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The Effects of Plant Residue Cover and Clod Structure on Soil Losses by Wind[1]

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ABSTRACT

Tests were conducted in the field to determine the interrelationships of surface drag, surface roughness, plant residue cover, percent of soil material less than 0.42 mm in diameter, and soil loss obtained by means of a portable wind tunnel. The tests were conducted at Garden City, Colby, and Manhattan, Kans. on plots prepared especially to obtain a range in residue cover over a range in soil structure.

The data obtained were analyzed according to standard multiple regression and correlation procedure and presented in terms of regression equations. The exponential regression equations provided a satisfactory expression of the functional relationships. Factors effecting variation in results between the different locations were cited.

The regression equations illustrate the effect of each factor on soil loss. On the basis of relationships secured at three locations, an exponential equation approximating the results of the tests as a whole was developed. In this equation, soil loss, X, in pounds per acre is shown to vary directly as the 2.5 power of the surface drag of the wind and the 3.5 power of the percent of soil fractions less than 0.42 mm in diameter. It varied inversely as the 0.8 power of the weight of surface residue. A simplified clod structure-residue index of soil loss, wherein the surface drag of the wind is held constant at 3,000 pounds per acre, is presented.

Residue cover and soil structure are two of the major factors governing the susceptibility of a soil to erosion by wind. Studies of the effects of crop residues in reducing erosion from trays of soil placed in a laboratory wind tunnel have been reported by Chepil (2). Again studies of soil structure in relation to soil erodibility by wind have been carried out by Chepil (1) in a laboratory wind tunnel. The purpose of this research is to express erosion of soil as a function of certain characteristics of wind force, surface residue, and soil structure.

It has been demonstrated by Zingg (5) that the erodibility of field surfaces can be evaluated with a portable wind tunnel; also, it has been shown that soil loss from a given plot at a given time can be expressed as a function of wind force and surface roughness. Erosion from plots in various crops or cultural systems varied greatly at a given time dependent upon vegetal cover, surface roughness, and soil structure. Soil losses for a given crop or cultural practice also varied greatly with time due to changes in the same factors.

Results of previous studies suggest the possibility of designing an experiment in which several factors affecting soil loss may be evaluated simultaneously. Such a procedure would give recognition to the interacting influences of the variables.

Procedure

Temporary field plots were established for the study. At a given location a plot of bare fallowed soil was selected. The site was approximately level and uniform in soil characteristics. The area was divided into four blocks arbitrarily identified as A, B, C, and D. Four plots 50 feet long and 8 feet wide were established in each block. The plots in each block were designated by numbers 1 to 4. The total number of plots was 16.

A range of clod structure was developed in each of the blocks by disking the number 1 plot once, the number 2 plot 3 times, the number 3 plot 6 times, and the number 4 plot 12 times. A tandem disk was used for this operation. After securing similar ranges of soil structure on the plots in each block, wheat straw was placed on the surface of each of the blocks. The straw was applied as uniformly as possible to each plot by hand. The rate of application was equivalent to 250, 500, 1,000, and 2,000 pounds per acre for the plots of blocks A, B, C, and D, respectively. A wheel packer was then pulled across the series of plots at right angles to the direction of their length. The packer tended to corrugate the soil surface uniformly and to anchor the straw. After treatment, the series of plots provided a range of residue cover over a soil varying in clod structure.

The 16 plots of a series at a given location were subjected to wind tunnel tests using the usual equipment and techniques (5, 6, and 7). On each plot the wind tunnel was operated at four progressively increasing pressure levels from which the surface drag of the wind and the "ridge roughness equivalent" of the test surface are calculable. Operation at each level of surface drag, expressed as the absolute force of the wind in pounds per acre over the test surface, was continued until soil movement ceased. During each operation, amounts of soil eroding from a plot were collected at heights of 1, 3¼, 6, and 10 inches above the soil surface at the end of the 30-foot length of the tunnel. Integration of the functional relationship of the weight of soil eroded to height above the surface provided the estimate of total soil removed at given surface drag level. These soil losses are expressed in the equivalent of pounds per acre from the 90-square-foot test area covered by the tunnel.

