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1130

Wind Erosion Equation: Computer Solution and Application[1]

E. L. SKIDMORE, P. S. FISHER, AND N. P. WOODRUFF[2]

ABSTRACT

A wind-erosion equation was programmed for computer solution. The relationships among variables are evaluated by the computer, and the general functional relationship between soil loss and independent variables, $E = f(I', C', K', L', V)$, is solved stepwise to give potential average annual soil loss, E, in tons per acre per annum for specified conditions of erodibility, I'; roughness, K'; climatic factor, C'; equivalent field length, L'; and equivalent vegetative cover, V. The computer also can solve the equation to determine field conditions necessary to reduce potential erosion to a tolerable amount and can compare the effectiveness of various combinations of erosion-control treatments.

Additional Key Words for Indexing: **wind erosion control, soil loss, computer program.**

A WIND-EROSION equation was developed (4) after nearly 30 years of research to determine the primary factors that cause soil erosion by wind. The equation expresses the amount of potential average annual erosion, E, that will occur from a given agricultural field in equivalent variables: $E = f(I', K', C', L', V)$ where I' is a soil-erodibility index, K' is a soil-ridge roughness factor, C' is a climatic factor, L' is median unsheltered travel distance across field, and V is equivalent quantity of vegetative cover.

The equation was designed to determine (i) the amount of potential wind erosion that will occur from a given agricultural field, and (ii) the different field conditions of cloddiness, roughness, vegetative cover, sheltering from wind barriers, or width and orientation of field required to reduce potential soil loss to a tolerable amount under different climates.

Because of the many tables and figures required to solve the functional relationships of the equation, manual solution is cumbersome. Users have pointed out the need to: (i) simplify the solution of the equation, especially the use of the chart with the detachable, movable scale; (ii) include alternative combinations of wind-erosion control practices; and (iii) note costs and degree of control.

Hence, we developed a computer solution of the wind-erosion equation that simplifies its use and thereby reduces costs, improves accuracy and speed, and allows the user to look at many combinations of wind-erosion control practices to select those that are most economical for his particular field and climatic conditions.

PROCEDURE

A computer program using Fortran IV was written to solve the wind-erosion equation. The computer solution is similar to the manual solution but requires a certain minimum amount of information, which can be supplied easily on "Form 1 for Computer Solution of Wind Erosion Equation" (Fig. 1). Appropriate data are entered in the blanks on Form 1 and appropriate boxes are checked. For length and mass measurements, either English or metric units may be used.

Item 1, percentage of soil aggregates greater than 0.84 mm, is determined from dry sieving as described by Chepil and Woodruff (1).

The information in item 2 is needed to find potential soil loss from knolls as a percentage of that on level ground, I_s. If no information is supplied for item 2, the program assumes no knoll influence.

From the information in items 1 and 2, soil and knoll erodibility, I', is determined. Soil-ridge roughness factor, K', is determined from the information of item 3, which provides for several alternatives: (*a*) ridge height and spacing (given in either inches or centimeters); or (*b*) ridge-roughness factor (from standard roughness photo comparisons and use of Fig. 7 in reference 3 or Fig. 4 in reference 4); or (*c*) whether field is smooth or rough. Soil-ridge roughness is 1.0 and 0.5 for smooth and rough fields, respectively. In case of default or no information, soil-ridge roughness of 1.0 is used.

That gives sufficient information to compute $E_2 = I'K'$. $E_3 = I'K'C'$ can be determined from additional information of item 4, the climatic factor, C'. For most regions of the United States, the climatic factor is found, on a monthly basis, in Agriculture Handbook no. 346 (3).

