IFET COLLEGE OF ENGINEERING

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UNIT- II - WIND EROSION AND DEPOSITION

MODULE

SYLLABUS:

Wind erosion - Types of soil movement - Erosion damage by wind erosion - Estimation of wind erosion - wind erodibility index, roughness factor, climate factor, unsheltered distance and vegetative cover factor - Detaching capacity of wind - transport capacity of wind - Factors affecting wind erosion.

2.1 WIND EROSION

Wind erosion is the natural process where wind detaches, transports, and deposits soil particles, common in dry, bare areas, causing land degradation, dust storms, and economic damage through processes like surface creep, saltation, and suspension. It's intensified by activities like deforestation and agriculture, but controlled by vegetation, tillage adjustments, and windbreaks, with saltation moving most soil.

2.2 SOIL MOVEMENT

Soil movement occurs primarily through erosion, mass wasting, or anthropogenic activity, categorized by the force and mechanism involved. Key types include wind-driven transport (suspension, saltation, surface creep), water-driven erosion (sheet, rill, gully), and gravity-driven mass movement (landslides, soil creep, flows).

Soil movement means subsidence or expansion of soil caused by shrinkage, swelling or consolidation. Soil movement may occur between terraces, but the soil caught in terrace channels will not pollute a stream. Of course, the channels must be cleaned periodically as a part of terrace maintenance. Various structures made of concrete, wood, metal, or other sturdy material limit erosion by controlling water flow. Critical points occur where water must drop to a lower elevation. The water may be conducted through a pipeline, down a flume or chute, or over a drop structure. Pilings, riprap, or other bank protection may be used to keep a stream from meandering to a new location. Mechanical methods of erosion control tend to be either very inexpensive or very expensive. Although the objective of soil movement is to improve the land for crop production, it can also have unintended and deleterious consequences. When soil is moved, its structure is broken and protective vegetation is buried. This leaves the soil more susceptible and exposed to the erosive forces of wind and water. Wind and water erosion are unintended and unwanted forms of soil movement that can be caused by agricultural activities. They involve the detachment and transport of soil particles which may be deposited elsewhere within the field or beyond the boundaries of the field. Water also acts as a lubricant, aiding gravity in mass soil movement. Landslides and mudflows occur in some areas with steeper topography.

2.2.1 TYPES OF SOIL MOVEMENT

Wind Erosion (Transportation Mechanisms):

- ✓ **Saltation:** Particles (0.1 to 0.5 mm) lift and bounce, dislodging other particles upon impact.
- ✓ **Suspension:** Very fine particles (<0.1 mm) are lifted high into the atmosphere and carried long distances.
- ✓ **Surface Creep:** Larger particles (0.5 to 2 mm) roll or slide along the surface, pushed by wind or saltating particles.

Water Erosion:

- ✓ **Sheet Erosion:** Uniform removal of topsoil by thin layers of running water or wind.
- ✓ **Rill Erosion:** Small, well-defined channels formed by runoff.
- ✓ **Gully Erosion:** Deep, wide channels carved by concentrated water runoff.
- ✓ **Bank/Coastal Erosion:** Removal of soil along streams or coastlines.

Mass Movement (Gravity-Driven):

- ✓ **Soil Creep:** Very slow, continuous downward movement of slope material.
- ✓ **Landslides/Landslips:** Sudden, rapid movement of soil and rock down a slope.
- ✓ **Flows/Earthflow:** Soil movement acting like a viscous fluid, often triggered by heavy rain.
- ✓ **Slumping:** Downward movement of a soil mass along a curved surface.

Other Causes:

- ✓ **Tillage Erosion:** Soil moved by agricultural machinery (plowing, harrowing, harvesting).
- ✓ **Heave:** Upward soil movement caused by freezing (frost heave) or wetting.
- ✓ **Glacial Erosion:** Movement caused by moving glaciers.

2.2.2 TYPES OF SOIL MOVEMENT BY WIND EROSION

Wind Erosion (Transportation Mechanisms):

Saltation: The major cause of soil movement is the jumping motion of the smaller soil particles, a process called saltation. The texture of the wind -blown surfaces of these soils becomes coarser, making them less chemically reactive and less able to retain plant nutrients or trap pollutants. Intermediate-sized grains, approximately 0.05 to 0.5 mm in diameter(very fine, fine, and medium sand sizes), move in a series of short leaps. The jumping grains gain a great deal of energy and may knock other grains into the air or bounce back themselves. These saltating grains are the key to wind erosion. They drastically increase the number of both smaller and larger grains that move in suspension and in surface creep. Another mode of transport is saltation, where under the influence of wind, still smaller particles, 1/10 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: Soil particles and aggregates less than 0.05 mm in diameter (silt size and smaller) are kept suspended by the turbulence of air currents. Suspended dust does not drop out of the air in quantity unless rain washes it out or the velocity of the wind is drastically reduced. Suspension occurs when particles less than 1/10 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.

