Kansas State University

Principles of Wind Erosion and its Control

Department of Agronomy MF-2860 Erosion

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,

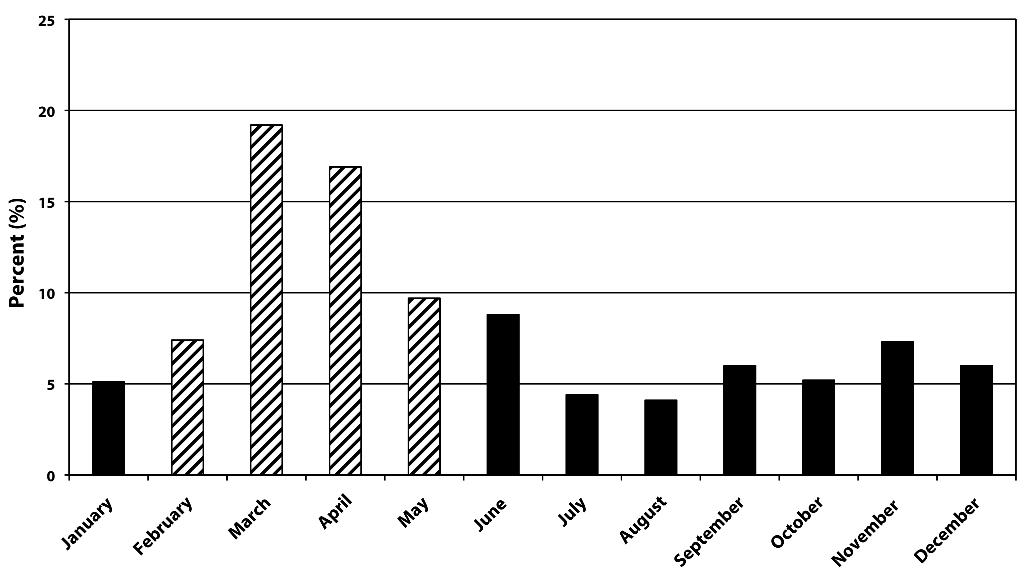

Figure 2. *Percent of Annual Erosive Winds Goodland, Kansas (Striped bars indicate the "critical wind erosion period")*

