Kansas State University

Department of Agronomy MF-2860 Erosion

Principles of Wind Erosion and its Control

A collection of minerals, organic matter, nutrients, gases, and water, soil is responsible for the production of the majority of the world's food supply. Soil is a virtual necessity for civilizations to thrive. If it blows away, soil is not of any use. In fact, when soil enters the atmosphere, it can obscure visibility and pollute the air and water. Airborne soil can lead to automobile accidents; damage machinery; and endanger animal, plant, and human health.

This publication examines the causes and effects of wind erosion and informs landowners about what can be done to control it.

Substantial portions of Asia, the Middle East, and North Africa were once fertile lands supporting prosperous populations. But through soil exhaustion and ruin, they changed to their present barren state. In many countries, soil erosion by wind has depleted the fertility of the soil; in some, it has transformed fertile lands into sandy deserts. In North America, relatively little wind erosion occurred while the land was under natural vegetation. Through overgrazing and cultivation of the land, the stage was set for wind erosion during dry periods or droughts, especially in the Great Plains.

Figure 1. *The winds of the Dust Bowl piled up large drifts of soil against this farmer's barn near Liberal, Kansas (1936).*

During the 1930s, the farming of marginal lands in the Great Plains, combined with a prolonged drought, culminated in dust storms and soil destruction of disastrous proportions (Figure 1.). This period, known as the Dust Bowl, inflicted great hardships on the people and the land, and has been called our nation's greatest ecological disaster. In the United States and throughout the world, the threat of wind erosion has not gone away, especially on agricultural land in arid and semiarid regions.

On 75 million acres of land in the United States alone, wind erosion is still a dominant problem, with 4 to 5 million acres moderately to severely damaged each year.

Wind erosion damages the soil by physically removing the most fertile part, lowering water-holding capacity, degrading soil structure, and increasing soil variability across a field, resulting in reduced crop production. It tends to remove silts and clays, making the soils sandier. It also causes plant damage from abrasion, exposure of roots by removing topsoil, or burial by windblown soil.

The Processes of Wind Erosion

The Dust Bowl helped to stimulate serious attention about the fundamental importance of our land. As a result, the basic causes, effects, and remedies of wind erosion have been the focus of research by the United State Department of Agriculture's Agricultural Research Service. To understand wind erosion and its control, we need to understand the processes involved.

Wind is simply air in motion. Air has mass and when mass is in motion, it has energy. That energy moves soil during wind erosion. It is important to know that erosive wind energy increases by a factor equal to the velocity cubed, so a small increase in wind velocity results in a large increase in erosive wind energy.

When planning conservation systems, it is important to consider wind direction and windy periods throughout the year. The greatest amount of soil is moved in the direction of the prevailing wind. This direction is primarily influenced by the duration and the velocity of wind from different directions. The effectiveness of wind barriers, strip cropping, ridges, and other methods in reducing wind erosion is determined by their orientation relative to the prevailing wind erosion direction for the particular months that control is desired. Tables listing the prevailing wind erosion direction by month for many locations in the United States are available (see the web site address at the end of this document)(Table 1.). The critical wind erosion period is when agricultural fields are particularly vulnerable to wind erosion due to higher wind speeds than normal and low vegetative cover on fields. In the Great Plains states, this period is typically February through May when winds are the greatest and crops are not high enough to protect the soil surface.

The wind high above the soil surface, unrestricted by barriers or objects, is known as "free stream" air flow and moves more or less parallel to the surface.

The wind near the surface affects the soil and vegetation, which removes energy from the wind and slows it. The average forward velocity near the soil surface is lower than in the free stream. The velocity increases as the distance above the surface increases. This velocity gradient is known as a "wind velocity profile." The nature of the surface over which the wind is traveling can greatly influence this wind profile, as well as the wind energy near the surface.

When the soil is rough, large clods or furrows protrude into the wind stream. While these protruding soils are exposed to stronger winds, they also remove energy from the wind and protect the lower surrounding soil. This protection allows particles eroding from the upper positions to be trapped in the lower positions. Vegetative material, either live or dead, also absorbs wind energy near the soil surface and can trap moving soil particles.

Rough, cloddy, or vegetated surfaces alter the wind speed at the soil surface and reduce the energy available to erode the soil. However, if the free stream wind speed is great enough, the wind at the surface will contain sufficient energy to initiate soil particle movement.

