

Wind Erosion

Overview

The Agricultural Research Service has primary responsibility for erosion prediction research within the U.S. Department of Agriculture (USDA). Wind erosion research is conducted by the Wind Erosion Research Unit at Manhattan, Kansas, and the Cropping Systems Research Unit at Big Spring, Texas.

The wind erosion problem

Wind is an erosive agent. It detaches and transports soil particles, sorts the finer from the coarser particles, and deposits them unevenly. Loss of the fertile topsoil in eroded areas reduces the rooting depth and, in many places, reduces crop yield. Abrasion by airborne soil particles damages plants and constructed structures. Drifting soil causes extensive damage also. Sand and dust in the air can harm animals, humans, and equipment.

The wind erosion process

The wind erosion process is complex. It involves detaching, transporting, sorting, abrading, avalanching, and depositing of soil particles. Turbulent winds blowing over erodible soils cause wind erosion. Field conditions conducive to erosion include:

- loose, dry, and finely granulated soil;
- smooth soil surface that has little or no vegetation present;
- sufficiently large area susceptible to erosion; and
- sufficient wind velocity to move soil.

Winds are considered erosive when they reach 13 miles per hour at 1 foot above the ground or about 18 miles per hour at a 30-foot height. This is commonly referred to as the threshold wind velocity (Lyles and Krauss 1971).

The wind transports primary soil particles or stable aggregates, or both, in three ways:

Saltation—Individual particles/aggregates ranging from 0.1 to 0.5 millimeter in diameter lift off the surface at a 50- to 90-degree angle and follow distinct trajectories under the influence of air resistance and gravity. The particles/aggregates return to the surface at impact angles of 6 to 14 degrees from the horizontal. Whether they rebound or embed themselves, they initiate movement of other particles/aggregates to create the *avalanching* effect. Saltating particles are the abrading *bullets* that remove the protective soil crusts and clods. Most saltation occurs within 12 inches above the soil surface and typically, the length of a saltating particle trajectory is about 10 times the height. From 50 to 80 percent of total transport is by saltation.

Suspension—The finer particles, less than 0.1 millimeter in diameter, are dislodged from an eroding area by saltation and remain in the air mass for an extended period. Some suspension-sized particles or aggregates are present in the soil, but many are created by abrasion of larger aggregates during erosion. From 20 percent to more than 60 percent of an eroding soil may be carried in suspension, depending on soil texture. As a general rule, suspension increases downwind, and on long fields can easily exceed the amount of soil moved in saltation and creep.

Surface creep—Sand-sized particles/aggregates are set in motion by the impact of saltating particles. Under high winds, the whole soil surface appears to be creeping slowly forward as particles are pushed and rolled by the saltation flow. Surface creep may account for 7 to 25 percent of total transport (Chepil 1945 and Lyles 1980).

Estimating wind erosion

How, why, and by whom wind erosion is estimated

Using the Wind Erosion Equation (WEQ), NRCS estimates erosion rates to:

- provide technical assistance to land users,
- inventory natural resources, and
- evaluate the effectiveness of conservation programs and conservation treatment applied to the land.

Wind erosion is difficult to measure. Wind moves across the land in a turbulent, erratic fashion. Soil may blow into, within, and out of a field in several directions in a single storm. The direction, velocity, duration, and variability of the wind all affect the erosion that occurs from a windstorm. Much of the soil eroding from a field bounces or creeps near the surface; however, some of the soil blown from a field may be high above the ground in a dust cloud by the time it reaches the edge of a field (Chepil 1963).

Methods of estimating wind erosion

No precise method of measuring wind erosion has been developed. However, various dust collectors, remote and in-place sensors, wind tunnels, sediment samplers, and microtopographic surveys before and after erosion have been used. Each method has its limitations. Research is continuing on new techniques and new devices, on modifications to older ones, and on means to measure wind erosion.

Estimates of wind erosion can be developed by assigning numerical values to the site conditions that govern wind erosion and expressing their relationships mathematically. This is the basis of the current Wind Erosion Equation (WEQ) that considers soil erodibility, ridge and random roughness, climate, unsheltered distance, and vegetative cover.

The wind erosion equation

The Wind Erosion Equation (WEQ) erosion model is designed to predict long-term average annual soil losses from a field having specific characteristics. With appropriate selection of factor values, the equation will estimate average annual erosion or erosion for specific time periods.

Development of the wind erosion equation

Drought and wind erosion during the 19th century caused wind erosion to be recognized as an important geologic phenomenon. By the late 1930's, systematic and scientific research into wind erosion was being pioneered in California, South Dakota, Texas, and in Canada and England. In 1947, USDA began the Wind Erosion Research Program at Manhattan, Kansas, in cooperation with Kansas State University. By 1954, Chepil and his coworkers began to publish results of their research in the form of wind erosion prediction equations (Chepil 1954; Chepil 1957; Chepil et al. 1955; Woodruff and Chepil 1956). In 1959, Chepil released an equation $E = IRKFBWD$. Wind velocity at geographic locations was not addressed in this equation (Chepil 1959). In 1962, Chepil's group released the equation $E = f(ACKLV)$. Factors C, K, L, and V were the same as in the present equation although they were not handled the same (Chepil 1962). A C-factor map for the western half of the United States was also published in 1962 (Chepil et al. 1962).

In 1963, the current form of the equation, $E = f(ICKLV)$ was first released (Chepil 1963). In 1965, the concept of preponderance in assessing wind erosion forces was introduced. In 1968, monthly climatic factors were published (Woodruff and Armbrust 1968). These are no longer used by NRCS. Instead, NRCS adopted a proposal for computing soil erosion by periods using wind energy distribution, which was published in 1980 (Bondy et al. 1980). In 1981, the Wind Erosion Research Unit provided NRCS with data on the distribution of erosive wind energy for the United States and in 1982 provided updated annual C factors.

Although the present equation has significant limitations (see 502.23), it is the best tool currently available for making reasonable estimates of wind erosion. Currently, research and development of improved

procedures for estimating wind erosion are underway.

The present Wind Erosion Equation is expressed as:

$$E = f(IKCLV)$$

where:

E = estimated average annual soil loss in tons per acre per year
f = indicates relationships that are not straight-line mathematical calculations
I = soil erodibility index
K = soil surface roughness factor
C = climatic factor
L = the unsheltered distance
V = the vegetative cover factor

The I factor, expressed as the average annual soil loss in tons per acre per year from a field area, accounts for the inherent soil properties affecting erodibility. These properties include texture, organic matter, and calcium carbonate percentage. I is the potential annual wind erosion for a given soil under a given set of field conditions. The given set of field conditions for which I is referenced is that of an isolated, unsheltered, wide, bare, smooth, level, loose, and noncrusted soil surface, and at a location where the climatic factor (C) is equal to 100.

The K factor is a measure of the effect of ridges and cloddiness made by tillage and planting implements. It is expressed as a decimal from 0.1 to 1.0.

The C factor for any given locality characterizes climatic erosivity, specifically windspeed and surface soil moisture. This factor is expressed as a percentage of the C factor for Garden City, Kansas, which has a value of 100.

The L factor considers the unprotected distance along the prevailing erosive wind direction across the area to be evaluated and the preponderance of the prevailing erosive winds.

The V factor considers the kind, amount, and orientation of vegetation on the surface. The vegetative cover is expressed in pounds per acre of a flat small-grain residue equivalent.

Solving the equation involves five successive steps. Steps 1, 2 and 3 can be solved by multiplying the factor values. Determining the effects of L and V (steps 4 and 5) involves more complex functional relationships.

Step 1: $E_1 = I$

Factor I is established for the specific soil. I may be increased for knolls less than 500 feet long facing into the prevailing wind, or decreased to account for surface soil crusting, and irrigation.