The clod structure of the surface of each of the plots was determined at the time of the tests from triplicate samples. The samples were taken to a depth of approximately one inch and

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passed through a rotary sieve. This dry sieving separated the soil mass into seven aggregate size-groups, ranging from <0.42 to >38 mm in diameter. The erodibility of a soil is related mainly to the percent weight of fractions <0.42 mm in diameter. Chepil (3) in laboratory studies of the dry aggregate structure as an index of erodibility has obtained a correlation coefficient of 0.98 for amounts of soil eroded as a function of apparent density and four size-fractions. A correlation coefficient of 0.96 is obtained, however, by using the fraction <0.42 mm as a single variable. While estimates based on several sizes yield a slightly better estimate of erodibility, the difference based on the data at hand is not significant. For purposes of this study the percent weight of surface soil <0.42 mm in diameter will be used as a parameter of soil structure related to erodibility.

Disking, as carried out in the present experiment, served two purposes: first, it provided a range of clod structure, and second, it mixed the surface soil to produce a fairly uniform distribution of clods near the surface of the soil. The latter is a condition approximated only in newly cultivated fields. The immediate surface of undisturbed field soils often has greatly different characteristics from those present in the upper inch of the horizon.

Tests, according to the procedures outlined above, were conducted at three locations. A series of plots was tested on fine sandy loam of undetermined series at the branch experiment station at Garden City, Kans. during June 1950. Again a series of plots was prepared on Sherman silt loam and tested in October 1950 on the branch experiment station at Colby, Kans. The last series of plots was prepared on Sarpy sandy loam on the Soil Conservation Nursery near Manhattan, Kans. and tested in the latter part of October 1950.

Certain difficulties were experienced in preparing plots and conducting tests at Garden City and Manhattan, Kans. At the Garden City location a windstorm and a light sprinkle of rain occurred between the time of the preparation of plots and their testing. The natural wind eroded some of the fine soil fractions from the plots serving to reduce the regimen of soil loss in subsequent tests. At Manhattan, Kans. unfavorable field conditions of a different nature were encountered. The soil contained considerable moisture at the time the plots were disked. This made it difficult to control the structure by tillage. Again, a wheel-type packer could not be obtained to anchor the straw, and a disk with the blades set straight was used for the purpose. The straw was poorly anchored, and some of it was lost during the wind tunnel tests. On the other hand, almost ideal soil and weather conditions prevailed for the preparation and testing of plots at Colby, Kans.

Due to the voluminous nature of the data secured in these studies the results are presented on a sample basis and in the form of multiple regression relationships.

Results

A sample of the results obtained in varying clod structure by systematic tillage procedures is given in table 1. These data are the averages of triplicate determinations of the proportion by weight of soil fractions of various size-ranges. They are for the series of plots at Garden City. It is apparent that a considerable increase in the proportion of the fraction <0.42 mm, subsequently termed "A-fraction," was obtained by increasing the intensity of tillage. The overall range in the percentage of fine material was from 39.2 to 55.8. Not on all of the plots, however, did 3 and 6 diskings increase the percent of fine material appreciably above that from one tillage operation. Reference to the values in the table shows that the increased proportion of A-fraction is accompanied by a decrease in the proportion of clods >6.4 mm in diameter. The proportion of material from 0.84 to 6.4 mm in size remained nearly constant. Similar results were obtained at the other two test locations. At Colby the soil material of a size <0.42 mm ranged from 26.0 to 41.5%. At Manhattan the range was from 34.4 to 54.0%.

The interrelationship of the amount of soil loss, X, in pounds per acre to other measured factors is shown by the correlation and regression coefficients of table 2. The independent variables were τ, the surface drag of the wind in pounds per acre; A, the percentage by weight of soil material <0.42 mm in diameter; R, the amount of dry wheat straw in pounds per acre applied to the plots to represent surface residue; and K, the ridge roughness equivalents of the plot surfaces in inches. It was found that surface roughness, K, was associated closely with the amount of surface residue and to some extent with the percentage of fine soil material. Values of K, therefore, could be omitted for purposes of analyses.