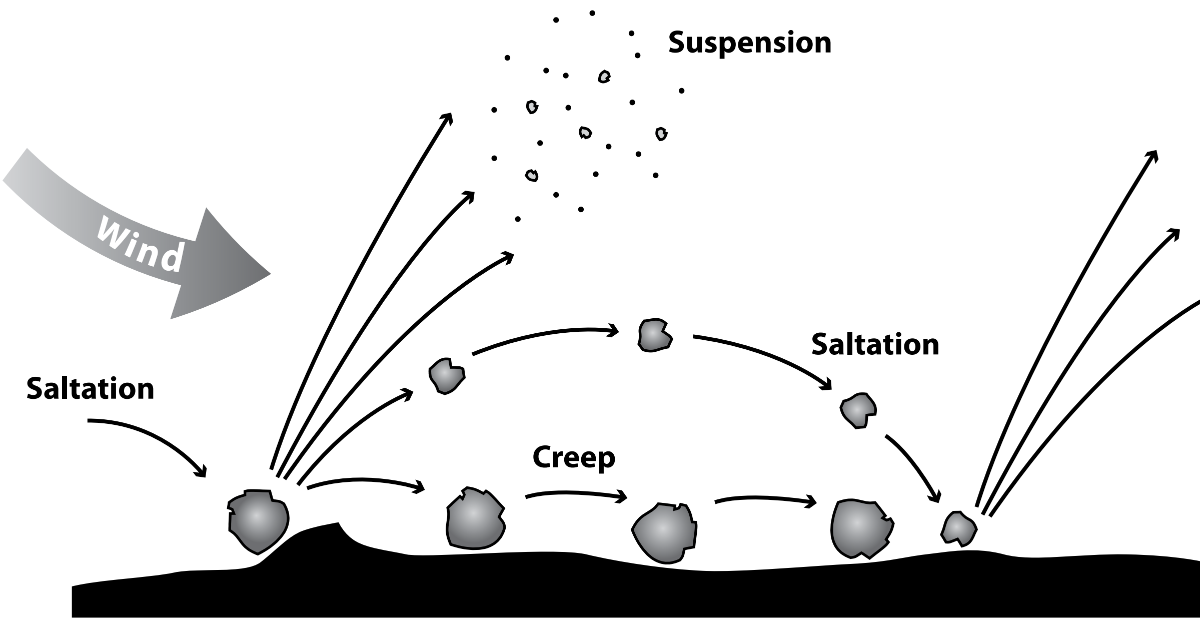

Figure 3. *Soil particles can move through saltation, creep, and suspension.*

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

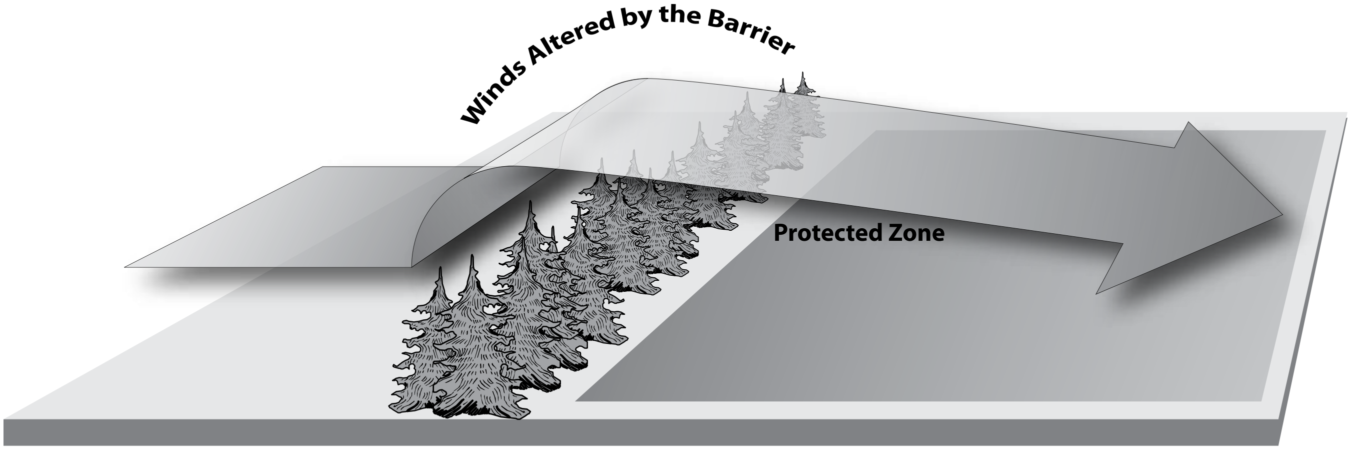

Figure 5. *A windbreak and the protected distance behind it.*

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

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Lesson 14 Wind Erosion and Its Estimation

14.1 Wind Erosion

Wind erosion is a serious environmental problem. It is in no way less severe than water erosion. High velocity winds strike the bare lands (having no cover), with increasing force. Fine, loose and light soil particles blown from the land surface are taken miles and miles away and thereby, causing a great damage to the crop productivity. It is a common phenomenon occurring mostly in flat, bare areas; dry, sandy soils; or anywhere the soil is loose, dry and finely granulated and where high velocity wind blows. Wind erosion, in India, is commonly observed in arid and semi-arid areas where the precipitation is inadequate, e.g. Rajasthan and some parts of Gujarat, Punjab and Haryana.

Wind erosion damages land and natural vegetation by removing soil from one place and depositing it at another location. It causes soil loss, dryness and deterioration of soil structure, nutrient and productivity losses and air pollution. Smaller particles of soil are more subject to movement by wind as silt, clay and organic matter are removed from the surface soil by strong wind, leaving the coarse, lesser productive material behind. Suspended dust and dirt are inevitably deposited over everything. It blows on and inside homes, covers roads and highways, and smothers crops. Sediment transport and deposition are significant factors in the geological changes which occur on the land around us and over long periods of time are important in the soil formation process. Most serious damage caused by wind erosion is the change in soil texture. Damage caused by wind erosion is demonstrated in Fig.14.1.

Fig. 14.1. An Illustration of Wind Erosion.