Surface creep: Soil grains larger than 0.5 mm in diameter cannot be lifted into the wind stream, but those smaller than about 1 mm may be bumped along the soil surface by saltating grains. 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. Naturally, shallow thickness of soils at specific hillside slopes would slid and slip down and such movement commonly occurs over a long period of time and there are sign that indicate such movements for example leaning trees. It is recommended to dug trial pits on sloping slides so as to explore the likelihood of debris, which have been brought down from higher places, movements in the future. It should be known that the structural weights does not have obvious influence on the mass of slipping ground and hence foundation loading would not affect the sliding safety factor, but construction process might influence slope stability. It should be remembered that vegetation at the area would improve stability and its removal during construction operation for clearance purposes would diminish that advantage. A proper measure that may be considered to answer such problem is varied according to the type of hillside slope soil. For example, instability of rocky hillside slopes can be tackled using grouting or rock bolting but it is recommended to avoid construction in such places if clay soil is present since its remediation is almost impossible or the foundation of the structure should be designed and constructed to move entirely as single object.

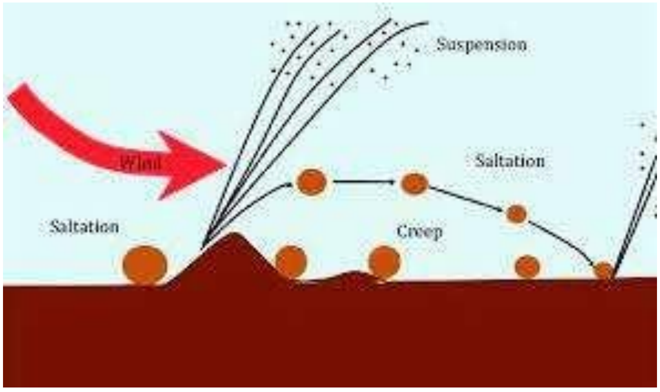

Figure 2.1 Types of soil movement

2.3 EROSION DAMAGE BY WIND EROSION

Wind-erosion damage includes loss of soil depth, textural change, nutrient and productivity losses, abrasion, air pollution, and sedimentation. Precise measurements are scarce and difficult to make, but qualitative observations are abundant and were first documented more than 2000 years ago. For example, dust storms were noted in China as early as 205 B.C.E. Wind erosion equations have been devised to estimate the rate of soil loss when actual measurements are not available.

2.3.1 Loss of Soil

Annual losses higher than 300 tons/ac (700 mt/ha) have been estimated for highly erodible, bare, sandy soils. An entire furrow slice (about 1000 tons/ac) could be blown away in three or four years at this rate if soil was removed uniformly from the entire surface. Actual losses are usually less than this because land is seldom left bare and unprotected for a whole year, but greater losses have occurred. Plow layers from many recently tilled farm fields in the Great Plains were blown away in single dust storms in the 1930s. Some fields in western Canada, such as the area in Figure 2.2, lost 1 ft (30 cm) of soil in a single year.

Figure 2.2 More than a foot (30 cm) of fine sandy loam soil was removed by wind erosion from this field in southwestern Manitoba. The concrete structure on the left is a geodetic survey marker.

A relatively new method of measuring soil loss since the 1950s is based on measurements of Cesium 137 (^{137}Cs). Atmospheric fallout of this radioactive element, associated with nuclear- weapons testing, provided a tracer for studies of soil erosion and sedimentation. Ping et al. (2001) used this approach to estimate wind erosion rates. They calculated 40-year average erosion rates of 84 mt/ha-yr (38 tons/ac-yr) for shrub coppice dunes, 70 mt/ha-yr (31 tons/ac-yr) for semi-fixed dunefields, 30.5 mt/ha-yr (14 tons/ac-yr) for farm-land, and 22 mt/ha-yr (10 tons/ac-yr) for grasslands in the Qinghai-Tibet Plateau in China.

2.3.2 Textural Change

Wind winnows soil much as it sifts chaff from threshed grain. Fine soil grains are carried great distances in suspension, saltating grains move to the fence rows or other barriers at the edges of fields, and coarse grains stay where they are or move relatively short distanceswithin the eroding field. The winnowing action of wind can coarsen textures in soils developed from glacial till, mixed residuum, and other materials having a wide range of particle sizes. Texture changes were reported during the erosion period of the 1930s in North America. The largest changes occur in the more erodible sandy soils. Medium- and fine-textured soils suffer less from texture change. In these soils, the coarser grains left in eroding fields and the finer grains in dunes are generally aggregates rather than particles. These have the same texture as the whole soil had before erosion. Many silt loam ―dunes‖ were deposited around buildings in the Great Plains during the 1910–1914 erosion periods. The textures of these old dunes and of associated cultivated fields are the same.

2.3.3 Nutrient Losses

Colloidal clay and organic matter are the seat of most of the soil's fertility. Colloidal material lost in dust storms contains a lot of fertility. Lyles and Tatarko (1986) showed that ten soils in the western half of Kansas had lost an average of one-fifth of their 1948 organic- matter content by 1984. Fertility loss is particularly severe in coarse-textured soils that be- come coarser as erosion progresses, but it is also important in medium-textured soils that lose surface soil but do not change texture. Fertility loss also occurs by crop removal and by oxidation of organic matter, so it is difficult to determine how much of it should be attributed to wind and water erosion.

2.3.4 Productivity Losses

Soil erosion decreases soil fertility, which can negatively affect crop yields. It also sends soil- laden water downstream, which can create heavy layers of sediment that prevent streams and rivers from flowing smoothly and can eventually lead to flooding. Once soil erosion occurs, it is more likely to happen again.Soils become less productive as winds erode them. Soils developed from glacial till and other mixed-textured material lose productivity mostly because of lowered nutrient content and reduced water-holding capacity. Soils developed from loess or other relatively uniform material loses productivity because of loss of friable, productive surface soil and the exposure of more clayey, less permeable, less fertile subsoil material.