Both simple and multiple correlations, for which the coefficients are presented in table 2, were of the exponential type. Exponential equations appear to provide a satisfactory functional relationship. The coefficients of simple correlation are not in themselves of great importance excepting as they are utilized in the subsequent calculation of beta values. With the exception of the correlation of soil loss and the A-fraction

Table 1.—Percent of soil fractions of Garden City test plots as determined by sieving.

Plot number	Soil fractions						
	A <0.42 mm	B 0.42–0.84 mm	C 0.84–2.0 mm	D 2.0–6.4 mm	E 6.4–12.8 mm	F 12.8–38.0 mm	G >38.0 mm
	%	%	%	%	%	%	%
1A	39.2	7.0	7.5	11.4	12.4	19.0	3.3
2A	43.5	8.6	8.8	12.0	11.7	13.8	1.7
3A	47.8	9.1	9.4	12.4	9.9	11.0	0.3
4A	53.0	8.7	8.9	11.4	8.3	9.5	0.0
1B	46.9	8.4	8.2	10.4	9.4	14.0	2.6
2B	43.1	8.7	8.8	11.8	10.9	16.1	0.4
3B	45.8	8.7	8.8	12.0	10.6	13.0	1.0
4B	50.9	8.6	9.0	12.1	9.6	9.8	0.0
1C	48.4	9.0	9.4	11.7	9.4	11.7	0.5
2C	47.2	9.0	9.0	12.0	10.2	12.1	0.4
3C	46.6	8.5	8.5	11.5	10.7	13.4	0.8
4C	54.5	9.0	8.6	11.7	8.5	7.7	0.0
1D	38.4	7.1	7.1	10.5	11.8	17.6	7.5
2D	47.5	8.9	8.4	11.2	11.0	10.6	2.5
3D	50.8	9.1	8.9	11.6	10.4	9.2	0.0
4D	55.8	9.7	9.3	11.6	9.1	4.6	0.0

Table 2.—Statistical data pertaining to correlation and regression analyses of soil loss with drag, percent of A-fraction, and pounds of crop residue.

	Garden City	Colby	Manhattan
r_{12}*	0.5567	0.3347	0.7212
r_{13}	0.3290	0.4839	0.1245
r_{14}	−0.2852	−0.2516	−0.2755
$\beta_{12.34}$	0.7514	0.8234	0.8871
$\beta_{13.24}$	0.3447	0.6094	0.1748
$\beta_{14.23}$	−0.6445	−0.7224	−0.5528
$R_{1.234}$	0.8458	0.8673	0.9273
$r_{12.34}$	0.7916	0.8033	0.8920
$r_{13.24}$	0.5333	0.7694	0.3842
$r_{14.23}$	−0.7348	−0.7668	−0.7808
$b_{12.34}$	2.4623	2.5312	2.6647
$b_{13.24}$	3.2403	3.9992	1.1984
$b_{14.23}$	−0.7990	−0.9001	−0.5547
a	−8.4995	−9.0927	−7.0005

*Subscript 1 = soil loss, X.
Subscript 2 = drag, τ.
Subscript 3 = percent A fraction, A.
Subscript 4 = residue, R.
r = a coefficient of correlation.
β = a measure of the individual importance of any one of several independent variables.
R = a coefficient of multiple correlation.
r (with subscripts such as 12.34) = a coefficient of partial correlation.
b (with subscripts such as 12.34) = a coefficient of partial regression; a constant in a multiple estimating equation.
a = a multiple regression constant.

from the Manhattan tests, they are, however, all significant statistically.

The coefficients of curvilinear multiple correlation, 0.846 at Garden City, 0.867 at Colby, and 0.927 at Manhattan, have very high statistical significance. This indicates simply that exponential equations may be developed to estimate soil loss. The squares of the multiple correlation coefficients, i.e. 0.716, 0.752, and 0.859 for the data from Garden City, Colby, and Manhattan, respectively, represent approximately the variation that is accounted for by the procedure.