There are three phases of particle movement — detachment, transport, and deposition.

Table 1. *Prevailing wind erosion direction for Goodland, Kansas.*

Month	Prevailing Wind Erosion Direction
January	NNW
February	NNW
March	NNW
April	NNW
May	SSE
June	S
July	SSE
August	SSE
September	S
October	NNW
November	NNW
December	NNW

Detachment occurs when the wind force against soil particles increases enough to overcome the force of gravity. Once detached, moving particles may collide with and detach other particles.

The detached soil particles are then subject to **transport** by the wind, either through the air or along the surface.

Eventually the wind velocity decreases and soil particles are deposited. In-field **deposition** typically occurs in furrows or vegetated areas. Deposition also occurs along the edge of fields in ditches, fencerows, or barriers such as windbreaks. For very fine particles,

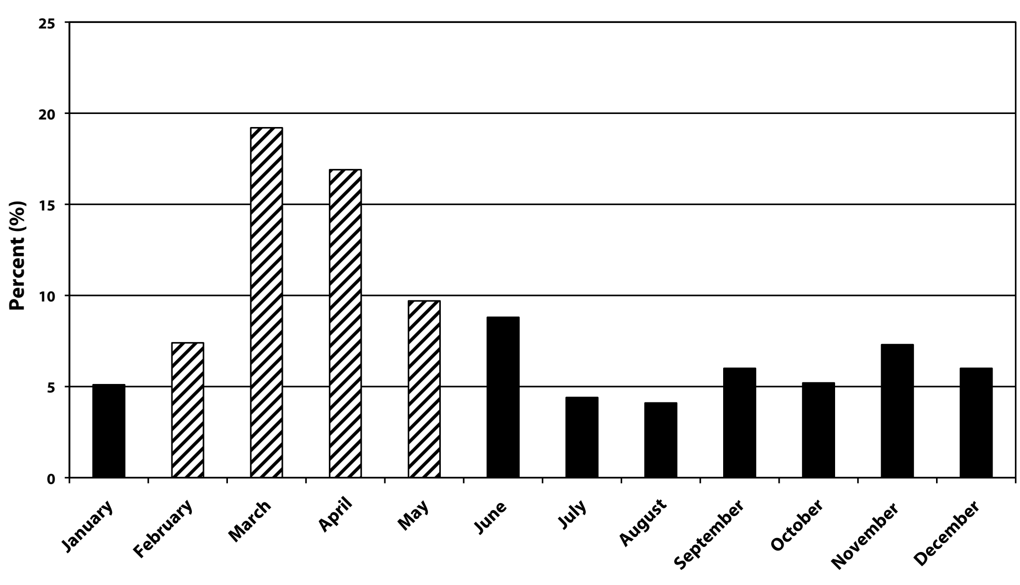

Figure 2. *Percent of Annual Erosive Winds Goodland, Kansas (Striped bars indicate the "critical wind erosion period")*