(Source: http://ecomerge.blogspot.in/2010/05/what-is-wind-erosion.html)

14.2 Factors Affecting Wind Erosion

Climate, soil and vegetation are the major factors affecting wind erosion at any particular location. The climatic factors that affect the wind erosion are the characteristics of wind itself (velocity and direction) in addition to the precipitation, humidity and temperature. Soil moisture conditions, texture, structure, density of particles, organic matter content are the soil characteristics that influence erosion by wind. Soil movement is initiated as a result of wind forces exerted against the surface of the ground. For each specific soil type and surface condition there is a minimum velocity required to move soil particles. This is called the threshold velocity. Once this velocity is reached, the quantity of soil moved is dependent upon the particle size, the cloddiness of particles, and wind velocity itself. Surface features like vegetation or other artificial cover (mulching etc) have the protective effect on wind erosion problem as surface cover increases the roughness over the land surface and thus reduces the erosive wind force on the land surface.

14.3 Mechanics of Wind Erosion

The overall occurrence of wind erosion could be described in three distinct phases. These are:

1. Initiation of Movement

2. Transportation

3. Deposition.

Movement of soil particles is caused by wind forces exerted against or parallel to the ground surface. The erosive wind is turbulent at all heights except very close to the surface. The lowest velocity occurs close to the ground and increases in proportion to the logarithm of the height above the surface. Soil particles or other projections on the surface absorb most of the force exerted by the wind on the surface. However, if the soil particles are lighter and loose, wind may lift them from the surface in the initiation process. A minimum threshold velocity (wind) is required to initiate the movement of soil particles. Thus, the threshold velocity is the minimum wind velocity needed to initiate the movement of soil particles. The magnitude of the threshold velocity is not fixed for all places and conditions but it varies with the soil conditions and nature of the ground surface. For example, for the most erodible soils of particle size about 0.1 mm; the required threshold velocity is 16 km/h at a height of 30 cm above the ground.

14.3.1 Initiation of Movement: The soil particles are first detached from their place by the impact and cutting action of wind. These detached particles are then ready for movement by the wind forces. After this initiation of movement, soil particles are moved or transported by distinct mechanisms.

14.3.2 Transportation: The transportation of the soil particles are of three distinct types and occur depending upon size of the soil particles. Suspension, saltation, and surface creep are the three types of soil movement or transport which occur during wind erosion. While soil can be blown away at virtually any height, the majority (over 93%) of soil movement/transportation takes place at or within one meter height from land surface. These transportation mechanisms of soil particles due to wind are shown in Fig. 14.2.

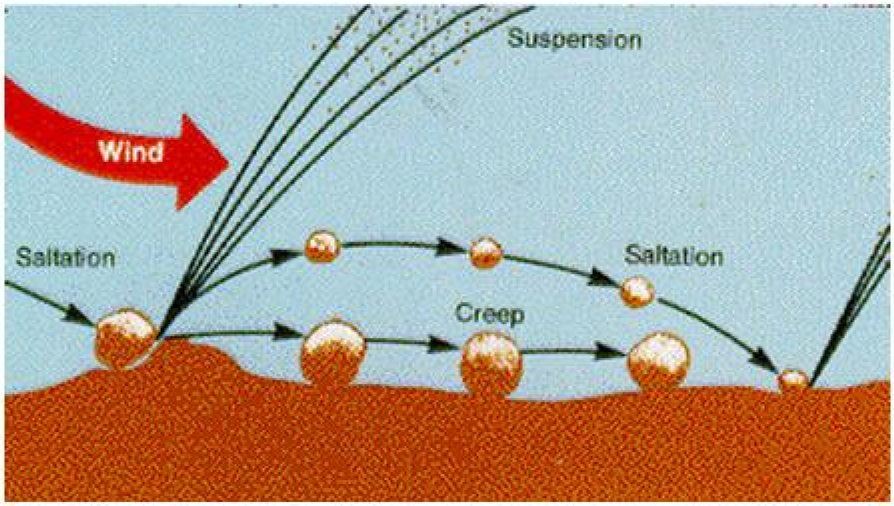

Fig. 14.2. Mechanics of Wind Erosion.