Loss of soil depth reduces crop production by making the root zone shallower and/or less favorable for root growth. Larney found that grain yields from their plotson three soil types in the northern Great Plains were reduced by an average of 53% by the removal of 20 cm of topsoil. They also found that heavy applications of manure were more effective than mineral nitrogen and phosphorus fertilizers for restoring short-term soil productivity. Lyles (1977) suggested a method for estimating productivity decline based on the prediction of surface soil loss and a known relationship between depth of surface soil and crop yield, but this relationship undoubtedly depends on the type of soil. Also, it may be partly incremental instead of gradational. Abrupt changes may occur when certain critical values are passed. For example, a small change in soil depth causes a comparable change in water storage capacity that influences plant survival during dry periods.

2.3.5 Abrasion

Soil grains carried by wind have etched automobile windows and sand blasted paint on houses, cars, and machinery. Soil particles sift into bearing surfaces in machinery and accelerate wear. This type of damage is costly, but it is insignificant compared to the damage done to young, growing plants.

Plants seldom suffer permanent damage solely from the flogging action of high winds, but severe damage is done, especially to young plants, when the erosive wind carries abrasive soil material. Damage ranging from delayed growth and reduced yield to actual death has been inflicted on cotton, sorghum, wheat, soybeans, sunflower, alfalfa, a number of native grasses, and several vegetables. A relatively short exposure to soil blast will reduce final yields; plants are killed when the exposure is long enough. Figure 2.3 shows a field of wheat in southwestern Kansas destroyed by severe wind erosion.

2.3.6 Air Pollution

The presence of soil particles in the air has long been noted. Early Greek writers mentioned dust storms that probably originated in the Sahara Desert. Most dust originates in deserts or in dry land areas temporarily bared of vegetative cover by overgrazing, cultivation, or fires. Atmospheric dust causes discomfort some distance from its source. Near the source, discomfort is much greater, and a dust storm can be fatal to travelers caught in it.

In addition to the physical hazards produced by dust in the air, chemical hazards also may be encountered. Wind-blown dust can carry toxic substances. Mine-spoil banks and waste-disposal sites often contain unusual chemicals. Some areas are accidentally, some purposely, contaminated with chemicals. Some of these chemicals are benign, while others, such as polychlorinated biphenyls (PCBs), are extremely toxic. Cultivated fields and some permanently vegetated areas are regularly or intermittently treated with agrochemicals. Many of these contaminants are adsorbed on the surface of the fine soil particles and are carried into the air by erosive forces. These chemicals add to the inconvenience and the hazard of living in, and breathing, dust-laden air. Dust that results from farming activities seldom causes death directly, but it can and does cause accidents and respiratory ailments that sometimes prove fatal. Dust in the air can reduce visibility dangerously on highways and at airfields. Dust may also carry pathogens that cause skin disorders.

Figure 2.3 The wheat crop in this field in southwestern Kansas was destroyed by a windstorm on February 10, 1976.

2.3.7 Deposition (Sedimentation)

Suspended dust is carried long distances and deposited as a thin film over exposed surfaces. It constitutes a nuisance that can be demoralizing to those who try to keep surfaces dust- free, but it generally does no great physical damage. Some soils may even gain from added nutrients and organic matter. Aeolian dust contributes to soil formation, furnishes essential nutrients for plants to invade hostile environments, and has considerable influence on arid-land ecosystems. They used particle-size and mineralogical analyses to estimate that soils on the Colorado Plateau are composed of as much as 20 to 30% aeoliandust and that much of it came from areas more than 60 miles (100 km) away. Variations inthe orientation of magnetite particles allowed them to infer a time line for the deposits andthis, coupled with changes in mineralogy, made it possible to estimate how much of the de- position had occurred since farming began in the upwind areas.

Measurements of airborn dust in the Southern High Plains plateau in Texas and New Mexico indicate a relatively stable level of background dust with sudden peaks representing specific dust events.

Figure 2.4 Wind erosion sediments have buried three snow fences erected to protect the road at the right of this picture. The surface of the dunes over the snow fences is 3 to 10 ft (1 to 3 m) above the former ground level.

The background dust was unrelated to wind, but the peaks were well correlated with wind velocities higher than 4 m/s (9 mph) when measurements were taken downwind from areas of dry soil with little surface cover.

Efforts have been made to develop prediction equations for the amount of dust in theair. These equations consider not only the rate of soil loss from source areas but also thewind direction, distance from the source area, and elevation profiles. Saltating soil material does not travel far, but it causes considerable physical damage.

Many farm fences were buried during the 1930s by soil that settled behind tumbleweeds that were trapped by the fences. Sometimes two fences had to be built successively on top of the original one to keep livestock confined and cropland protected, or to control soil andsnow drifts (see Figure 2.4). Drainage and irrigation ditches have also been plugged withblowing soil. Land leveled for irrigation as well as ordinary farm fields have been made hummocky by drifting soil. An uncultivated area can be a source of sediment that can fill corrugations or even furrows, thus making it difficult or impossible to maintain these formsof surface irrigation.

Crops can be buried by drifting soil, particularly when they are planted in furrows. Young plants are most likely to be damaged, but even mature plants on the windward edgesof fields next to eroding areas can be completely covered. Sand dunes can move into wind- breaks and tree shelterbelts, eventually killing them if the drifts get too deep. Highways and other engineering works can be covered with blown soil. Huszar and Piper (1986) surveyed off-site costs of wind erosion in New Mexico and reported annual costs of over $465 mil- lion. This dwarfs the $10 million on-site costs claimed annually for the state.