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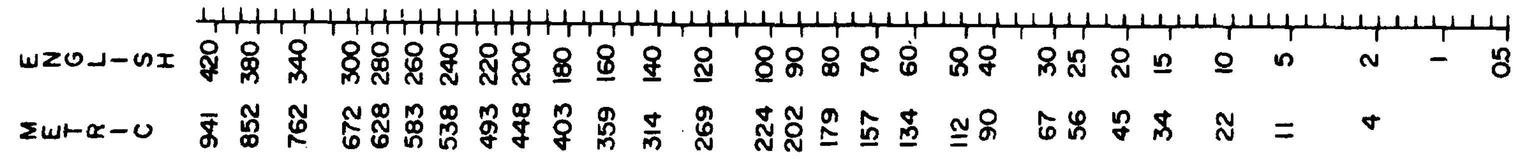
Table 1—Deviations of curve of E_2 vs L' from reference for use in determining E_4

SOIL LOSS, E_2 TONS/A /YR and TONS/HA /YR		MEDIAN UNSHELTERED DISTANCE ACROSS FIELD, L' (METERS AND FEET)																		
		3,048	2,438	1,829	1,219	914	610	305	244	183	122	91	61	30	24	18	12	9	6	3
METRIC	ENGLISH	10,000	8,000	6,000	4,000	3,000	2,000	1,000	800	600	400	300	200	100	80	60	40	30	20	10
672	300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	1.00	2.75	3.50	4.90	6.90	8.50	11.00	15.50
650	290	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.75	1.25	3.00	3.75	5.10	7.00	8.75	11.50	16.00
628	280	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.75	1.50	3.50	4.25	5.80	7.90	9.50	12.00	16.50
605	270	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.80	1.80	3.90	4.70	6.00	8.10	10.00	12.50	17.00
583	260	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	1.00	1.80	3.70	4.50	6.00	8.20	10.10	12.80	17.50
560	250	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	1.00	2.00	4.00	5.00	7.50	8.75	10.60	13.00	17.60
538	240	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.75	1.10	2.10	4.20	5.20	7.00	9.00	11.00	13.50	18.20
516	230	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.95	1.50	2.50	4.80	5.90	7.50	9.75	11.50	14.00	18.60
493	220	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	1.00	1.60	2.80	5.00	6.10	7.90	10.00	11.80	14.30	18.80
471	210	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.75	1.50	2.00	3.30	5.90	6.90	8.20	10.40	12.20	14.50	18.90
448	200	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.80	1.50	2.10	3.40	6.00	7.00	8.75	10.90	12.50	15.00	19.40
426	190	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.80	1.30	2.00	2.80	4.00	6.10	7.00	8.80	11.00	12.60	15.10	19.75
403	180	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.50	1.00	1.90	2.50	3.90	6.50	7.50	9.20	11.40	13.00	15.80	20.00
381	170	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.75	1.10	2.00	3.00	4.25	7.00	8.00	9.80	11.80	12.50	16.00	20.00
359	160	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.90	1.40	2.40	3.10	4.80	7.40	8.50	10.10	12.30	14.00	16.50	20.60
336	150	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.90	1.50	2.50	3.50	5.00	7.75	8.90	10.50	12.60	14.50	17.00	21.00
314	140	0.00	0.00	0.00	0.00	0.00	0.00	0.75	1.00	1.80	2.90	3.60	5.20	8.00	9.00	10.60	12.90	14.50	17.00	21.00
291	130	0.00	0.00	0.00	0.00	0.00	0.00	0.80	1.00	1.95	3.00	3.90	5.40	8.00	9.20	11.00	13.00	14.90	17.30	21.10
269	120	0.00	0.00	0.00	0.00	0.00	0.25	1.10	1.80	2.60	3.80	4.75	6.20	9.00	10.00	11.80	13.80	15.50	17.75	21.50
247	110	0.00	0.00	0.00	0.00	0.00	0.30	1.50	1.95	2.90	4.00	5.00	6.75	9.50	10.60	12.30	14.50	16.20	18.60	22.60
224	100	0.00	0.00	0.00	0.00	0.00	0.30	1.50	2.00	3.00	4.25	5.40	7.00	10.00	11.00	13.00	15.00	16.50	19.20	23.00
202	90	0.00	0.00	0.00	0.00	0.00	0.50	1.80	2.25	3.30	4.80	5.90	7.60	10.60	11.50	13.45	15.75	17.50	19.80	24.00
179	80	0.00	0.00	0.00	0.00	0.20	0.75	2.00	2.50	3.60	4.90	6.00	7.60	10.70	11.90	13.60	16.00	17.50	20.00	24.00
157	70	0.00	0.00	0.00	0.50	0.80	1.25	2.75	3.20	4.00	5.25	6.20	8.00	10.80	12.00	13.75	16.00	18.00	20.50	26.10
134	60	0.00	0.00	0.00	0.25	0.60	1.20	2.90	3.30	4.40	5.70	6.80	8.45	11.50	12.70	14.75	17.00	19.00	21.70	26.50
112	50	0.00	0.00	0.00	0.50	0.90	1.50	3.00	3.75	4.80	6.00	7.10	9.00	12.40	13.55	15.60	18.00	20.10	23.00	28.00
90	40	0.00	0.00	0.00	0.60	1.00	1.90	3.50	4.20	5.20	6.80	7.90	9.80	13.10	14.50	16.50	19.20	21.00	-1.00	-1.00
78	35	0.00	0.00	0.25	1.00	1.40	2.10	3.95	4.50	5.60	7.00	8.10	10.10	13.90	15.25	17.40	20.50	-1.00	-1.00	-1.00
67	30	0.00	0.00	0.25	0.90	1.30	2.20	4.00	4.80	6.00	7.50	8.90	11.00	15.00	16.40	19.00	-1.00	-1.00	-1.00	-1.00
56	25	0.00	0.00	0.40	1.00	1.80	2.50	4.50	5.30	6.75	8.25	9.90	12.00	16.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
45	20	0.00	0.00	0.50	1.00	1.80	2.50	5.00	5.80	7.10	9.10	10.80	13.80	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
34	15	0.00	0.25	0.75	1.50	2.00	3.25	5.50	6.50	8.00	10.10	12.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
22	10	0.00	0.25	0.50	1.25	2.00	3.10	5.75	6.80	8.60	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
11	5	0.00	0.60	1.00	2.00	2.75	3.75	6.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00