The standard partial regression coefficients, or beta values, indicate the relative importance of the factors involved in predicting soil loss from the specific data at hand. Thus, at Garden City both residue and surface drag are more than twice as important as the percentage of A-fraction in predicting soil loss. At Colby the surface drag has the greatest, and the percentage of A-fraction the least, influence. In this case, however, the differences are not as great, and all are important. At Manhattan surface drag has a five-fold, and residue a three-fold, influence in comparison with the apparent influence of the percentage of the A-fraction.

If the measurements of the various factors were applicable to describing actual conditions encountered in the tests and no extraneous influences were present, beta values for a given factor should be the same at all locations. Beta values of soil loss on surface drag show minor variation between locations. Similar values designating the effect of residue on soil loss show somewhat greater variation. They vary from −0.7224 to −0.5528. The low value obtained at Manhattan is undoubtedly associated with the poor anchorage of straw. Part of the residue was removed from the surfaces, especially at the higher levels of surface drag on the plots having large amounts of residue. The quantities of residue that were effective in reducing soil losses were, apparently, somewhat smaller than those applied.

The greatest differences in standard partial correlation coefficients for a given factor occurred for the relationship of soil loss to the percent of erodible fractions <0.42 mm as determined by dry sieving. As shown in table 2, the values were 0.3447, 0.6094, and 0.1748 at Garden City, Colby, and Manhattan, respectively. As indicated previously, the plots at Garden City were somewhat affected by wind and a light rain. This lowered the regimen of soil loss in relation to measured levels of the A-fraction. A similar effect was experienced at Manhattan where disking the soil in a somewhat moistened condition resulted in the formation of weakly consolidated granules which appeared to resist the surface drag applied in wind tunnel tests. They were, however, too weak in structure to retain their identity during the dry sieving procedure. It is doubtful if the results of dry sieving reflect properly the surface condition exposed to wind tunnel tests.

The following multiple regression equations yielding estimates of soil loss were obtained:

$$\text{Log } X = 2.4623 \log \tau + 3.2403 \log A - 0.7990 \log R - 8.4995$$
$$\text{Log } X = 2.5312 \log \tau + 3.9992 \log A - 0.9001 \log R - 9.0927$$
$$\text{Log } X = 2.6647 \log \tau + 1.1984 \log A - 0.5547 \log R - 7.0005$$

These three equations in logarithmic form represent average relationships for the test data at Garden City, Colby, and Manhattan, respectively. As in the case of the beta values, the exponents of τ, A, and R should be equal in all three equations, providing the influence of the variables is the same or that they have been properly evaluated.

Reduced soil losses effected by increasing amounts

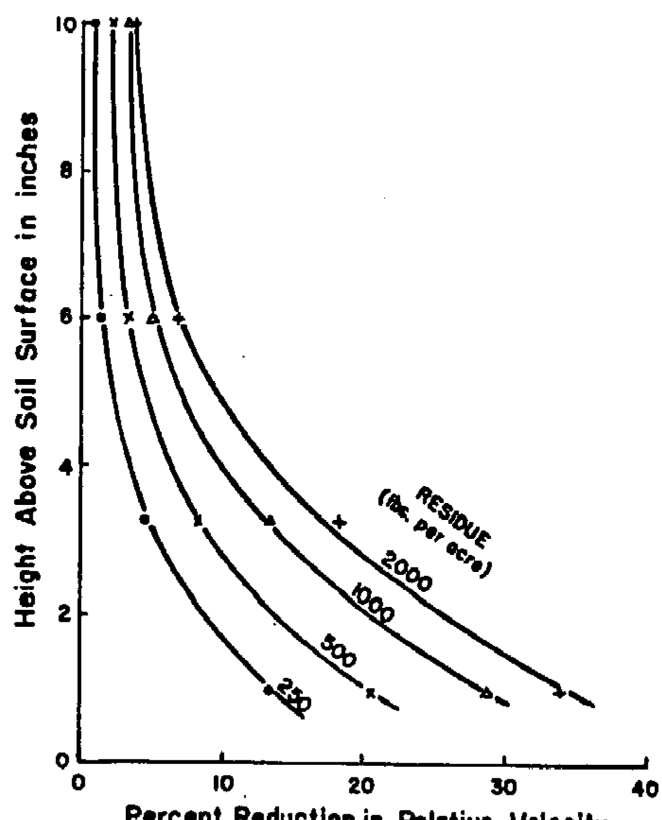

FIG. 1.—Percent reduction in relative velocity at various heights with different amounts of residue. Based on data from experiment at Colby, Kans.

of surface residue are due in part to accompanying reduction in the wind velocity near the soil surface. In other words, increasing proportions of the direct force of the wind are transferred from the soil surface to the residue.