Sand deposits are expensive to remove. The Santa Fe Railway found this out when the John Martin Dam was built in eastern Colorado. The mainline track had to be relocated from the river valley to the uplands south of the river, passing through a very sandy region. Blowouts were common during the 1930s and sand frequently covered the right-of-way. Soil drifting was controlled only after livestock numbers were reduced and the area was re-vegetated with the help of large government input.

2.4 ESTIMATION OF WIND EROSION

Wind erosion estimation involves calculating soil loss (E) based on factors like wind erodibility index (I), roughness factor (K), climate factor (C), unsheltered distance (or) field length (L), and vegetation cover factor (V), commonly expressed as $E=f(IKCLV)$.

Methods for Estimating Wind Erosion

- ✓ **Wind Erosion Equation (WEQ):** The standard equation $E=(IKCLV)$ estimates average annual soil loss (tons/acre/year) by evaluating soil erodibility, surface roughness, climate, field width, and vegetation.

- ✓ **Revised Wind Erosion Equation (RWEQ):** A more modern, process-based model, often used in conjunction with software like SWEEP, which provides improved, event-based soil loss calculations.
- ✓ **WECON Model:** A model designed for disturbed, construction-related surfaces to estimate potential erosion based on wind data.
- ✓ **Direct Field Measurements:** Techniques include using sediment samplers (e.g., PI-SWERL), passive dust traps, and microtopographic surveys (before/after) to measure soil loss directly.

2.4.1 The wind erodibility index (I)

The wind erodibility index (I) is a numerical value used to quantify a soil's susceptibility to wind erosion based on its texture, surface aggregates (>0.84mm), and stability. It acts as a key factor in the Wind Erosion Equation (WEQ), ranging from 0 to 310+ tons per acre per year, with coarser-textured soils (sand, sandy loam) exhibiting the highest indices.

- ✓ **Definition & Purpose:** The index (I) measures the potential annual soil loss in tons per acre ($t/ac/yr$) due to wind, assuming a dry, bare, and smooth soil surface.
- ✓ **Soil Texture & Groups (WEG):** Soils are classified into 8 Wind Erodibility Groups (WEGs) based on surface texture. Group 1 (sands) has the highest index (e.g., 310 $t/ac/yr$), while groups with higher silt/clay or organic matter (e.g., clay loam, organic soils) have lower values.
- ✓ **Measurement:** The index is directly related to the percentage of dry, non-erodible surface soil aggregates larger than 0.84mm.
- ✓ **Application in Modeling:** It is used in the WEQ ($E=f(I',K',C',L',V)$) to calculate potential erosion, allowing land managers to assess risk and determine necessary conservation measures, such as maintaining crop cover, reducing tillage, or installing windbreaks.
- ✓ **Range:** Values typically range from 0 to 310+, with higher numbers indicating higher susceptibility to erosion.

The index provides a quick, standardized method for estimating the inherent erodibility of a soil, but it must be considered alongside factors like climatic conditions and management practices.

2.4.2 The soil roughness factor (Kor K')

The soil roughness factor ($\underline{K}$or $\underline{K'}$) in wind erosion models (WEQ/RWEQ) quantifies how surface irregularities-specifically tillage ridges (oriented) and soil aggregates (random)-reduce soil loss by trapping particles and reducing wind velocity. A higher, rougher surface (higher K) generally reduces erosion, with the factor influenced by ridge height, spacing, and orientation relative to the wind.

- ✓ **Definition:** (or K') represents the capacity of a soil surface to resist wind erosion due to its roughness.
- ✓ **Components:**
  - ✓ **Oriented Roughness (Kr):** Ridges created by tillage, planting, or cultivation implements.
  - ✓ **Random Roughness (Crr):** Surface roughness caused by soil clods and aggregates, generally created by tillage but not oriented in a specific direction.
- ✓ **Mechanism:** Rougher surfaces absorb wind energy, create turbulence, and physically trap soil particles moving through saltation, thus reducing the overall soil loss (E).
- ✓ **RWEQ vs. WEQ:** In the original Wind Erosion Equation (WEQ), $K$is often limited to ridge roughness. In the Revised Wind Erosion Equation (RWEQ), K' is used, which often incorporates both random and oriented roughness and can change based on erosion events.
- ✓ **Factors Affecting K':**
  - ✓ **Wind Direction:** Ridges perpendicular to the wind offer more protection than parallel ones.
  - ✓ **Rainfall:** Rain reduces roughness over time by smoothing the soil surface, causing a decay in the K' value.
  - ✓ **Soil Type:** The degradation rate of roughness differs by soil type.
- ✓ **Modeling and Estimation**
- ✓ **Measurement:** K' is often estimated using the chain method, which measures surface roughness, combined with ridge height and spacing.
- ✓ **Role in RWEQ:** It is one of the primary factors in the equation E=(I',K',C',L',V), where E is soil loss, I' is erodibility, K' is roughness, C' is climate, L' is field length, and V is vegetation.
- ✓ **Impact:** A higher K' value generally indicates a more protective surface.

2.4.3 Climatic Factor (C):

The climate factor (C) in soil erosion by wind is a key component of the Wind Erosion Equation (E=($IKCLV$)) representing a region's erosivity based on wind speed and surface soil moisture. It calculates the potential erosion by quantifying the average annual or monthly wind velocity and the Thornthwaite "effective precipitation" index (soil moisture).