Step 2: $E_2 = IK$

Factor K adjusts E_1 for tillage-induced oriented roughness, K_{rd} (ridges) and random roughness, K_{rr} (cloddiness). The value of K is calculated by multiplying K_{rd} times K_{rr} . ($K = K_{rd} \times K_{rr}$).

Step 3: $E_3 = IKC$

Factor C adjusts E_2 for the local climatic factor.

Step 4: $E_4 = IKCL$

Factor L adjusts E_3 for unsheltered distance.

Step 5: $E_5 = IKCLV$

Factor V adjusts E_4 for vegetative cover.

Limitations of the equation

When the unsheltered distance, L , is sufficiently long, the transport capacity of the wind for saltation and creep is reached. If the wind is moving all the soil it can carry across a given surface, the inflow into a downwind area of the field is equal to the outflow from that same area of the field, for saltation and creep. The net soil loss from this specific area of the field is then only the suspension component. This does not imply a reduced soil erosion problem because, theoretically, there is still the estimated amount of soil loss in creep, saltation, and suspension leaving the downwind edge of the field.

Surface armoring by nonerodible gravel is not usually addressed in the I factor.

The equation does not account for snow cover or seasonal changes in soil erodibility. The equation does not estimate erosion from single storm events.

Alternative procedures for using the WEQ

The WEQ Critical Period Procedure is based on use of the Wind Erosion Equation as described by Woodruff and Siddoway in 1965 (Woodruff and Siddoway 1965). The conditions during the critical wind erosion period are used to derive the estimate of annual wind erosion.

- The Critical Wind Erosion Period is described as the period of the year when the greatest amount of wind erosion can be expected to occur from a field under an identified management system. It is the period when vegetative cover, soil surface conditions, and expected erosive winds result in the greatest potential for wind erosion.
- Erosion estimates developed using the critical period procedure are made using a single set of factor values ($IKCL$ & V) in the equation to describe the critical wind erosion period conditions.
- The critical period procedure is currently used for resource inventories. NRCS usually provides specific instructions on developing wind erosion estimates for resource inventories.

The WEQ Management Period Procedure was published by Bondy, Lyles, and Hayes in 1980. It solves the equation for situations where site conditions have significant variation during the year or planning period where the soil is exposed to soil erosion for short periods, and where crop damage is the foremost conservation concern, rather than the extent of soil loss. The management period procedure is described as being more responsive to changing conditions throughout the cropping year but is not considered more accurate than the critical period procedure.

Comparisons should not be made between the soil erosion predictions made by the management period procedure and the critical period procedure. In other words, where a conservation system has been determined to be acceptable by the management period procedure and placed in a conservation plan or the FOTG, then only the management period procedure will be used to determine if other conservation systems, planned or applied, provide equivalent treatment.

Factor values are selected to describe management periods when cover and management effects are approximately uniform. The cropping system is divided into as many management periods as is necessary to describe the year or planning period accurately. Erosive wind energy (EWE) distribution is used to derive a weighted estimate of soil loss for the period. The general procedure is as follows:

- Solve for E in the basic equation ($E = f(IKCLV)$) using management period values for I , K , L , and V , and the local annual value for C .
- Multiply the annual soil loss rate E obtained from management period values by the percentage of annual erosive wind energy that occurs during the management period to estimate average erosion for that management period.
- Add the management period amounts for the crop year, or add the period amounts for a total crop sequence and divide by the number of years in the sequence to estimate average annual wind erosion.

Exhibit 502–7a is an example of tables showing the expected monthly distribution of erosive wind energy at specific locations. The complete table is available for downloading at:

<http://www.weru.ksu.edu/nrcs/windparm.doc>

Exhibit 502–7b shows how these values are used in the management period method computations. Erosive wind energy values are entered on the form in the column identified “% EWE”.

Estimates for management periods less than 1 year in duration are often useful in conservation planning. Examples include:

- When crop damage (crop tolerance) during sensitive growth stages is the major concern.
- When a system or practice is evaluated for short-term effects.

States will use critical period or the management period procedure, within published guidelines, for conservation planning. The management period procedure will not be used for resource inventories unless specifically stated in instructions. Refer to individual program manuals for more specific instructions pertaining to the use of the Wind Erosion Equation.

Adjustments to the WEQ soil erodibility factor, I , can be made for temporary conditions that include irrigation or crusts, but such adjustments are to be used only with the management period procedure. The use of monthly preponderance data to determine equivalent field width is also applicable only to the management period procedure.

Data to support the WEQ

ARS has developed benchmark values for each of the factors in the WEQ. However, the NRCS is responsible for developing procedures and additional factor values for use of the equation. The local Field Office Technical Guides will include the local data needed to make wind erosion estimates.

ARS has computed benchmark C factors for locations where adequate weather data are available (Lyles 1983). C factors used in the field office are to reflect local conditions as they relate to benchmark C factors. Knowledge of local terrain features and local climate is needed to determine how point data can be extended and how interpolation between points should be done.

ARS has developed soil erodibility I values based on size distribution of soil aggregates. Soils have been grouped by texture classes into wind erodibility groups. Wind erodibility group numbers are included in the soil survey database in NASIS.

Using WEQ estimates with RUSLE calculations

The WEQ provides an estimate of average annual wind erosion from the field width along the prevailing wind erosion direction (L) entered in the calculation; RUSLE provides an estimate of average annual sheet and rill erosion from the slope length (L) entered into the model. Although both wind and water erosion estimates are in tons per acre per year, they are not additive unless the two equations represent identical flow paths across identical areas.

Tools for using the WEQ

Graphs and tables for determining factor values are in Exhibits.

E tables

The ARS WEROS (Wind Erosion) computer program has produced tables that give estimated erosion (E values) for most of the possible combinations of I, K, C, L, and V.

Use of the management period procedure can be simplified through the use of worksheets on which information for each management period is documented.

An acceptable WEQ calculator has been developed in Microsoft Excel, and is being adapted for use in many states. A copy of this spreadsheet can be obtained from the NRCS state agronomist in Kansas.

WEQ Factors

The wind erosion estimate, E

The wind erosion estimate, E, is the estimate of average annual tons of soil per acre that the wind will erode from an area represented by an unsheltered distance L and for the soil, climate, and site conditions represented by I, K, C, and V. The equation is an empirical formula. It was initially developed by relating wind tunnel data to observed field erosion for 3 years in the mid 1950's (Woodruff et al. 1976). The field data was normalized to reflect long-term average annual erosion assuming given conditions during the critical period without reference to change in those conditions through the year. The estimate arrived at by using the critical period procedure for estimating wind erosion does not track specific changes brought about by management and crop development; nor does it assume that critical period conditions exist all year. The calibration procedure accounted for minor changes expected to occur during a normal crop year at that time in history. The WEQ annual E is based on an annual C and field condition during the critical wind erosion.

Trade names mentioned are for specific information and do not constitute a guarantee or warranty of the product by the Department of Agriculture or an endorsement by the Department over other products not mentioned. year. This procedure does not account for all the effects of management.

The management period procedure for estimating wind erosion involves assigning factor values to represent field conditions expected to occur during specified time periods. Using annual wind energy distribution data, erosion can be estimated for each period of time being evaluated. The period estimates are summed to arrive at an annual estimate. Cropping sequences involving more than 1 year can be evaluated using this procedure. It also allows for a more thorough analysis of a management system and how management techniques affect the erosion estimate.

