland soils, however, can be lost if less productive sediments are deposited on them.

Damage to Structures

Water erosion damages buildings, roads, bridges, and other engineering structures by washing out or undermining foundations, causing landslides, or promoting soil creep. Also, terraces, dams, and other structures intended as conservation measures can be damaged or destroyed when they are overtopped during intense, high volume rainstorms or by excessive water flow through or adjacent to them.

Tillage Erosion

Tillage erosion increases soil variability and causes a general decline in field productivity. It results in steep boundaries between adjacent fields, causing some loss of land for crop production purposes and subjecting those zones to increased soil movement during rainstorms. Due to the removal of topsoil from upslope positions, productivity in fields decreases because the remaining soil generally is less productive than the original topsoil.

Exposure of the underlying subsoil and its subsequent redistribution over the landscape by tillage modifies existing soil properties. The lower structural stability of the subsoil combined with its inherently lower soil organic matter content makes it more vulnerable to wind and water erosion (Lobb et al., 1995; Govers et al., 1996).

Water erosion is greatest along the central axis of hillslope concavities or draws where most runoff occurs, which is also the zone of soil deposition by tillage erosion. The balance between deposition and removal depends on the relative intensity of the two processes and landscape morphology. In the southern U.S.Great Plains, more soil was moved into two major ephemeral gullies by tillage than was removed by water erosion (Thomas and Welch, 1988).

The magnitude of erosion rates by tillage vs. by water is affected by variables such as topography, rainfall intensity, tillage intensity (depth and frequency), and land use. Quine and Walling (1993) found that landscape curvature had the greatest effect on tillage erosion at four of the five sites investigated. These results differed from those for water erosion, for which slope angle and upslope lengths or areas are the primary influences.

Quine et al. (1999) differentiated between erosion processes (tillage and water) at field sites in China, Lesotho, and Zimbabwe. Soil movement due to tillage was determined by an iterative process to determine the best fit k-value for explaining the loss of ^{137}Cs at upper field boundaries and landscape positions where soil movement due to water erosion would be minimal. (The k-value is a measure of the mean distance a mass of soil per unit width is moved by tillage in a specified direction relative to the direction of tillage.) Tillage erosion accounted for about 50% of soil movement at the sites.

The impact of tillage erosion on soil productivity is primarily related to soil removal from a specific landscape position and its deposition at another site. Direct effects of soil erosion on crop yield include a reduction in rooting depth, loss of plant nutrients, loss of available plant water, loss of land area, and damage to seedlings (Lal, 1988), with tillage erosion acting through the first three. Changes in soil quality parameters, that is, soil organic matter, plant available nutrients, and bulk density, in terraced fields and along a steep cultivated hillslope in the Loess Plateau of China were attributed to changes in soil deposition by tillage (Li and Lindstrom, 2001).

Using tillage erosion (Lindstrom et al., 1992) and water erosion (Flanagan and Nearing, 1995) models, Schumacher et al. (1999) evaluated the effects of erosion patterns on soil property distribution on summit, shoulder, backslope, footslope, and toeslope positions of common soil series in eastern South Dakota and western Minnesota. Root zone properties due to movement by the two eroding processes were evaluated for each landscape position for change in productivity using a productivity model (Pierce et al., 1983). The simulation suggested that spatial changes in productivity were due to loss or gain in topsoil thickness. The net combined effect of tillage and water erosion was a potential decrease in productivity at shoulder and upper backslope positions and an increase at the footslope position, but that increase did not compensate for losses at the other positions.

SOIL CONSERVATION PRINCIPLES

The principles for soil conservation are simple. To control wind erosion, the force of the wind on the soil surface must be reduced to a non-erosive level or the soil roughness must be increased to a level that resists the force of the wind. In essence, wind velocity at the soil–air interface must be reduced to below the threshold value needed to initiate soil movement.

The principles for controlling water erosion are to reduce the impact of raindrops on the soil surface, reduce the volume and flow rate of water across the soil surface, and increase the resistance of the soil to erosion. To achieve these, the energy of falling raindrops must be dissipated so that soil particles are not detached, water infiltration must be maintained so that runoff is reduced or avoided, water flow across the surface must be reduced to non-erosive rates, and soils must be maintained in a condition that minimizes or avoids the potential for erosion.

Because tillage erosion results from human activities, the principle to control such erosion is to alter the way tillage is performed on the land, which requires a change in land management. This may involve altering the direction of tillage across the field so that most soil movement is upslope rather than downslope or changing to the use of tillage implements that minimize or avoid the downslope movement of soil when tillage is performed.

