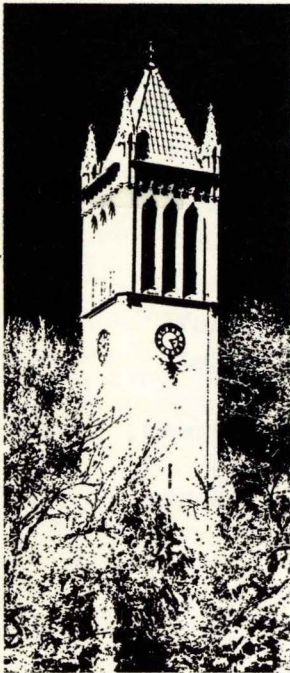


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Principles and Methods of Wind-Erosion Control in Iowa

by W. C. Moldenhauer and E. R. Duncan



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SUMMARY

Wind erosion in Iowa has been increasing in frequency and intensity with the increase in acreage of row crops and consequent increase in fall-plowed acres. This erosion has attracted widespread attention because blowing dust has created a hazard to health and safety. This bulletin is a report of research conducted in areas where wind erosion has been a problem for many years and the application of the findings in Iowa.

The main factors affecting soil erosion by wind are characteristics of the soil itself, prevalence of climatic conditions conducive to erosion, vegetative cover on a field, length of the field, and roughness of the field.

The most erodible discrete soil particles are about 0.1 mm in equivalent diameter. Thus, sandy soils are very erodible. Particles greater than 0.5 mm ordinarily

are not moved. The greater the proportion of clay, the greater is the degree of cementation between structural units. Clay soils are less erodible because stable units of larger than the erodible size are formed. Knolls in a field increase erosion.

Ridges reduce the wind velocity over the soil surface and trap soil on the leeward side of ridges. Greatest effectiveness is attained with ridges 2 to 5 inches high, spaced 8 to 20 inches apart.

The climatic factor is a direct function of the cube of wind velocity and an inverse function of the square of the effective moisture. Wind forces and prevailing direction have been determined for many locations in the central United States, and this data has been published.

On an unprotected eroding field, the rate of soil flow is zero on the windward edge. The rate increases with distance leeward until it reaches the maximum that wind of a particular velocity can sustain. This acceleration of soil flow with distance is known as avalanching. The total distance across a given field is measured along the prevailing wind-erosion direction. Reducing this unprotected distance by any means will prevent avalanching.

The effectiveness of vegetative cover depends on its quantity, kind, and directional orientation. Small grain in the seedling and stooling stage is more than 10 times as effective as corn stubble and stover because small-grain seedlings are finer and have more surface area. The more erect and the higher the vegetative matter stands above the ground, the more it slows the wind velocity near the ground.

An equation has been developed whereby the amount of soil loss can be predicted for a given set of conditions. This equation has proved very valuable in other areas for determining needed control measures for keeping wind erosion within reasonable limits.

Erosion control methods are developed on the principle of reducing wind velocity near the soil surface and manipulating the soil to bring up unerodible clods. To control avalanching, vegetated strips are left in the field at intervals to trap moving particles and to reduce wind velocities to zero near the surface at intervals. Vegetative cover over the entire field reduces the velocity of wind near the soil surface and traps erodible products from adjacent areas. Emergency tillage roughens the soil surface and brings up unerodible particles, which mix with and cover the highly erodible particles.

The best erosion-control practice is to leave all residue from the previous crop undisturbed through the winter. This can be done and is done on most well-drained loam and silt loam soils where spring plowing is the usual practice. Also, till planting or variations of it and disking of soybean ground are being adopted as practices in these areas. Corn harvested for grain leaves between 2 and 3 tons of residue on the soil surface, but soybeans leave less

than 1 ton of residue. Ordinarily, however, if soybean residue is spread evenly over the surface and is left undisturbed over winter, it will prevent serious erosion the following spring. Soybean residue may be double disked just before planting rather than plowed.

Soils not so well drained or with 40 percent or more clay have a problem of excess moisture in the spring, which delays tillage. Undisturbed residue from the previous crop aggravates this problem by preventing surface evaporation. For these soils, alternate strips of plowing and residue in the ratio of 4/5 plowed and 1/5 undisturbed are recommended (100 feet plowed to 25 feet undisturbed would be a reasonable ratio in many instances). Strips should be at right angles to the prevailing wind direction for best results. If this is not practical, an east-west row direction may be more effective than a north-south one because of the angle of the prevailing wind direction.

Ridging of the soil surface can reduce erosion to half or less of that on flat ground—if ridges are spaced correctly and are at right angles to the wind. The most effective height is 3 to 5 inches with a 1:4 height-spacing ratio. Ridging can be used as a spring emergency tillage practice or as a supplemental control practice where vegetative cover is sparse.

Emergency tillage cannot be relied on to control erosion in Iowa because the soil is not firm nor dry enough to be worked when the frost is coming out of the ground. Many of our most damaging winds occur during this period. Much erosion and abrasion take place at this time leaving the soil surface very loose and difficult to control with emergency tillage. The effectiveness of emergency tillage depends on soil moisture, soil texture, speed of travel, depth of tillage, spacing between tool-head carriers and type of tool head. Emergency tillage is much less effective on sandy soils than on finer-textured ones because the sandy soils have fewer and weaker clods.

Tree windbreaks and artificial barriers can be used on high-value crops and where the problem is very serious. Tree windbreaks must be established over a wide area or they create problems by trapping wind-blown material from adjacent fields.

WIND-EROSION CONTROL IN BRIEF

1. Plan for wind-erosion control in the fall; spring control is emergency control.
2. Complete residue cover is the best control.
3. If fall plowing is considered essential after corn or sorghum, plow 100- to 150-foot-wide strips, alternating with 25-foot-wide stubble strips. Leave strips at right angles to the prevailing wind.
4. In soybean residue and corn or sorghum harvested for forage if fall tillage is considered essential, form ridges at right angles to the prevailing wind with a duck-foot cultivator or chisel. Form 2- to 5-inch-high ridges, but maintain a 1:4 height-spacing ratio. The higher ridges will be more effective in soybean residue.
5. On eroding fall-plowed land, chisel compact soil 3 inches deep on 20- to 30-inch centers. On loose soil, use shovels 5 inches deep on 20-inch centers. Travel 3.5 to 4 mph for the most lasting results. Faster travel will be effective, but for a shorter time because it tends to pulverize the clods. Bring up as many nonerodible clods as possible. Till the entire area. Repeat if necessary.

Principles and Methods of Wind-Erosion Control In Iowa¹

by W. C. Moldenhauer and E. R. Duncan²

Sandy soils in Iowa have always been susceptible to wind erosion. In recent years, however, with the proportion of land in row crops increasing, the incidence of wind erosion has also been increasing. Fall plowing of row-crop land is a major contributing factor in this increase. Also, for unknown reasons, soil on which soybeans are grown is more susceptible to wind erosion than soil on which corn is grown. Wind erosion, thus, becomes more serious as the soybean acreage increases.

Wind erosion has attracted widespread attention mainly because of offsite damages and has become too serious to be ignored. Road ditches and drainage ditches are being filled with windblown sediment, and costly dredging operations are required to make them functional again (fig. 1). In a few instances, sediment fans form across roads and highways. Maintenance crews must clear these sediment fans after every wind, and they create a serious traffic hazard during windstorms. Blowing dust and silt-size particles cut visibility on highways and often create a serious driving hazard. Fine particles pollute the air we breathe and sift into homes, resulting in perpetual dusty conditions both indoors and out. Since most of the eroded material is coming from corn and soybean fields, the problem is a concern and responsibility of everyone working in agriculture.

This is a report of research conducted in areas where wind erosion has been a problem for many years. The developed principles are then applied to the Iowa situation to arrive at alternative methods of wind-erosion control.

FACTORS AFFECTING SOIL EROSION BY WIND

Wind erosion depends on many factors, mainly the susceptibility of the soil itself to erosion, the prevalence of climatic conditions conducive to erosion, the vegetative cover on a field, the length of the field in the direction of the wind, and the roughness of the field. Following is a description of these five factors:

Soil Erodibility Index, I'

Soil erodibility index, I' , is the potential soil loss in tons per acre per year from a wide, unsheltered,

isolated field with a bare, smooth, uncrusted surface. The index I' includes adjustments for knolls in the field and for a crusted surface.

Soil erodibility is mainly a function of the size and stability of soil particles. The most erodible, discrete soil particles are about 0.1 mm in equivalent diameter.³ Dust tends to hinder the movement of larger particles, and relatively few particles greater than 0.5 mm in equivalent diameter are moved by common erosive winds (Chepil, 1958).

Size and stability of soil particles are functions of soil texture. The greater the proportion of soil particles smaller than 0.02 mm in diameter dispersible by water, the greater is the degree of cementation between structural units. The greater this cementation, the greater is the resistance of the soil to breakdown by mechanical forces and abrasion from eroding, wind-blown particles (Chepil, 1958). Thus, sandy soils with a high proportion of discrete particles about 0.1 mm in diameter are very erodible. Relative erodibilities of soils of various textural classes are shown in table 1.

Soil cloddiness and mechanical stability of clods increase during the summer and decrease during the winter. Thus, erodibility of field surfaces also decreases during the summer and increases during the winter. Soil erodibility also depends on the field's erosional history since the last tillage. Exposure to a series of erosive winds results in the breakdown of clods until, finally, these soils will start to erode at

³ Equivalent diameter expresses the relation of a particle or aggregate of given erodibility to a sphere of equal erodibility and a specific gravity of 2.65.