The percent reduction in velocity with height is calculable from velocity readings taken at the four heights in conjunction with the dust sampling procedure at the end of the tunnel. The distribution of velocity with height is given on a dimensionless basis by determining the ratio $\frac{V}{V_c}$. In this ratio, V is the velocity at a given height and V_c is the velocity at the center of the 3-foot tunnel duct, i.e., a height of 18 inches. Values of the ratio $\frac{V}{V_c}$ for the condition where no residue is present can be estimated by extrapolation of the trend established for known amounts of residue. The percent reduction in relative velocity is given by the expression

$$100\left[1-\frac{\frac{V}{V_c}\text{(for any residue)}}{\frac{V}{V_c}\text{(for no residue)}}\right]$$

Values obtained from the above expression for amounts of residue applied in the experiment at Colby, Kans. are shown in figure 1. It will be noted that reductions in the relative velocity at a one-inch height above the average elevation of the soil surface range from 13 to 34% for 250 to 2,000 pounds of residue per acre. Progressively less reduction is obtained with height above the surface.

Interpretation of Results

The exponential relationship which best expresses the results of the tests as a whole is

$$X = C\frac{\tau^{2.5}A^{3.5}}{(10)^9 R^{.8}}$$

In the above equation X is the estimated soil loss in pounds per acre, C is a constant of variation associated with conditions other than those measured, and $\frac{1}{(10)^9}$ is a dimensional constant where X, τ, and R are measured in pounds per acre and A is measured in percent. Soil loss is shown to vary directly as the 2.5 power of the surface drag of the wind, and the 3.5 power of the percent of A-fraction. Soil loss varies inversely as the 0.8 power of the weight of surface residue in the form of wheat straw.

The value of C for any specific condition can be obtained by calculating soil loss from the group of functional variables and determining the ratio of this quantity to the soil losses measured with the wind tunnel. As determined by this procedure, the values of C are 3.67 for the Colby, 0.99 for the Garden City, and 0.35 for the Manhattan data. Thus, approximately a

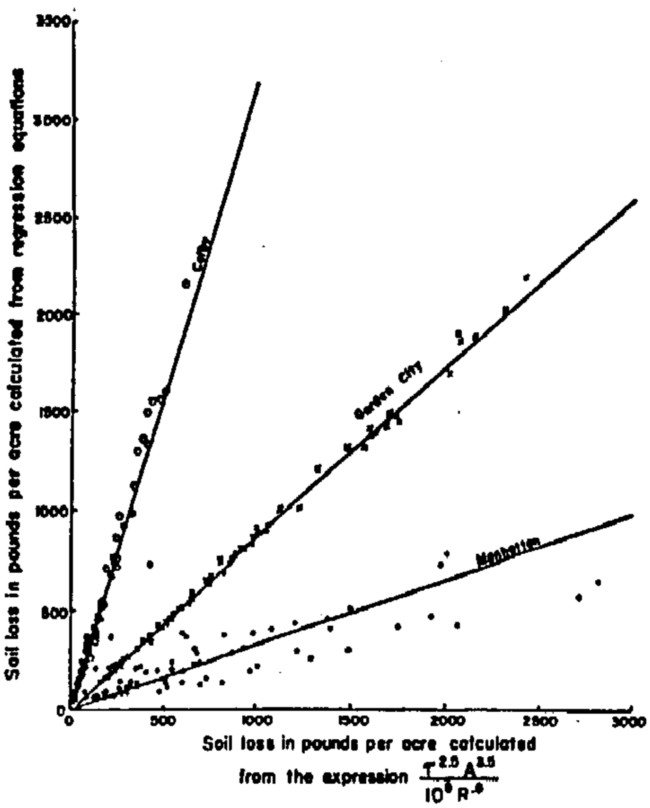

FIG. 2.—Amounts of soil loss as determined by the generalized formula compared with amounts of soil loss as determined by regression equations for each of three locations.