Although the principles of soil conservation (erosion control) are simple, achieving soil conservation is complex and challenging because of the myriad of situations involved, including soil, climate, resource availability, technical support availability, and landowner/operator knowledge, capabilities, and preferences. While the same principles may apply, not all control practices or techniques are applicable to all situations.

CONSERVATION PRACTICES AND TECHNIQUES

Soil movement due to wind or water forces occurs when conditions are favorable for detachment and transportation of the detached soil particles. Factors affecting movement due to wind include the soil's resistance to erosion, surface ridges, climate (rainfall, wind velocity, humidity, freezing and thawing), land slope (hummocks), length of exposed area (in direction of the wind), and surface cover. Those affecting movement due to water include climate, soil erodibility, slope gradient and length, surface cover, and soil surface conditions. Soil movement due to tillage results from management practices imposed on the land by humans. Soil movement has been researched extensively, especially regarding wind and water erosion, and the literature is replete with articles and books dealing with practices and techniques for reducing or avoiding this problem.

A review or discussion of the vast literature dealing with soil conservation, even of only that related to dryland agriculture, is beyond the scope of this chapter. Rather, we discuss the basic practices suitable for dryland conditions, and give some selected examples pertaining to their effectiveness for conserving the soil.

Controlling Wind Erosion

Wind erosion is a basic geomorphological process that predates the influence of humans. Human activities can accelerate erosion or may partially control it. Whenever humans interrupt the natural processes, the results can be devastating. Tilling a moist soil before wind erosion begins can effectively reduce the potential for erosion until the cloddy surface is smoothened by rainfall. Tilling a dry soil may accelerate erosion because stable clods are destroyed. Tillage can be used in combination with other practices to control wind erosion.

Controlling wind erosion, which is essential for successful long-term dryland agriculture, requires a soil surface that allows rapid water infiltration and resists movement of soil particles by wind. Both objectives can be accomplished if crop residues and aggregates on the soil surface are effectively used and properly managed (Logie, 1982; Lyles and Allison, 1981; Sterk and Spaan, 1997). Rapid water infiltration is important for conserving water, which is a major goal for successful and improved crop production under dryland conditions. Good infiltration improves conditions for greater vegetative production, which, in turn, increases the potential for having adequate crop residues that can be managed to aid in controlling erosion. The high effectiveness of surface cover provided by crop residues for reducing soil movement is illustrated in Fig. 4–1. Unfortunately, surface residues decompose, are consumed by insects or foraging animals, or are removed for other uses, and surface soil aggregates can be dislodged and broken down. As soil aggregates are abraded, very fine soil particles are emitted into the airstream and often transported great distances before being deposited onto the soil surface or into surface waters (Tsoar and Pye, 1987).

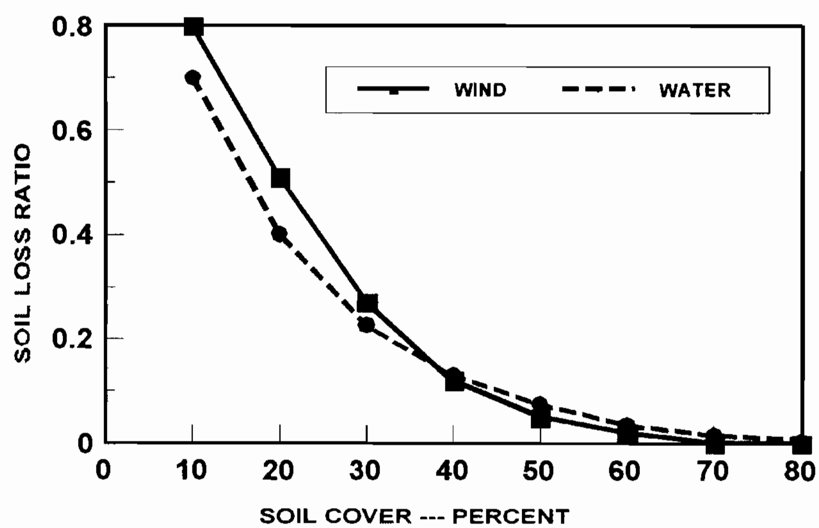

Fig. 4–1. Relationship between soil loss (movement) ratio (loss with cover divided by loss from bare soil) and percentage of surface covered with residues. Redrawn from Papendick et al. (1990).