(Source: http://commons.wikimedia.org/wiki/File:Saltation-mechanics.gif)

14.3.3 Suspension: It occurs when very fine dirt and dust particles are lifted into the atmosphere. They can be thrown into the air through impact with other particles or by the wind itself. These particles can be carried very high and be transported over very long distances in the atmosphere by the winds. Soil moved by suspension is the most spectacular and easiest to recognize among the three forms of movement. The soil particles of less than 0.1 mm size are subjected to suspension and around 3 to 40 % of soil weights are carried by the suspension method of soil transport under the wind erosion.

14.3.4 Saltation: The major fraction of soil moved by the wind is through the process of saltation. Saltation movement is caused by the pressure of the wind on soil particles as well as by the collision of a particle with other particles. Soil particles (0.1 to 0.5 mm) move in a series of bounces and/or jumps. Fine soil particles are lifted into the air by the wind and drift horizontally across the surface increasing in velocity as they move. Soil particles moved in the process of saltation can cause severe damage to the soil surface and vegetation. They travel approximately four times longer in distance than in height. When they strike the surface again they either bounce back into the air or knock other soil particles from the soil mass into the air. Depending on soil type, about 50 to 75% of the total weight of soil is carried in saltation. The height of the jump varies with the size and density of the soil particles, the roughness of the soil surface, and the velocity of the wind.

14.3.5 Surface Creep: The large particles which are too heavy to be lifted into the air are moved through a process called surface creep. In this process, the particles are rolled across the surface after coming into contact with the soil particles in saltation. In this process the largest of the erosive particles having diameters between 0.5 to 2 mm are transported and around 5 to 25% of the total soil weights are carried in this fashion. Overall, the mass of soil moved by wind is influenced primarily by particle size, gradation of particles, wind velocity and the distance along the eroding area. Winds being variable in velocity and direction produce eddies and cross-currents that lift and transport soil. The amount of soil moved/transported depends on the median particles (soil) diameter and the difference in threshold and actual wind velocity. The mass of soil moved can be related to the influencing parameters by the following equation:

Quantity of soil moved $(V - V^{th})^3 / D^{0.5}$

where V = wind velocity, V^{th} = threshold velocity, and D = particle diameter.

14.3.6 Deposition: Deposition of soil particles occurs when the gravitational force is greater than the forces holding the particle in the air. This generally happens when there is a decrease in the wind velocity caused by vegetative or other physical barriers like ditches or benches. Raindrops may also take dust out of air.

14.4 Estimation of Soil Loss Due to Wind Erosion

An equation in the form of universal soil loss equation has been developed and can be used for estimating soil loss by wind. However, the evaluation of the constants in the equation for wind erosion is comparatively difficult than the universal soil loss equation. The equation is of the form,

$$E = IRKFCWDB \qquad (14.1)$$

Where, E is soil loss by wind erosion, I is soil cloddiness factor, R is surface cover factor, K is surface roughness factor, F is soil textural class factor, C is factor representing local wind condition, D is wind direction factor, and B is wind barrier factor, W is field width factor.

Another model of wind erosion estimation used in USA is as follows:

$$E = f(I, K, C, L, V) \qquad (14.2)$$

Where, E is estimated average annual soil loss (t/ha/yr), I is soil erodibility index (t/ha-yr), K is ridge roughness factor, C is climate factor, L is unsheltered length of eroding field (m), and V is vegetative cover factor.

The soil erodibility index (I) can be estimated as given below

$$I = 525(2.718)^{-0.05F} \qquad (14.3)$$

Where, F is % of dry soil fraction greater than 0.84 mm, K is ridge roughness factor; a measure of ridges made by tillage implements on wind erosion and can be estimated as given below

$$K_r = \frac{0.16h^2}{d} \qquad (14.4)$$

Where, K_r is ridge roughness, h is ridge height in mm, d is ridge spacing in mm, and K can be estimated as a function of ridge roughness.

$$K = 0.35 + \frac{12}{(K_r + 18)} + \left(6.2 * 10^{-6} K_r^2\right) \qquad (14.5)$$

The climatic factor (C) depends on wind velocity and soil surface moisture. The mean wind velocity profile above the soil surface is estimated as given below.

$$U_z = \left(\frac{U_*}{k}\right)\ln\left(\frac{z-d}{z_o}\right) \quad (14.6)$$

Where, $U_* = Frictional\ Velocity = \frac{\tau_0(shear\ stress\ at\ boundary)}{\rho(airdensity, 1.2kg/m^3)}$ (14.7)

$k = vonKarman's\,constant = 0.4\,(usually\ taken)$

$Z_0 = a\ roughness\ parameter$

$d = effective\ surface\ roughness\ height$

$\log d = \log h - 0.15$

$\log z_0 = \log h - 0.09$

$c = crop\ height$

Solved Problem:

Find out the wind velocity at 10 and 15 m height from ground surface over a wheat cropped field of plants height 1.3 m and friction velocity of 6 m/s.

