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PROPERTIES OF SOIL WHICH INFLUENCE WIND EROSION: IV. STATE OF DRY AGGREGATE STRUCTURE

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The development and maintenance of a wind-resistant soil structure comprises one of the most important phases of a wind erosion control program. Although the influence of soil structure on erodibility by wind has long been recognized, it has not been thoroughly understood. Some studies were undertaken over a decade ago in an attempt to elucidate this influence. The purpose of the studies was twofold: to find what structure is most resistant to the action of the wind, and to devise methods of estimating the erodibility of soil by wind.

The relationship between soil structure and erodibility is complex because it involves an interaction of numerous structural factors. The studies so far completed in a wind tunnel have indicated individually the nature and degree of influence of each important structural factor. This report includes the consideration of these factors in relation to one another and proposes methods of estimating the erodibility of soil by wind under the usual range of erosive velocity.

REVIEW OF PREVIOUS WORK

Chepil (2, 4) initiated the study of the relation between the dry aggregate structure of a soil and its erodibility by wind. Many aspects of this problem, because of its intricacy, were not included in the initial study. Consequently, additional experiments were undertaken. These experiments had the following primary objectives: to devise a basic interpretation of the relationship between the dry aggregate structure and erodibility (9), to check the validity of the basic relationship on an entirely new series of soils (10), and to find any possible effect of variations in the apparent density of the various soil fractions on erobility (11).

It was found that the severity of erosion is affected appreciably by the proportion of fine dust in the soil (2), by the ratio of erodible to nonerodible fractions in the soil (9), by the roughness of the soil surface (3), by the distance within the eroding field at which the measurements are being made (8), and by the previous erosional history of the field (7). The cloddy structure was found to reduce the erosive capacity of the wind by retarding wind velocity (4). Clods and ridges were found to act as soil traps, thereby reducing the severity of erosion (6). It was found also that the effectiveness of clods and ridges may be lost by the intense abrasive action of the transported soil fractions and by the filling of surface depressions with drifting soil (8).

What constitutes an erodible or a nonerodible fraction was found to depend in large measure on the velocity of the wind (11). Van Doren (14) found, however, that the critical diameter of a soil fraction that separates the erodible from the nonerodible fractions under normally encountered winds in the field is about 2 mm.

[1] Contribution 435, department of agronomy, Kansas Agricultural Experiment Station, Manhattan, and the Soil Conservation Service, U. S. Department of Agriculture. Cooperative investigations in the mechanics of wind erosion.

SCOPE OF THE PRESENT STUDY

Obviously, there are many soil structural factors that influence the amount and intensity of wind erosion. In an attempt to measure the erodibility of a soil, the major structural factors that influence the amount of erosion must, therefore, be recognized and adequately evaluated. The evaluation of some of the factors, such as those connected with the length of the exposed field and the changes in elevation, cannot be obtained in a wind tunnel of fixed orientation and limited length and width. It is important, therefore, to describe thoroughly the conditions under which the erosional tests in the wind tunnel are carried out. It is equally important to consider the wind tunnel a tool that will measure only the relative erosional property of a soil.

In this study consideration is given to the effect of variations in wind velocity and in the amount, size, shape, and apparent density of discrete soil fractions on erodibility under an artificial wind in a tunnel. Factors of surface roughness, duration of exposure to the wind, soil moisture content, length of exposed area, direction of the wind, recency of cultivation, and surface conditions other than roughness were kept constant throughout the various experiments. Most of the latter factors, however important, could not be studied solely in a wind tunnel.

DIRECT MEASUREMENT OF ERODIBILITY IN A WIND TUNNEL

Measurement of erodibility of a soil in a wind tunnel has been described previously (10). The method has been used to test the erodibility of thoroughly mixed cultivated soils. When in this condition, the characteristic surface crust, such as that developed in the field as a result of rain, was absent. The conditions under which all tests were carried out were as follows: (*a*) a soil surface, leveled by hand or by a metal roller, over which the roughness varied somewhat depending only on the size of the soil aggregates contained in the soil: (*b*) a soil uniformly mixed and free from organic residue; (*c*) a soil dried thoroughly at a temperature of 175°F.; (*d*) a 5-foot length of the exposed soil area; (*e*) a dry air stream with a relative humidity of not more than 25 per cent; and (*f*) a wind free from gusts and blowing from one direction.

On exposure of soil to an erosive wind, removal of erodible fractions continued for some time and ceased as soon as the height of the nonerodible fractions and their number per unit area increased to a degree that completely sheltered the erodible fractions from the wind. A determination of the amount of soil removed up to the time erosion ceased indicated the total amount of soil removable under some definite wind blowing from one direction. Because of the short length of the exposed area, abrasion by impacts from saltation, such as commonly occurs in the field, was virtually absent.