The magnitude and duration of wind above the threshold velocity required to initiate soil movement determines the quantity of erosion that occurs. The quantity being transported varies as the cube of the wind velocity (Chepil and Woodruff, 1963), duration of erosive wind velocities, and, to a lesser extent, wind turbulence. The goal is to provide conditions at the surface (plants, crop residues, soil aggregates) that prevent wind at the soil surface from exceeding the threshold velocity. Under emergency conditions, that is, when wind erosion is in progress, emergency tillage can be used to adequately roughen the surface so that wind at the soil surface is reduced to below the threshold velocity. Implements suitable for emergency tillage include chisels, rotary hoes, and sandfighters (Unger, 1984).

Most agricultural soils are composed of a broad size range of particles and aggregates. The size and distribution of clods can be increased if soil density is increased (Lyles and Woodruff, 1960), which then potentially improves surface soil conditions for resisting wind erosion.

In most agricultural regions, a portion of the crop biomass is left in the field when crops are harvested. This includes all plant materials, except the harvested grain or fiber, and it may be standing stubble or flat residues. The kind, amount, and placement of these residues significantly influence wind erosion (Lyles and Allison, 1981; Michels, 1994; Siddoway et al., 1965; Sterk and Spaan, 1997). As these residues weather and decompose, their mass decreases. The rate of decomposition is determined by the specific crop under consideration and soil temperature and water content variables (Schomberg and Steiner, 1997).

When plant residues (flat on the soil surface) are present, they cover a portion of the surface and help reduce wind erosion (Chepil, 1944; Englehorn et al., 1952). The reasons why the cover is so effective are described by Laflen et al. (1981) for water erosion and by Fryrear (1985) for wind erosion. Crop residue retention on the soil surface can be maximized by using tillage methods that undercut the surface (e.g., stubble mulch tillage) to control weeds and to prepare a seedbed or by using conservation tillage methods, including no-tillage (Heilman and Valco, 1988; Jones et al., 1990). In the USA, conservation tillage is defined as any tillage system that results in a 30% or greater cover of crop residues on the soil surface (SSSA, 1997). For no-tillage, the succeeding crop is planted with no primary or secondary tillage since harvest of the previous crop, thus retaining most residues on the surface. A special planter may be needed to open a narrow slit in the soil for seed placement under no-tillage conditions (SSSA, 1997).

Standing residues (stubble) are about six times more effective for reducing wind erosion than the same quantity lying flat on the surface (Bilbro and Fryrear, 1994). The effect of different types of standing plant materials on the potential for erosion can be quantified by multiplying stalk height by stalk diameter by the number of stalks on one square meter of the soil surface. Greater values indicate a lower potential for erosion. As indicated by the above quantification, wind erosion control increases with increases in stubble height (van de Ven et al., 1989; Wilkins et al., 1996). For small grains, stubble heights should range from about 0.15 to 0.40 m for wind erosion control (Bauer and Black, 1990).

Barriers comprised of standing residues or growing plants (grasses, bushes, or trees) oriented perpendicular to prevailing winds can effectively reduce the potential for wind erosion (Aase et al., 1985). Barriers provide control of wind erosion for a leeward distance of 8 to 12 times the barrier height. A disadvantage of such barriers is that they compete with crops for water, thereby potentially reducing crop yields.

A type of barrier system used extensively in the U.S. Great Plains and Canadian Prairie Provinces is strip cropping, which involves strips of erosion-resistant crops being alternated with equal-width strips of land susceptible to wind erosion. Strip width may range from about 6 m on a sandy soil to 130 m on a silty clay loam (Siddoway, 1970). Strip cropping combined with other practices such as stubble mulch tillage or no-tillage greatly reduces the wind erosion potential on erosion-susceptible strips.

The presence of barrier plants greatly impacts wind erosion control (Armbrust and Bilbro, 1997). Barrier plants should have strong flexible stems at least 0.45-m tall, but not so tall that lodging becomes a problem; have a population that provides for optical porosities <50%; and have a uniform porosity with height. Also, the barriers should consist of two or more rows of plants so that airflow gaps are not a problem (Schwartz et al., 1995; 1997). Flax (*Linum usitatissimum* L.), forage sorghum, grain sorghum, corn (*Zea mays* L.), kenaf (*Hibiscus cannabinus* L.), sunflower (*Helianthus annuus* L.), tall wheatgrass (*Agropyron elongatum* L.), and switchgrass (*Panicum virgatum* L.) have been used as barrier plants in the U.S. Great Plains (Bauer and Black, 1990; Bilbro and Fryrear, 1997; Black and Aase, 1988) and Canadian Prairies (McConkey and Dyck, 1996).