Solution: The mean wind velocity above the soil surface is estimated as-

$$U_z = \left(\frac{U_*}{k}\right)\ln\left(\frac{z-d}{z_o}\right)$$

Given: frictional velocity (U_z) = 6 m/s

Plants height of wheat cropped field = 1.3 m (h)

z = 10 and 15 m,

$$\log d = \log h - 0.15$$
$$\log z_0 = \log h - 0.09$$

Estimating d and z_0

log d = log(1.3) - 0.15 = -0.03606

d = 0.92033 m

log z_0 = log(1.3) - 0.09 = -0.023943

z_0 = 1.05668 m

Now: U_{10} = 32.26359 m/s, *and* U_{15} = 38.84401 m/s.

Keywords: Wind Erosion, Soil Loss Equation, Mechanics of Wind Erosion, Initiation of Movement, Transportation, Deposition.

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Lesson: 15 Wind Erosion Control Measures

Wind erosion is the process of detachment, transportation and deposition of soil particles by the action of wind. It occurs in all parts of the world and is a cause of serious soil deterioration. In India, Rajasthan has severe wind erosion problem. A large part of area the state is affected by sand dune formation. Some parts of coastal areas also have such problems. It most commonly occurs in the regions where soil is loose, finely divided and dry, soil surface is smooth and bare, and where wind is strong to detach the soil particles from the surface.

15.1 Wind Erosion Control

A suitable surface soil texture is the best key to wind erosion protection. Properly managed crop residues, carefully timed soil tillage, and accurately placed crop strips and crop barriers can all effectively reduce wind erosion. Proper land use and adaptation of adequate moisture conservation practices are the main tools which help in wind erosion control. In arid and semiarid regions where serious problem of wind erosion is common, several cultural methods can help to reduce the wind erosion. In the absence of crop residue, soil roughness or soil moisture can reduce the wind erosion effectively.

Three basic methods can be used to control wind erosion:

- Maintain Vegetative Cover (Vegetative Measures)
- Roughen the Soil Surface by Tillage Practices (Tillage Practices or may be called Tillage Measures)
- Mechanical or Structural Measures (Mechanical Measures)

There is no single recipe for erosion control as many factors affect the outcome. However, with an understanding of how soil is eroded, strategies can be devised to minimize erosion.

15.2 Vegetative Measures

Vegetative measures can be used to roughen the whole surface and prevent any soil movement. The aim is to keep the soil rough and ridged to either prevent any movement initially or to quickly trap bouncing soil particles in the depressions of the rough surface. A cover crop with sufficient growth will provide soil erosion protection during the cropping season. It is one of the most effective and economical means to reduce the effect of wind on the soil. It not only retards the velocity near the ground surface but also holds the soil against tractive force of wind thereby helping in reduction of soil erosion.

From the basic concept, the velocity of wind decreases near the ground surface because of the resistance offered by the vegetation. The variation in wind velocity with respect to height above the land surface increases exponentially (chapter 14).

Vegetative measures can be of two types:

1. Temporary Measures

2. Permanent Measures

The use of these measures depends upon the severity of erosion.

15.3 Tillage Practices

The tillage practices, such as ploughing are importantly adopted for controlling wind erosion. These practices should be carried out before the start of wind erosion. Ploughing before the rainfall helps in moisture conservation. Ploughing, especially with a disc plough is also helpful in development of rough soil surface which in turn reduces the impact of erosive wind velocity. Both the above effects are helpful in controlling the wind erosion.