Measurement of wind velocity at some particular height was found to be meaningless unless the effects of surface roughness on the velocity distribution above the ground were known. The drag, or the drag velocity, gives a better indication of the force of the wind on the ground than does the velocity at some fixed height. The drag velocity V_* which determines the slope of the velocity distribution curve when the velocity is plotted against the logarithm of height (fig. 1) is equal to $\frac{V_z}{5.75 \log \frac{z}{k}}$, in which V_z is the velocity at any height z and k is the height at which the projected velocity curves intersect the ordinate. Accord-

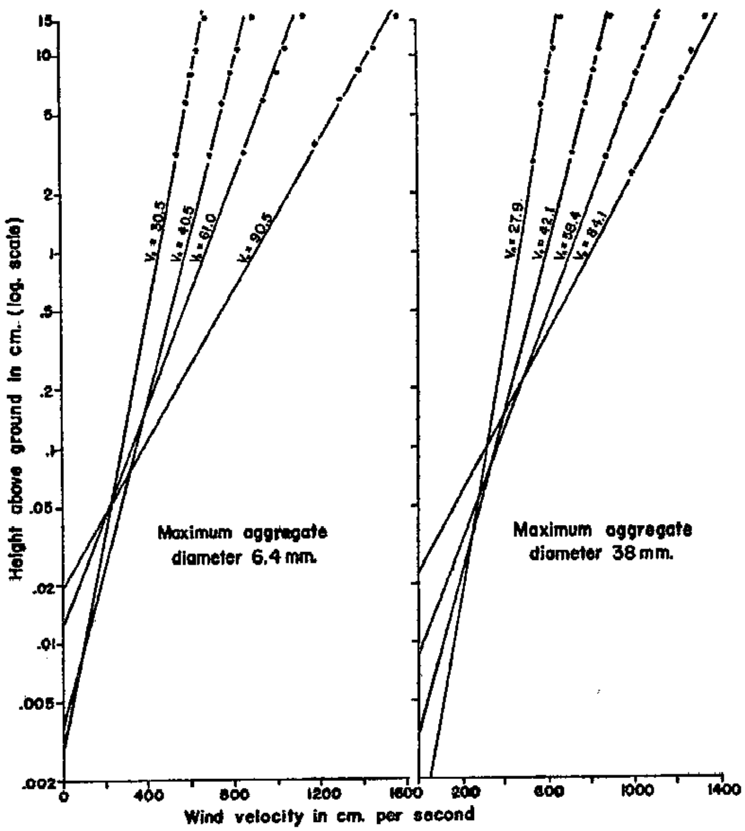

FIG. 1. INFLUENCE OF SIZE OF SOIL AGGREGATES ON WIND VELOCITY DISTRIBUTION AFTER CESSATION OF SOIL REMOVAL

ing to Prandtl and von Kärmän (1, pp. 232–235), k is equal to about $\frac{1}{30}$ of the height of surface projections. The drag velocity V_* is also equal to $\frac{v_1}{8.5}$ where v_1 is the velocity at a height equal to 30 k. The surface drag τ can be computed from the drag velocity, since $\tau = \rho V_*^2$, in which ρ is the density of the air.

In the wind tunnel, this relationship held to about 3 inches in height (fig. 1). From this height upward, velocity usually increased slightly. Since the average height of soil saltation is below 3 inches, it was concluded that the slight velocity deviation from the commonly accepted aerodynamic pattern above this height had little, if any, influence on the movement of the soil.

The data in figure 1 show that the roughness of the surface, as exemplified by the value of k after cessation of soil removal, increased with an increase in the drag velocity. Consideration was given, therefore, to the possible effect of existing differences of surface roughness on the drag velocity and especially on the surface drag. It was impossible to determine the drag velocity accurately by the usual technique of extrapolation shown in figure 1. This value, therefore, was computed from the surface drag determined directly by the method of Zingg.[2] For a definite velocity through the middle of the tunnel, the surface drag varied somewhat, depending on the roughness of the soil surface. Since it was impossible to measure the surface drag in every case, it was necessary to make specific measurements of surface roughness and actual velocity. The necessary adjustments in the drag velocity were then made from the actual velocity and the surface roughness. The values of soil erodibility herein reported are based on equal drag velocity rather than on a velocity at some fixed height. Whether the erodibility should be based on the drag velocity or on the velocity at some fixed height is debatable at present. The drag velocity was chosen for the sake of expediency.