SCALE USED WITH TABLE ABOVE FOR DETERMINING SOIL LOSS E_4

SCALE DIVISIONS



SOIL LOSS E_3 = I'K'C' OR E_4 = I'K'C' f(L') (TONS/A /YR AND TONS/HA /YR)

If the information for this form is given in metric units, check /_/.

1. Percentage of soil aggregates greater than 0.84 mm _____.
2. Windward knoll slope, (for slope lengths less than 500 feet) _____ %.
   a. From top of knoll /_/
   b. From upper 1/3 /_/
   Default I_s = 1
3. Fill in the appropriate (not more than one entry):
   a. Ridge height _____ (in or cm)
   Ridge spacing _____ (in or cm)
   b. Ridge roughness factor _____ (dimensionless)
   c. Field is smooth /_/ or rough /_/
   Default K' = 1
4. The climatic factor is _____ %.
5. Fill in the following:
   a. The angle of deviation of prevailing wind erosion direction from right angles to field strip is _____ degrees.
   b. Preponderance of wind erosion forces in prevailing wind erosion direction is _____.
   c. Height of barrier _____ (ft or m)
   d. Field width _____ (ft or m)
   Default = 5,000 feet
6. Quantity of vegetative cover _____ (lbs /acre or kg /ha)
7. Type of vegetative cover (check all correct responses):
   a. Small grain stubble /_/
   1. Flat /_/
   2. Standing /_/
   b. Small grain crops in seedling or stooling stage /_/
   1. Furrow /_/
   2. Smooth /_/
   c. Sorghum stubble /_/
   1. Flat /_/
   2. Standing /_/
   3. Height _____ (in. or cm.)
8. Check if Form 2 follows /_/.

Fig. 1—Form 1 for computer solution of wind erosion equation.

The information for item 5 is required to determine median unsheltered travel distance across field, L'. Formerly (3, 4) referred to as unsheltered distance along prevailing wind-erosion direction, L' is a measure of equivalent field width based on the preponderance of wind-erosion forces in the prevailing wind-erosion direction as well as on deviation of the right angle of the strip from prevailing wind-erosion direction. Such wind-erosion data for 212 locations in 39 states is found also, by months, in USDA Agriculture Handbook no. 346 (3).