- ✓ **Components:** C is primarily determined by mean annual or monthly wind speed and soil surface moisture. High wind speeds coupled with low moisture (dry conditions) increase C values, while high moisture/low wind decreases it.
- ✓ **Role in WEQ:** It serves as a multiplier in the Wind Erosion Equation, representing climatic erosivity, typically in units of percentage relative to a base location (C=100).

- ✓ **Impact:** A higher C-factor implies greater wind erosion potential (tons per acre per year) for a given area.
- ✓ **Variability:** C -factors are often computed on an annual or monthly basis to account for seasonal variations in wind intensity and soil moisture.
- ✓ **Factors affecting:** It is influenced by climatic trends, with studies indicating that decreasing wind speeds can lead to a reduction in the C-factor.

2.4.4 Unsheltered distance (or) field length (L)

In soil erosion by wind, field length (L) represents the unsheltered distance of an open, erodible area along the direction of the prevailing wind. It is a critical, variable component in the Wind Erosion Equation (WEQ) (E=(I,K,C,L,V)) that determines how wind velocity accelerates and increases soil transport capacity.

- ✓ **Impact on Erosion:** As field length increases, the wind accumulates more energy and erodes more soil, up to a maximum transport capacity.
- ✓ **Critical Length:** For most agricultural surfaces, the critical field length required for wind to reach 63% of its maximum transport capacity is generally less than 150 meters.
- ✓ **Management:** Reducing the unsheltered field length (L) using windbreaks, barriers, or strips is a key strategy to decrease total soil loss.
- ✓ **Relationship:** The relationship between field length and soil movement is often described by a sigmoidal curve, where erosion increases rapidly before flattening as it hits maximum capacity.

2.4.5 Vegetative Cover factor (V):

The vegetation factor (V) in wind erosion models (like the Wind Erosion Equation, $E=f(IKCLV)$) quantifies the protection provided by crop residue or standing plants, reducing soil loss by covering the surface and absorbing wind energy. It is expressed as the equivalent quantity of small-grain residue (in pounds per acre) that reduces soil transport.

- ✓ **Function:** It reduces the soil erodibility (I), soil ridge roughness (K), climate (C), and unsheltered distance (L) factors to determine total erosion (E).
- ✓ **Measurement:** V is calculated based on the type, amount, and orientation of vegetative cover.
- ✓ **Protection Mechanism:** Vegetation increases surface roughness, which absorbs wind forces and reduces the shear stress exerted on soil particles, effectively slowing wind speed at the surface level.
- ✓ **Effectiveness:** It is generally considered the most effective tool for controlling wind erosion, particularly in arid and semi-arid regions.

- ✓ **Calculation:** It can be modeled using exponential curves related to ground cover, for instance, by combining vegetation retention factors (Vmj) with fractional cover (FCm) derived from NDVI data.

2.5 DETACHING AND TRANSPORT CAPACITY OF WIND

Wind has power to detach and transport soil grains. After transportation, particles and aggregates come to rest short or long distances from their origin. Coarse sand particles roll only a short distance and saltating sand particles move in short jumps, but silt particles may travel many miles and tiny clay particles may be carried around the world.

2.5.1 Detaching Capacity of Wind

The detaching capacity of wind is related to its friction velocity, or shear stress, and to the size of the erodible grains.

$$D = f(u)^2$$

Where, D = detaching capacity, g/cm^2, u = friction velocity over an eroding surface, cm/s

A sharp velocity gradient near the soil causes grains that protrude higher into the wind stream to be struck by stronger wind force. Larger particles stick up higher, but their larger mass requires more force to detach them. Any particle from 0.05 to 0.5 mm in diameter can be detached if the wind is strong enough, but those from 0.1 to 0.15 mm are the easiest to detach of any grains that move in saltation. Silt- and clay-sized grains (< 0.05 mm) and very coarse sand and gravel sizes (> 1.0 mm) cannot be separated from the soil mass even by strong winds if they are free of saltating particles. Fine particles can only move in saltation if they are bound together into aggregates of the right size. Winds containing abrasive material can detach both smaller and larger grains. These abrasive materials not only detach erodible grains from the soil, they also abrade non-erodible clods, detaching small erodible grains from them. If the wind continues long enough, whole clods may be disintegrated (Figure 2.5).

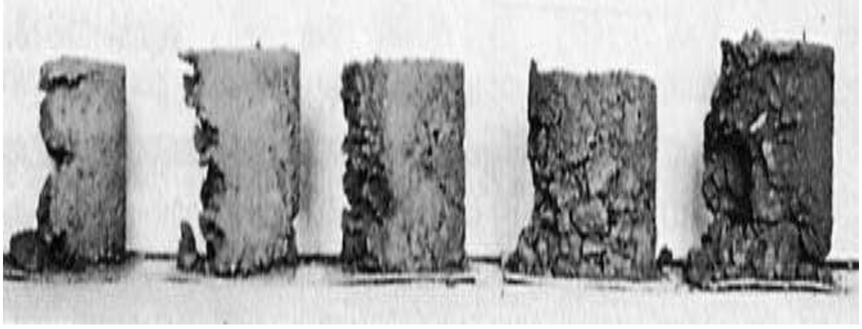

Figure 2.5 Abrasion of soil cylinders 3 in. (7.5 cm) in diameter and 2.5 in. (6.2 cm) tall by dune sand carried in a wind blowing from left to right with a friction velocity of 2 ft/sec (61 cm/s). Soils from left to right are fine sandy loam, loam, light silt loam, heavy silt loam, and silty clay.