The direct method of measuring erodibility in a wind tunnel was reasonably reproducible, provided all conditions under which comparable tests were made were kept constant. The direct measurement, by itself, however, gave no indication of the causes of variations in erodibility of soils. It was necessary, therefore, to supplement the wind tunnel tests with analyses of structural factors of the soil that have a direct bearing on erodibility. The dry aggregate structure, as determined by dry-sieving, and the apparent density were found to give an approximate indication of the erodibility.

INFLUENCE OF SOIL STRUCTURAL FACTORS ON ERODIBILITY

The relationships between the various soil structural factors and erodibility by wind have been established from a series of detailed experiments in a wind tunnel. These relationships are four in number, each of which is herein represented by a table or some form of graph. Erodibility of any soil of which the dry aggregate structure is known can be computed readily from the tables and graphs.

Let it be assumed that the soil for which the relative erodibility is to be computed is subjected to a drag velocity of 88 cm. per second, that it is composed of 67 per cent of erodible fractions of a mean weighted equivalent diameter of 0.24 mm. of a size distribution shown in table 2, and that the proportions by volume of the nonerodible fractions C and D are 12 and 21 per cent, respectively.

Proportion of erodible and nonerodible soil fractions in relation to velocity

Figure 2 shows an approximate dividing line between the erodible and nonerodible soil fractions as influenced by wind velocity. This dividing line is dependent on the largest equivalent diameter that will be moved by the wind from

[2] Zingg, A. W. Some characteristics of the expanding turbulent boundary layer in a wind tunnel designed for the study of soil erosion. (Unpublished.)

the soil that contains a mixture of various sized fractions. The wind velocity required barely to move the largest discrete soil unit is known as the threshold velocity. The equivalent diameter of a discrete erodible unit is equal to $\frac{\sigma d}{2.65}$, in which σ *is the apparent density of the units of diameter* d. The equivalent diameter is equal to the diameter of a standard sand grain that has an apparent density of 2.65 and an erodibility equal to that of a discrete soil unit of some particular diameter and apparent density. Ottawa sand and washed silt were

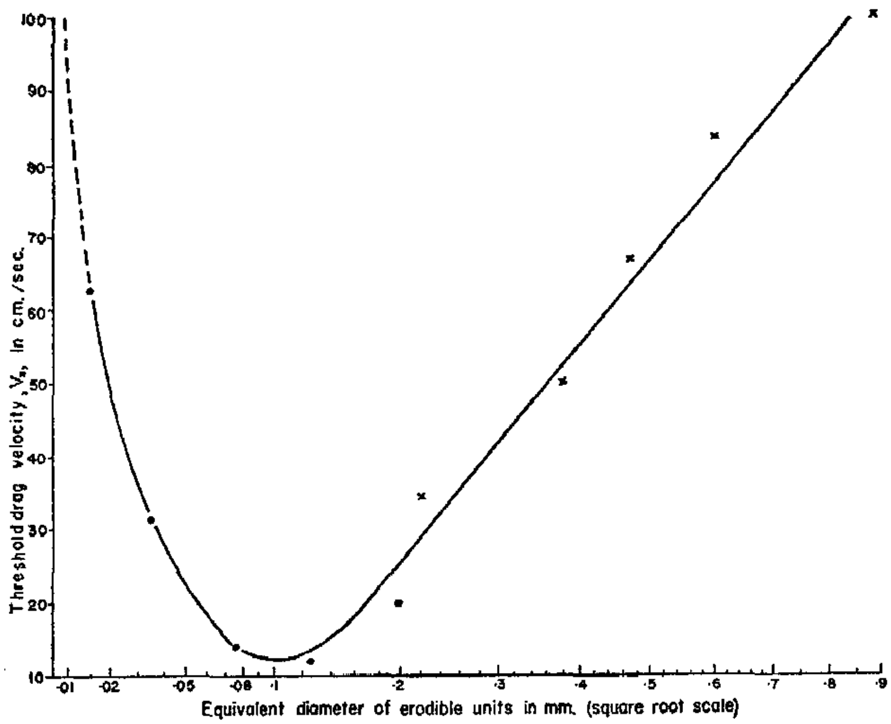

FIG. 2. RELATIONSHIP OF THE THRESHOLD DRAG VELOCITY OF THE WIND TO THE EQUIVALENT DIAMETER OF THE ERODIBLE SOIL UNITS

The data represent the average values for soils containing different proportions of erodible and nonerodible fractions. The plotted values of equivalent diameter show the average of the highest and the lowest equivalent diameters of each sieve grade tested.

taken as this standard. Both are nearly spherical throughout the whole range of size; their bulk density is about 1.53 for any size; their apparent and real density varies little from 2.65.