The new E tables can be downloaded from the WERU server, Manhattan, Kansas. These tables can be accessed in two ways:

- Through your WWW browser. To view, direct your web browser to:

<http://www.weru.ksu.edu/nrcs>

Download the Adobe Acrobat Reader (if not already installed on your computer) by clicking on the icon and installing per the installation instructions. When the Adobe Acrobat Reader is running on your browser you can click the PDF icon to view and print the table. When on the WERU Web page, copies of the files can be downloaded by clicking on the hypertext for the following:

etab.pdf for PDF or
etab.wpd (for WordPerfect) or
etab.ps for Postscript

- Through FTP—For those without a web browser but have FTP access, FTP to:

<ftp://ftp.weru.ksu.edu>

go to the appropriate directory, for example

cd pub/nrcs/etables

Be sure that you are in binary mode.

To download the table format of your choice, type:

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get "etab.pdf" for PDF or
get "etab.wpd" for WordPerfect or
get "etab.ps" for Postscript
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The appropriate E table will download to your computer.

Soil erodibility index, I

I is the erodibility factor for the soil on the site. It is expressed as the average annual soil loss in tons per acre that would occur from wind erosion, when the site is:

- **Isolated** – incoming saltation is absent
- **Level** – knolls are absent
- **Smooth** – ridge roughness effects are absent and cloddiness is minimal
- **Unsheltered** – barriers are absent.
- At a location where the **C factor is 100**
- **Bare** – vegetative cover is absent
- **“Wide”** – the distance at which the flow of eroding soil reaches its maximum and does not increase with field size
- **Loose** – and non-crusted, aggregates not bound together, and surface not sealed.

The **I** factor is related to the percentage of nonerodible surface soil aggregates larger than 0.84 millimeters in diameter. For most NRCS uses, the **I** value is assigned for named soils based on wind erodibility groups (WEG). The WEG is included in the soil survey data base in NASIS. If the soil name is not known, exhibit 502–2 can be used to determine the WEG from the surface soil texture.

To determine erodibility for field conditions during various management periods throughout the year, follow the sieving instructions in exhibit 502–3. (Do not use this procedure to determine average annual **I** values.) A soil erodibility index based solely on the percentage of aggregates larger than 0.84 millimeters has several potential sources of error. Some of these follow:

- Relative erodibility of widely different soils may change with a change in wind velocity over the surface of the soil.
- Calibration of the equation is based on the volume of soil removed, but the erodibility index is based on weight.
- Differences in size of aggregates have considerable influence on erodibility but no distinction for this influence is made in table 1, exhibit 502–3.
- Stability of surface aggregates influences erodibility; large durable aggregates can become a *surface armor*; less stable aggregates can be abraded into smaller, more erodible particles.
- Surface crusting may greatly reduce erodibility; erodibility may increase again as the crust deteriorates (Chepil 1958).

Knoll erodibility—Knolls are topographic features characterized by short, abrupt windward slopes. Wind erosion potential is greater on knoll slopes than on level or gently rolling terrain because wind flowlines are compressed and wind velocity increases near the crest of the knolls. Erosion that begins on knolls often affects field areas downwind.

Table 502-1 Knoll erodibility adjustment factor for I		
Percent slope change in wind erosion direction	A Knoll adjustment of I	B Increase at crest area where erosion is most severe
3	1.3	1.5
4	1.6	1.9
5	1.9	2.5
6	2.3	3.2
8	3.0	4.8
10 and greater	3.6	6.8

Adjustments of the Soil Erodibility Index (I) are used where windward-facing slopes are less than 500 feet long and the increase in slope gradient from the adjacent landscape is 3 percent or greater. Both slope length and slope gradient change are determined along the direction of the prevailing erosive wind (fig. 502-2).

Table 502-1 contains knoll erodibility adjustment factors for the Soil Erodibility Index I. The I value for the Wind Erodibility Group is multiplied by the factor shown in column A. This adjustment expresses the average increase in erodibility along the knoll slope. For comparison, column B shows the increased erodibility near the crest (about the upper 1/3 of the slope), where the effect is most severe.

No adjustment of I for knoll erodibility is made on level fields, or on rolling terrain where slopes are longer and slope changes are less abrupt. Where these situations occur, the wind flow pattern tends to conform to the surface and does

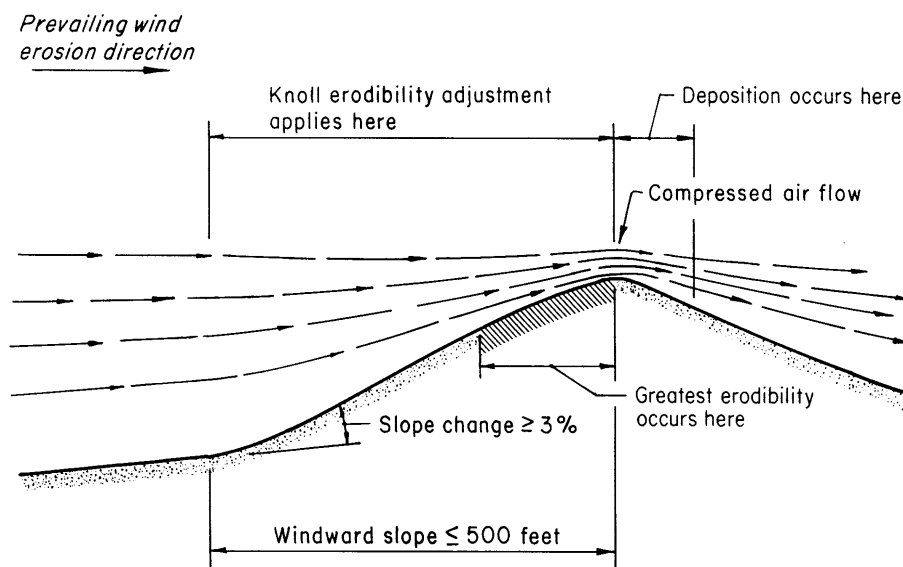


Figure 502-2 Graphic of knoll erodibility

Surface crusting—Erodibility of surface soil varies with changing tillage practices and environmental conditions (Chepil 1958). A surface crust forms when a bare soil is wetted and dried. Although the crust may be so weak that it has virtually no influence on the size distribution of dry aggregates determined by sieving, it can make the soil less erodible. The resistance of the crust to erosion depends on the nature of

the soil, intensity of rainfall, and the kind and amount of cover on the soil surface. A fully crusted soil may erode only one-sixth as much as non-crusted soil. However, a smooth crusted soil with loose sand grains on the surface is more erodible than the same field with a cloddy or ridged surface.

Under erosive conditions, the surface crust and surface clods on fine sands and loamy fine sands tend to break down readily. On silt loams and silty clay loams the surface crust and surface clods may be preserved, and the relative erosion may be as little as one-sixth of *I*. Other soils react somewhere between these two extremes (Chepil 1959).

Because of the temporary nature of crusts, no adjustment for crusting is made for annual estimates based on the critical wind erosion period method (Woodruff and Siddoway 1973). However, crust characteristics may be estimated and adjustment to *I* may be made for management period estimates when no traffic, tillage, or other breaking of crusts is anticipated. Such adjustments may be up to, but may not exceed the percentages shown in table 502-2.

Irrigation adjustments—The *I* values for irrigated soils, as shown in exhibit 502-2, are applicable throughout the year. *I* adjustments for irrigation are applicable only where assigned *I* values are 180 or less.

Adjustments based on dry sieving—Temporal changes in the surface fraction > 0.84 millimeter may be measured by dry sieving. These measurements may be used to establish a basis for adjusting *I* for conservation planning when sieving has been performed for each management period and for 3 years or more. The adjustment to *I* applies only to the respective time periods when the soil surface is influenced by changes in the nonerodible fraction. Therefore, the adjustment is used only with the management period procedure of estimating wind erosion. The procedure does expand the applicability of the equation to a management effect not previously addressed. When the *I* factor is adjusted based on the results of sieving, no additional adjustment to *I* will be made for irrigated fields. Adjustments to *I*, based on sieving, should not be used without adequate supporting data. These adjustments reflect specific soil and management conditions and are only applicable in the area(s) from which samples were obtained and in areas that have similar soil and management conditions.