Surface roughening should only be considered when there is insufficient (less than 50%) vegetation cover to protect the soil surface or when the soil type will produce sufficient clods to protect the surface. Roughening can be used in both crop and pasture areas. Surface roughening alone is inadequate for sandy soils because they produce few clods. Tillage ridges, about 100 mm high, should be used to cover the entire area prone to erosion. Ridges that are lower than 100 mm get quickly filled with sand, whilst the crest of the ridge that is higher than 100 mm tends to erode very quickly.

The common tillage practices used for wind erosion control are as under:

- Primary and Secondary Tillage

- Use of Crop Residues
- Strip Cropping

15.4 Mechanical Measures

This method consists of some mechanical obstacles, constructed across the prevailing wind, to reduce the impact of blowing wind on the soil surface. These obstacles may be fences, walls, stone packing etc., either in the nature of semi-permeable or permeable barriers. The semi-permeable barriers are most effective, because they create diffusion and eddying effects on their downstream face. Terraces and bunds also obstruct the wind velocity and control the wind erosion to some extent. Generally, in practice two types of mechanical measures are adopted to control the wind erosion; i) wind breaks and ii) shelter belts.

15.4.1 Wind Breaks

This is a permanent vegetative measure which helps in the reduction of wind erosion. It is most effective vegetative measure used for controlling severe wind erosion. The term wind break is defined as any type of barrier either mechanical or vegetative used for protecting the areas like building apartments, orchards or farmsteads etc. from blowing winds. The wind break acts as fencing wall around the affected areas, normally constructed by one row or maximum up to two rows across the prevailing wind direction.

A further use for "windbreaks" or "wind fences" is for reducing wind speeds over erodible areas such as open fields, industrial stockpiles, and dusty industrial operations. As erosion is proportional to the cube of wind speed, a reduction in wind speed by 1/2 (for example) will reduce erosion by over 80%. The largest one of these windbreaks is located in *Oman* (28 m high by 3.5 km long) and was created by Mike Robinson from Weather Solve Structures.

15.4.2 Shelter Belts

A shelterbelt is a longer barrier than the wind break, is installed by using more than two rows, usually at right angle to the direction of prevailing winds. The rows of belt can be developed by using shrubs and trees. It is mainly used for the conservation of soil moisture and for the protection of field crops, against severe wind erosion.

Shelterbelt is more effective for reducing the impact of wind movement than the wind break. Apart from controlling wind erosion, it provides fuel, reduces evaporation and protects the orchard from hot and cold winds.

Woodruff and Zingg (1952) developed the following relationship between the distance of full protection (d) and the height (h) of wind break or shelter belt.

$$d = 17h\left(\frac{v_m}{v}\right)\cos\theta$$

Where, d is the distance of full protection (m), h is the height of the wind barrier (wind break or shelter belt) (m), v_m is the minimum wind velocity at 15 m height required to move the most erodible soil fraction (m/s), v is the actual velocity at 15 m height, and θ is the angle of deviation of prevailing wind direction from the perpendicular to the wind barrier.

This relationship (equation) is valid only for wind velocities below 18 m/s. This equation may also be adapted for estimating the width of strips by using the crop height in the adjoining strip in the equation. The value of v_m for a bare smooth surface after erosion has been initiated and before wetting by rainfall and subsequent surface crusting is about 9.6 m/s.

15.5 Sand Dunes Stabilization

A ‘Dune’ is derived from English word ‘Dun’ means hilly topographical feature. Therefore a sand dune is a mount, hill or ridge of sand that lies behind the part of the beach affected by tides. They are formed over many years when windblown sand is trapped by beach grass or other stationary objects. Dune grasses anchor the dunes with their roots, holding them temporarily in place, while their leaves trap sand promoting dune expansion. Without vegetation, wind and waves regularly change the form and location of dunes. Dunes are not permanent structures.

Sand dunes provide sand storage and supply for adjacent beaches. They also protect inland areas from storm surges, hurricanes, flood-water, and wind and wave action that can damage property. Sand dunes support an array of organisms by providing nesting habitat for coastal bird species including migratory birds. Sand dunes are also habitat for coastal plants. For example: ‘The Seabrook dunes’ are home to 141 species of plants, including nine rare, threatened and endangered species.