The force required to move a given equivalent diameter of erodible units from soils that contain mixtures of erodible and nonerodible fractions has been found to be much higher than the force required to move the same size of unit from a soil composed only of erodible fractions. The force required to initiate the movement, especially of the semierodible fractions, varies somewhat with the proportion of the nonerodible fractions contained in the soil. To move the highly erodible fractions between 0.1 and 0.15 mm. in equivalent diameter, the force required is virtually the same irrespective of whether the erodible units are alone or mixed with nonerodible fractions.

The results of previous experiments (11) indicated that zero erodibility of any soil occurs when the equivalent diameter of the most erodible fractions barely exceeds that removable by the wind. Figure 2 indicates that the minimal drag velocity of the wind required to initiate erosion of a soil which contains any mixture of erodible and nonerodible fractions varies as the square root of the equivalent diameter of erodible soil units larger than 0.15 mm. The relationship is somewhat more complex for equivalent diameters smaller than 0.15 mm.

The drag velocity V_* under consideration is 88 cm. per second. Therefore, the equivalent diameter of the grains or aggregates that can be transported by direct pressure of this wind, under the conditions of the experiment, will range up to 0.7 mm. (fig. 2). This and other values of equivalent diameter can be read more conveniently from scale A_1 of figure 3. The nonerodible soil units above the

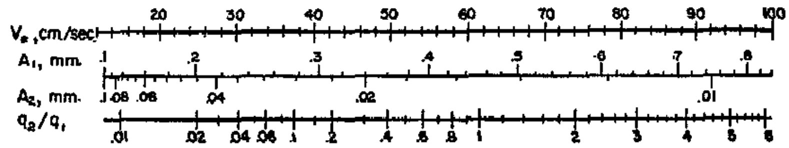

FIG. 3. GUIDE FOR ESTIMATING THE RELATIVE ERODIBILITY (q_2/q_1) AND THE MAXIMUM AND MINIMUM EQUIVALENT DIAMETERS (A_1 AND A_2) OF ERODIBLE FRACTIONS FROM THE DRAG VELOCITY (V_*) OF THE WIND. CORRESPONDING VALUES ARE ALIGNED ALONG A VERTICAL AXIS.

maximum erodible equivalent diameter and up to 6.4 mm. in actual diameter are considered as fraction C and those above 6.4 mm. as fraction D. The minimum equivalent diameter of fraction C will vary, depending on the drag velocity of the wind.

Relationship of volume of nonerodible fractions to erodibility

The erodibility of the soil containing any percentage volume of nonerodible fractions is governed by the principle of surface roughness, which has been described previously (9). According to this principle, the amount of soil erodible under any wind varies directly with the ratio of erodible to nonerodible fractions contained in the soil, provided the volume of nonerodible clods projecting above the surface before exposure to the wind is the same in all comparable cases.

The volume of the nonerodible fractions was determined as follows:

A 2,925-ml. bucket was fitted on the outside with a sleeve extending 2 inches above the top of the bucket. The bucket and sleeve were filled with thoroughly air-dry soil to within 1 inch of the top of the sleeve and tapped on the tapping device (12) until there was no more change in soil volume. The sleeve was removed and excess soil pushed off with a straight edge. The weight of the soil was determined.

The soil, equal in volume to that of the bucket, was gently shaken on a sieve of 6.4 mm. square openings. The weight of the fraction greater than 6.4 mm., known from the original experiments as fraction D, was recorded for the purpose of determining its percentage volume later. More soil was shaken on the 6.4-mm. sieve to obtain more than enough of fraction D to fill the bucket. The bucket with sleeve and their contents were tapped as before. The bulk density of fraction D was computed by dividing the weight in grams of the full contents of the bucket by the volume of the bucket in milliliters. The apparent density of discrete soil units in fraction D was computed by dividing the bulk density by 1.53 and multiplying the quotient by 2.65 (12). If W_1 is the weight in grams of fraction D contained in the bucket and d_1 is its apparent density, then the volume of fraction D in milliliters is equal to $\frac{W_1}{d_1}$. The percentage volume of fraction D is $100\,\frac{V_1}{V}$, where V is the volume of the bucket and V_1 is the volume of fraction D.

The fraction passing through the 6.4-mm. sieve was then weighed, and 250 gm. placed on the elutriator (13) to determine the size-frequency distribution of equivalent diameter up to 2 mm. The fraction remaining in the elutriator, known as part or all of fraction C, depending on wind velocity under which the erodibility was to be determined, was weighed. The apparent density of discrete units in this fraction was determined by the bulk density method as described for fraction D, except that a 54-ml. test tube instead of a bucket was used.