Use of adjusted soil erodibility *I* factor, arrived at by using standard rotary sieving procedures, is warranted provided it represents soil surface conditions during the appropriate management period. Adjustments may be made up to, but should not exceed, limits assigned for crusting in table 502-2.

Table 502-2 *I* adjustment guidelines for crusts

WEG	<i>I</i>	Max. mgt prd. adj. factor ¹	Calculated <i>I</i> ²	Rounded <i>I</i>
1	310	.7	217	220
1	250	.7	175	180
1	220	.7	154	160
1	180	.7	126	134
1	160	.7	112	134
2	134	.7	67	86
3	86	.4	34	38
4	86	.4	34	38
4L	86	.4	34	38
5	56	.3	17	21
6	48	.3	14	21
7	38	.3	11	12

¹The management period adjustment to *I* has not been validated by research and is based on NRCS judgment.

²The calculated *I* can be used without rounding when used in the FOCS WEQ program.

The **I** factor adjustment may be used where applicable in determining whether an adequate conservation system is being followed. However, **I** factor adjustments are not to be used in the erodibility index (CI/T) when determining highly erodible land because this index is the potential erodibility and not an estimate of actual erosion.

Current instructions for the National Resources Inventory (NRI) are to be followed. These instructions do not allow for any adjustment of the **I** factor. This ensures uniformity between States and allows for trend analysis.

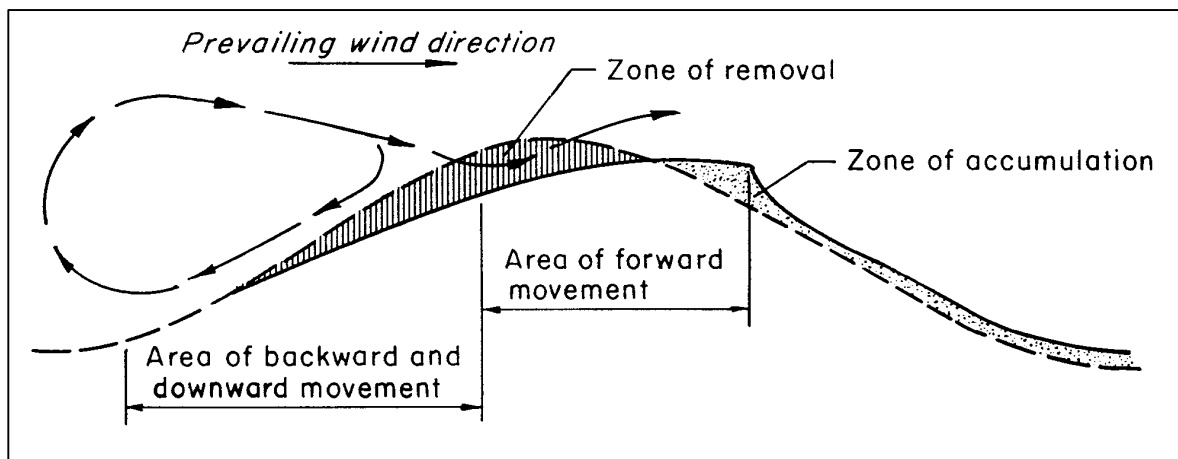
Studies to adjust **I** should be made systematically and include all related soil in a given area. Multiple-year soil sieving data is required before adjustments are to be considered.

The National Soil Survey Center must review and concur in any proposal to adjust **I** and arrange for laboratory assistance. Adjustments to **I** must also be approved by the National Soil Survey Center and correlated across state and regional boundaries before implementation. Any adjustment to **I** must be within the framework of the existing **E** tables.

Surface stability—A significant limitation of the **I** factor is that it does not account for changes in the soil surface over time that are caused by the dynamics of wind erosion. The erodibility of a bare soil surface is based on the interaction of the following:

- Soils that have both erodible and nonerodible particles on the surface tend to stabilize if there is no incoming saltation. As the wind direction changes, the surface is disturbed, or the wind velocity increases, erosion may begin again.
- Saltation destroys crusts, clods, and ridges by abrasion.
- Fields tend to become more erodible as finer soil particles, which provide bonding for aggregation, are carried off in suspension.
- If the surface soil contains a high percentage of gravel or other nonerodible particles that are resistant to abrasion, the surface will become increasingly armored as the erodible particles are carried away. Desert pavement is the classic example of surface armoring. A surface with only nonerodible aggregates exposed to the wind will not erode further except as the aggregates are abraded.
- A surface may be virtually nonerodible and yet allow saltation and creep to cross unabated. A paved highway is an example. Other surfaces may be relatively stable and trap some, or all, of the incoming soil flow. Examples of this type of stability usually relate to some roughness, sheltering, or vegetative cover. A ridged field may trap a significant portion of the incoming soil flow until the furrows are filled and the surface loses its trapping capability. A vegetated barrier will provide a sheltered area downwind until the barrier is filled with sediment.

Soil roughness factor **K**, ridge and random roughness

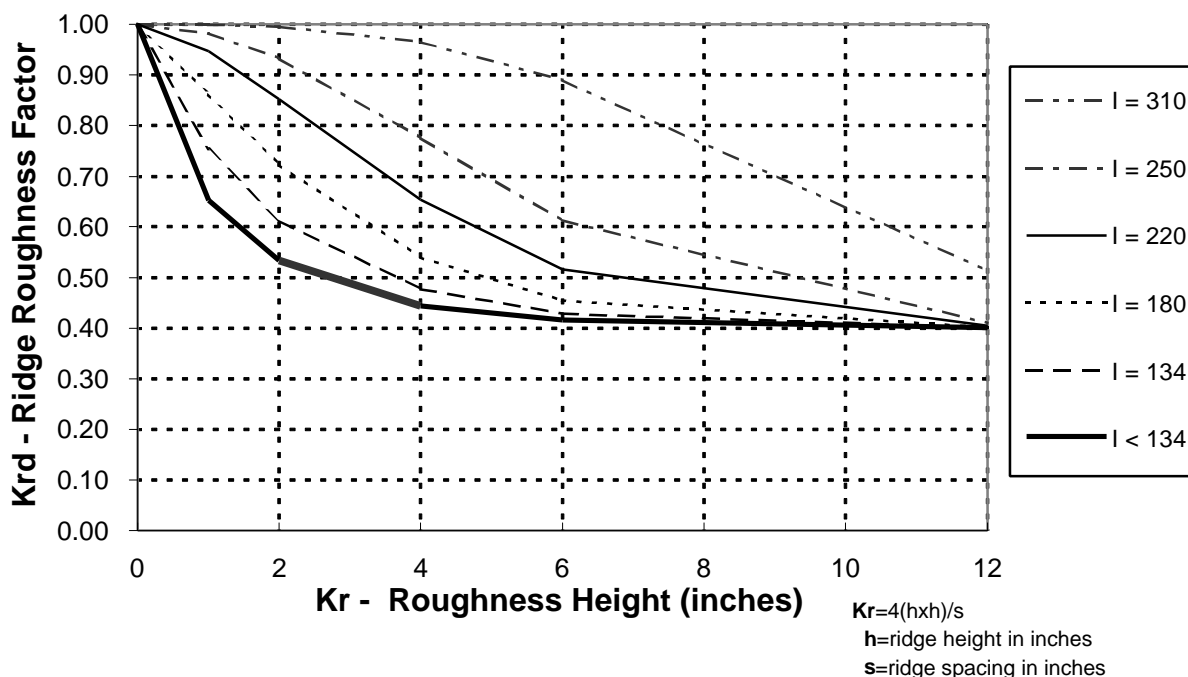


K_{rd} is a measure of the effect of ridges made by tillage and planting implements. Ridges absorb and deflect wind energy and trap moving soil particles (fig. 502-3).