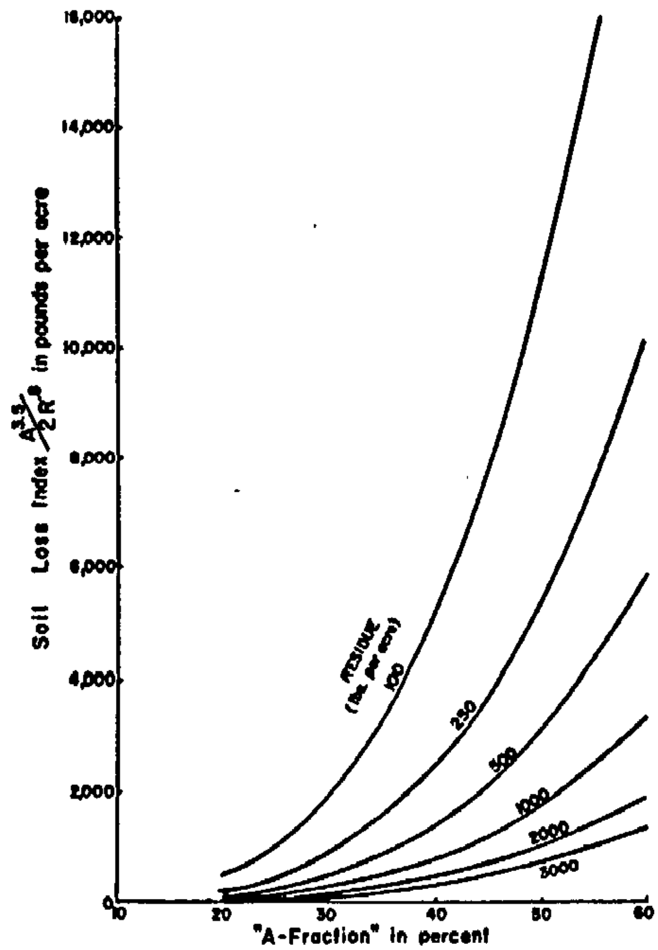

FIG. 3.—Soil loss index in terms of residue and A-fraction when drag is 3,000 pounds per acre.

ten-fold difference in the regimen of soil losses was obtained in the results of tests at Manhattan and Colby.

A graphic representation of the results from the generalized formula in comparison to values calculated by the specific regression equations is given in figure 2. It will be noted that little error is involved in using the simplified general formula in lieu of the regression equations. The values of C obtained graphically by this method are the slopes of the straight lines drawn through the average of values for each of the three test locations.

A simple structure-residue index can be obtained by holding τ constant at a level of 3,000 pounds per acre. This value of surface drag has been used previously to approximate the erosive force of the wind expected at 1 to 2 year recurrence-intervals in the month of April (4). When $\tau = 3{,}000$

$$X = C\frac{3000^{2.5}A^{3.5}}{(10)^{9}R^{.3}} = C\frac{A^{3.5}}{2R^{.3}}$$

Plottings of this index, where C = 1, are shown in figure 3. The plotted curves are for values of A ranging from 20 to 70% and of R ranging from 250 to 3,000 pounds per acre. They demonstrate the relative importance of given characteristics of clod structure and surface residue in controlling erosion by wind.

Elements of soil structure and surface residues in addition to those considered here influence the phenomenon of soil erosion by wind. For example soil conditions at the immediate surface, such as crusting, stability of structure, puddling, and grading of the materials on the immediate surface by the impact of raindrops, as well as the effects of freezing, thawing, wetting, and drying, all play a part. Methods of characterizing these immediate surface conditions are nonexistent or extremely difficult. Again residue cover may vary in kind, height, distribution, and orientation on the surface in addition to the amount of weight present. These items must be recognized as having influences not accounted for in the present research.

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