The Agriculture Handbook gives a series of figures that relate percentages of wind-erosion forces traveling distances equal to or greater than k times field width, W, in traversing field for various preponderances of wind-erosion forces in prevailing wind-erosion direction and angles to field strip. Because k_{50} times field width equals median travel distance, that value is recommended for use with the wind-erosion equation. The five figures in the Agriculture Handbook were combined into one (Fig. 3) to give k_{50} as a function of preponderance of wind erosion forces, R_m, for various angles of deviations, A, of prevailing wind-erosion direction from right angles to field strip. This new figure is used by the computer in solving the wind erosion equation but is neither used nor needed by the user of Form 1.

The L' used to determine soil loss, $E_4 = I'K'C'\ f(L')$, equals median travel distance, $k_{50}W$, less 10 times the height of any wind barrier present.

The chart that has been used previously (3, 4) to determine $E_4 = I'K'C'\ f(L')$ from soil loss, $E_2 = I'K'$, and $E_3 = I'K'C'$, and unsheltered median travel distance across the field, L', has a movable scale. This movable scale created a problem for computer manipulation. Using the data from the old chart, we generated tables compatible with computer manipulation. The numbers in Table 1 represent distance deviations of curve of E_2 versus L' from E_2 at an L' of 3,048 m (10,000 ft). For example,

If the information for this form is given in metric units, check /_/.

1. What is tolerable amount of wind erosion (tons/acre/yr or metric tons/ha /yr)?

   Lower limit _____ Upper limit _____ Increment _____
2. Check the blank opposite the variable under investigation. Check the box opposite the variable specified and specify this variable by entering appropriate values.

   ___ /_/ a. Soil cloddiness (percentage of aggregates greater than 0.84 mm)

   Lower limit _____ Upper limit _____ Increment _____

   ___ /_/ b. Soil ridge roughness factor (dimensionless)

   Lower limit _____ Upper limit _____ Increment _____

   ___ /_/ c. Quantity of vegetative cover (lbs /acre or kg /ha)

   Lower limit _____ Upper limit _____ Increment _____

   ___ /_/ d. Barrier height (ft or m)

   Lower limit _____ Upper limit _____ Increment _____

   ___ /_/ e. Field width (ft or m)

   Lower limit _____ Upper limit _____ Increment _____

   ___ /_/ f. Climatic factor (percent)

   Lower limit _____ Upper limit _____ Increment _____
3. The program searches the conditions necessary to limit potential soil loss to amount specified in item 1, ± _____ %. Default = 5%

Fig. 2—Form 2 for computer solution of wind erosion equation.

Table 1 value for E_2 = 224 metric tons/ha/yr and L' = 305 m is 1.50. Thus, E_2 for an L' of 305 m is 1.50 less than E_2 for L' of 3,048 m. The units of distance deviation are arbitrary.

To find E_4, after getting a value of E_2L' from Table 1, locate E_3 on scale at bottom of Table 1 and then move to the left or right (right if E_2 is greater than E_3) the number of divisions on the scale equal to the number from Table 1. If E_3 were 202 and the value from Table 1 were 1.5, then E_4 = 184, which is 1.5 marks (scale divisions) to the right from 202.

Table 1 and Fig. 3 are used by the computer to solve the wind-erosion equation; therefore, anyone using the computer