Crop seedlings grow rapidly and may effectively control wind erosion when they cover about 30% of the soil surface. The tolerance of crop seedlings to wind blown sand injury can be estimated (Downes et al., 1977) and varies for different plant species (Sterk, 1997). A small amount of injury may stimulate crop yields (Fryrear et al., 1975). Additional injury, however, can greatly reduce yields or even totally destroy a crop (Fryrear et al., 1975; Michels, 1994; Sterk, 1997).

Under some conditions, wind and water erosion enhance each other (Gao and Tang, 2000; Visser, 2004). Wind erosion will not occur when soils potentially erodible by wind are wet, as from rainfall or irrigation. Rapid downward movement and evaporation of water from the soil surface, however, may result in the soil becoming erodible within minutes after being saturated. In addition, raindrop impact may destroy soil aggregates, leaving individual soil grains on an aerodynamically smooth surface, and highly susceptible to wind erosion. The magnitude of wind erosion from wet soil will be reduced, but may still occur. Wind erosion may deposit fine, loose soil material in low areas most susceptible to entrainment and movement by water. Water erosion, in turn, may leave smooth fans of loose deposits that are easily eroded by wind. Under such conditions, the goal of soil conservation practices should be to control both types of erosion.

Research summarized by Chepil and Woodruff (1963) and additional studies by Fryrear (1984), Lyles and Woodruff (1960), Potter and Zobeck (1990), and Saleh (1994) have resulted in the development of improved models to describe the impact of aggregates, ridges, and other variables on wind erosion (Fryrear et al., 1998; Hagen et al., 1995). These models were developed to identify and test parameters responsible for erosion, and to assist in planning more effective control systems. Before the erosion process can be modeled, the factors responsible must be quantified in an organized manner. A detailed discussion of models dealing with wind erosion is beyond the scope of this chapter, but brief information about several models follows.

Wind Erosion Equation

The wind erosion equation (WEQ) was first published in 1961 and the final form was published in 1965 (Woodruff and Siddoway, 1965). This was the first model developed to test and evaluate practices for controlling wind erosion.

Revised Wind Erosion Equation

The revised wind erosion equation (RWEQ) was developed to use technology developed since 1965 and to reflect the dynamics of the wind erosion process. The RWEQ is a combined empirical and theoretical model that has been extensively tested against field measurement of wind erosion (Fryrear et al., 1998; 2000).

Wind Erosion Prediction System

Development of the wind erosion prediction system (WEPS) was started in 1986. The WEPS is a process-based complex model with a continuous, daily time step that simulates weather, field conditions, and wind erosion (Hagen et al., 1995). It can estimate soil movement subhourly, and will describe changes in soil surface conditions during erosion events. Development of the WEPS is continuing.

Wind Erosion Assessment Model

The wind erosion assessment model (WEAM) was developed in Australia by Shao et al. (1996). This process-based model considers the combination of established and theoretical results on sand drift and dust entrainment, provides for an approximated quantitative assessment of wind erosion, and evaluates our knowledge of the erosion process. When used with large computers, WEAM has the capability to estimate the movement of dust clouds across complex landscapes. By using WEAM, the regional or continental impacts of wind erosion can be described.

Texas Erosion Analysis Model

The Texas erosion analysis model (TEAM) was developed at Texas Tech University to simulate wind profile development, soil movement, and to predict soil erosion (Gregory, 1986). This computer model can estimate soil erosion hourly for single events and can be extended to estimate yearly movement.

Wind Erosion on European Light Soils

The wind erosion on European light soils (WEELS) model was developed to provide a suitable, GIS-based model of wind erosion with the following objectives: (i) to examine the existing public policy measures used in several European Union Member countries that are intended to control wind erosion directly or indirectly, (ii) to review policy measures in the USA, Australia, and New Zealand, and to identify those measures that might be suitable for consideration in Europe, and (iii) to evaluate measures that can abate the harmful effects of erosion and contribute to the mitigation of its on- and off-site effects [Warren, (n.d.)].