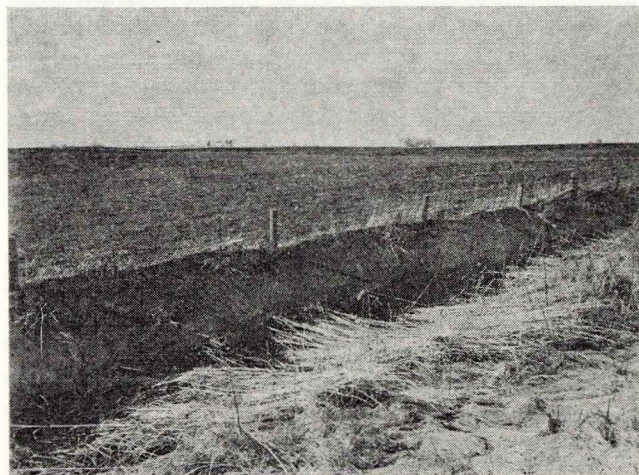


Fig. 1. Sediment collecting in road ditches necessitates costly removal to make them functional again.

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Table 1. Relative erodibility of soils of various textural classes.

Soil textural classes	Relative factor
Fine sand	6
Fine loamy sand	4
Fine sandy loam and clay (except saline clay)	2
Loam, silt loam, clay loam or silty clay loam	1

W. S. Chepil, 1958. Soil conditions that influence wind erosion. U. S. Dept. Agr. Tech. Bul. 1185. 40 pp.

the same threshold wind velocity as dry dune materials (13 mph at 1-foot height). Raindrops often tend to smooth the soil surface, loosen some of the surface particles, and accelerate soil movement by wind (Chepil, 1958).

Knolls in a field increase erosion. This varies with length of slope. The erosion rate for windward slopes greater than 500 feet long is about the same as for level land. For slopes less than 500 feet long, erosion can be many times greater than from level land and is greater from the top of the knoll than from the slope (Woodruff and Siddoway, 1965; Chepil, Siddoway, and Armbrust, 1964).

Surface crusting reduces soil erodibility. However, after wind erosion has started, abrasion rapidly disintegrates the crust. Where the average erodibility for the entire soil drifting period is being determined, surface crusting can be disregarded as a factor in erodibility (Woodruff and Siddoway, 1965).

Soil Ridge-Roughness Factor, K'

The soil-surface roughness, K' , is expressed in terms of height of standard soil ridges. The standard ridges have a height-spacing ratio of 1:4 and have no clods greater than $\frac{1}{4}$ inch in diameter. Usually, if the distance between ridges is increased beyond the 1:4 ratio, their ridge-roughness equivalent is decreased proportionately (Chepil and Woodruff, 1963).

Factors that tend to reduce the rate of soil flow over a ridged as compared with a smooth surface are the reduction in average wind velocity above the surface and the trapping of soil on the leeward side of ridges. There are factors, however, tending to increase the rate of soil movement when the soil is ridged. These are greater eddying of wind and greater wind velocity at the crests of ridges than over level surfaces. The gross effect of factors decreasing erosion is always markedly greater than the effect of factors increasing erosion (Chepil and Milne, 1941). These factors of greater eddying and greater velocities at the crests make lister ridges less effective in controlling wind erosion than smaller ridges. Greatest effectiveness is attained with ridges 2 to 5 inches high, spaced 8 to 20 inches apart.

Climatic Factor, C'

The rate of soil movement varies directly as the cube of wind velocity and inversely as the square of effective moisture (Chepil, Siddoway, and Armbrust,

1962). Wind velocity data are available from weather records, but information on moisture of the soil surface is not. However, the Thornthwaite (1948) moisture index and the P_e^4 index (Thornthwaite, 1931) are available and can be used. If it is assumed that the effective moisture of the surface soil particles varies as the moisture index M or as the P_e index, then the combined wind-erosion climatic Factor C' may be expressed in percentage of that at Garden City, Kan., as

$$C' = (100 v^3 / (M + 60)^2) / 1.9$$

or

$$C' = (100 v^3 / P_e^2) / 2.9$$

In this equation, v is the corrected mean annual wind velocity for a standard height of 30 feet, 1.9 is the value of $v^3 / (M + 60)^2$ for Garden City, Kan., and 2.9 is the value of v^3 / P_e^2 for Garden City, Kan. At this location $v = 13.5$ miles per hour, $M = -24$, and $P_e = 29$. The relationship between M and P_e is

$$P_e = 0.8 M + 48$$

The wind-erosion climatic factor C' indicates the relative mean rate of wind erosion that would occur at any geographic location as a percentage of the mean rate that would occur at Garden City, Kan., if conditions other than climate were the same. (Chepil, Siddoway, and Armbrust, 1962).

Wind forces and their effect on soil erosion are discussed by Skidmore and Woodruff (1968). They have calculated effective wind forces, prevailing direction, and preponderance of wind-erosion forces in a prevailing wind-erosion direction for many locations in the United States.

Field Length, L'

On an unprotected eroding field, the rate of flow is zero on the windward edge. It increases with distance leeward until it reaches the maximum that a wind of a particular velocity can sustain. This acceleration of soil flow with distance is known as avalanching. Maximum rate of flow is approximately the same for all soils. Most fields, however, are not large enough for maximum rate of soil flow to develop. The more erodible the soil surface, the shorter is the distance in which maximum flow is reached (Chepil and Woodruff, 1963).

The total distance across a given field is measured along the prevailing wind-erosion direction (Woodruff and Siddoway, 1965). Knowledge of the prevailing wind direction and of the preponderance of wind from that direction is very important in determining the control methods for wind erosion discussed later.

Vegetative Cover, V

The equivalent quantity of vegetative cover, V , is determined by combining three variables, 1) the

⁴ P_e as used here is Thornthwaite's (1931) P-E index or 10 (P/E), where P/E is the sum of the 12 monthly ratios (as decimal values) of precipitation to evaporation at a given location. P_e is used here to avoid the confusion caused by P-E, which Thornthwaite (1931) called in turn a ratio, a quotient, and finally an index.

quantity, R', 2) the kind, S, and 3) the orientation, K_0 , of vegetative cover (Woodruff and Siddoway, 1965). The quantity of residue is determined by a standardized procedure (Agricultural Research Service, 1962). The kind and orientation of residue are more important than is the quantity alone.

S denotes the total cross-sectional area of the vegetative material. The finer the material and the greater its surface area, the more it reduces wind velocity and, thus, wind erosion. The following are assigned values of S for different kinds of vegetation (Woodruff and Siddoway, 1965): small grain in seedling and stooling stage, dead or alive, 2.50; small grain stubble and stover, 1.00; sorghum stubble and stover, 0.25; corn stubble and stover, 0.20.

K_0 is a vegetative surface-roughness variable. The more erect and the higher the vegetative matter stands above the ground, the more it slows the wind velocity near the ground, and the lower is the rate of soil erosion. Small-grain stubble, for example, is approximately 2.5 times more effective standing than flat in row widths up to 10 inches. Standing sorghum stubble 20 inches high is 2.5 times more effective than flat sorghum stubble of any length. Standing grain-sorghum stubble 8 inches high, on the other hand, is only 1.3 times more effective than flat sorghum stubble of any length. Living or dead, small-grain crops in the seedling or stooling stage are 1.3 times more effective in reducing wind erosion if they are on smooth ground than if they are in a furrow (Woodruff and Siddoway, 1965).

One-and-one-half tons of corn or sorghum stubble 20 inches high is 4.25 times more effective in controlling wind erosion than the same weight of residue from a normally harvested soybean crop. One-and-one-half tons of flat corn or sorghum residue is twice as effective as the same weight of soybean residue (Craig and Turelle, 1964).

Wind-Erosion Equation

The factors affecting wind erosion are used in the following equation to estimate wind erosion (Woodruff and Siddoway, 1965):

$$E = f(I', K', C', L', V)$$

where E is wind erosion in tons per acre annually, I' is a soil erodibility index, K' is a soil ridge-roughness factor, C' is a climatic factor, L' is a field length along the prevailing wind erosion direction, and V is an equivalent quantity of vegetative cover.

Values can be determined for all five factors involved, and an estimate of wind erosion calculated. The data needed for the various calculations and the procedures involved are discussed by Woodruff and Siddoway (1965) and by Skidmore and Woodruff (1968). The equation can be used in Iowa for estimating the erosiveness of particular situations and the measures necessary to keep erosion within prescribed

limits. The key measurement is of soil erodibility. This can be done with a 20-mesh (0.84 mm) sieve. For those interested in using the equation for estimating wind erosion, a table or graph for determining each factor and some examples for determining E are given in the Appendix.

PRINCIPLES OF WIND EROSION CONTROL

Of the five factors in the wind-erosion equation, some are not directly concerned in the erosion process, but serve to modify it. The two direct agents are the wind acting on the soil and the soil being acted upon by the wind. The other three factors—roughness, field length, and vegetation—modify the two direct factors by altering the drag forces created by the wind or by creating a cloddy surface that cannot be moved by the wind.

That barriers deflect the wind upward and reduce its velocity near the soil surface for some distance downwind can be used in developing wind-erosion control methods. Barriers influence wind patterns for a distance many times their height downwind. From the standpoint of wind-erosion control, however, the effective protected distance is about 10 times the height of the barrier. Effectiveness of the barrier depends on, in addition to its height, its width, shape, and porosity.