2.5.2 Transporting Capacity of Wind

Transport capacity of wind is related to wind velocity, but not to soil-grain size. Greater numbers of smaller-sized grains can be picked up, but the total weight of material that a specific wind can carry remains relatively constant. The proportion of material in suspension, saltation, and creep depended on the aggregate- and particle-size composition of the soil. Minor quantities of suspended material were found over very coarse-textured soils and over strongly aggregated, fine-textured soils. Quantities of creeping particles were relatively large. Suspension was greater and creeps noticeably smaller over dusty, silty, and fine sandy soils. In every soil Chepil studied, the amount of material in saltation was always greater than that in suspension and creep combined. Amounts in suspension ranged from 3 to 38%, in saltation from 55 to 72%, and in creep from 7 to 25% of the moving soil.

The rate of dune sand and soil movement by wind (weight of material moving past a unit width, normal to the direction of movement, per unit time) was related to the third power of the friction velocity:

$$q = \frac{\rho}{g} * u^3$$

Where, q = rate of soil movement, g/(cm width)-

s ρ = air density, g/cm^3

g = gravitational constant, 980 cm/s^2

u = friction velocity over an eroding surface, cm/s^2

The relationship between amount of soil removed from a unit area and erosive wind force probably has greater significance than that between rate of loss and wind force.

$$X = f(u)^5$$

Where, X = the transportation capacity, g/cm^2

This relationship is influenced by a number of factors, but the total soil removal appears to be proportional to the fifth power of the friction velocity.

2.6 FACTORS AFFECTING WIND EROSION

High-velocity winds do not always cause soil drifting, and erosive winds do not cause the same amount of erosion in all situations. Factors that influence the amount of erosion that wind will cause are the soil’s resistance to erosion, surface roughness, rainfall, land slope (hummocks), length of exposed area, and vegetative cover.

2.6.1 Soil Resistance

The major factor that makes soil resist wind erosion is size (mass) of individual soil grains. If the mass is sufficient, particles, aggregates, or clods are non-erodible. Large grains also protect and stabilize erodible grains in their wind shadow. Chepil (1950) called this ―the governing principle of surface roughness.‖ This is roughness caused by soil cloddiness, not by mechanical ridging.

Dry Aggregate Size Distribution: Grains larger than 1 mm in diameter resist wind erosion; those between 1 and 0.5 mm (coarse sand size) are erodible only in very high- velocity winds; those less than 0.5 mm in effective diameter are highly erodible. The more non-erodible grains the surface contains, the less erodible the soil is. The proportion of non-erodible grains present on or near the soil surface affects the ease and speed with which soil starts to move, how long erosion will continue before a non-erodible blanket forms to halt it, and the total amount of soil that will be lost. A relatively smooth soil containing non-erodible clods may become rough as it erodes and thus re- duce erosion losses. The likelihood of a field forming a protective surface condition can be assessed by determining the size distribution of stable clods in the top inch (2.5 cm) of soil. The relationship between proportion of non-erodible clods and soil erodibility is shown in Figure 2.6.

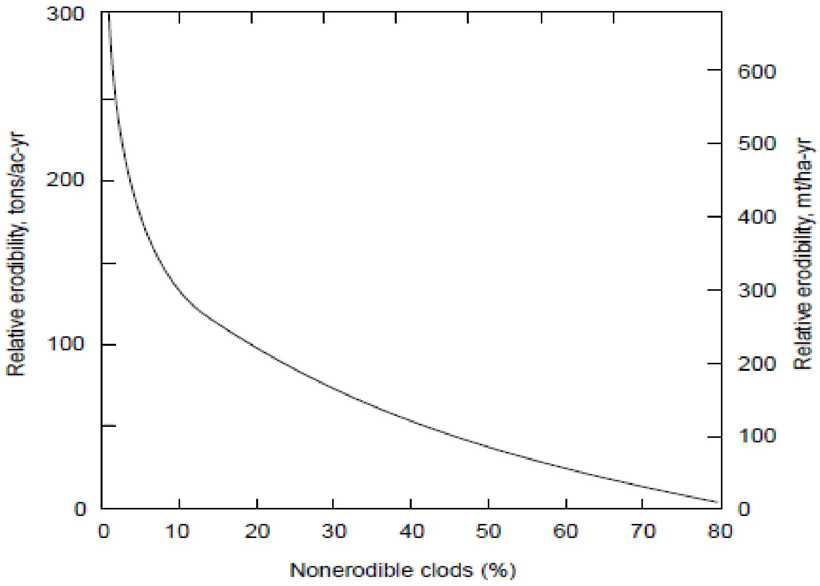

Figure 2.6 Relationship between percentage of non-erodible clods in a soil and its relative erodibility (*I*).

A smooth, bare, infinitely wide field with only 2% non-erodible clods could lose 250 tons/ac (560 mt/ha) in a year under the high winds common in the central Great Plains. A similar field with 40% non-erodible clods would lose 56 tons/ac-yr (125 mt/ha-yr) under the same conditions.

Mechanical Stability of Structural Units: The presence of non-erodible structural units does not, by itself, prevent soil erosion. Aggregates and clods that are easily abraded do not resist erosion for long. Accordingly, aggregate stability is an important at-tribute also.