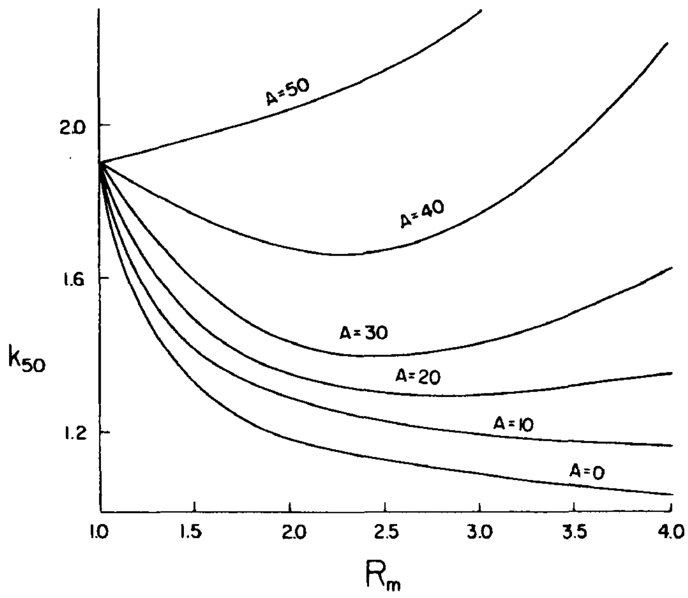


Fig. 3—Composite (at 50%) of figures relating percent of wind erosion forces traveling distances equal to or greater than k times field width in traversing field for various preponderances of wind erosion forces in prevailing wind erosion direction, R_m, and angles of deviation of prevailing wind erosion direction from right angles to field strip, A.

to solve the equation does not need to concern himself with them. However, Table 1 and Fig. 3 may be used to solve the equation manually.

The quantity of vegetative cover (item 6) and type and orientation of vegetative cover (item 7) are both required to determine equivalent vegetative cover, V, and to compute the final answer of potential annual soil loss for the specified conditions. If the vegetative cover is other than that specified (item 7), an estimate must be made as to its effectiveness until additional research data are available.

Item 8 of Form 1 is checked if Form 2 (Fig. 2) is also used. When the data from Form 1 are punched on IBM cards and added to the source deck, the program is ready to run to determine the annual potential soil loss for the conditions specified. As many sets of data as desired may be added to the deck and all run at the same time.

Information from Form 2 (Fig. 2) is used to supplement information from Form 1 to evaluate various combinations of wind-erosion control practices for desired levels of control. Decide on the range for tolerable amounts of wind erosion and enter it in item 1. Combinations of variables (two at a time) in item 2 are examined for controlling erosion to amounts specified in item 1. To designate the variables, check the blank opposite the variable under investigation. The variable checked may be thought of as the dependent variable. The equation is solved to find the level of that variable required (levels of other variables are specified) to control erosion to amounts indicated in item 1.

Check the box opposite another variable and specify this second variable by entering appropriate values for lower limit, upper limit, and increment.

The information from Form 2 is added to the information from Form 1 and the program is executed. The wind erosion equation is solved to determine the level of the variable opposite the blank checked in item 2 for all combinations of tolerable amounts of wind erosion specified in item 1 and levels of variable with checked box. The computer ends the search when it finds the conditions that limit potential soil loss to plus or minus 5 percent of the amounts indicated in item 1 of Form 2. If you desire to terminate search at some other level of precision, indicate tolerance in item 3, Form 2.

If you desire to search for only one value for tolerable amount of wind erosion, enter this value in both blanks for lower and upper limit of item 1 and leave increment blank.

RESULTS AND DISCUSSION

A few copies of Form 1 (Fig. 1) were completed for a wide variety of conditions. The data were punched on cards and the program executed. The same data were used to solve the equation manually. Agreement between computer and manual solutions was excellent, even though the interpolation procedure of the computer solution was much more precise than was the manual solution.

Speed is probably the greatest advantage of the computer solution. The short execution time allows the user to look at many possible situations with nominal cost. For example, suppose we are interested in soil loss as influenced by angle of deviation of field strip from right angles to prevailing wind-erosion direction for preponderance of wind-erosion forces in the prevailing wind-erosion direction of 1.0, 2.0, and 4.0. Field conditions of cloddiness, roughness, width, and vegetative cover are 44%, smooth, 122 m (400 ft), and none, respectively, and climatic factor is 100%. The results for those conditions for various angles of deviation and preponderance are shown in Fig. 4. When preponderance is 1.0, soil loss is not affected by angle of deviation; when preponderance is 2.0, soil loss increases with angle of deviation for all angles of deviation less than 45 degrees and is less than soil loss when preponderance is 1.0. As the preponderance increases, soil loss decreases at low angles of deviation but increases at large angles of deviation.