The weight of fraction C in 250 gm. of the portion of soil being elutriated was determined directly from the elutriation data. Let it be assumed that W_2 is the weight of fraction C in the 250-gm. portion and W_3 is the weight of the fractions with a diameter smaller than 6.4 mm. contained in 2,925 ml. of soil. Then W_4, which is the weight of fraction C in 2,925 ml. of soil, is equal to $W_3\,\frac{W_2}{250}$. The volume of fraction C, V_2, is equal to $\frac{W_4}{\sigma}$, where σ is the apparent density of discrete units in fraction C. The percentage volume of fraction C is $100\,\frac{V_2}{V}$.

The values of erodibility for any volume of nonerodible fractions contained in the soil are given in table 1. The soil under consideration contains, under a drag velocity of 88 cm. per second, 12 per cent by volume of fraction C and 21 per cent by volume of fraction D. According to table 1, the erodibility q_1 under a drag velocity of 61.5 for soil containing erodible fractions of an average equivalent diameter of 0.18 mm. is 4.4 tons per acre. As erodibility must be determined for conditions other than these, however, it will be necessary to proceed further with the estimation.

Relation of wind velocity to erodibility

The data in figure 4, based on previous measurements in a wind tunnel (2), indicate that erodibility, as measured by the amount eroded before soil movement ceases, varies as some power of the drag velocity. This power relationship is not altogether uniform. It varies to some degree with soil structure and surface roughness and probably with some other factors as well. Under the conditions of the wind tunnel experiment, the amount of erosion varied, on the average, nearly as the fifth power of the drag velocity. The rate of soil movement, on the other hand, varies as the cube of the drag velocity.

As has been assumed, a determination of erodibility under a drag velocity of 88 cm. per second instead of 61.5 is required. According to scale q_2/q_1 of figure 3, the erodibility q_2 under a drag velocity of 88 cm. per second is equal to 3.9

TABLE 1

Erodibility q_1 in tons per acre for any percentage volume of fractions C and D in mixture with erodible fractions 0.18 mm. in equivalent diameter[1]