The K_r value is based on a standard ridge height to ridge spacing ratio of 1:4. Because of the difficulty of determining surface roughness by measuring surface obstructions, a standard roughness calibration using nonerodible gravel ridges in a wind tunnel was developed. This calibration led to the development of curves (fig. 502-4 and exhibit 502-4) that relate ridge roughness, K_r , to a soil ridge roughness factor, K_{rd} , (Skidmore 1965; Skidmore and Woodruff 1968; Woodruff and Siddoway 1965; and Hagen 1996).

Figure 502-3 Detachment, transport and deposition on ridges and furrows

Figure 502-4 Chart to determine soil ridge roughness factor K_{rd} , from ridge roughness, K_r , (inches). Only this chart, representing an angle of deviation of 0° , will be used for the WEQ **critical period procedure**. When using the **management period procedure**, see exhibit 502-4 for graphs representing additional angles of deviation. Note: This graph represents erosive wind energy 60% parallel and 40% perpendicular to the prevailing erosive wind. (Hagen, 1996)



The K_r curves are the basis for charts and tables used to determine K_{rd} factor values in the field (exhibits 502-4 and 502-5). The effect of ridges varies as the wind direction and erodibility of the soil change. To take into account the change in wind directions across a field, we consider the angle of deviation. The angle of deviation is the angle between the prevailing wind erosion direction and a line perpendicular to the row direction. The angle of deviation is 0 (zero) degrees when the wind is perpendicular to the row and is 90 degrees when the wind is parallel to the row. Following is an example of how the angle of deviation affects K_{rd} values: when evaluating a soil with an assigned I value of <134, and the prevailing erosive wind direction is perpendicular to ridges 4 inches high and 30 inches apart, then K_{rd} is 0.5. But when the prevailing erosive wind direction is parallel to those ridges, the K_{rd} value is 0.7. Random roughness, particularly in the furrows, significantly reduces wind erosion occurring from erosive winds blowing parallel to the ridges.

In 1996, ARS scientists provided a method for adjusting the WEQ K_{rd} factor with consideration for preponderance (erosive wind energy 60% parallel and 40% perpendicular to prevailing erosive wind direction) when using the Management Period Procedure. The use of preponderance recognizes that during the periods when the prevailing erosive winds are parallel to ridges, there are other erosive winds during the same period which are not parallel, thus making ridges effective during part of each period. Preponderance keeps the K factor value less than 1.0, when the I factor values are 134 or less. When estimating wind erosion rates by management periods, without the aid of a computer model, the prevailing wind erosion direction and a *default* preponderance are used for each period. This procedure

more adequately addresses the effects of the ridges in wind erosion control since erosive wind directions may vary within each management period.

Note: When using the WEQ Excel spreadsheet model, the actual preponderance, up to and including a value of 4, for the period will be used, rather than a default value.

The WEQ K_{rr} factor accounts for random roughness. Random roughness is the nonoriented surface roughness that is sometimes referred to as cloddiness. Random roughness is usually created by the action of tillage implements. It is described as the standard deviation (in inches) of the soil surface elevations, measured at regular intervals from a fixed, arbitrary plane above a tilled soil surface, after oriented (ridge) roughness has been accounted for. Random roughness can reduce erosion significantly. Note: The random roughness factor will only be used with the WEQ management period procedure.

Random roughness values have been developed for various levels of WEQ I factor values and surface random roughness (exhibit 502–6). Random roughness curves only adjust the K factors of a soil that has an I factor value of 134 and less.

The random roughness values used in the WEQ are the same random roughness values used in RUSLE. Random roughness (inches) from the machine operations data base in RUSLE can be used to determine WEQ random roughness values (exhibit 502–7). However, keep in mind that these RUSLE random roughness values were determined for medium textured soils tilled at optimum moisture conditions for creating random roughness. Under most circumstances random roughness is determined by comparing a field surface to the random roughness (standard deviation) photos in the RUSLE handbook (Agriculture Handbook 703, appendix C).

The photos in Agriculture Handbook 703, appendix C, may be downloaded from:

<http://www.nrcs.usda.gov/technical/ECS/agronomy/roughness.html>

State agronomists should download, reproduce, and distribute the photographs to field offices.

When both random roughness and ridge roughness are present in the field, they are complimentary. When both are present, the K_{rd} factor for ridges and K_{rr} factor for random roughness will be multiplied together to obtain the total roughness K -factor.

Example problem: Take into consideration just one WEQ management period. The soil in the field being evaluated has an I value of 86. The field has just been fertilized with anhydrous ammonia using a knife applicator. Considering the height and spacing of the oriented roughness, the ridge roughness K_{rd} factor was determined to be 0.8. Using exhibit 502–7, under random roughness (inches), the anhydrous applicator has a core value of 0.6. Going into the random roughness (inches) graph (exhibit 502–6), on the horizontal axis to 0.6, and then vertically to the line representing an I factor of 86, the K_{rr} factor is rounded to 0.8. The total roughness value (K factor) is $0.8 \times 0.8 = 0.64$, then rounded to 0.6.

The major effects of random roughness on wind erosion are to raise the threshold wind speed at which erosion begins and to provide some sheltered area among the clods where moving soil can be trapped. Hence, when the effectiveness of random roughness increases the total K -value decreases.

Random roughness, particularly in the furrows, significantly reduces wind erosion occurring from erosive winds blowing parallel to the ridges.

Random roughness is subject to much faster degradation by rain or wind erosion than large tillage ridges. Therefore the WEQ management period, where random roughness is effective, may be of short duration.

For fields being broken out of sod, such as CRP, random roughness will be credited for erosion control. The field surface is usually covered with the crowns of plants, their associated roots, and adhering soil. The total random roughness of the field should be compared to the photos in the RUSLE handbook and credited appropriately.

Surface roughening (emergency tillage)—In some situations, there is a need to control erosion on bare fields where the surface crust has been destroyed or where loose grains are on the surface and can abrade an existing crust. One method to reduce the erosion hazard on such fields is emergency or planned tillage to roughen the surface or increase nonerodible clods on the surface (random roughness). This may be accomplished by one or more of the following:

- Soil that characteristically forms a crust with loose sand grains on the surface may be worked to create clods. The loose grains fall into the crevices between clods. This is the principle of sand fighting used in some emergency tillage.
- The soil may be deep tilled to bring up finer textured soil material that will form more persistent clods.
- Irrigation increases the nonerodible fraction of a soil (exhibit 502–2).
- The surface may be worked into a ridge-furrow configuration that will trap loose, moving soil.
- The soil may be tilled in strips or in widely spaced rows to provide some degree of ridge and random roughness to break the flow of saltation and creep.

Climatic factor, C

The C factor is an index of climatic erosivity, specifically windspeed and surface soil moisture. The factor for any given location is based on long-term climatic data and is expressed as a percentage of the C factor for Garden City, Kansas, which has been assigned a value of 100 (Lyles 1983). In an area with a C factor of 50, for example, the IKC value would be only half of the IKC for Garden City, Kansas.

The climatic factor equation is expressed as:

$$C = 34.48 \times \frac{V^3}{(PE)^2}$$

where:

C = annual climatic factor

V = average annual wind velocity

PE = precipitation-effectiveness index of Thornthwaite

34.48 = constant used to adjust local values to a common base (Garden City, Kansas)

The basis for the windspeed term of the climatic factor is that the rate of soil movement is proportional to windspeed cubed. Several researchers have reported that when windspeed exceeds threshold velocity, the soil movement is directly proportional to friction velocity cubed which, in turn, is related to mean windspeed cubed (Skidmore 1976).