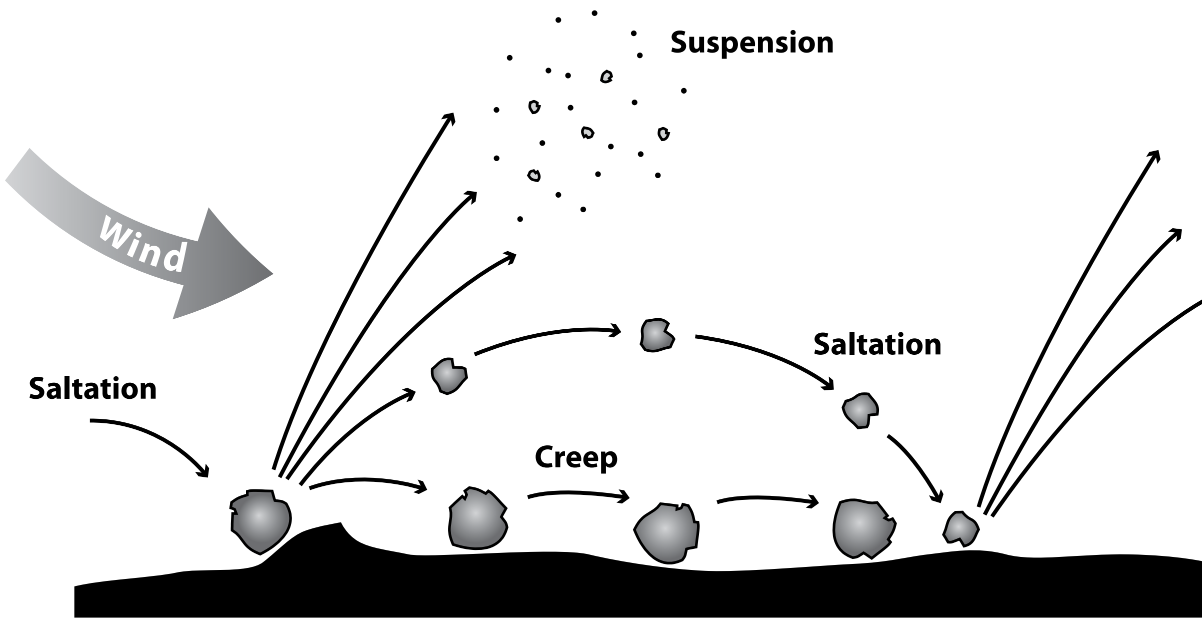

Figure 3. *Soil particles can move through saltation, creep, and suspension.*

deposition may not occur until the particles have traveled thousands of miles.

The wind speed at which particle movement is initiated is called the **threshold velocity** and is dependent on the state of the soil surface. A soil surface that is rough or protected with non-erodible material will require a stronger wind to initiate particle movement than a bare, smooth surface. This means that for a given field, there is no single threshold velocity but rather a range of velocities depending on the soil surface type — aggregation, roughness, crop status, and moisture. Most of these properties also can change during a storm due to the erosive action.

There are three ways soil particles are moved by wind: surface creep, saltation, and suspension. Each has its own characteristics and effects. (See Figure 3.)

Under **surface creep**, the force of the wind causes soil particles to roll along the soil surface until the wind slows, they are stopped by other particles, or they are trapped in a sheltered location, such as a furrow or a vegetated area. Surface creep generally involves particles approximately ½ to 1 millimeter in size, small enough to be moved by the wind but too massive to be lifted off the surface. Surface creep contributes to loss and deposition within a localized area.

Another mode of transport is **saltation**, where under the influence of wind, still smaller particles, ⅒ to ½ millimeter in size, bounce or hop along the surface. As they bounce, they strike other particles, causing them to move. The higher the grains jump, the more energy they derive from the wind. Because of this wind-derived energy, the impact of saltating grains initiates movement of larger grains and smaller dust particles that can be suspended in the air and carried great distances. Saltating grains collide with clods and cause their breakup, reducing roughness.

Saltation also damages young plants, threatening their survival and damaging their fruit, which reduces their marketability. Like particles under surface creep, saltating particles continue to move until the wind slows or they are trapped in sheltered areas.

Suspension occurs when particles less than ⅒ of a millimeter — smaller than the diameter of a human hair — are lifted far above the surface and carried great distances. Some of these form dust clouds that have been traced across continents, oceans, and around the world.

Suspension can cause visibility problems. A small fraction of suspension particles may cause health problems when inhaled. These particles are known as PM10, which are particulate matter smaller than 10 microns in size.

The amount of soil that erodes as surface creep, saltation, or suspension depends on the soil type. Soils that are pure sand will move almost completely by surface creep and saltation. However, if the soil is almost pure clay with clods that break down under saltation, a high percentage of soil loss will be by suspension.

On an eroding field, the amount of soil movement will tend to increase with distance downwind due to the impact of saltating grains breaking up clods and initiating other particles to move. This increase in erosion across a field is known as the **avalanche effect**. If the field is large enough, the creep and saltation flow reaches a maximum that a wind of a particular velocity can sustain. On the other hand, the amount of suspension particles can keep increasing as they diffuse into the atmosphere.

Wind Erosion Control

Many conservation practices can be implemented to control wind erosion. Conservation practices are designed to either reduce the wind force at the soil surface or create a soil surface more resistant to wind forces. Some practices also trap saltating particles to reduce the abrasion of soil surfaces downwind.