Where the potential for wind erosion exists, the available resources must be properly managed if successful soil conservation is to be achieved. Conservation tillage farming, for which most crop residues are retained on the soil surface, may successfully reduce wind erosion, but insufficient residues may be produced or remain available to protect the soil under dryland conditions, especially when droughts occur. When crop residue levels are below the minimum required to protect the soil, tillage to produce a cloddy, ridged soil surface may be required. Wind barriers consisting of annual crops or perennial plants can also be used to provide protection against erosion. Annual crops grow much faster and may allow a more flexible farming operation than perennial plants, but annual crops must be established each year, and may not grow during droughts. It is not necessary to establish perennial plants each year, but they usually grow slower and may die during prolonged droughts.

For most dryland regions, no single conservation strategy will be effective every year. The most effective system will use combinations of crop residues, tillage, and, where applicable, barriers to reduce wind erosion and, hence, conserve the soil.

Controlling Water Erosion

Controlling water erosion may be partially or wholly achieved if water capture is maximized, which is a major goal where dryland agriculture is practiced. This is because practices that increase storage of precipitation as soil water generally have soil conservation benefits, and vice versa. When water infiltrates the soil or is retained on the land, as behind terraces, in furrow dikes, or on contour-furrowed land, runoff is reduced or prevented, thus reducing or eliminating water flow across the surface, which is the mechanism for soil particle transport during an erosion event. The additional stored soil water usually results in greater plant growth and crop yields, which then potentially provide for greater amounts of residues on the soil to help control erosion. Most practices discussed in Chapter 3 "Water Conservation and Efficient Use" (Unger et al., 2006, this publication) also provide soil conservation benefits.

Provided adequate amounts are present, vegetation on the soil surface, whether growing plants or crop residues, generally provides the greatest soil conservation benefits where the potential for water erosion exists (Fig. 4–1). Surface vegetative materials dissipate the energy of raindrops, thereby reducing their impact on the soil surface and minimizing or eliminating particle detachment and splash erosion. As a result, the potential for movement of fine soil particles is reduced, which, in turn, reduces surface sealing and increases water infiltration (Hoogmoed, 1999; Le Bissonnais et al., 1995; Loch, 1989). By maintaining favorable water infiltration, the amount of runoff is reduced, which reduces the potential for soil particle transport across the surface. Surface vegetative materials also retard the flow rate of runoff across the surface, thus providing more time for infiltration and contributing to less sediment transport (Alberts and Neibling, 1994). In addition, soil particles settle out of water when the flow rate is reduced. Most crop residues can be retained on the soil surface by avoiding tillage that inverts the surface layer of soil. Surface residue-retaining methods include stubble mulch, chisel, conservation, and no-tillage (Heilman and Valco, 1988; Jones et al., 1990). In rare cases when large amounts of residues are produced by dryland crops, a disk implement could be used on a limited bases while still retaining adequate residues on the surface to achieve soil conservation. Repeated operations with a disk and other soil disturbing implements, however, result in a reduction of surface residues, which could result in inadequate amounts being available by the time the next crop is planted. Residue losses occur even with no-tillage due to decomposition, weathering, and insect and animal damage or consumption.

An example of the effects of different tillage and residue management practices on sediment movement is available from a field study conducted at Bushland, TX (Unger, 1992), which is in the semiarid southern U.S. Great Plains. The soil was Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) and sediment movement was determined for dry and wet runs under simulated rainfall conditions. Sediment movement for both runs after dryland grain sorghum was greater with moldboard plowing than with rotary, mulch (sweep), or no-tillage, with residues either removed or retained on the surface for the latter two tillage treatments. After dryland winter wheat, movement tended to be lower with rotary, mulch, and no-tillage than with moldboard plowing, but all differences were not significant. In all cases for both crops, however, movement was lower with no-tillage (<1.0 Mg ha^{-1}) than with moldboard plowing (2.7–4.8 Mg ha^{-1}). Pretreatment residue amounts were 4.49 Mg ha^{-1} after sorghum and 2.17 Mg ha^{-1} after wheat.

Although crop residues retained on the soil surface provide major soil conservation benefits, plant growth under dryland conditions often is insufficient to produce adequate residues to achieve the desired level of soil conservation. Also, residues of some crops, for example, cotton, have limited effectiveness for controlling erosion. Furthermore, even when residue amounts produced would be adequate to achieve soil conservation, the residues may be destroyed, devoured, or removed for other uses. In some cases, crop residues are plowed under or even burned. Whatever the reason for insufficient residues remaining on the land, other practices or techniques must then be used to achieve soil conservation. A host of practices have been developed for soil conservation under conditions where in-place crop residues are limited or nonexistent.