The basis for the soil moisture term of the climatic factor is that the rate of soil movement varies inversely with the equivalent surface soil moisture. Effective surface soil moisture is assumed to be proportional to the Thornthwaite precipitation-effectiveness index (PE) (Thornthwaite 1931). The annual PE index is the sum of the 12 monthly precipitation effectiveness indices. The formula is expressed as follows:

$$PE = \sum_{12} 115 \times \left[\frac{P}{T - 10} \right]^{\frac{10}{9}}$$

where:

PE = the annual precipitation effectiveness index

P = average monthly precipitation

T = average monthly temperature

The C factor isoline map developed by NRCS in 1987 can be accessed at:

<http://data4.ftw.nrcs.usda.gov/website/>

c-values

Complete instructions for viewing the map are given in Exhibit 502-8.

The map displays C factors for all areas of the conterminous United States and Alaska. The isolines were drafted to conform with local C factors calculated from 1951–80 weather data and were correlated across state and regional boundaries. Procedures for developing local C factors are explained in exhibit 502–8a.

1. Interpolation of WEQ climatic factors (C)— States may interpolate between county assigned C values to the nearest 5 units based on the National C Factor Isoline Map or the state C Factor Isoline Map in the Field Office Technical Guide (FOTG). When interpolating between values, knowledge of the local climatic and topographic conditions is extremely useful since climatic conditions can vary disproportionately between C factor value isolines.
2. Where WEQ soil loss (E) tables have been developed with C factor increments greater than 5 units, a straight line interpolation to the nearest C factor value of 5 may be made from existing E tables. Straight line interpolations can also be made from the soil losses (E) calculated with approved WEQ computer software, when C factors programmed into the model are in increments greater than 5 units.
3. C factor interpolations are for the purpose of conservation planning only and are NOT to be used in determining or adjusting previous highly erodible land (HEL) designations. However, they may be used during status reviews to determine if an individual is actively applying a conservation system. Previous national policy, regarding the changing of prior HEL designations, remains in effect.

Effects of irrigation water on the C factor— When irrigation water is applied to a dry soil surface, a reduction in wind erosion can be expected. A specific procedure to directly adjust the climatic factor C for irrigation is not available. However, a procedure has been developed by researchers to adjust the Erosive Wind Energy (EWE) by the fraction of time during which the soil is considered wet and nonerodible because of irrigation. See 502.31 and exhibit 502–2.

The procedures that follow adjust the Erosive Wind Energy (EWE) value which planners are to use when estimating wind erosion on irrigated fields. This adjustment is for the WEQ Management Period Procedure. States where wind erosion is a concern should replace previous methods used to adjust for the effects of irrigation and utilize this procedure and the procedure for adjusting the I factor, for all plan revisions or new planning activities. This new procedure, however, does not impact designated highly erodible lands (HEL) or new determinations since management practices are not considered in the HEL formula.

Note: Irrigation adjustments to EWE and to the I factor, apply to fully irrigated fields and to fields that receive *supplemental* irrigation water.

- Research scientists have developed an Irrigation Factor (IF) that adjusts the EWE or period erosion loss to account for the effect of irrigation wetting the soil surface and making it less erodible. The IF takes into account the number of days in a management period, number of irrigation events during a management period, and a Texture Wetness Factor (TWF).
- To account for the *nonerodible wet* condition of various soil textures after irrigation, a TWF of 1, 2, or 3 is assigned to coarse, medium, and fine textured soil, respectively. See exhibit 502.2 for values assigned to the various soil groups.
- The IF is calculated with the following equation:
$$IF = \frac{\text{number of days in period} - \text{nonerodible wet days in period (NEWD)}}{\text{number of days in period}}$$

Nonerodible Wet Days (NEWD) are equal to the Texture Wetness Factor (TWF) times the number of irrigation events in the period.
- When using the WEQ to account for the effects of irrigation, multiply the EWE for the period by the IF.
- Example: A fine textured soil was irrigated three times during 45 days. Twelve percent of the annual EWE occurs during this period.

Therefore:

$$\begin{aligned} TWF &= 3 \text{ for fine textured soil} \\ \text{Number of irrigations during the period} &= 3 \\ NEWD &= (3)(3) = 9 \\ IF &= (45 \text{ days} - 9)/45 = 0.80 \end{aligned}$$

The adjusted EWE for 45 days is then determined by multiplying IF times the percentage of annual erosion wind energy during the period being evaluated.

$$\text{Adjusted EWE} = (.80)(12\%) = 9.6 \%$$

Note: The EWE shall not be adjusted for any management period where irrigation does not occur.

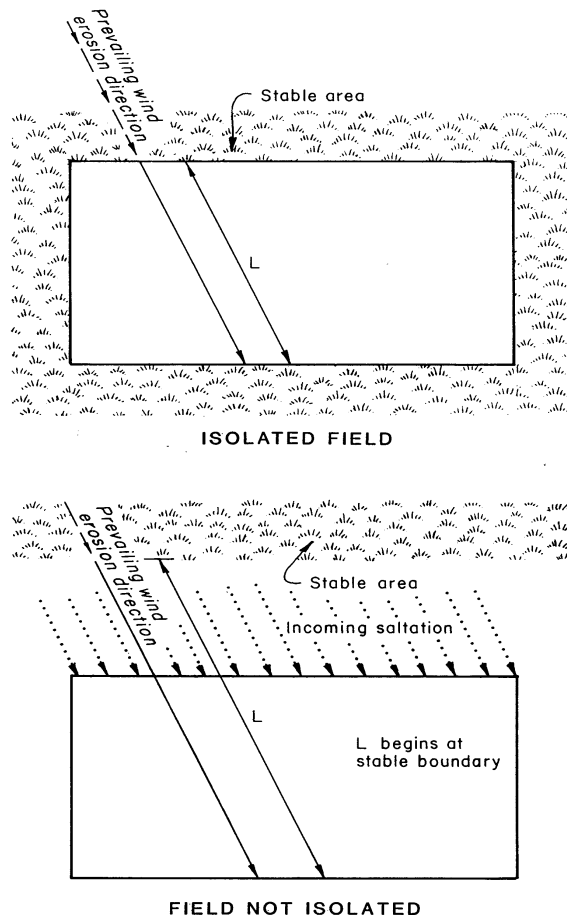
- The WEQ factors (C & I) used to determine the Erodibility Index (EI), will not be adjusted when determining highly erodible land (HEL) on cropland that is irrigated.

Unsheltered distance, L

The L factor represents the unsheltered distance along the prevailing wind erosion direction for the field or area to be evaluated. Its place in the equation is to relate the *isolated, unsheltered, and wide* field condition of I to the size and shape of the field for which the erosion estimate is being prepared. Because V is considered after L in the 5-step solution of the equation (502.22), the unsheltered distance is always considered as if the field were bare except for vegetative barriers.

1. L begins at a point upwind where no saltation or surface creep occurs and ends at the downwind edge of the area being evaluated (figure 502–5). The point may be at a field border or stable area where vegetation is sufficient to eliminate the erosion process. An area should be considered stable only if it is able to trap or hold virtually all expected saltation and surface creep from upwind. If vegetative barriers, grassed waterways, or other stable areas divide an agricultural field being evaluated, each subdivision will be *isolated* and shall be evaluated as a separate *field*. Refer to the appropriate NRCS Conservation Practice Standards to determine when practices are of adequate width, height, spacing, and density to create a stable area.

Figure 502–5 Unsheltered distance L



2. When erosion estimates are being calculated for cropland or other relatively unstable conditions, upwind pasture or rangeland should be considered a stable border. However, if the estimate is being

made for a pasture or range area, L should be determined by measuring from the nearest stable point upwind of the area or field in question (figure 502-6). The only case where L is equal to zero is where the area is fully sheltered by a barrier.