Vegetation or Vegetative Residues

A conservation practice that preserves crop residue or keeps growing vegetation in the field is the most practical way to reduce wind erosion potential. Plants and crop residues protect soil particles on the surface by absorbing a portion of the direct force of the wind, trapping moving soil particles, and enhancing soil particle cohesion. Crop rows perpendicular to the prevailing winds will control wind erosion more effectively than rows parallel with the wind. Also, standing residues are more than twice as effective as flattened residues. Other conservation practices such as windbreaks, grass barriers, strip cropping, or clod-producing tillage should be considered to supplement vegetative cover.

Residue Management

Cropping systems that preserve surface residue are a practical approach to reduce the potential of soil erosion by wind.

No-till or **strip till** involves managing the amount, orientation, and distribution of plant residues on the soil surface year-round, while growing crops in narrow slots or tilled strips in the field. This practice is also referred to as no-till, zero-till, direct seeding, slot plant, row-till, strip-till, or more generally, conservation tillage.

Mulch tillage maintains crop residues on the entire soil surface year-round. It is one of the simplest systems to use in reducing wind erosion and at the same time, contributes to the control of water erosion. Excessive tillage that buries crop residue is a major cause of inadequate vegetative cover on cropland. Mulch tillage practice uses non-inversion tillage where residue is only partially incorporated using chisels, sweeps, field cultivators, or similar implements.

Ridge till manages crop residue on the soil surface year-round by growing crops on preformed ridges alternating with furrows, which are protected by crop residue.

Figure 4. *Suspended dust in the air from small wheat on conventionally tilled cropland. The soil surface did not have enough crop residue.*

Seasonal residue management leaves protective residue on the soil surface during a prescribed time of year by delaying primary tillage or seedbed preparation until immediately before planting.

Permanent Vegetative Cover

Permanent vegetative cover is one of the most effective ways to control wind erosion. It protects the soil from wind and water erosion forces throughout the year.

Pasture and hay planting establishes native or introduced forage species for livestock grazing or feed.

Conservation cover involves establishing and maintaining permanent vegetative cover on land retired from agriculture production, such as land considered highly erodible in the Conservation Reserve Program.

Critical area planting involves planting vegetation, such as trees, shrubs, vines, grasses, or legumes, on highly erodible areas. This practice is used on areas that cannot be stabilized by ordinary planting techniques and may suffer severe erosion if left untreated. Critical areas include dams, levees, surface-mined land, and areas of agriculture land with severe erosion. The importance of vegetative cover for land protection cannot be overstressed. Permanent vegetation or crop residues are valuable resources when considering their ability to conserve soil, water, and air resources. Removing residues from fields for other uses or burning should not be done without an understanding of the erosion control consequences.

Surface Roughening and Maintaining Stable Aggregates

Vegetation can sometimes be sparse as a result of drought, cropping practices, or crop types. When vegetation is insufficient, ridges and large soil clods (or aggregates) are frequently the only means of controlling erosion on large areas. Roughening the land surface with ridges and clods reduces the wind velocity and traps drifting soils. While a cloddy soil surface will absorb more wind energy than a flat, smooth surface, a soil surface that is both ridged and cloddy will absorb even more.

Soil crusts also can increase resistance of the surface soil to wind forces, but this effect is only temporary and should not be relied on for erosion control.

Crosswind ridges are formed by tilling or planting across the prevailing wind erosion direction. If erosive winds show no seasonal or annual prevailing direction, this practice has limited protective value.

Tillage implements can form ridges and depressions that alter wind velocity. The depressions also trap saltating soil particles and stop avalanching of eroding material downwind. However, soil ridges protrude higher into the turbulent wind layer and are subject to greater wind forces. Therefore, it is important that cloddiness on top on the ridge is sufficient to withstand the added wind force, otherwise they will quickly erode, and the beneficial effects will be lost. Ridging sandy soils, for example, is of little value because the ridges of sand are erodible and soon leveled by the wind.

Clod-forming tillage produces aggregates or clods that are large enough to resist the wind force and trap smaller moving particles. They are also stable enough to resist breakdown by abrasion throughout the wind erosion season.

If clods are large and stable enough, as smaller particles are removed or trapped, the surface becomes stable or "armored" against erosive action. The duration of protection depends on the resistance of the clods to abrasion or changes in the wind direction.

Of the factors that affect the size and stability of soil aggregates, most notable is soil texture. Sandy or coarse-textured soils lack sufficient amounts of silt and clay to bind particles together to form aggregates. Such soils form a single-grain structure or weakly cemented clods, a condition that is quite susceptible to erosion by wind. Loams, silt loams, and clay loams tend to consolidate and form stable aggregates that are more resistant to erosive winds. Clays and silty clays are subject to fine granulation and more subject to erosion.