Crop residues from outside sources can be placed on soil as a mulch and have been shown to be effective for reducing runoff and sediment movement. Other mulches that reduced runoff and sediment movement were stones, gravel, paper, coal, and bitumen. The use of these materials usually has been limited to high-value crops and where labor was abundant (Unger, 1995).

Cover crops are close-growing crops such as grasses, legumes, or small grains that are used primarily to provide seasonal protection against soil erosion and for soil improvement. Benefits of such crops with respect to soil conservation are similar to those achieved from other close-growing crops or crop residues.

The potential for runoff and, hence, sediment movement decreases with increases in plant density and surface cover (Roth et al., 1987; Sidiras et al., 1985). A major disadvantage of using cover crops in dryland regions is that these crops use valuable water that could be used by the subsequent crop (Unger and Vigil, 1998). When cover crops are grown under dryland conditions, timely above average precipitation is essential for achieving good yields of a following dryland crop.

Surface seal formation occurs when fine soil particles dislodged by raindrop impact or flowing water migrate into soil pores at or near the surface. Such seals reduce water infiltration and, hence, increase runoff and the potential for soil erosion, especially when few or no crop residues are on the surface. Under such conditions, the potential for seal development could be reduced by applying appropriate stabilizing materials to the surface. Application of phosphogypsum (PG) at 10 Mg ha^{-1} to the surface of a ridged sandy field soil in Israel reduced runoff sixfold and soil movement from ridge tops to furrow bottoms 20-fold. For the same soil under laboratory conditions using a rainfall simulator, increasing the slope from 5 to 25% increased soil movement twofold for the PG treatment and 12-fold for the control treatment (no additive). Both studies showed that application of PG was highly effective for reducing soil movement on those steeply-sloping soils (Agassi et al., 1989). Undoubtedly, similar results are possible on other soils.

Applications of anionic polymers [polyacrylamide (PAM) or starch copolymer solutions] have stabilized soil surfaces and reduced sediment movement. Polyacrylamide, which is an anionic polymer, holds soil in place and ionically bonds soil particles together to increase particle size (Nwankwo, 2001). When used under furrow-irrigated conditions (Lentz et al., 1992) and under broadcast conditions on limited, high value areas (Nwankwo, 2001), soil movement was significantly lower than under control conditions. These studies did not involve dryland agriculture and, at present, the cost of PAM would be prohibitive for widespread use under dryland cropping conditions. Because of its effectiveness, its use may be economical at present under other conditions. Eventually, if its cost decreases sufficiently, it may find use for conserving soil in fields used for dryland agriculture.

Because runoff transports sediments across the soil surface, sediment movement can be reduced or avoided if runoff can be sufficiently reduced or avoided by using practices such as contour tillage, furrow dikes, level terraces, and land leveling. These practices increase detention storage of potential runoff through manipulation of the soil surface and, in general, their effectiveness increases in the order listed. With these practices, runoff from small storms is prevented, but large storms may result in overtopping and washing out of these structures.

Contour tillage involves performing cultural operations across the slope of the land so that elevations along rows are as close to level as possible. When ridge-forming tillage is used and the resultant furrows are blocked at their ends, runoff and sediment movement are prevented for low and medium intensity and duration storms. Large storms may cause ridge overtopping and, hence, runoff and sediment movement.

Furrow diking, also known as tied ridging, furrow damming or blocking, and basin listing, is the practice of forming small earthen dikes or dams in furrows resulting from the use of, for example, lister tillage in a ridge-furrow management system. While furrow diking is used primarily to retain water on the surface under dryland farming conditions (Jones and Stewart, 1990), retaining the water also results in preventing sediment movement. Water retention was achieved under a range of conditions where furrow diking was evaluated (Agassi et al., 1989; Hudson, 1981; Jones and Clark, 1987; Rawitz et al., 1983), which resulted in a soil conservation benefit.

Soil pitting and chain diking are practices that result in the formation of small depressions at close intervals to retain water from rainfall, which then results in the potential for soil conservation. Pitting is done with equipment similar to that used for furrow diking. As the equipment is pulled across the land, paddles or blades on a tripping drag or rotating mechanism having some resistance to turning results in the formation of soil depressions. Pitting is well adapted for use with drilled or broadcast-planted grain crops. Chain diking results in surface conditions similar to those achieved by pitting, and is accomplished with a heavy ship-anchor chain to which specially-shaped blades have been welded to the links. The chain is mounted on a frame with fittings that allow the chain to rotate as it is pulled across the soil surface. When pulled across loose, flat-tilled soil, depressions about 0.10-m deep are made, which provide for water storage and potential for soil conservation. Chain diking does not appear to interfere with subsequent crop production operations (Wiedemann and Smallacombe, 1989).