That the rate of soil flow is zero at the windward edge of an unprotected field, has been recognized in the use of field strips of vegetation in controlling avalanching. Each field strip acts essentially as the windward edge of a field—if the strips are at right angles to the wind direction. Thus, flow rate is reduced to zero at short intervals, preventing the buildup of flowing material that occurs when sediment-laden wind sweeps unhindered across a long field. If the wind were parallel to the direction of the field strips, they would have little or no effect on soil movement.

Vegetative cover serves the twofold purpose of reducing the velocity of the wind near the soil surface and of trapping erodible products from adjacent areas. Tillage also serves a twofold purpose of covering or mixing the erodible particles at the soil surface with larger, unerodible particles, and of roughening or ridging the surface.

METHODS OF CONTROL FOR IOWA

Winter and spring conditions greatly affect susceptibility of Iowa soils to erosion by wind. This is especially true of the silty clay loam of north-central Iowa. A mild winter with little snow results in much freezing and thawing of the soil surface. This breaks down soil clods on fall-plowed land to an easily erodible size.

The conditions just described do not occur every year and are most likely to happen during dry periods. Although it might seem reasonable to continue the present practice of fall plowing and to plan to control

erosion by emergency tillage, much soil movement may take place while the frost is going out of the ground. During this period, the soil is very soft beneath the surface, and tillage is impossible. Thus, to control potential wind erosion in the spring, some fall planning must be done.

As a general statement, the best erosion-control practice is to leave all residue from the previous crop through the winter. The alternatives then are 1) spring plowing, 2) one of a number of no-plow tillage or till-plant methods, or 3) spring disking instead of plowing soybean ground. (If disking creates an erosion problem on soybeans, sweeps may be an alternative.) In areas where spring plowing is a problem because of wet soils, field strips are a good alternative. If a large area of land becomes susceptible to wind erosion, it may be necessary to consider barriers such as tree windbreaks or even artificial barriers. From a practical standpoint, the measures taken to control wind erosion must balance the seriousness of the problem against the cost in time and money to the farmer.

Field Strips in Relation to Prevailing Wind

In some areas of Iowa, fall plowing of corn stubble is considered a necessity. The most practical wind-erosion control for this situation seems to be to leave the plowed surface as rough as possible and to leave 25 foot strips of standing corn stover at 100 to 150

Table 2. Relative magnitude, prevailing wind-erosion direction, and preponderance of wind-erosion forces in the prevailing wind-erosion direction for March, April, and May at five locations in and adjacent to Iowa.^a

	Climatic factor C ^b	Magni-tude	Direc-tion ^c	Pre-pon-derance	Row direction	
					Best	Preference of NS or EW direction
Omaha, Nebr.						
March	20	848	113	1.7	ENE-WSW	E-W
April	30	623	135	1.9	NE-SW	Equal
May	15	802	90	1.7	E-W	E-W
Des Moines, Iowa						
March	22	732	135	1.4	NE-SW	Equal
April	25	693	135	1.6	NE-SW	Equal
May	15	533	112	1.3	ENE-SWS	E-W
Burlington, Iowa						
March	13	731	180	1.2	N-S	N-S
April	12	345	157	1.4	NNE-SSW	N-S
May	9	266	22	1.3	NNW-SSE	N-S
La Crosse, Wisc.						
March	10	304	135	1.5	NE-SW	Equal
April	14	440	135	1.8	NE-SW	Equal
May	10	548	121	1.1	ENE-WSW	E-W
Sioux Falls, S. D.						
March	20	809	135	1.5	NE-SW	Equal
April	25	686	113	1.9	ENE-WSW	E-W
May	20	512	135	1.4	NE-SW	Equal

^a E. L. Skidmore and N. P. Woodruff. Wind erosion forces in the United States and their use in predicting soil loss. U. S. Dept. Agr., Agr. Handbook 346. 1968. 42 pp.

^b C' values were furnished by N. P. Woodruff, research investigations leader, Erosion Laboratory, Agricultural Research Service, U. S. Department of Agriculture, Manhattan, Kan.

^c Degrees: E is zero degrees; N is 90 degrees.

foot intervals perpendicular to the prevailing wind. Although this may not control erosion completely, it will control avalanching and, thus, will reduce erosion greatly. The most desirable situation from the farmer's standpoint is to plow as much as possible and to leave as little as possible in the stubble strips and still get maximum effectiveness. The extent to which this can be done will depend on the roughness of the plowing, the soil condition after overwintering, the density of residue in the corn stubble strips, and the extent to which strips can be placed perpendicular to the prevailing wind. The last factor is very important in determining the effectiveness of this practice.

Prevailing wind-erosion direction for March, April, and May at five locations in or adjacent to Iowa is shown in table 2 and fig. 2. Also shown in table 2 is the magnitude of the wind-erosion force, preponderance or prevalence of wind-erosion forces in the prevailing wind direction, and the best row orientation for these conditions.

Explanation and equations for obtaining magnitude, prevailing direction, and preponderance values are given by Skidmore and Woodruff (1968). Following is a brief explanation of what the values in table 2 represent:

Magnitude of a wind-erosion "force"⁵ vector is obtained by summing, for all speed groups with windspeeds greater than 12 mph, the product of a mean windspeed cubed and a duration factor for a specified direction. The sum of the magnitudes of the wind-erosion force vectors for all directions gives the total magnitude of wind-erosion forces for a location.

The magnitude of erosion forces in a prevailing direction is obtained from the wind-erosion force vectors. The total forces parallel to an imaginary line are computed. Then, the sum of the forces perpendicular to this line are computed. Finally, an orienting line is obtained where the ratio of wind-erosion forces parallel to forces perpendicular is a maximum. This is the prevailing wind-erosion direction. The value given in table 2 represents an angle. Zero degrees is east, 90° is north, and 180° is west. For a more complete explanation see Skidmore and Woodruff (1968).

The row directions most effective in controlling erosion are shown in table 2. Strips or barriers oriented in this direction would be at right angles to the prevailing wind-erosion direction. Also shown is the most effective row or barrier direction if rows are run parallel to an east-west or a north-south fence. Preponderance of the wind direction will determine the importance of strip or barrier orientation.

The greater the preponderance value given in table 2, the greater is the prevalence of the prevailing wind-erosion direction. A value of 1.0 indicates no prevailing wind erosion and a wind barrier would be equally

⁵ Not a force unit as conventionally defined, but here used as a parameter to define effect of wind velocity and direction.

effective in any direction. A value of 2.0 indicates a prevailing wind erosion direction with wind-erosion forces twice as great at parallel as at right angles to the prevailing wind-erosion direction.

Preponderance values for the five locations in table 2 are all greater than 1.0 for March and April, but are all less than 2.0. This means that none is unusually high.

At La Crosse, Wis., relative magnitude of wind-erosion forces increases from March to May, whereas at Sioux Falls, S. D., and Burlington and Des Moines, Iowa, the relative magnitude decreases from March to May. At Omaha, Nebr., it decreases in April and rises again in May.

Climatic factors are lower at Burlington and La Crosse than at the other three locations because of the greater rainfall and lower wind velocities. At Omaha and Des Moines, the climatic factor goes down in May even though the wind-erosion forces are higher at Omaha in May. This evidently is the effect of having more moisture in May than in April. The C' factor is highest in April at all locations except Burlington.

The width of strips that can be plowed in a corn field is influenced by several factors. Most important is the soil texture, which has the greatest influence on soil erodibility. Another factor is the expected wind-erosion forces. The higher the relative magnitude of these forces, the narrower the strips should be for equal effectiveness. Also, the effectiveness of the strips decreases as the wind direction deviates from right angles to the strips (Chepil, 1959).

Chepil (1960) presents a method for determining width of strips under a number of prevailing conditions. One of the main values required is either a measurement or an estimate of the percentage of nonerodible clods greater than 0.84 mm in diameter. On a Webster silty clay loam soil near Ames, which had been eroding since early April 1968, 83 percent of the clods were less than 0.84 mm in diameter. Chiselling this field reduced the amount of clods less than 0.84 mm to 55 percent. By using the method of Chepil (1960) and assuming a negligible ridge roughness of 1 inch and negligible quantity of crop residue (100 pounds), we found the width of plowed strips could be 100 feet if the stubble strips were at right angles to the prevailing wind-erosion direction (NE-SW in Des Moines area). Because the wind does not blow at right angles to the stubble strips all the time, however, the width of plowed strips should be reduced to 70 feet, according to the Des Moines data (preponderance factor 1.4 and 1.6). If the rows are run north and south or east and west, the width of plowed strips should be reduced to 50 feet to keep wind erosion to a minimum.