Percentage fraction D	Percentage fraction C																						
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	22	24	26	28	30	32	36
0	∞	—	78.3	58.9	44.2	34.4	28.7	24.8	22.3	18.7	16.1	13.1	11.1	9.4	7.5	6.0	4.9	4.1	3.3	2.6	2.1	1.8	1.1
1	—	90.5	71.0	54.4	41.6	32.9	27.6	24.0	21.4	18.0	15.6	12.7	10.6	9.0	7.2	5.7	4.6	3.8	3.0	2.5	1.9	1.5	0.9
2	132.1	81.6	64.6	50.1	39.1	31.5	26.6	23.1	20.5	17.4	15.0	12.2	10.2	8.6	6.8	5.5	4.4	3.5	2.7	2.3	1.8	1.4	0.8
3	113.7	73.6	58.6	46.2	36.8	30.1	25.5	22.2	19.7	16.8	14.5	11.8	9.9	8.2	6.5	5.1	4.0	3.2	2.5	2.0	1.6	1.3	0.7
4	97.9	66.7	53.2	42.4	34.5	28.7	24.5	21.3	18.9	16.1	14.0	11.3	9.4	7.8	6.2	4.9	3.8	3.0	2.3	1.9	1.5	1.2	0.6
5	84.9	60.7	48.3	39.2	32.4	27.4	23.5	20.4	18.0	15.5	13.5	11.0	9.0	7.4	5.8	4.5	3.6	2.8	2.1	1.7	1.4	1.1	0.6
6	74.2	55.1	44.1	36.0	30.4	25.9	22.5	19.6	17.3	14.8	13.0	10.5	8.7	7.0	5.5	4.3	3.3	2.5	1.9	1.6	1.3	1.0	0.5
7	65.7	50.1	40.5	33.4	28.3	24.5	21.8	18.5	16.5	14.2	12.5	10.0	8.3	6.6	5.1	4.0	3.0	2.3	1.8	1.5	1.1	0.9	0.4
8	59.8	45.6	37.2	31.1	26.4	23.2	20.4	17.8	15.8	13.6	12.0	9.7	7.8	6.3	4.8	3.8	2.8	2.1	1.7	1.3	1.0	0.8	0.3
9	53.4	41.6	34.1	28.6	24.7	21.8	19.3	17.0	15.0	13.0	11.5	9.2	7.5	5.8	4.6	3.5	2.6	2.0	1.5	1.2	0.9	0.7	0.3
10	48.2	37.9	31.3	26.6	23.0	20.5	18.2	16.1	14.2	12.4	11.1	8.8	7.2	5.5	4.2	3.2	2.4	1.9	1.4	1.1	0.8	0.6	0.2
11	43.8	34.5	28.8	24.8	21.5	19.2	17.0	15.3	13.5	11.8	10.6	8.5	6.7	5.2	3.9	3.0	2.2	1.7	1.2	1.0	0.7	0.5	0.1
12	39.6	31.3	26.6	23.0	20.2	18.0	16.0	14.5	12.9	11.3	10.0	8.1	6.4	4.8	3.7	2.8	2.0	1.6	1.1	0.9	0.6	0.4	0.1
13	35.8	28.6	24.3	21.3	18.6	16.8	15.0	13.6	12.2	10.7	9.6	7.7	5.9	4.5	3.4	2.6	1.9	1.5	1.0	0.8	0.6	0.4	
14	32.6	26.0	22.6	19.9	17.3	15.6	14.0	12.9	11.5	10.1	9.1	7.2	5.5	4.2	3.2	2.4	1.7	1.3	0.9	0.7	0.5	0.3	
15	29.4	23.8	20.8	18.5	16.1	14.5	13.1	12.0	10.8	9.5	8.6	6.9	5.2	3.9	2.9	2.2	1.5	1.2	0.8	0.6	0.4	0.2	
16	26.8	21.9	19.2	17.2	14.9	13.4	12.2	11.2	10.2	8.9	8.1	6.5	4.8	3.5	2.6	1.9	1.4	1.1	0.7	0.5	0.3	0.1	
17	24.3	19.9	17.7	16.0	13.8	12.4	11.4	10.4	9.4	8.4	7.6	6.0	4.4	3.2	2.4	1.8	1.3	1.0	0.6	0.4	0.3	0.1	
18	21.9	18.2	16.2	14.8	12.7	11.5	10.5	9.6	8.7	7.9	7.0	5.6	4.2	3.0	2.2	1.6	1.1	0.9	0.5	0.3	0.2		
19	19.8	16.8	14.8	13.5	11.6	10.4	9.7	8.9	7.9	7.2	6.5	5.2	3.8	2.7	2.0	1.4	1.0	0.8	0.4	0.2	0.1		
20	18.0	15.5	13.6	12.3	10.7	9.5	8.9	8.1	7.3	6.7	5.9	4.8	3.4	2.5	1.8	1.3	0.9	0.7	0.3	0.1			
22	15.2	12.7	11.2	10.1	8.7	7.7	7.3	6.7	6.1	5.6	4.9	3.9	2.8	2.0	1.4	1.0	0.7	0.4	0.2				
24	12.6	10.4	9.0	8.2	7.0	6.1	5.7	5.2	4.7	4.4	3.8	3.0	2.1	1.6	1.1	0.7	0.5	0.2					
26	10.0	8.1	6.9	6.3	5.5	4.6	4.2	3.8	3.6	3.2	2.9	2.3	1.6	1.2	0.8	0.5	0.3	0.1					
28	7.7	6.2	5.5	4.7	4.1	3.5	3.1	2.8	2.6	2.4	2.1	1.7	1.2	0.9	0.6	0.3	0.1						
30	5.7	4.7	4.0	3.4	2.9	2.6	2.3	2.1	1.8	1.7	1.4	1.2	0.9	0.6	0.3	0.2							
32	4.4	3.5	3.0	2.6	2.2	1.9	1.7	1.6	1.3	1.2	1.0	0.8	0.6	0.4	0.1	0.1							
34	3.3	2.5	2.2	1.9	1.6	1.4	1.3	1.2	0.9	0.8	0.7	0.5	0.5	0.2									
36	2.3	1.9	1.6	1.4	1.2	1.1	1.0	0.8	0.6	0.6	0.5	0.3	0.2										
38	1.7	1.4	1.4	1.0	0.9	0.8	0.6	0.5	0.5	0.4	0.3	0.2	0.1										
40	1.2	1.0	0.9	0.7	0.6	0.5	0.5	0.4	0.2	0.2	0.1												
42	0.7	0.7	0.6	0.5	0.4	0.3	0.3	0.2															

[1] Erodibility for a 5-foot length of exposed area and a wind blowing from one direction at a drag velocity, V_* equal to 61.5 cm. per second. Soil was exposed to wind until erosion ceased.

q_1, or 17.2 tons per acre when the average equivalent diameter of erodible fractions is 0.18 mm.