The amount of potential erosion that can be tolerated depends on economic loss of soil resource, damage to crop, pollution of environment, and expense and complexity of

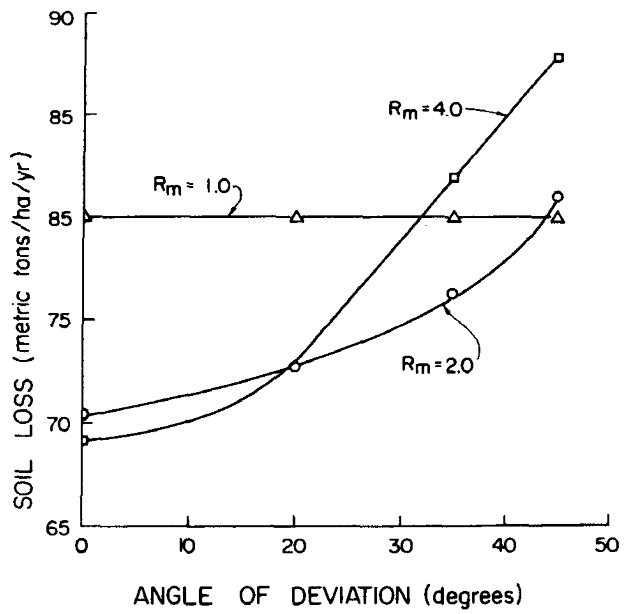


Fig. 4—Soil loss as influenced by angle of deviation of field strip from right angles to prevailing wind erosion direction, A, for preponderances of wind erosion forces in the prevailing wind erosion direction, R_m, of 1.0, 2.0, and 4.0. $I' = 50$, $K' = 1.0$, $C' = 100$ percent, $FW = 122$ m (400 ft), $V = 0$.

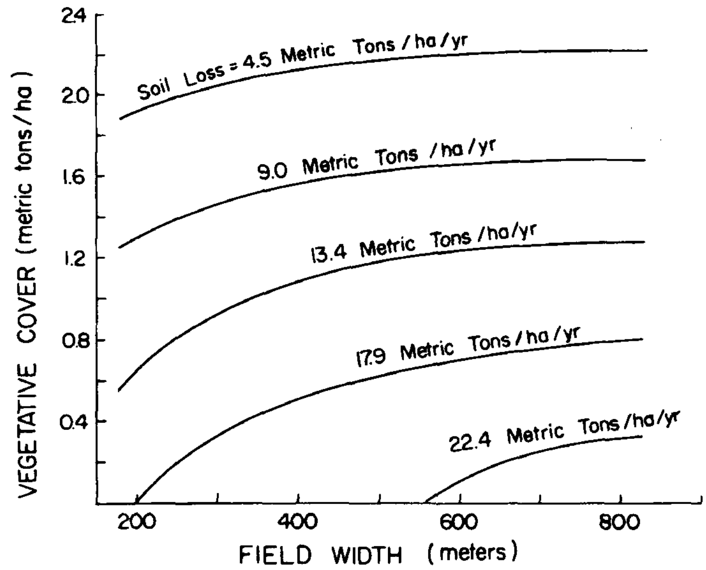


Fig. 5—Combination of vegetative cover (standing sorghum stubble 30 cm high) and field widths required to control potential soil loss to specified amounts from a rough field with 10% of soil aggregates greater than 0.84 mm. Climatic factor is 20; field strip is at right angles to prevailing wind erosion direction; and preponderance of wind erosion forces in prevailing wind erosion direction is 1.5.