This, however, must be qualified to some degree. Considerable erosion and abrasion had been taking

place on this field from early April to early May when samples were taken. We have not had enough experience in Iowa to know what will happen to our plowed strips if avalanching is controlled by use of stubble strips. We expect that it will reduce abrasion and keep the surface from becoming as erodible as it did in the example just given. If so, plowed strips can be wider than the 50 to 70 feet just calculated. A suggested procedure would be to double the width cal-

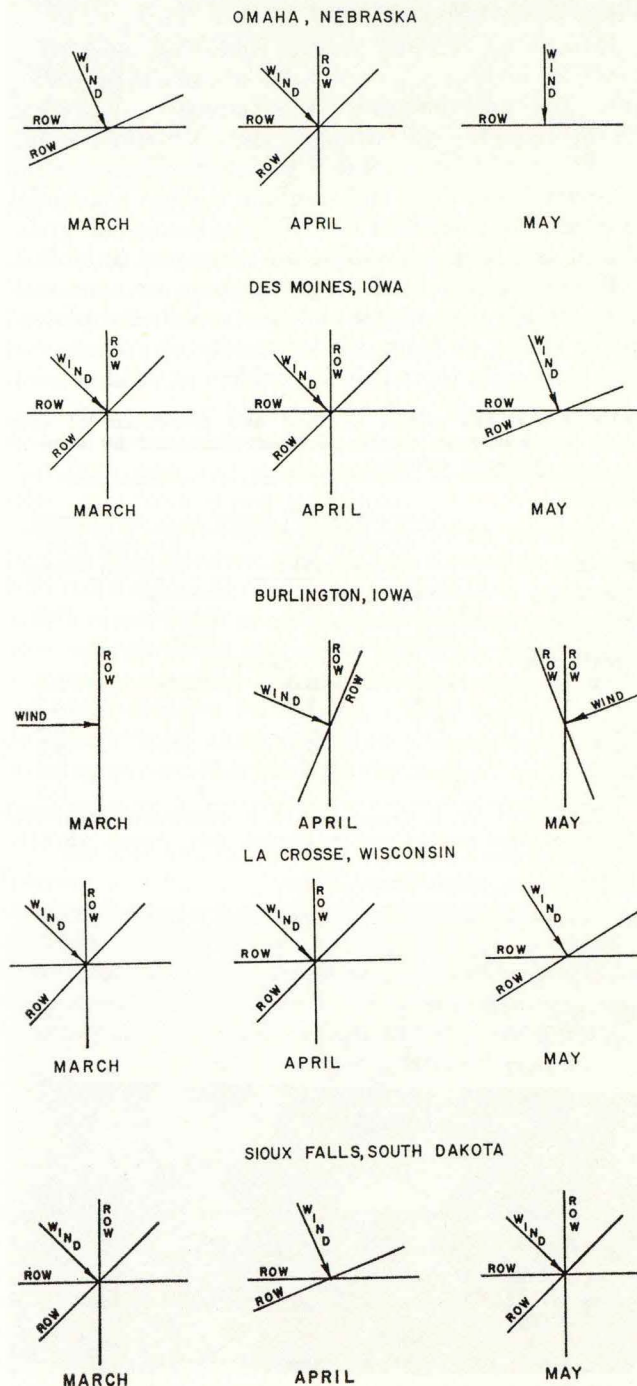


Fig. 2. Prevailing wind direction and row direction at right angles and in an east-west or north-south direction.

culated here for the plowed strips (100 feet if in a north-south or east-west direction, 140 feet if in a northeast-southwest direction, Des Moines area). If experience shows this to be too wide, plowed strips can be narrowed the next year.

The stubble strips must be wide enough to trap and still the eroding soil particles. A ratio of 1:4 stubble strip to plowing should be safe. Stubble strips should not be less than 25 feet wide, however.

Crop-Residue Management

Erosion on cropped land is controlled most effectively by making full use of residues of the preceding crop. These residues differ in effectiveness, depending on the crop, the quantity, and the orientation. Standing grain-sorghum stubble is the most effective of the common crops. Corn and sorghum stubble are similar in effect, but somewhat less effective than small grain. Wheat and sorghum residue are compared in table 3.

If undisturbed small-grain, sorghum or corn residues are left over winter and then moldboard plowed in the spring on loam, silt loam, silty clay loam, and clay loam soils, there is little problem of wind erosion.

Table 3. Average effects of kind and orientation of crop residue on erosion of sandy loam soil by wind of uniform velocity^a.

Quantity of crop residue above soil surface pounds/acre	Quantity of soil eroded in a wind tunnel			
	Covered with wheat residue		Covered with sorghum residue	
	Standing, 10 inches high	Flat	Standing, 10 inches high	Flat
0	16.0	16.0	16.0	16.0
500	2.8	8.5	13.0	14.5
1,000	0.1	2.5	8.1	10.4
2,000	T ^b	0.1	3.9	5.3
3,000	T	T	1.4	2.2
6,000	T	T	T	0.2

^a Table XVI, W. S. Chepil and N. P. Woodruff. 1963. The physics of wind erosion and its control. *Adv. Agron.* 15:211-302.

^bT = trace, insignificant.

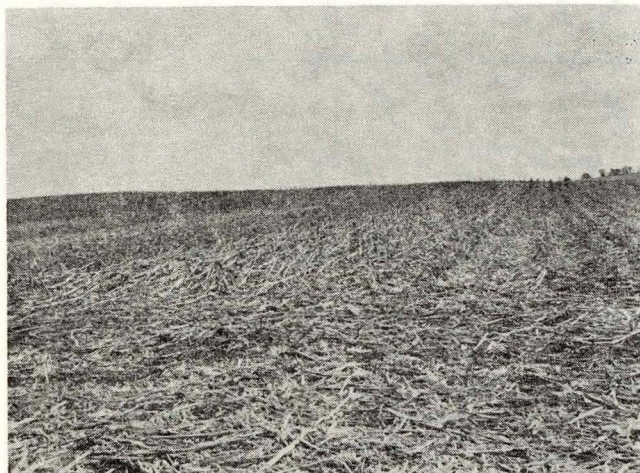


Fig. 3. Corn stubble and stover furnishes very effective control of wind erosion.

Likewise, if soybean residue is left over winter and plowed, there is little wind-erosion problem after plowing. There may be a problem before plowing with soybean residue, however, unless the residue is heavy and well distributed. Farmers try to combine soybeans as close to the ground as possible to get all the pods, reducing the standing stubble height to a minimum and leaving only flat residue for protection. The weight of soybean residue is low compared with that of corn in Iowa (0.8 ton for soybeans compared with nearly 2 tons for corn at the Shelby-Grundy Experimental Farm, Beaconsfield, Iowa). Since corn usually has a considerable amount of standing residue and has more than double the total quantity, the reason for the greater effectiveness of corn residue over that of soybeans is obvious (figs. 3, 4, 5, and 6).

If we use the erodibility (*I'*) value from the Webster silty clay loam near Ames, with 83 percent of the clods less than 0.84 mm in diameter, 2 tons of corn stubble standing 20 inches high will control wind erosion completely. Two tons of flat stubble will allow 2.5 tons per acre of erosion from soil in this highly erodible condition, and 0.8 ton of soybean residue will allow 18 tons per acre of erosion by wind. Here again, however, significant abrasion would almost certainly not have taken place in these amounts of cover, and the highly erodible condition would not have existed. One ton of corn stubble standing 20 inches high is approximately as effective as 2 tons of flat residue.

Once-over implements of various kinds are now available for planting in crop residues (Parsons, 1967). Nearly all commercial companies manufacture at least one type of once-over implement. Planting in crop residues, not only helps to control wind erosion up to and after planting time, but it also is an excellent measure for water-erosion control and water conservation as well.

Surface Configuration (Ridge Roughness)

Roughness can be attained in three ways—by rough

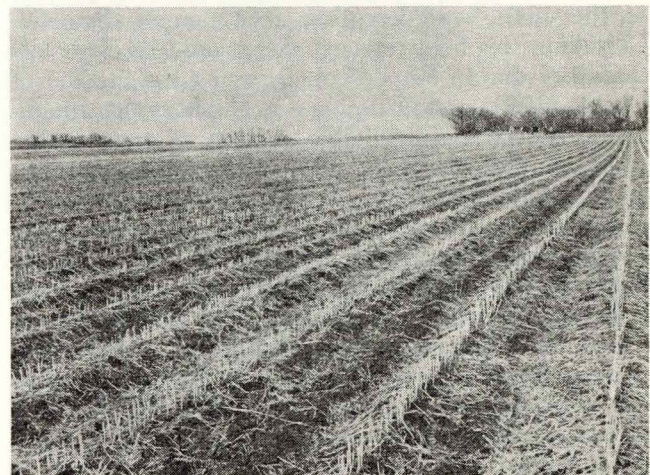


Fig. 4. Undisturbed soybean residue with some stubble is effective in control of wind erosion.

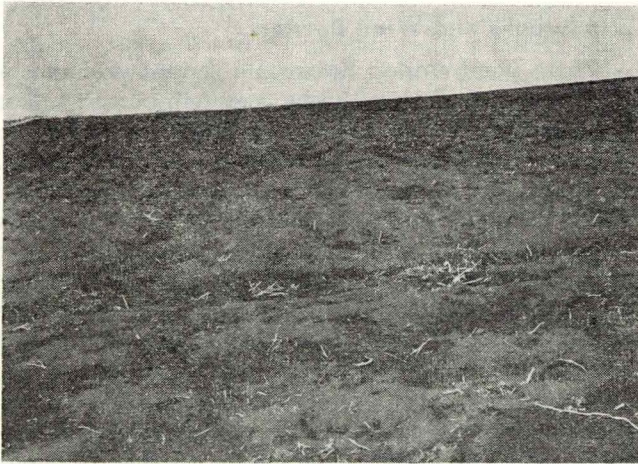


Fig. 5. Disked soybean stubble gives poor control of wind erosion.

plowing, by leaving standing vegetation, and by ridging the soil surface. The roughness left by rough plowing is largely random in orientation and is the result of soil cloddiness. The effect of this cloddiness is taken into account in the percentages of nonerodible soil fractions used in determining the soil erodibility index, I' . The effect of standing vegetation is evaluated during determination of the vegetative cover factor, V' .

Ridging of the soil surface can reduce erosion to half or less of that on flat ground if ridges are spaced correctly and are at right angles to the wind. The most effective height is 2 to 5 inches with a 1:4 height-spacing ratio. Ridging has two possibilities as a practice in Iowa. One is as a spring emergency-tillage practice to control erosion on fall-plowed land. The other is as a supplemental control practice where vegetative cover is sparse, such as soybean ground or where corn or sorghum has been harvested for forage.