Factors Affecting Aggregate Size and Stability: Soil properties such as texture, organic matter, exchangeable cations, and free calcium carbonate influence aggregate size and stability. Coarse-textured soils do not contain enough clay to bind the sandy particles into structural units. Clayey soils develop aggregates and clods, but weathering, especially freezing and drying while frozen, breaks them down. A clay content of about 27% is best for clod development. Clay content less than 15% almost precluded a stable cloddy condition. The presence of large amounts of fine and medium sand influences soil erodibility directly because these sizes can saltate. Very coarse sand and gravel help reduce soil erodibility because they are too large to be moved by most winds.

Soil organic matter is often associated with high levels of aggregation and with structural stability, but soils with very high organic-matter levels are often more erodible than those with moderate contents. Wind erosion is a major hazard on organic soils that are drained and cropped. Additions of cereal straw and legume hay increased non-erodible dry clods and reduced erodibility while the materials were undergoing active decomposition (about six months). As decomposition slowed down, initial cementing materials lost their aggregating ability, and microbial fibers disintegrated. Non-erodible-clod size decreased and soil erodibility increased, especially on high-residue treatments. Often a high proportion of highly erodible small to medium sized aggregates developed.

Applications of lime to acid soils in humid areas often improve soil structure. This is not true for soils in arid and semiarid regions. These are rarely calcium deficient. Their surface soils have an abundance of calcium, and their sub soils invariably contain free calcium carbonate. In fact, shallow calcium carbonate horizons in drier areas may be mixed with surface soil by cultivation. The presence of as little as 1% free calcium carbonate in a soil generally caused clod disintegration and increased erodibility. Despite this relationship, when calcareous B or C horizons are exposed by erosion, surface crusts often develop that effectively protect soils from further erosion.

2.6.2 Surface Ridges and Roughness

Surface ridges produced by tillage reduce erosion. Effectiveness of ridges depends on height, lateral frequency, shape, and orientation relative to the direction of the wind. Ridges reduce wind velocity near the ground and trap eroding soil grains in the furrows between ridge crests. Bielders used hoes to make ridges 8-in. (20-cm) high and 5 ft (1.5 m) apart in Niger. Soil ridges reduced wind erosion by 57%, and the reduction was 87% when millet stover residues were included to stabilize the soil. However, the ridges had to be oriented across the wind direction; little or no reduction in erosion occurred when the wind blew parallel to the ridges. They noted that ridge orientation may be a problem where both wind and water erosion are likely to occur.

Wind tunnel measurements by Batt and Peabody showed that ridges across the wind direction were the most effective form of surface roughness for reducing wind erosion, but that any erosion-resistant surface roughness was helpful. Ridges, clods, stubble, and gravel all reduced wind erosion caused by both low-velocity and high-velocity winds. They evaluated a normalized roughness factor by dividing the height difference between high and low points by the average spacing between high points (H/S) and found that the amount of soil loss decreased linearly as the H/S factor increased from 0 to 0.12. The soil loss rate remained nearly constant at about 10% of the flat surface value for H/S factors greater than 0.12.

2.6.3 Rainfall

Rain moistens surface soil, and moist soil is not eroded by wind. Studies show soil erodibility decreases slowly at first, then more rapidly—as a soil is moistened from the air-dry condition to the wilting point. Chepil (1956) worked with four Great Plains soils and found they became non- erodible at moisture contents ranging from 0.82 to 1.16 times the water content at 15-atm tension. Bisal and Hsieh (1966) studied three Canadian soils and found moisture contents from 0.32 to 1.46 times that at 15-atm tension prevented soil drifting. Unfortunately, the direct effect of moisture on soil erodibility is transitory; it takes only a very thin layer of dry surface soil to permit erosion to start, even if moisture is abundant immediately below. Wind soon reduces the moisture content of surface layers. Some sandy soils can begin to drift 15 or 20 minutes after an intense shower.

Rainfall also reduces erosion indirectly by increasing plant growth. Crop response to rainfall is extremely important because plant cover controls wind erosion best.

Rain can also increase wind erosion. This happens when raindrops break exposed wind-resistant grains, detach erodible grains from the soil mass, and smooth soil surfaces so they are more susceptible to erosion.

2.6.4 Knoll Slopes

Over long slopes, short slopes not exceeding 1.5%, and level land, the velocity gradient and friction velocity are reasonably constant for a given wind. Over hummocky topography, where slopes are relatively short, layers of higher wind velocity move closer to the soil surface as they pass over knoll crests (Figure 2.7). Z_O is a relatively constant height above the surface, so the shorter vertical distance to the higher-velocity flow makes the friction velocity greater over the knolls. This makes the wind's erosive force much greater on the crests than on level land or on long slopes. Chepil (1964) calculated probable in- creases in erosion on the crests and upper slopes of relatively short 3, 6, and 10% slopes.