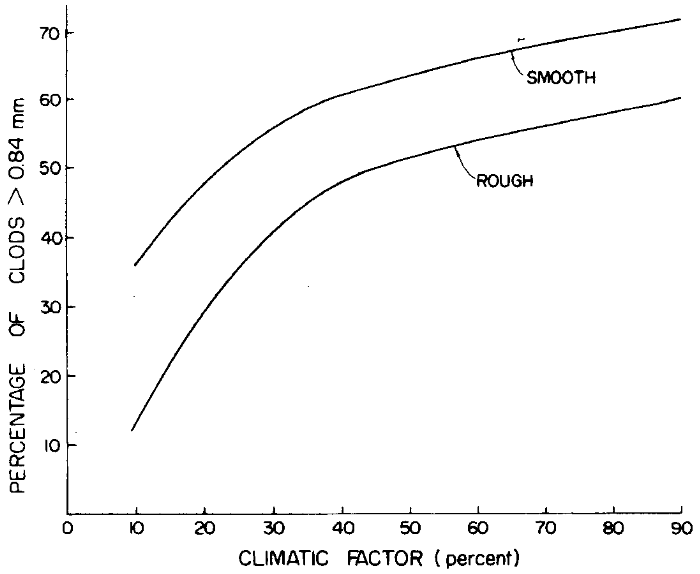


Fig. 6—Combination of clods greater than 0.84 mm and climatic factors required to control potential soil loss to 11.2 metric tons/ha/yr (5 tons/acre/yr) from a smooth and a rough field 450 m wide. Field has no vegetative cover and deviates 20 degrees from right angles to prevailing wind erosion direction; preponderance of wind erosion forces in prevailing wind erosion direction is 2.0.

reducing the potential soil loss. Suppose for a particular situation we would like to control potential soil loss to 4.5 metric tons/ha/yr (2 tons/acre/yr) but would tolerate up to 22.5 metric tons/ha/yr (10 tons/acre/yr). We look at some combinations of practices we could use to control soil loss between 4.5 and 22.5 metric tons/ha/yr in increments of 4.5 metric tons/ha/yr.

We have several alternatives for controlling wind erosion to the specified amounts: increasing soil cloddiness, optimizing soil ridge roughness, increasing vegetative cover, establishing wind barriers, and decreasing field width.

Suppose for a particular situation we are most interested in various combinations of two of those variables, say vegetative cover of standing sorghum stubble 30 cm high at field widths from 200 m to 800 m in increments of 200 m. When that information is entered properly on Form 2 and added to the information of Form 1 and cards are punched and the program is executed, we get the data shown in Fig. 5. Between 1.9 and 2.2 metric tons/ha of standing sorghum stubble are required to control potential soil loss to 4.5 metric tons/ha/yr for field widths between 200 and 800 m, with field width only slightly affecting amount of vegetative cover required. At greater amounts of tolerable soil loss, field width has a greater influence on amount of vegetative cover and less vegetation is required. At field width less than 550 m, no stubble is required to limit potential soil loss to 22.4 metric tons/ha/yr.

For another example, suppose we would like to know the percentage of clods greater than 0.84 mm required to limit potential soil loss to 11.2 metric tons/ha/yr (5 tons/acre/yr) for various climatic factors between 10 and 90%. We would like to know the percentage for both a smooth and a rough field each 450 m wide. The field has no vegetative cover and deviates 20 degrees from right angles to prevailing wind-erosion direction. Preponderance of wind-erosion forces in prevailing wind-erosion direction is 2.0.

The solution of the problem is presented in Fig. 6. The percentage of clods greater than 0.84 mm required increases quickly as the climatic factor increases from 10 to 40%. As the climatic factor increases above 40 percent, the percentage of clods greater than 0.84 mm increases more slowly and almost linearly with increase in climatic factor. The percentage of clods greater than 0.84 mm required to control soil loss to 11.2 metric tons/ha/yr is about 24% more for a smooth field than for a rough field at climatic factor of 10. The difference between smooth and rough field decreases to about 12% of clods greater than 0.84 mm at a climatic factor of 40 and remains almost unchanged as the climatic factor increases to 90%.

Examples given illustrate that the computer solution of the wind-erosion equation greatly simplifies use of the equation and improves accuracy and speed. Most important, the computer solution allows the user to look at many combinations of wind-erosion control practices for particular field and climatic conditions. With that information he can select more judiciously the most economic practice or practices to achieve the desired control of wind erosion.

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