From the preceding information about crop residues, it is obvious that, if corn or sorghum is harvested for grain and all the residue is left on the field during the winter, no further control is necessary. With soybeans and sorghum or corn harvested for forage, there may be a need for more protection than the crop residue will afford if winter conditions leave the soil erosive. An effective job of ridging in the fall, covering as little residue as possible, can provide this additional protection.

For illustration, the example can be used of the field near Ames, with a potential for 27 tons per acre of erosion with no ridging or residues, with a field width of $\frac{1}{4}$ mile, with 50 percent of the wind forces traveling twice this distance and with a normal Des Moines climatic factor for April of 25. With 0.8 ton of soybean residue, the potential is reduced to 18 tons per acre. With no soybean residue, but with effective ridging, the potential is reduced to 14 tons per acre. With soybean residue and ridging together, the potential is 7 tons per acre. A field of corn harvested for forage

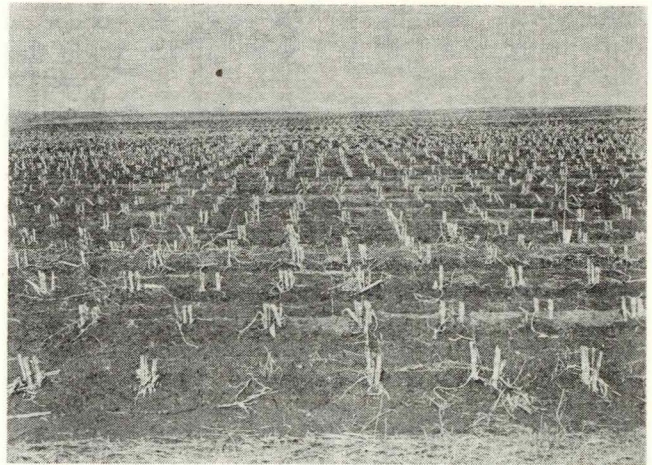


Fig. 6. Corn stubble combined with ridging in the rows prevented soil erosion.

with 1,000 pounds of residue standing 8 inches high has an erosion potential similar to that of a soybean field with 0.8 ton of residue remaining. Ridging would reduce the potential by a similar amount under these conditions. The main difference would be that standing corn stubble would less likely be partly covered during ridging than would flat soybean residue. Both corn and soybeans may, in fact, be ridged effectively from spring cultivation.

Ridges at right angles to the prevailing wind direction are most effective. They can be formed by using a field cultivator, a heavy spring-tooth harrow equipped with a chisel point or an ordinary duckfoot cultivator used for cultivating row crops with some adjustments to even up the ridge spacing. Duckfoot types of tools are quite effective for ridging. Chisel types of tools do some ridging along with their primary function of bringing nonerodible clods to the surface.

Emergency Tillage

If the soil was fall plowed and if raindrop action, freezing and thawing, wetting and drying, and abrasion by blowing soil particles have left the surface very erodible, the only alternative is some type of tillage. If soybean residue was left undisturbed over winter and subjected to the same forces, it may be necessary, in cases of very light residue, to till these fields as well. Emergency tillage serves a twofold purpose. It brings up clods that reduce the percentage of the erodible size fraction in the surface, and it creates an oriented or ridge roughness that reduces the wind velocity near the soil surface and traps particles in the furrows between the ridges. Depending on this type of tillage for erosion control, however, has two shortcomings. It is temporary because raindrop action and abrasion quickly reduce the effectiveness of the clods and ridges. Also, a period of high wind velocities occurs in Iowa when it is impossible to get into the field because of wetness resulting when frost leaves the soil. Abrasion during this period can leave the

surface very erodible. In this condition, erosion is difficult to control by emergency tillage when this finally can be done.

The effectiveness of emergency tillage depends on soil moisture, soil texture, speed of travel, depth of tillage, spacing between tool-head carriers, and type of tool head (Woodruff et al., 1957). Lyles and Woodruff (1962) found that the cloddiness was greater when the soil was tilled at less than 15-percent or greater than 23-percent moisture. (The range of moisture at which tillage is usually performed is 15 to 23 percent.) Least pulverization occurred in soil with less than 8-percent moisture. This effect holds only if the soil at this moisture percentage was compact initially. Tilling a loose, dry soil does little good. They found that clods formed by a moldboard plow broke down faster than those formed by a 1-way plow or a 5-foot, V-type subsurface sweep.

Soil texture is a very important factor in the effectiveness of emergency tillage because the clay content, especially, influences greatly the strength of clods. Emergency tillage is much less effective on sandy soils than on finer-textured ones because the sandy soils have fewer and weaker clods.

Roughness and cloddiness are generally produced with deeper depths and slower speeds of tillage. On compacted soils, a tillage depth of 3 inches is usually satisfactory; on loose soils, a 5-inch depth is more effective. Too slow a speed will not bring clods to the surface; too high a speed will tend to pulverize or shatter clods. Speed should never be slower than 2 mph; speeds of 3.5 to 4 mph give the greatest long-term effectiveness (Woodruff, Chepil, and Lynch, 1957).

Narrow spacing is more effective than wider spacing. A spacing of 20 to 30 inches is recommended. Spacing wider than this, especially on an erodible soil, leaves too much erodible area between the tillage-formed ridges.

The best tools to use for emergency tillage are chisels and duckfoot cultivators. In compacted soils, a heavy-duty, narrow chisel is the preferred tool; in loose soils, a shovel is more effective. In sandy soils, about the only really effective tool is a lister, operated as deeply as possible when the soil is moist. Disk harrows tend to pulverize and loosen the soil and to provide no ridge roughness. They should not be used to till smooth, bare soils where blowing is a hazard. An ordinary spring-tooth harrow is somewhat better than a spike-tooth harrow because it penetrates more deeply, brings some clods to the surface and causes some ridging (Chepil, Woodruff, and Siddoway, 1961). Either of these implements can be used to provide very temporary control of wind erosion, but the spike-tooth harrow should be used only if the soil is fairly moist. Emergency tillage should be done over the entire field rather than intermittently.

Windbreaks and Wind Barriers

Where wind erosion becomes a serious problem in establishing seedings of crops, a system of permanent windbreaks or wind barriers may be the only effective control. These must be established over a large area; otherwise, the barriers will become a trap for wind-blown material from adjacent fields. Since barriers are effective only when placed at right angles to the wind direction, it is often necessary to provide protection against wind from all directions. Permanent barriers most often used are tree windbreaks, but artificial barriers such as earthen banks, wooden or rock walls, sheetmetal and snowfencing have been used.

Windbreaks or wind barriers absorb or deflect sufficient wind to lower velocities below the threshold required for soil movement. The effect of any barrier depends mainly on wind velocity and direction, and on shape, width, height, and porosity of the barrier (Chepil and Woodruff, 1963). A very abrupt vertical barrier will provide less protection than a sloped or triangular one. In barriers of several rows of trees, the shape can be controlled by proper selection of species within the barrier rows.

During the 1930's, windbreak plantings were 10 or more rows wide. The trend today is toward 1-, 2-, 3-, and 5-row barriers, which are just as effective as the wider ones in reducing wind velocities (Chepil and Woodruff, 1963). Porosity of tree windbreaks depends on the season of the year if deciduous trees are used. The protection provided by these trees is reduced 20 to 40 percent during the winter. Much erosion may occur before these trees leaf out.

Tree windbreaks are very effective, especially for 30- and 40-mph winds (Woodruff, Fryear, and Lyles, 1963). Valuable cropland must be used in windbreaks, however, and the trees may interfere with operation of large machinery and compete with crops for available moisture and nutrients. If wind erosion becomes an increasing problem in Iowa, single-row tree windbreaks could conceivably become a desirable alternative to increasingly frequent emergency tillage.

Artificial barriers, because of the high cost, are justified only in unusually erodible situations with high-value crops. Solid board or sheet-metal barriers provide protection for distances equal to 8 to 10 times their height. Snowfences and other porous barriers are effective for distances 10 times their height.

Methods of Control Summarized

Methods of control have been discussed, beginning with the one most likely to be adopted in north-central Iowa, field strips. North-central Iowa, or more specifically, the Clarion-Webster soil association area, is largely fall-plowed because of the spring wetness problem. Residues from the previous crop, if left on the surface, aggravate the problem. Thus, fall plowing,

with field strips left at intervals, is considered a reasonable alternative to a complete residue cover. Some farmers are not plowing at all in the Clarion-Webster area. They are using a till planter in their cornstalks and are double disking and planting in their soybean residue. If adoption of these practices becomes widespread, the wind erosion problem will be greatly reduced.

In areas where spring plowing can be done early and fall plowing is merely a convenience, the most effective erosion-control practice is to leave all crop residue untouched until spring. Till planting or some variation of it is very promising in these areas, and there is little justification for plowing soybean ground.

Fall ridging with a field cultivator is an acceptable practice where subsurface drainage is poor and the soils need as much warming and evaporation as possible in the spring. If some soybean stubble is standing

in the rows, ridging should be done in such a way as to leave this as little disturbed as possible. Usually, tilling again in the spring with the cultivator at an angle to the previous ridging will prepare a satisfactory seedbed for corn or soybeans.

Emergency tillage must be carried out in many years if no erosion control practices have been carried out in the fall. This practice has the great disadvantage that much erosion and abrasion has taken place in the spring before the field is firm and dry enough to work. This leaves a highly erosive soil surface throughout the spring until wind velocities begin to decrease about May 1.