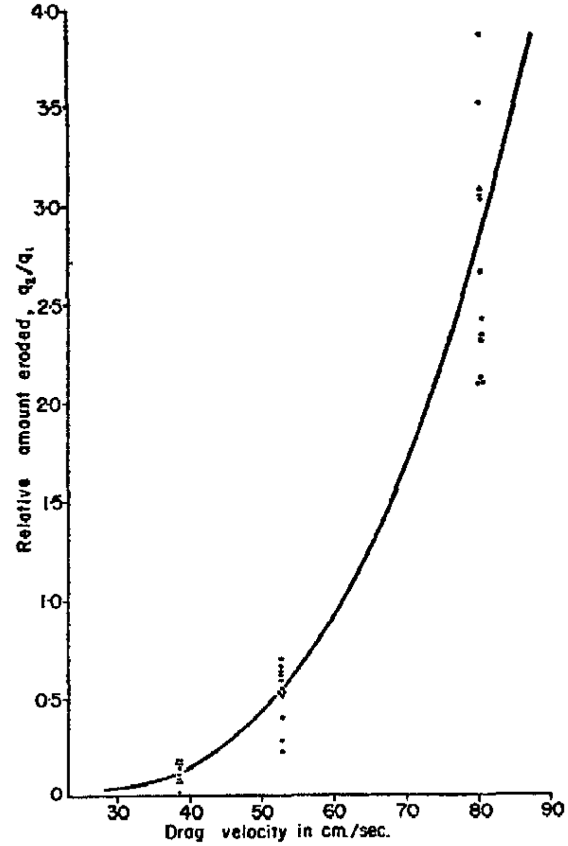

FIG. 4. RELATIONSHIP OF THE RELATIVE AMOUNT OF EROSION TO THE DRAG VELOCITY OF THE WIND

Relation of equivalent diameter of erodible fractions to soil erodibility

Previous measurements (11) have indicated that soil erodibility by wind is dependent in large measure on the equivalent diameter distribution of the erodible units. This distribution can be determined directly by the elutriator (13) or indirectly by dry-sieving and apparent-density determinations. It was found that the soils usually contain a wide range of equivalent diameter of erodible fractions. The erodibility of the soil depends on the weighted mean of each increment of equivalent diameter. The smaller the increments chosen for estimation of erodibility, the more accurate is the estimated erodibility. There is a minimal limit of size of increment that can be applied in practical use.

Other factors being equal, the erodibility is highest on soils that contain erodible units of about 0.1 mm. in equivalent diameter. The erodibility decreases when the equivalent diameter of erodible units becomes greater or smaller than 0.1 mm. Consequently, for each increment of equivalent diameter below 0.1

mm. there is a counterpart of equivalent diameter above 0.1 mm. of which the erodibility is equal. This is shown in figure 2 and, for convenience, in aligned scales A_1 and A_2 of figure 3.

Measurements (11) have shown that the erodibility of cultivated soils varies inversely and proportionately as the square root of equivalent diameter of erodible fractions above 0.15 mm. For equivalent diameter between 0.1 and 0.15 mm. the actual erodibility is slightly lower than the rule would indicate. The relationship appears to be more complex for equivalent diameters smaller than 0.1 mm.

TABLE 2

Estimation of weighted mean equivalent diameter of erodible soil units under a drag velocity of 88 cm. per second (soil 1 of table 4)

INCREMENT OF EQUIVALENT DIAMETER	AVERAGE EQUIVALENT DIAMETER	COUNTERPART OF EQUIVALENT DIAMETER ABOVE 0.1 MM. (d)	WEIGHT (W_5)	dW_5
mm.	*mm.*	*mm.*	*gm.*	
<0.044	.02	.34	13.8	4.7
0.044–0.074	.06	.16	39.5	6.3
0.074–0.1	.09	.11	22.6	2.5
0.1–0.15	.12	.12	33.9	4.1
0.15–0.18	.16	.16	10.2	1.6
0.18–0.25	.22	.22	29.4	6.5
0.25–0.30	.28	.28	17.6	4.9
0.30–0.42	.36	.36	23.0	8.3
0.42–0.59	.50	.50	14.0	7.0
0.59–0.84	.72	.72	8.2	5.9
Sum (Σ)			212.2	51.8

Weighted mean equivalent diameter of erodible units is equal to $\frac{\Sigma(dW_5)}{\Sigma W_5} = 0.24$ mm.

According to results of elutriation or of dry-sieving and density determinations, the erodible portion of the soil under consideration contains units with equivalent diameters or counterparts of equivalent diameters in amounts shown in table 2. It follows that the weighted mean equivalent diameter is equal to $\frac{\Sigma(d\,W_5)}{\Sigma W_5}$, where ΣW_5 is the sum of the weight of each increment of equivalent diameter and $\Sigma(d\,W_5)$ is the sum of the product of the weight and the average equivalent diameter of each increment. In the case considered in table 2 the weighted mean equivalent diameter of erodible fractions is 0.24 mm.