Many other factors also affect aggregate consolidation and stability — climate, including moisture; compaction; organic matter; lime; microorganism activity; and other cementing materials.

Any process that reduces soil consolidation also increases erodibility. The persistence of aggregates is greatly affected by the climatic process of wetting and drying, freezing and thawing, or freeze-drying, which generally disintegrate clods and increase erodibility.

Mechanical action, such as tillage, animal or machine traffic, and abrasion by saltating soil particles also can affect cloddiness. Tillage may either increase or decrease clods at the surface, depending on the soil condition in the tilled layer and the type and speed of the implement. Repeated tillage usually pulverizes and smoothes dry soils and increases their erodibility, especially if done with implements that have an intensive mechanical action, such as tandem disks, offset disks, or harrows.

Soil water at the time of tillage also has a decided effect on cloddiness. Research has found that different soils have differing water contents at which soil pulverization is most severe. If the soil is either extremely dry or extremely moist, smaller clods are produced than at intermediate water contents.

Crosswind Strip Cropping

Crosswind strip cropping is the practice of growing crops in strips, arranged perpendicular to the prevailing wind erosion direction. Strips susceptible to wind erosion alternate with strips having a cover resistant to wind erosion. This practice reduces the downwind avalanche effect by limiting the distance particles can travel before being trapped. As prevailing wind direction deviates from the perpendicular, correspondingly narrower strips are required.

When designing strip-cropping systems, soil aggregation, machinery size, exposure to knolls, residue management, and windbreaks must all be considered, in addition to the prevailing wind erosion direction.

On extremely erodible soils where narrow strips are required, consideration should be given to permanent vegetation such as grass or grass-legume mixtures.

Barriers

In contrast to methods that make the soil surface more resistant to the forces of the wind, barriers alter the effect of the wind force on the soil surface. Barriers help by reducing wind speed on the downwind side of the barrier and by trapping moving soil.

Research has shown that barriers significantly reduce wind speed for a distance of about 10 times the height of the barrier, in effect, reducing the field length along the erosive wind direction. However, the fully protected zone of any barrier diminishes as wind velocity increases and as the wind direction deviates

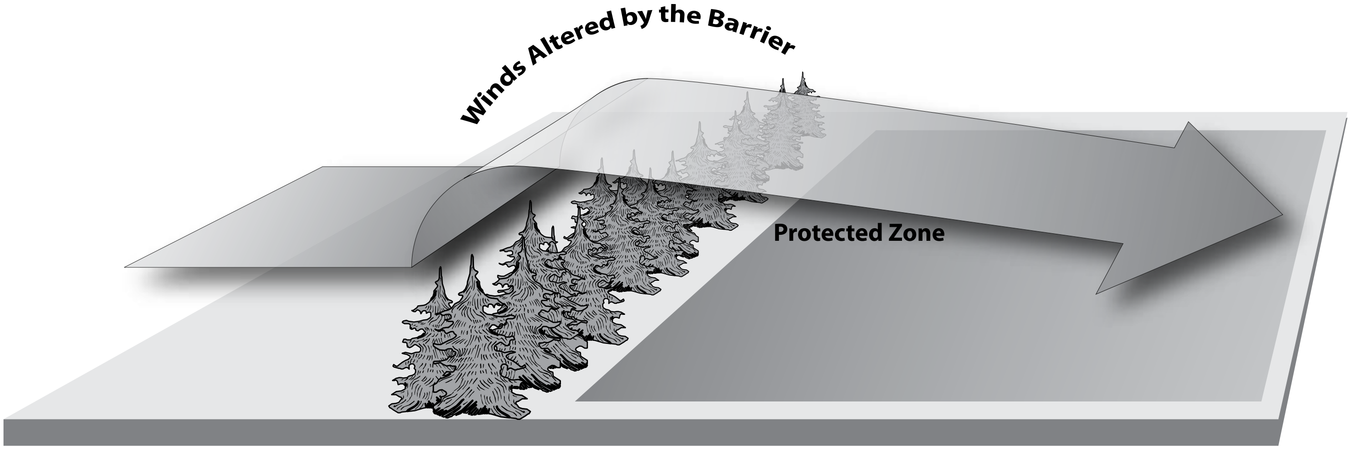

Figure 5. *A windbreak and the protected distance behind it.*

from perpendicular to the barrier. There are various types of barriers used for wind erosion control. (See Figure 5.)