Tree windbreaks are very effective if established over a wide area and with sufficient frequency. The need, however, is not considered great enough to warrant recommending this as a practice at this time.

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APPENDIX

The wind erosion, E , in tons per acre is estimated by using the following equation:

$$E = f(I', K', C', L', V)$$

where I' is a soil erodibility index in tons per acre, K' is a soil ridge-roughness factor, C' is a climatic factor, L' is a field length along the prevailing wind-erosion direction, and V is an equivalent quantity of vegetative cover.

To evaluate I' take 5 4-pound samples at 1-inch depth. Use a 20-mesh sieve to separate the less-than 0.84 mm from the greater-than 0.84 mm particles. From the percentage of dry soil fractions greater than 0.84, the potential soil loss from a wide, unsheltered field can be determined from table A-1. The potential loss from knolls can be determined from fig. A-1.

The knoll factor was put into the equation to take care of the fact that the tops of hills are more susceptible to wind erosion than the flat portions of the field. If one is calculating erosion or determining how much residue is needed to control erosion on a field with both flat and knolly land, then he should apply the equation twice—once with an I' for regular conditions to determine E_s or, conversely, residue requirements for the flat land, and once with the knoll factor to determine these same factors for the tops of the hills. He would use the same field length L' for both applications. Supposedly then if one was applying mulch, he would put the amount indicated by the equation when the knoll factor was used on the top one-third of the slope of the knoll and the lesser amount indicated by the equation without the knoll factor on the flat land. Theoretically with this interpretation the number of knolls really doesn't make any difference—simply make calculations for the two conditions and apply two different remedies. From a practical standpoint,

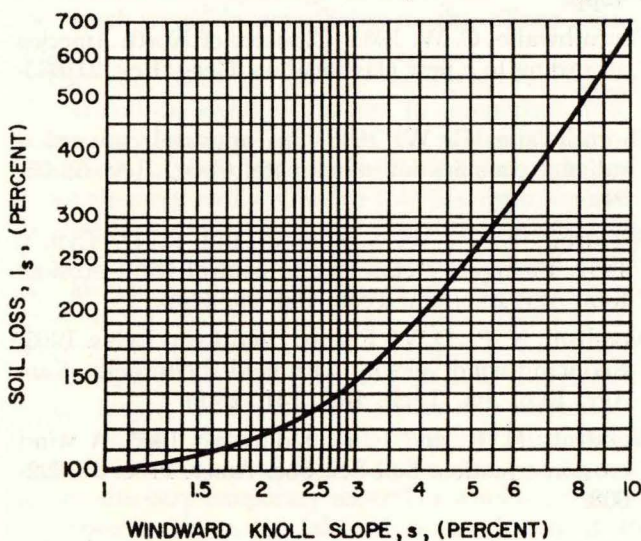


Fig. A-1. Potential soil loss from knolls, expressed as percentage of that on level ground.

however, in a field with a number of knolls, it is best to make all calculations with the knoll factor in the equation. The flat parts of the field may be over-treated, but in this instance, it is better to have too much than too little.

Length and percentage slope of knolls are critical factors. The largest soil association on which significant knolls will be found is the Clarion-Nicollet-Webster. Many of these knolls will be less than 500 feet in length and slope gradient will be mainly in the 3 to 6 percent range. There are, of course, other areas in which knolls less than 500 feet in length occur. The knoll factor, using the appropriate windward knoll slope in fig. A-1, should be used wherever knolls occur. Where knolls are longer than 500 feet, the knoll factor is not used.

The soil ridge-roughness factor is obtained from fig. A-2. K_r is obtained from

$$K_r = \text{Standard value (4)} \times \text{height of field ridges in inches} \div \text{field measured value (d/h)}.$$

For example, if field ridges were 3 inches high and 18 inches apart, the soil ridge roughness, K_r , is

$$K_r = [4/(18/3)] \times 3 \text{ inches} = (4/6) (3) = 2 \text{ inches}.$$

Entering fig. A-2 with the K_r value of 2 inches gives a value of K' of 0.52. This value is used in the equation and modifies the I' value obtained in table A-1 and fig. A-1.

The climatic factor C' for Iowa during April can be obtained from fig. A-3. Most of the wind erosion in Iowa occurs in April, and thus, the calculations using the April C' value are most likely to represent what will occur. C' values range from 30 in the far western part of the state to 15 in the eastern part in March and April. In May they range from 20 to 10. The western half of Iowa especially has a higher C' in April than in March.

Table A-1. Soil erodibility I for soils with different percentages of nonerodible fractions as determined by standard dry sieving.^{a, b}

Dry soil fractions > 0.84 mm (percentage)	Units									
	0	1	2	3	4	5	6	7	8	9
	(tons per acre)									
0	310	250	220	195	180	170	160	150	140	
10	134	131	128	125	121	117	113	109	106	102
20	98	95	92	90	88	86	83	81	79	76
30	74	72	71	69	67	65	63	62	60	58
40	56	54	52	51	50	48	47	45	43	41
50	38	36	33	31	29	27	25	24	23	22
60	21	20	19	18	17	16	16	15	14	13
70	12	11	10	8	7	6	4	3	3	2
80	2									

^a For fully crusted soil surface, regardless of soil texture, erodibility I is, on the average, about one-sixth of that shown.

^b N. P. Woodruff and F. H. Siddoway. 1965. A wind erosion equation. Soil Sci. Soc. Proc. 29:602-607.

The equivalent field length, L' , is the unsheltered distance across the field along the prevailing wind-erosion direction.

$$L' = D_r - D_b$$

where D_r is the distance across the field and D_b is the distance along the prevailing wind-erosion direction sheltered by a barrier, if any, adjoining the field.

Distance across a field depends on the angle of deviation of the prevailing wind from a north-south or east-west direction and the preponderance. These values can be found in table 2. Unless all wind-erosion forces occur along the prevailing wind-erosion direction, some of the wind will travel distances greater than L' in traversing a field strip (Skidmore and Woodruff, 1968). It is desirable to choose a width for field strips such that 50 percent of the wind erosion forces will travel more, and 50 percent less, than this width. The 50-percent value is also most desirable for calculating the travel distance L' to be used in the prediction of erosion from an unprotected field. A factor calculated by using angle of deviation from a north-south or east-west direction is designated k_{50} . Multiplying the actual field width by k_{50} gives the mean travel distance of the wind-erosion forces. Calculated k_{50} values for April for the locations are shown in table A-2. Values for Omaha, Des Moines, and La Crosse are the same, whether field width is measured in east-west or north-south direction. At Burlington, the value refers only to a field width in the north-south direction and, at Sioux Falls, in the east-west direction. At Burlington, wind from the prevailing direction would travel 1.0 times the distance of a field or strip oriented at right angles to the wind, but would travel 1.1 and 2.5 times this distance in N-S and E-W strips, respectively. At Sioux Falls the prevailing wind would travel 1.1 and 2.5 times the right angle distance in E-W and N-S strips, respectively. This illustrates why a N-S orientation is much

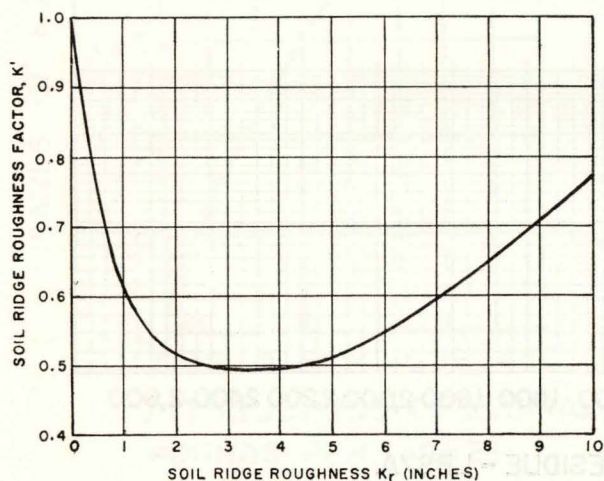


Fig. A-2. Chart to determine soil ridge-roughness factor K' from soil ridge-roughness K .

more effective at Burlington and an E-W orientation is much more effective at Sioux Falls.

The vegetative factor, V , can be obtained by using fig. A-4 and fig. A-5. From fig. A-4, the equivalent amount of flat small-grain stubble can be determined from the amount and orientation of the particular residue in question. Then, the value, V , can be obtained from this equivalent amount of flat small-grain stubble by using fig. A-5.

For an example, take a field near Des Moines, Iowa, with a 1,320-foot north-south width. There are significant knolls in the field with an average windward slope of 4 percent. Taking 5 4-pound samples at one-inch depth and dry sieving with a 20-mesh sieve indicates that 23 percent of the soil fractions is greater than 0.84 mm in diameter. The field has 4-inch ridges, 30 inches apart, and 1,600 pounds per acre of soy-bean stubble and stover.

The value for soil loss, E , is obtained by steps.

Step 1. Calculate $E_1 = I' = (I)(I_s)$

Since 23 percent of the soil fractions is greater than 0.84 mm, $I = 90$ tons per acre (table A-1). To obtain I' , knoll erosion, I_s , must be taken into account. Thus, for a knoll with 4-percent slope, use the value for the top of the knoll to be safe, and the I value, or 90 tons, must be multiplied by I_s or 1.95 (fig. A-1). (For knolls greater than 500 feet in length the erosion rate is about the same as for level land and I_s is taken as 1.00.)

Table A-2. Values (k_{50}) for calculating travel distance, L' , of wind in April.