Practices that involve more extensive manipulation of the soil surface than furrow diking, pitting, and chain diking are terracing and land leveling. Terraces decrease slope length in fields. Terraces that retain water on the land and, therefore, help conserve soil may be level with ends either open or blocked, level with all land between adjacent terraces leveled, and conservation bench for which a portion of the land between adjacent terraces is leveled. Again, because runoff is reduced or prevented, use of terraces increases the potential for soil conservation.

Under some conditions, it may not be practical or desirable to prevent all runoff. Where some runoff is allowed, soil conservation is still possible if the runoff occurs at non-erosive rates. Practices that provide for runoff at controlled rates include land smoothing, graded furrows, graded terraces, variations of bench terraces, discontinuous parallel terraces, land imprinting, and tillage per se (Unger, 1996). These practices provide for nonerosive movement of excess water within fields or to nearby waterways or streams.

A practice that controls runoff and, therefore, water erosion within fields on hilly land is strip cropping on the contour. Such strip cropping involves strips of row crops being alternated with strips of solid-planted crops having the same width. Sediments from the row-crop strips are trapped in the solid-planted strips, thus preventing their movement from the field (Laflen et al., 1985). A departure from equal width strip cropping is the use of narrow strips of plants, which form dense barriers that trap sediments when water flows through them. Vetiver grass [*Vetiveria zizanioides* (L.) Nash ex Small] was found to be highly effective for trapping sediments (Erskine, 1992).

A variety of other practices developed mainly for water conservation purposes also provide soil conservation benefits. Some such practices are vertical mulching, slot mulching, deep plowing, and soil profile modification (Unger, 1996).

As for wind erosion, several models have been developed to identify and test the parameters responsible for water erosion, and to assist in planning more effective control practices. Factors considered in the models include, among other things, various aspects of climate, soil, crop (or other plants or plant materials), landscape features, and management options. Detailed discussion of the models is beyond the scope of this chapter. Information for the models can be obtained via the Internet or other sources, as available.

Universal Soil Loss Equation

The universal soil loss equation (USLE) is considered one of the most significant developments of the 20th century that deals with soil and water conservation. It was developed over the past 60 yr, is used on all continents, and is still undergoing evolution (Laflen and Moldenhauer, 2003). By using this equation, the long-term average annual soil movement caused by sheet and rill erosion under specific conditions of climate, soil, topography, land use, and management practice can be predicted. It does not apply to erosion in channels.

Revised Universal Soil Loss Equation

The revised universal soil loss equation (RUSLE) is a revision of the USLE. It is based extensively on the USLE model and its data, and offers several major improvements to USLE users. Each factor value of the USLE has been updated, expanded, and improved for the RUSLE. Like the USLE, it is used to predict sheet and rill erosion and not channel erosion.

Water Erosion Prediction Project

The water erosion prediction project (WEPP) is a process-based, distributed-parameter, continuous-simulation, erosion prediction model for use on personal computers with appropriate capabilities. The current version is applicable to hillslope erosion processes (sheet and rill erosion) and for simulation of the hydrologic and erosion processes on small watersheds.

Chemicals, Runoff, and Erosion from Agricultural Management Systems

Chemicals, runoff, and erosion from agricultural management systems (CREAMS) is a field-scale model applicable for predicting chemical transport, runoff, and water erosion from field-sized agricultural lands. It can be used for individual storms and can also predict long-term averages (2–50 yr). Several of the equations developed for the CREAMS model were used or modified for use in the WEPP model.

Simulator for Water Resources in Rural Basins

The simulator for water resources in rural basins (SWRRB) model provides for the efficient computation of sediment yield from small to large complex watersheds. As a modification of CREAMS, SWRRB is designed to simulate sediment movement for 100 yr or more.

Erosion/Productivity Impact Calculator

The erosion/productivity impact calculator (EPIC) model is used for determining the relationship between soil erosion and soil productivity. It is used to calculate crop yield loss due to soil erosion and other factors. EPIC is a continuous simulation model that uses a set of modified USLE functions to predict erosion.

Areal Nonpoint Source Watershed Environment Response Simulator

The areal nonpoint source watershed environment response simulator (ANSWERS) model predicts erosion on agricultural land caused by specific land uses and management practices. It also provides a water quality analysis associated with sediment associated chemicals. ANSWERS is event based, being primarily limited to a single storm. The erosion component in the ANSWERS and CREAMS models is very similar.