Windbreaks and shelterbelts are linear plantings of single or multiple rows of trees or shrubs established for wind erosion control as well as snow management. They protect crops, shelter livestock, and provide wildlife habitat. One advantage of windbreaks over most other types of wind erosion control is they are relatively permanent. During drought years, windbreaks may be the only effective and persistent control measure on cropland.

Many of the windbreaks planted in the 1930s and 40s were several rows deep because it was believed that wide belts were necessary to provide adequate wind reduction. The trend today is toward narrower plantings. Single-row plantings are most common in field windbreaks because they occupy the least amount of land area for the amount of protection derived from them.

The type of species planted in a windbreak has a considerable bearing on the year-round effectiveness because the amount of protection depends on the barrier shape, width, height, and porosity. The seasons also govern porosity of many species and therefore influence the effectiveness of the windbreaks.

During establishment of windbreaks, protection is limited and unless other erosion control measures are in place, severe damage to the plantings and the land can result.

Crosswind trap strips consist of herbaceous vegetation resistant to wind erosion, established in one or more strips, perpendicular to the prevailing wind direction. Since saltating particles can travel up to 15 feet, the crosswind trap strips should be at least 15 feet in width and up to 25 feet for shorter strip vegetation. The purpose of trap strips is to trap saltating particles and to provide protection from the effects of wind erosion. Trap strips, however, require frequent and expensive maintenance.

Herbaceous wind barriers are tall, nonwoody vegetative barriers, established in one- to two-row narrow strips across the prevailing wind direction. These are primarily used on soils where stubble mulching and strip cropping do not adequately control wind erosion. Perennial barriers are often the only control alternative here, short of retiring the land to permanent grass.

Perennial grass barriers work well for wind erosion control, as well as trapping snow and reducing evaporation on dryland cropping areas. Other advantages of these types of barriers are ease of establishment and low cost.

Annual crops can be used as herbaceous wind barriers; so one crop provides protection for another crop. Sundangrass, flax, grain and forage sorghum, broomcorn, and Kochia are crop barriers that provide adequate protection from wind erosion if spaced sufficiently close.

Artificial barriers, such as snow fences, board walls, bamboo and willow fences, earthen banks, hand-inserted straw rows, and rock walls have been used for wind erosion control, but only on a limited basis. There is usually a high cost in material and labor to construct these barriers and their use is generally restricted to high-value crops. They can be used in sand dune areas to aid in the initial stabilization phase, while grass and trees are being established.

Reshape The Land

Like an airfoil, hills and knolls cause wind velocity to increase over the surface, increasing the erosion potential on the windward slope and hilltop.

Reshaping the land by leveling knolls and benching slopes to shorten the unsheltered distance is an option in wind erosion control, but is usually not

Figure 6. *Emergency wind erosion control, creating a cloddy surface.*

economical or practical. Because land reshaping is costly, other effective control measures, such as no-till or seeding to permanent grass, are usually more viable options.

Emergency Wind Erosion Control

The practices discussed so far are known to substantially reduce wind erosion. However, if a soil begins to blow, it should be controlled as soon as possible because serious damage to seedlings or soil can occur in minutes. Often, wind erosion will start in a small area of a field where soil texture, aggregation, or vegetation conditions are more vulnerable to wind forces. Highly erodible areas also include knolls, wheel traffic areas, and blowouts. If these areas are allowed to erode, the saltating material can cause other areas of the field to erode until eventually, the entire soil surface is blowing. These vulnerable areas or "hot spots" will be the areas that need emergency control first. Watching the field over the years and within a season can show where such areas are within a field. Anticipating erosion on these spots when high winds are forecast is a valuable tool for fighting erosion. It is easier to control erosion before it starts than to stop it after.

Emergency tillage is tillage performed on an actively blowing field to provide a rough, ridged, cloddy surface that reduces wind velocity and helps trap windblown soil particles. Emergency tillage is only a temporary measure for two reasons. First, because clods can disintegrate rapidly under saltating conditions. Second, a change in wind direction can occur, and the result can be soil loss from the untilled strips.