3. When a barrier is present on the upwind side of a field, measure L across the field along the prevailing wind erosion direction and subtract the distance sheltered by the barrier. Use 10 times the barrier height for the sheltered distance (figure 502-7).

Figure 502-6 Unsheltered distance L, perennial vegetation (pasture or range)

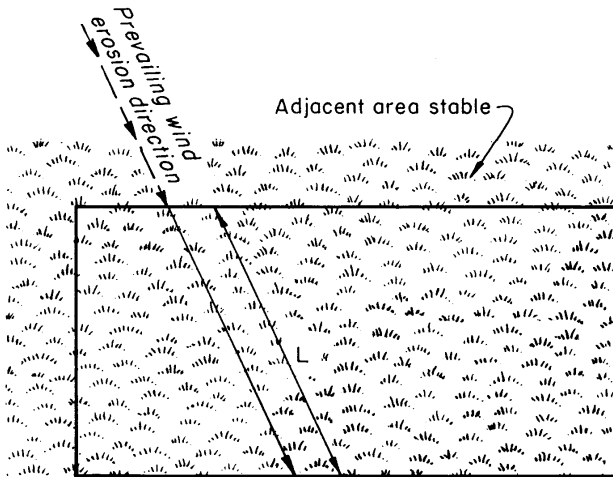
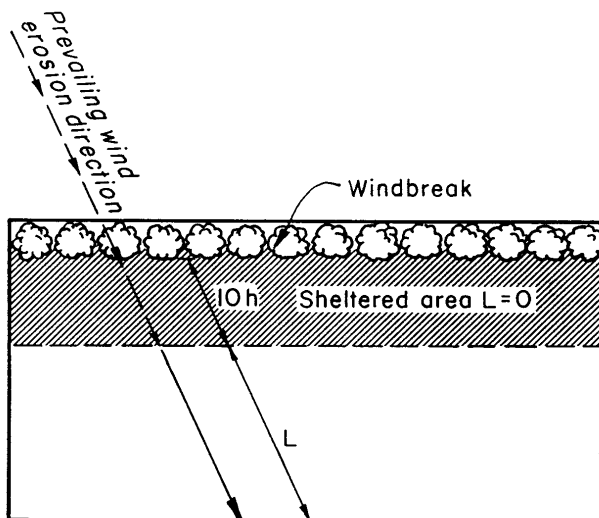


Figure 502-7 Unsheltered distance L – windbreak or barrier



4. When a properly designed wind stripcropping system is applied, alternate strips are protected during critical wind erosion periods by a growing crop or by crop residue. These strips are considered stable. L is measured across each erosion-susceptible strip, along the prevailing wind erosion direction (figure 502-8).

The prevailing wind erosion direction is the direction from which the greatest amount of erosion occurs during the critical wind erosion period. The direction is usually expressed as one of the 16 compass points. When predicting erosion by management periods, the prevailing wind erosion direction may be different for each period (exhibit 502-7a).

Preponderance is a ratio between wind erosion forces parallel and perpendicular to the prevailing wind erosion direction. Wind forces parallel to the prevailing wind erosion direction include those coming from the exact opposite direction (180°). A preponderance of 1.0 indicates that as much wind erosion force is exerted perpendicular to the prevailing direction as along that direction. A higher preponderance indicates that more of the force is along the prevailing wind erosion direction. Wind patterns are complex; low preponderance indicates high complexity and as a result, less wind will be from the prevailing erosive wind direction than locations that have a high preponderance.

L can be measured directly on a map or calculated using a wind erosion direction factor:

- For uses of the Wind Erosion Equation involving a single annual calculation, L should be the measured distance across the area in the prevailing wind erosion direction from the stable upwind edge of the field to the downwind edge of the field. When the prevailing wind erosion direction is at an angle that is not perpendicular to the long side of the field, L can be determined by multiplying the width of the field by the appropriate conversion factor obtained from table 502-3.
- For management period calculations, wind erosion direction factors based on preponderance are to be used instead of a measured distance to determine L except
 - Where irregular fields cannot be adequately represented by a circle, square, or rectangle.
 - Where preponderance data are not available.

Steps to determine L for management period estimates:

1. Obtain local values for prevailing the wind erosion direction and preponderance (exhibit 502–7a).
2. Measure actual length and width of the field and determine the ratio of length to width.
3. Determine angle of deviation between prevailing wind erosion direction and an imaginary line perpendicular to the long side of the field.

Figure 502–8 Unsheltered distance L, stripcropping system

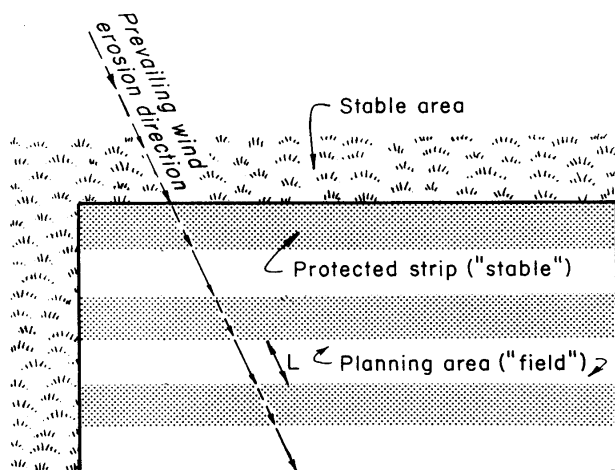


Table 502-3 Wind erosion direction factors ^{1/}
Angle of deviation 2/ Adjustment factor

Table 502-3 Wind erosion direction factors ¹

Angle of deviation ²	Adjustment factor
0	1.00
22.5°	1.08
45°	1.41
67.5°	2.61
90°	L = length of field

^{1/} These adjustment factors are applicable when preponderance is not considered. L cannot exceed the longest possible measured distance across the field.

^{2/} Angle of deviation of the prevailing erosive wind from a direction perpendicular to the long side of the field.

Using data from steps 1 through 3, determine the wind erosion direction factor from wind erosion direction factor tables, exhibit 502–9. These are adjustment factors that account for prevailing wind erosion direction, preponderance of wind erosion forces, and size and shape of the field.

Multiply the width of the field by the wind erosion direction factor. This is the L for the field.

If a barrier is on the upwind side of the field, reduce L by a distance equal to 10 times the height of the barrier.

For circular fields, $L = 0.915$ times the diameter, regardless of the prevailing wind erosion direction or preponderance.

Vegetative cover factor, V

The effect of vegetative cover in the Wind Erosion Equation is expressed by relating the kind, amount, and orientation of vegetative material to its equivalent in pounds per acre of small grain residue in reference condition Small Grain Equivalent (SGe). This condition is defined as 10 inch long stalks of small grain, parallel to the wind, lying flat in rows spaced 10 inches apart, perpendicular to the wind. Several crops have been tested in the wind tunnel to determine their SGe. For other crops, small grain equivalency has been computed using various regression techniques (Armbrust and Lyles 1985; Lyles and Allison 1980; Lyles 1981; Woodruff et al. 1974; Woodruff and Siddoway 1965). NRCS personnel have estimated SGe curves for other crops. SGe curves are in exhibit 502–10.

Position and anchoring of residue is important. In general, the finer and more upright the residue, the more effective it is for reducing wind erosion. Knowledge of these and other relationships can be used with benchmark values to estimate additional SGe values.

Research is underway to develop a method of estimating the relative erosion control value of short woody plants and other growing crops.