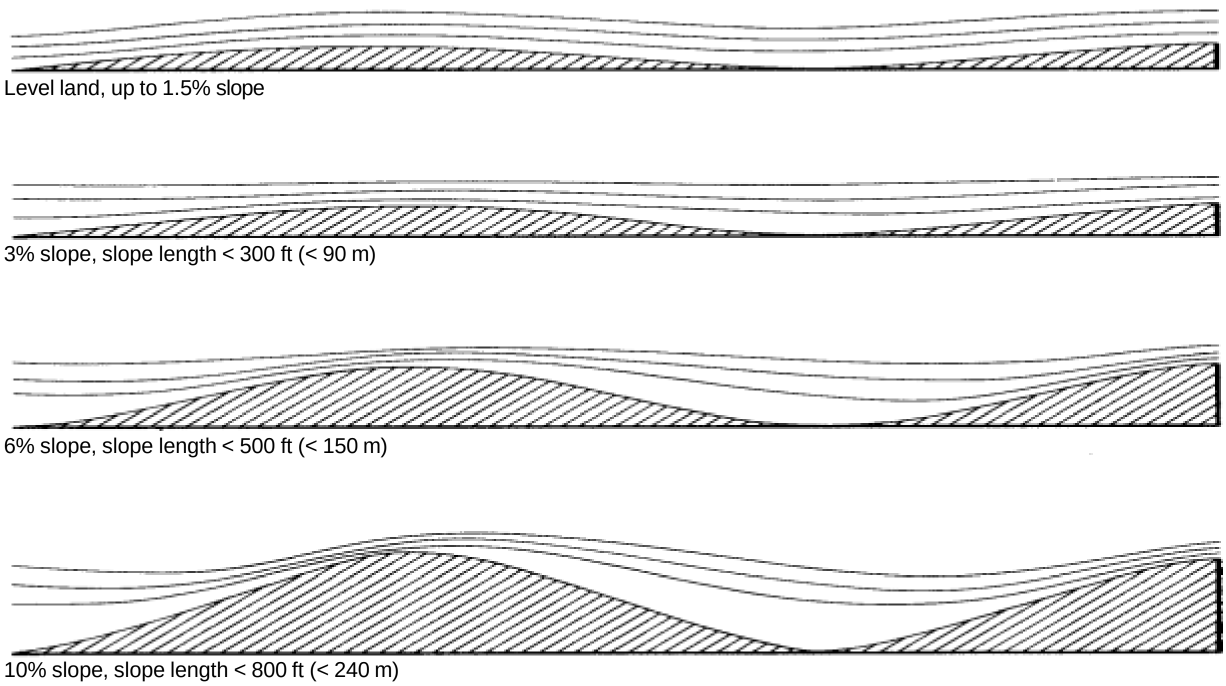

Figure 2.7 Lines of equal wind velocity over different land slopes. If the top line in each diagram represents 14 mi/hr (625 cm/s), this velocity is reached 1.0, 0.6, 0.32, and 0.18 ft (30.5,18.3, 9.8, and 5.5 cm) above the knoll crest on the 1.5%, 3%, 6%, and 10% slopes, respectively.

They assumed that the zone of 14-mi/hr (625-cm/s) wind was found approximately 1.0, 0.6, 0.32, and 0.18 ft (30.5, 18.3, 9.8, and 5.5 cm) above the crests of knolls with side slopes of 3, 6, and 10%, respectively. Their calculated values are presented in Table 2.1.

TABLE 2.1 RELATIVE AMOUNTS OF EROSION FROM LEVEL (1.5% SLOPE) AND FROMSHORT-SLOPING (HUMMOCKY) LAND

Relative amounts of erosion		
Slope (%)	Crest	Upper Slopes
1.5 (level)	100	100
3.0	150	130
6.0	320	230
10.0	660	370

2.6.5 Length of Exposed Area

Soil drifting increases substantially with increasing length of the eroding strip. Wind starts to pick up soil grains close to the windward side of an erodible field. It continues to add to its load as it passes over the field until it can carry no more. The wind may continue to pick up other soil grains as it travels farther, but it also drops some of its load because its carrying capacity is finite.

The transport capacity of wind at a specific friction velocity is similar for all soils, but the distance the wind must travel across a field to pick up its full load depends on soil.

The more erodible the soil, the shorter the distance required to reach its load capacity. Distance needed to acquire maximum load varies from less than 180 ft (55 m) for a structure less fine sand to more than 5000 ft (1500 m) for a cloddy, medium-textured soil (Chepil and Woodruff, 1963). Many fields are not wide enough for the wind to pick up its maximum load.

2.6.6 Vegetative Cover

The most effective way to reduce wind erosion is to cover the soil with a protective mantle of growing plants or with a thick mulch of crop residue. Barriers of plant material increase the thickness of the blanket of still air ($D + Z_O$) next to the soil.

The protection that plant cover provides is influenced by plant species (amount of vegetative cover and time of year when cover is provided), plant geometry and population, and row orientation. Crop residues left on the surface, especially if tall and dense; offer al- most as much protection as a comparable amount of growing plants. Standing residues pro- vide more protection than the same amount of flattened residues. One anomaly is that a sparse cover over less than 10% of the surface can increase the turbulence of wind gusts and actually increase wind erosion to more than that from bare soil. A complete cover of growing plants offers maximum protection, but individual plants and rows of plants across the direction of the wind also reduce ground-level wind velocity and erosion.

This is apparent where isolated weeds in fallow fields trap saltating grains and where soil piles up around wind barriers such as field shelterbelts.

Barriers are effective because air is a fluid. As air moves toward a porous barrier, part of it is pushed over or around the barrier. Air that is not deflected builds up pressure that forces it through the barrier at a fast rate (funneling effect). This air immediately slows down as it spreads out to occupy all the space behind the barrier. Wind speed returns to normal only when the deflected air returns its initial position in the wind stream.