An implement used for emergency wind erosion control should gently lift the soil, creating as many large stable clods as possible. Disks and harrow-type implements with several ranks of closely spaced tines that pulverize the soil should not be used. Implements such as listers, chisels, shovels, and sandfighters do a good job of roughening the soil surface and creating clods. Listers and narrow chisels are the most effective for emergency tillage. Listers provide a high degree of roughness on extremely sandy soils, where clods can be produced only by deep tillage. Chisels are more widely used on moist or heavy soils because they provide good ridges and clods, require less power, and destroy less crop or residue than listers.

Some operators prefer a soil ripper to bring up large, dry clods when subsurface soil is dry. Where clayey subsoil exists under a sandy surface, deep plowing the entire field is sometimes used to bring clayey stable clods to the surface. If the clods brought to the surface are numerous and stable, deep plowing is only necessary once every several years. Another method is to time tillage when the top of the soil is frozen, to bring up frozen clods.

Close spacing with any implement will create a rougher surface than a wide spacing. However, if a crop is involved, such as winter wheat, and there is a possibility of saving part of it, then wide spacings of 4 to 5 feet provide sufficient roughness for some control and at the same time permit most of the crop to survive.

Tilling strips across the field perpendicular to the expected wind direction is most effective. The success of emergency strip tillage is highly dependent on climatic, soil, and cover condition. If strips are used, they should be as narrow as practical and cover 50 percent of the eroding part of the field. Narrow chisel spacing of 20 to 24 inches is needed for the strip. If 50 percent coverage does not stop erosion, the omitted strips can be emergency tilled to make full coverage.

Addition of crop residue to the surface reduces wind velocity and traps moving soil particles. Almost any kind of residue, such as hay, straw, or corn stalks can be used. Approximately 2,000 to 4,000 pounds of residue per acre is required to control erosion in areas where erosion has already begun.

Residue can be distributed with a manure spreader, or even by hand if the area is small. This method is not normally used in entire fields or with row crops, but is most practical as an emergency treatment. A rotary hoe or mulch treader helps spread the residue uniformly. Normally the residue must be anchored in place with a stubble puncher or a disk with gangs set at a minimum angle and shallow depth. Large stemmed residues such as corn stalks are effective and might not require anchoring. The direction of operation for residue distribution and anchoring should be perpendicular to the direction of the wind.

Livestock manure acts like crop residue or large clods and can reduce wind erosion by slowing the wind velocity at the soil surface and by trapping soil particles. It can be effective in growing wheat, fallow fields, and row crops. Typically, 6 to 8 tons of manure per acre effectively controls wind erosion on vulnerable spots. Manure should have sufficient moisture and size so it will not dislodge or break into smaller particles. Precautions should be taken when storing and applying manure, so it does not contaminate water sources.

Irrigation to control erosion is generally impractical and wastes water because the surface tends to dry rapidly under high wind conditions. The impact of large water droplets from spinklers also deteriorates soil structure, smoothes the soil surface, and produces loose particles, which encourages wind erosion once the surface has dried. However, if a high-value cash crop is being severely damaged by wind erosion, irrigation might be a practical solution if enough water can be applied to keep the surface sufficiently moist.

Temporary, artificial wind barriers can be used for emergency control if the eroding area is relatively small. For example, a stock watering area or knoll can be protected by board fences, snow fences, or hay bales. Protection can be expected for a downwind distance approximately 10 to 15 times the height of the barrier.

Soil stabilizers are soil additives or spray-on adhesives, which bind soil particles together. They are generally expensive, temporary, and used only for high-value cash crops, such as vegetables. Several materials of petroleum or organic origin are available. They are not compatible with all soils and often made ineffective by subsequent rainfall, cultivation, or abrasion from untreated areas.

Research

The USDA - Agricultural Research Service, with support from the Natural Resources Conservation Service, along with partners such as Kansas State University, continues to research processes, causes, and control of soil erosion by wind. Through this research it is hoped that even better control strategies will be developed for current and future land managers.

Summary

A sound understanding of the processes that cause wind erosion is key in developing effective control strategies. Although conservation practices can be successful in controlling erosion, droughts can cause a shortage of residue, and erosive winds will not always blow in a prevailing direction. Thus, land managers must be vigilant and combinations of practices may need to be considered when planning a wind erosion control system.

For More Information

Wind Erosion Research Unit: *www.weru.ksu.edu/*

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