Location	k_{50}	Row direction
Omaha, Nebr.	2.4	N-S or E-W
Des Moines, Iowa	2.1	N-S or E-W
Burlington, Iowa	1.6	N-S only
LaCrosse, Wis.	2.3	N-S or E-W
Sioux Falls, S. D.	1.5	E-W only

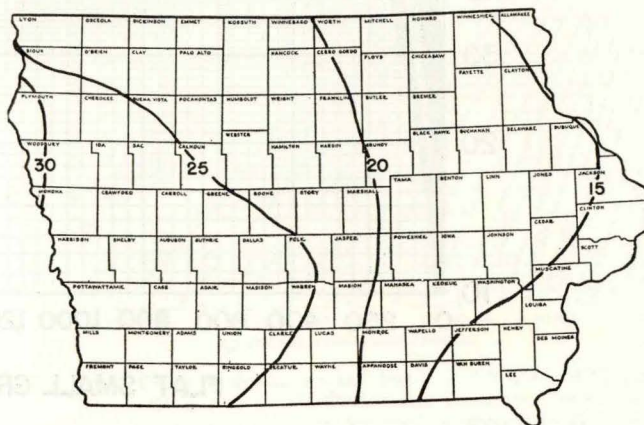


Fig. A-3. Climatic factor C' for Iowa in April.

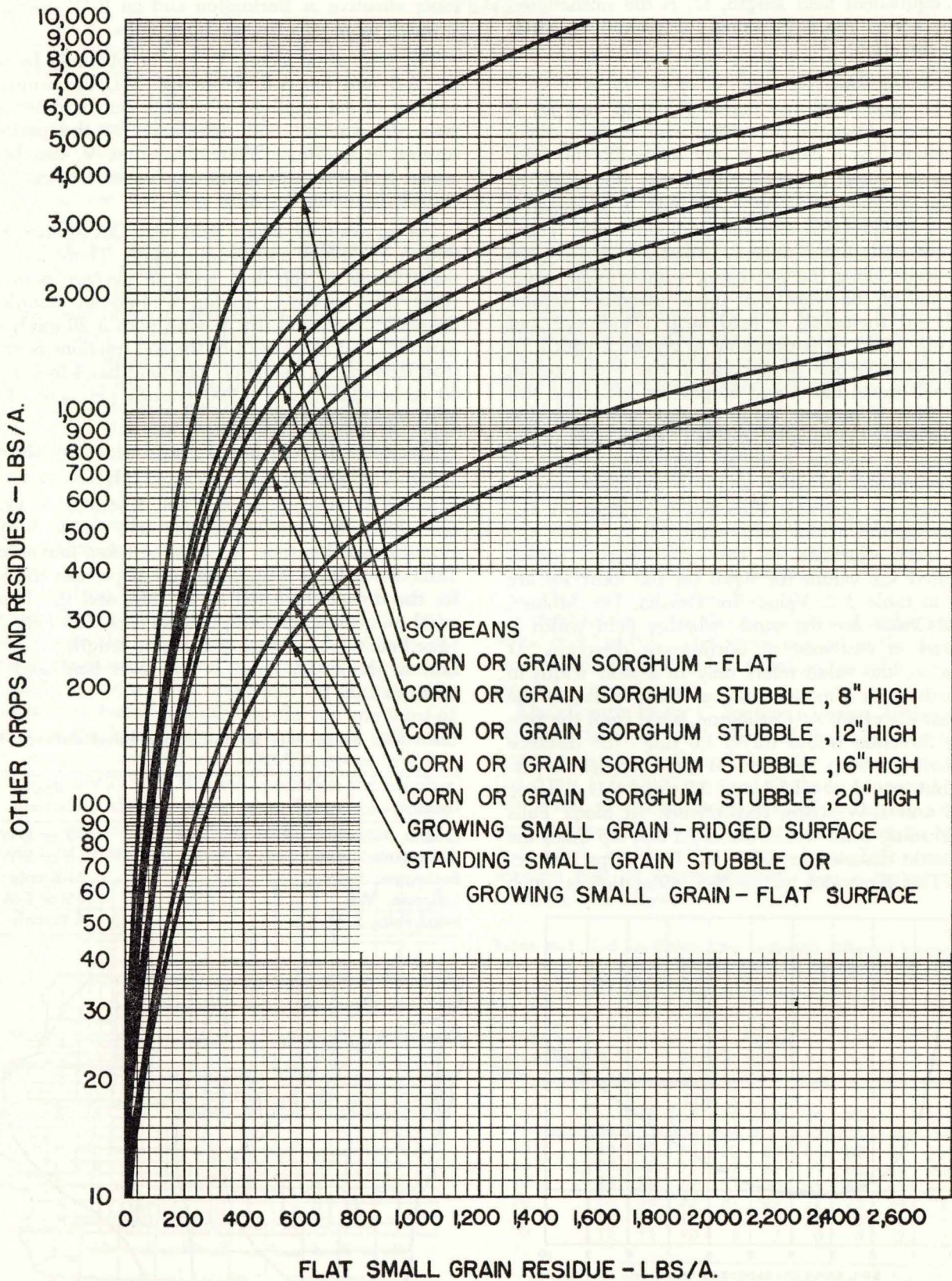


Fig. A-4. Chart to determine the equivalent amount of flat small-grain residue from the amount and orientation of various kinds of residue.

$$E_1 = (I)(I_s) = (90)(1.95) = 175 \text{ tons per acre.}$$

Step 2. $E_2 = I' K'$

The field measured ridges are 4-inches high and 30 inches apart. Thus,

$$K_r = [4/(30/4)](4) = (0.53)(4) = 2.1 \text{ inches.}$$

K' is obtained by entering fig. A-2 on the abscissa with K_r (2.1) and reading vertically upward to the curve. Then by reading horizontally on the ordinate, $K' = 0.5$.

$$E_2 = I' K' = (175)(0.5) = 87.5 \text{ tons per acre}$$

Step 3. $E_3 = I' K' C'$

C' for Des Moines in April is 25 percent (fig A-3). Thus,

$$E_3 = (175)(0.5)(0.25) = 21.9$$

Step 4. $E_4 = I' K' C' f(L')$

L' is obtained by multiplying the field length by the factor k_{50} , or 2.1 for Des Moines (table A-2). Thus $L' = (1320)(2.1) = 2,772$.

To obtain E_4 from fig. A-6 cut out the movable scale and place it so that E_3 (approximately 22) on the movable scale coincides with E_2 (87.5) on the ordinate. From the movable scale move down along 87.5 interpolated between curved lines 80 and 90 to the intersection of $L' = 2,772$ feet. Then move horizontally left to the movable scale and read

$$E_4 = 21 \text{ tons per acre.}$$

Step 5.

E_5 or E is determined from fig. A-7. The equivalent

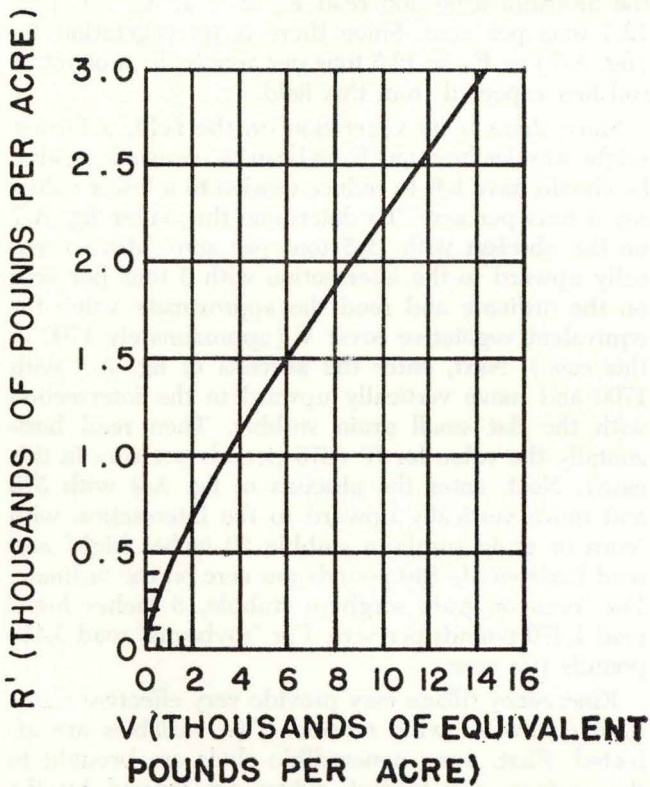


Fig. A-5 Chart to determine V from R' or R' from V of flat, anchored small-grain stubble with any row width up to 10 inches, including stover.

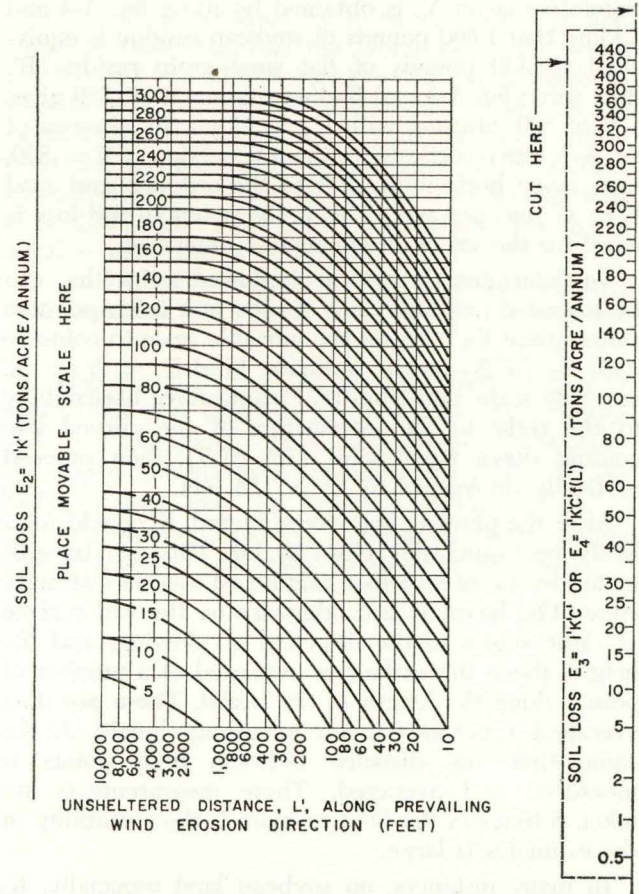


Fig. A-6. Chart to determine soil loss $E_4 = I'K'C'/f(L')$ from soil loss $E_2 = I'K'$ and $E_3 = I'K'C'$ and from unsheltered distance L' across field.