Several methods are used to estimate the kind, amount, and orientation of vegetation in the field. Often the task is to predict what will be in the field in some future season or seasons. Amounts of vegetation may be predicted from production records or estimates and these amounts are then reduced by the expected or planned tillage. It may be desirable to sample and measure existing residue to determine quantity of residue. Local data should be developed to estimate surface residue per unit of crop yield and crop residue losses caused by tillage.

The crown of a plant, its associated roots, and adhering soil should also be credited when doing transects to determine residue cover. Employees will need to use their best judgment when deciding which crop curve to use when converting from percent ground cover to mass and then selecting a curve to convert the residue mass to SGe.

If you encounter a crop, residue, or a type of vegetation for which an SGe curve has not been developed. Exhibits 502–11 and 502–12 give procedures to develop an interim SGe curve. Any SGe curve developed in this way must be submitted to the National Agronomists or the Cooperating Scientist for wind erosion for approval.

Principles of wind erosion control

General

Five principles of wind erosion control have been identified (Lyles and Swanson 1976; Woodruff et al. 1972; and Woodruff and Siddoway 1965). These are as follows:

- Establish and maintain adequate vegetation or other land cover.
- Reduce unsheltered distance along wind erosion direction.

- Produce and maintain stable clods or aggregates on the land surface.
- Roughen the land with ridge and/or random roughness.
- Reshape the land to reduce erosion on knolls where converging windflow causes increased velocity and shear stress.

The *cardinal rule* of wind erosion control is to strive to keep the land covered with vegetation or crop residue at all times (Chepil 1956). This leads to several principles that should be paramount as alternative controls are considered:

- Return all land unsuited to cultivation to permanent cover.
- Maintain maximum possible cover on the surface during wind erosion periods.
- Maintain stable field borders or boundaries at all times.

Relation of control to WEQ factors

The Wind Erosion Equation (WEQ) was developed to relate specific field conditions to estimated annual soil loss. Of the five factors, two (*I* and *C*) are often considered to be *fixed* while the other three (*K*, *L*, and *V*) are generally considered *variable* or management factors. This is not precisely true.

The *I* factor is related to the percentage of dry surface soil fractions greater than 0.84 millimeters. Its derivation is usually based on the Wind Erodibility Group.

However, if a special management condition is going to be maintained, such as crusts or irrigation, a modification of *I* is appropriate. Also, *I* is increased by a knoll erodibility factor where appropriate. See 502.31. This adjustment is not appropriate if the knoll condition is modified through landforming or use of barriers to protect the knoll.

Knoll erodibility adjustments to *I* relate to wind direction; low preponderance indicates that knoll erodibility will vary widely as wind direction changes.

Total *K* reflects the tilled ridge roughness and random roughness in a field. This is a management factor. Stability of tilled roughness is related, however, to soil erodibility, climate, and the other erosion factors.

Ridge roughness relates to ridge spacing in the wind erosion direction. Even with optimum orientation of rows, some of the winds will be blowing parallel to the rows when preponderance is low.

Random roughness relates to the nonoriented surface roughness that is often referred to as cloddiness. Random roughness is described as the standard deviation of elevation from a plane across a tilled area after taking into account oriented (ridge) roughness.

The *C* factor is based on long-term weather records. Conservation treatment should be planned to address the critical climatic conditions when high seasonal erosive wind energy is coupled with highly erodible field conditions.

The unsheltered distance *L* is a management factor that can be changed by altering field arrangement, stripcropping, or establishing windbreaks or other barriers. *L* is a function of field layout as it relates to prevailing wind direction and preponderance of erosive winds in the prevailing direction.

When preponderance values are high (more than 2.5 and approaching 4.0), conservation treatment should be concentrated on addressing potential erosion from the prevailing wind erosion direction.

When preponderance values are low (approaching 1.0), knowledge of local seasonal wind patterns becomes more important in planning treatment. Conservation treatment should be planned to allow for the effect of seasonal changes in the prevailing wind erosion direction.

A stable strip across an agricultural field divides the area into separate fields. Examples of stable areas include grass waterways, hedges and their sheltered area, brushy draws or ravines, roadways with grass borders, grass strips, and drainage or irrigation ditches.

To be considered stable, an area must be able to stop and hold virtually all of the expected saltation and surface creep. Be aware that an area may be stable during one crop stage, but not stable in other seasons.

V is the equivalent vegetative cover maintained on the soil surface. It is directly related to the management functions of crop establishment, tillage, harvesting, grazing, mowing, or burning.

Tolerances in wind erosion control

In both planning and inventory activities, NRCS compares estimated erosion to soil loss tolerance (T). T is expressed as the average annual soil erosion rate (tons/acre/year) that can occur in a field with little or no long-term degradation of the soil resource, thus permitting crop productivity to be sustained for an indefinite period.

Soil loss tolerances for a named soil are recorded in the soil survey data base in NASIS. The normal planning objective is to reduce soil loss by wind or water to T or lower. In situations where treatment for both wind and water erosion is needed, soil loss estimates using the WEQ and USLE or RUSLE are not added together to compare to T.

Additional impacts of wind erosion that should be considered are potential offsite damages, such as air and water pollution and the deposition of soil particles.

Crop tolerance to soil blowing may also be an important consideration in wind erosion control. Wind or blowing soil, or both, can have an adverse effect on growing crops. Most crops are more susceptible to abrasion or other wind damage at certain growth stages than at others. Damage can result from desiccation and twisting of plants by the wind.

Crop tolerance can be defined as the maximum wind erosion that a growing crop can tolerate, from crop emergence to field stabilization, without an economic loss to crop stand, crop yield, or crop quality.

(a) Blowing soil effects on crops

Some of the adverse effects of soil erosion and blowing soil on crops include:

- Excessive wind erosion that removes planted seeds, tubers, or seedlings.
- Exposure of plant root systems.
- Sand blasting and plant abrasion resulting in
 - crop injury
 - crop mortality
 - lower crop yields
 - lower crop quality
 - wind damage to seedlings, vegetables, and orchard crops.
- Burial of plants by drifting soil.

(b) Crop tolerance to blowing soil or wind

Many common crops have been categorized based on their tolerance to blowing soil. These categories of some typical crops are listed in table 502-4. Crops may tolerate greater amounts of blowing soil than shown in table 502-4, but yield and quality will be adversely affected.

(c) The effects of wind erosion on water quality

Some of the adverse effects of wind erosion on water quality include:

- Deposition of phosphorus (P) into surface water
- Increased Biochemical Oxygen Demand (BOD) in surface water
- Reduced stream conveyance capacity because of deposited sediment in streams and drainage canals

Local water quality guidelines under Total Maximum Daily Loads (TDML) for nutrients may require that

wind erosion losses be less than the soil loss tolerance (T) in order to achieve local phosphorus (P) or other pollutant reduction goals.

For a phosphorus (P) entrapment estimation procedure, see the Core 4 manual, chapter 3C, Cross Wind Trap Strips.

Table 502-4 Crop tolerance to blowing soil

Tolerant T	Moderate tolerance 2 ton/ac	Low tolerance 1 ton/ac	Very low tolerance 0 to 0.5 ton/ac
Barley	Alfalfa (mature)	Broccoli	Alfalfa seedlings
Buckwheat	Corn	Cabbage	Asparagus
Flax	Onions (>30days)	Cucumbers	Cantaloupe
Grain Sorghum	Orchard crops	Garlic	Carrots
Millet	Soybeans	Green/snap beans	Celery
Pats	Sunflowers	Lima beans	Eggplant
Rye	Sweet corn	Peanuts	Flowers
Wheat		Peas	Kiwi fruit
		Potatoes	Lettuce
		Sweet potatoes	Muskmelons
		Tobacco	Onion seedlings (<30 days)
			Peppers
			Spinach
			Squash
			Strawberries
			Sugar beets
			Table beets
			Tomatoes
			Watermelons