Agricultural Nonpoint Source Pollution Model

The agricultural nonpoint source pollution model (AGNPS) was developed for analyzing nonpoint-source pollution from agricultural fields. It estimates the quality of runoff water from such fields and compares it with the expected quality of water from lands on which other management strategies are used. AGNPS is for single events, but continuous simulated versions are under development. AGNPS uses a set of modified USLE equations in its erosion component.

Where the potential for water erosion exists, no single soil conservation strategy will be effective every year for most dryland regions. Conservation tillage farming, for which most crop residues are retained on the soil, may successfully reduce water erosion, but, similar to wind erosion control, insufficient residues may be available for water erosion control under dryland conditions, especially when droughts occur. When crop residue levels are below the minimum needed to protect the soil, some combination of crop residue management, tillage, soil surface manipulation, or other soil conserving practices will be required.

Controlling Tillage Erosion

Tillage erosion is a serious problem under some conditions that may need consideration when choosing soil conservation practices. Tillage erosion is directly proportional to the degree and scale of landscape topographic complexity. The magnitude of soil movement from upslope positions can greatly exceed levels that would be considered sustainable. Although the soil is not lost from fields, it is deposited at field or terrace borders and concave slope positions, which may enhance subsequent water erosion. The interactions between tillage and water erosion, therefore, require that both processes be considered when choosing soil conservation plans. The net effect of tillage or water erosion is an increase in field variability and a reduction in crop production potential.

Reduction in tillage erosion can be accomplished primarily through a change in land management, namely, by changing the direction of tillage (across the slope rather than with the slope) and the direction the soil is turned (upslope rather than downslope) when tilling across the slope. Changes in the implement type may also reduce soil displacement due to tillage. Unfortunately, for undulating landscapes, any tillage direction or method will result in some downslope soil displacement at some sites in a field.

For less mechanized tillage systems involving animal power or hand labor, it is common to always direct soil movement toward the downslope direction. This is done to conserve energy. Quine et al. (1999) concluded that net downslope soil translocation by animal powered tillage always in the downslope direction may exceed those associated with mechanized agriculture.

Tillage erosion has received considerable attention in recent years. To better understand factors involved with tillage erosion, various relationships involving different factors have been developed. Detailed information, including various equations dealing with tillage erosion, has been developed by Lindstrom et al. (1992) and Govers et al. (1994).

NEED FOR RESEARCH

Although numerous practices suitable for conserving soil are available, soil erosion remains a serious problem in many cases under dryland conditions. The following are some possibilities for achieving improved soil conservation under dryland agriculture conditions.

Because many practices are already available, research should be directed toward developing means for achieving greater adoption of conservation practices. This may involve, for example, greater participation of the landowner/operator in selecting appropriate practices, providing incentives, changes in land use policies, and education activities. For the latter, all students should be made aware of the importance of soil conservation so that future efforts at soil conservation will be more readily accepted.

Crop residues are known to provide for excellent control of erosion when adequate amounts are available. Under dryland conditions, however, plant growth often is limited, which results in limited amounts of residues being available after crop harvest. In addition, residues decompose, are destroyed by insects, are eaten by foraging animals, or are removed and used for other purposes. Research possibilities for retaining greater amounts of residues for conservation purposes include plant breeding to achieve greater plant growth under dryland conditions, plant breeding to develop cultivars more resistant to decomposition, and developing suitable alternative forage plants for animal feed so that more crop residues could be retained on the land and not required as animal feed.

Crop residues often are limited under dryland conditions and some types of tillage provide soil conservation benefits. Therefore, practices should be developed that identify the conditions under which crop residue management and tillage can be combined to achieve improved soil conservation.

SUMMARY

Crop production under dryland conditions accounts for a significant portion of the food and fiber products used by humans and the feed needed for animals. Because of the increased production needed for an ever-increasing world population, the limited or declining supply of water for irrigation in some regions, and increasing competition for water among agricultural, urban, industrial, and recreational users in some regions, emphasis is increasing to maintain or even achieve greater production under dryland conditions in many regions. To accomplish this, soil resources must be managed to sustain productivity, which entails reducing or preventing soil erosion due to wind, water, and tillage. In this chapter, we discussed the processes and consequences of erosion; principles, practices, and techniques for controlling erosion; and research needed to achieve greater use of control practices currently available or to develop practices that would result in achieving improved control of erosion.

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