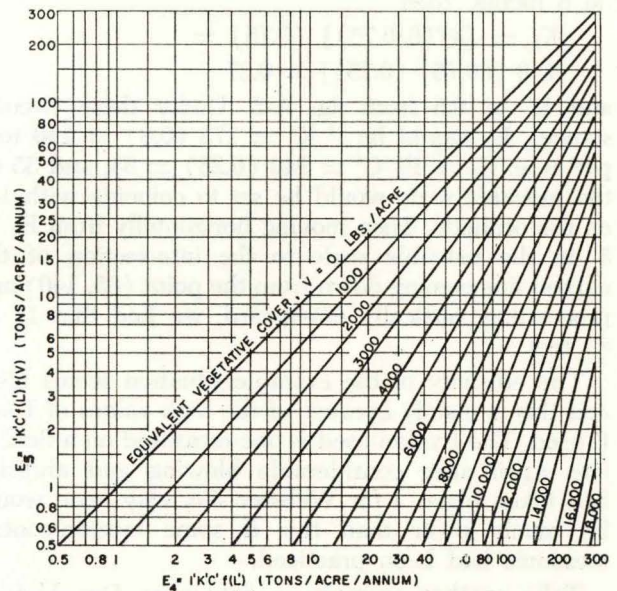


Fig. A-7. Chart to determine soil loss $E = I'K'C'f(L')f(V)$ from soil loss $E_3 = I'K'C'f(L')$ and from vegetative cover factor V . Chart can be used in reverse to determine V needed to reduce soil loss to any degree.

vegetative cover V , is obtained by using fig. A-4 and finding that 1,600 pounds of soybean residue is equivalent to 330 pounds of flat small-grain residue R' , then using fig. A-5 and finding that an R' of 330 gives a V of 800. Starting with $E_4 = 21$ on the abscissa of fig. A-7, move vertically to the intersection of $V = 800$, then move horizontally left to the ordinate and read $E = 17$ tons per acre. This is the potential soil loss in April for the set of circumstances described.

To determine the width of plowed strips that can be tolerated and still keep erosion to a 5-ton-per-acre value, place E_3 (22) on the movable scale to coincide with E_2 (87.5) on the ordinate. Find $E_4 = 5$ on the movable scale, and from this point, move horizontally to the right to the intersection of the curved line coming down from point (22, 87.5), then proceed vertically downward to $L' = 125$ feet.

After the plowing had overwintered, K' would most likely be some value close to 1.0. This can be estimated by use of an 8-foot long board used as a straight edge. The board is laid edgewise on the soil surface at right angles to the direction of plowing, and the height above the surface is measured at a number of points along the length of the board. These are then averaged to get an estimate of average height. At the same time the distance between high points is measured and averaged. These measurements are taken 5 times in the field or more if the variability of the estimates is large.

In many instances, on soybean land especially, K_r will equal 0 and K' will equal 1. In the instance we are considering, if we found the average height to be $\frac{3}{4}$ inch and the average distance apart of high points to be 6 inches, then

$$K_r = [4/(6/0.75)] (0.75) = 4/6 [(0.75) (0.75)] = 0.37$$

and $K' = 0.8$ from fig. A-2. Under these circumstances, E_2 would be $I' K' = 175 (0.8) = 140$ tons per acre. $E_3 = E_2 C' = 140 (0.25) = 35$, and 35 on the movable scale would be set to coincide with 140 on the ordinate. Then moving horizontally from $E_4 = 5$ on the movable scale to the intersection of the curved line coming down from the point (35, 140) and proceeding vertically downward, we find that $L' = 30$ feet.

The erosivity of the example situation seems high, and this is mainly because of the high values of I and I' used. The I value used is one measured on a field in late April after considerable blowing and abrasion had taken place. I for Webster silty clay loam would be much lower than this if some erosion-control measures had been practiced.

Take another example, a field near Des Moines, Iowa, with a 1,320 foot north-south or east-west width. Several knolls less than 500 feet long with an average windward slope of 3 percent occur in the field.

Dry sieving with a 20-mesh sieve indicates 50 percent of the soil fractions are greater than 0.84 mm in diameter. The field has been smoothed by freezing and thawing and early spring rains so there is essentially no roughness and $K_r = 0$. The field has no residue.

Step 1. Calculate $E_1 = I'$

I is obtained from table A-1. For 50 percent of clods greater than 0.84 mm $I = 38$. For knolls with an average windward slope of 3 percent the I value must be multiplied by 1.48 (fig. A-1) to obtain I' . Thus $I' = (38) (1.48) = 56$ tons per acre. $E_1 = 56$ tons per acre.

Step 2. Calculate $E_2 = I' K'$

Since $K_r = 0$, K' is 1.0 from fig A-2. Thus $E_2 = (56) (1.0) = 56$

Step 3. $E_3 = I' K' C'$

Since $C' = 25$ percent for Des Moines $E_3 = (56) (1.0) (0.25) = 14$ tons

Step 4. E_4 is obtained using fig. A-6. The field length is 1,320 feet and the factor k_{50} is 2.1 (table A-2). Thus $L' = (1320) (2.1) = 2,772$ ft. Place the movable scale of fig. A-6 so that E_3 (14) on the movable scale coincides with E_2 (56) on the ordinate. From the movable scale, move down along 56 interpolated between curved lines 50 and 60 to the intersection with $L' = 2,772$ feet. Then move horizontally left to the movable scale and read $E_4 = I' K' C' f(L') = 12.5$ tons per acre. Since there is no vegetation E_5 (fig. A-7) = $E_4 = 12.5$ tons per acre is the amount of soil loss expected from this field.

Since there is no vegetation on the field, a farmer might wonder how much soybean or cornstalk residue he should have left to reduce erosion to a lower value, say 5 tons per acre. To determine this, enter fig. A-7 on the abscissa with 12.5 tons per acre. Move vertically upward to the intersection with 5 tons per acre on the ordinate and read the approximate value for equivalent vegetative cover V (approximately 1700 in this case). Next, enter the abscissa of fig. A-5 with 1700 and move vertically upward to the intersection with the flat small grain stubble. Then read horizontally the value for R' (575 pounds per acre in this case). Next, enter the abscissa of fig. A-4 with 575 and move vertically upward to the intersection with "corn or grain sorghum stubble 20 inches high" and read horizontally 840 pounds per acre on the ordinate. For "corn or grain sorghum stubble, 8 inches high" read 1,470 pounds per acre. For "soybeans" read 3,450 pounds per acre.

Emergency tillage may provide very effective short-term control of wind erosion. Two variables are affected. First, some nonerodible clods are brought to the surface, and second, ridges are formed by the emergency tillage tool. The nonerodible clods affect I' and the ridges affect K' .

In the example just cited, use of a field cultivator might increase the soil fraction greater than 0.84 mm from 50 percent to 70 percent.

Step 1. Calculate $E_1 = I'$

I is obtained from table A-1. For 70 percent of clods greater than 0.84 mm $I = 12$. The knoll factor does not change, and so the I value is multiplied by 1.48. Thus $I' = (12) (1.48) = 18$ tons per acre. $E_1 = 18$ tons per acre.

Step 2. Calculate $E_2 = I' K'$

A field cultivator with shovels on 12-inch spacings is used as the emergency tillage tool. Ridges formed are 3 inches high. Thus

$$K_r = [4/(12/3)] (3) = 3 \text{ inches}$$

and $K' = 0.5$ (fig. A-2). $E_2 = I' K' = (18) (0.5) = 9$ tons per acre.

Step 3. $E_3 = I' K' C' = E_2 C'$

Since $C' = 25$ percent for Des Moines (fig. A-3) $E_3 = (9) (0.25) = 2.25$ tons per acre.

Step 4. E_4 is obtained by using fig. A-6. The field length is 1,320 feet, and the factor k_{50} is 2.1 (table A-2). Thus $L' = (1320) (2.1) = 2,772$ feet. Place the movable scale of fig. A-6 so that E_3 (2.25) on the movable scale coincides with E_2 (9) on the ordinate. From the movable scale move down along 9 interpolated between 5 and 10 to the intersection with $L' = 2,772$ feet. Then move horizontally left to the movable scale and read $E_4 = I' K' C' f(L') = E_3 f(L') = 1.4$ tons per acre. Since there is no vegetative cover involved, E_5 (fig. A-7) $= E_4 = 1.4$ tons per acre.

Emergency tillage is a very temporary means of control, but very effective as shown by this example. When the emergency tilled surface loses its effectiveness, the operation can be repeated. On sandy soils the field cultivator may not create a stable surface. It may be necessary to use a lister to cover highly erodible material and bring up nonerodible clods.