There are three essential prerequisites for sand dune formation:

(1) An abundant supply of loose sand in a region generally devoid of vegetation (such as an ancient lake bed or river delta);

(2) A wind energy source sufficient to move the sand grains.

(3) A topography whereby the sand particles lose their momentum and settle down.

The best method by which the sand dunes can be stabilized is to reduce the erosive velocity. Therefore, various methods which are employed for sand dune stabilization are based on the principle to dissipate the erosive power of wind, so that the detachment and transportation of soil particles cannot take place. Some methods employed for sand dune stabilization are:

- Vegetation/Vegetative Measures
- Mechanical Measures
- Straw (Checkerboard and Bales)/Mats and Netting
- Chemical Spray

15.5.1 Vegetative Measures

This method is most common and preferred worldwide for sand dune stabilization. It is a most effective, least expensive, aesthetically pleasing method which mimics a natural system with self- repairing provision. However, it has some disadvantages as the plant establishment phase is critical, it needs irrigation and maintenance until self-sustaining system is developed. Most common practices adopted under this are:

15.5.1.1 Raising of Micro Wind Breaks

It is preferred in those areas where wind velocity is intensive and rainfall is less than 300 mm per year. The raising of wind break should be completed before the onset of monsoon. Twigs or brush woods are inserted into the soil parallel to one another at about 5 m spacing. The spacing depends on the intensity of erosive wind velocity, if the velocity is more spacing is less and vice versa. The fencing of dunes using brush woods reduces evaporation loss and also enriches the humus content in the soil.

15.5.1.2 Retreating the Dunes

In this, the micro wind breaks are treated again by planting tree saplings and grasses in the space left. The grasses grown in the intersection of plants of wind break reduce the soil loss from the dune surface significantly.

15.5.2 Mechanical Measures

Wind breaks, shelterbelts, stone pitching, fences etc., either manmade or natural barriers are helpful to reduce the wind velocity thereby favoring the stabilization of sand dunes.

15.5.3 Straw Checker Boards

This technique of sand dunes stabilization is extensively used in China since 1950’s. Wheat or rice straw or reeds (50 – 60 cm in length) are placed vertically to form the sides of the checkerboard, which are typically 10 to 20 cm high. Optimum grid size of checker ranges from 1 x 1 m to 2 x 2 m, depending on local wind and sand transport conditions. Smaller grids are used in areas where winds are stronger.

15.5.4 Chemical Spray

Sometimes crude oils are used for the successful stabilization of sand dune. The oil is heated to 50 °C and sprayed on the dune at the rate of 4 m^3/ha. It is a temporary measure, lasting only for 3-

4 years and during those years, it is expected that the vegetation growth will take place in that area. This method is costly and suitable only for small areas.

Solved Problems:

1. Determine the spacing between windbreaks that are 15 m high. 5 year return period wind velocity at 15 m height is 15.6 m/s and the wind direction deviates 10° from the perpendicular to the field strip. Assume a smooth, bare soil surface and a fully protected field.

Solution:

Given: h = 15 m

V = 15.6 m/s

θ = 10°

Vm = 9.6 m/s (for smooth, bare soil surface)

Spacing = distance of full protection by a windbreak,

Therefore,

$$d = 17h\left(\frac{V_m}{V}\right)\cos\theta \quad = 17\text{x}15\left(\frac{9.6}{15.6}\right)\cos 10^\circ$$
$$= 154.54\,m$$

Thus, the spacing between windbreaks = 154.54 m.

2. Determine the full protection strip width for field strip cropping if the crop in the adjacent strip is wheat, 0.9 m tall, and the wind velocity at 15 m height is 8.9 m/sec at 90° with the field strip.

Solution:

Given: h = 0.9 m

v = 8.9 m/s

θ = 0°

Assuming v_m = 8.9 m/sec (Because theoretical v_m = 9.6 m/sec which is greater than the prevailing wind velocity). Since the field conditions are not specified taking $v_m = v$.

Full protection width-

$$d = 17h\left(\frac{V_m}{V}\right)\cos\theta \quad = 17\text{x}0.9\left(\frac{8.9}{8.9}\right)\cos\theta$$
$$= 15.3\,m$$

Thus, strip width = 15.30 m.

Keywords: Vegetative Measures, Tillage measures, Mechanical Measures, Sand Dune Stabilization

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