The relative erodibility of the soil under consideration is read from figure 5 as follows: A straightedge is passed through the value of q_2 (17.2 tons per acre in this case) on the vertical line AB and through the maximum equivalent diameter erodible under the drag velocity of the wind under consideration (0.7 mm.). The erodibility value lying on the straightedge and corresponding to the equivalent diameter of 0.24 mm. is read. In this case it is equal to 14 tons per acre.

This soil under a drag velocity of 61.5 cm. per second instead of 88 cm. per second is estimated to have an approximate erodibility of about 3.6 tons per acre (fig. 3). In like manner, the erodibility of any soil of which the dry aggregate structure and apparent density are known may be determined.

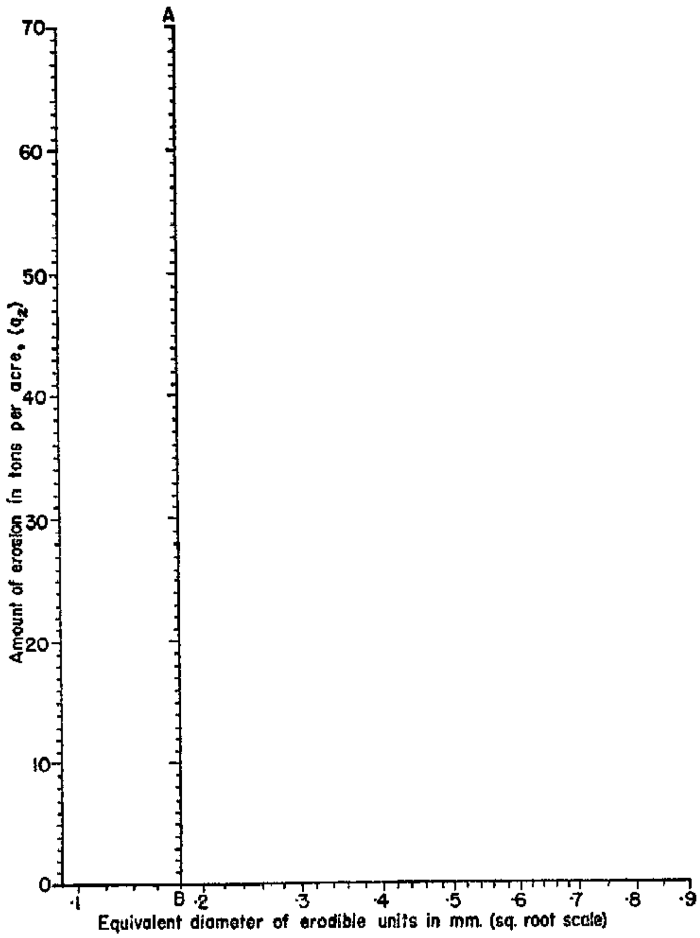

FIG. 5. GUIDE FOR ESTIMATING THE AMOUNT OF EROSION FROM THE EQUIVALENT DIAMETER OF ERODIBLE SOIL UNITS

SIMPLIFIED METHODS OF ESTIMATING RELATIVE ERODIBILITY

The above brief description of the relationships between the various soil structural factors and erodibility by wind gives a general insight into what constitutes an erodible and a nonerodible soil. From these relationships, the erodibility of any uniformly mixed soil can be estimated. In practical use, some simple method of estimating the relative erodibility is expedient, especially where large numbers of cases are involved. Two such methods have been used, depending on equipment and information available at the time.

Method 1: Estimation of relative erodibility from dry-sieving and apparent-density determinations

A method of estimating the relative erodibility proposed in a previous publication (10) has been used with a reasonable degree of success on related soils. This method is based on (*a*) one arbitrarily chosen wind velocity, (*b*) wind velocity measured at some fixed height, (*c*) apparent density determination of the semierodible fractions only, and (*d*) the proportionate weight of the erodible and nonerodible fractions. Each of these conditions will be considered briefly as they relate to erodibility:

(*a*) The order of erodibility on any group of related soils is usually the same, irrespective of wind velocity to which they are subjected. On widely different soils the order of erodibility might be reversed with a change of wind velocity. This is especially true when comparisons are made of extremely different soils such as a fine sandy soil which contains a preponderance of highly erodible fractions, on one hand, and a clay soil containing a large proportion of semierodible fractions, on the other.

(*b*) Wind velocity at any one height does not give a complete indication of the actual force of the wind acting on the soil surface. For this reason the measurement of a drag velocity, which is directly dependent on surface drag, appears, for the present, to be a better indicator of the force of the wind.

(*c*) The apparent density of any erodible fraction has a considerable influence on erodibility (11). Its greatest effect appears to be on the semierodible fraction. For this reason, the effect of apparent density of the highly erodible fractions was disregarded in this method.

(*d*) Erodibility is dependent on the volume of the nonerodible fractions rather than on their weight. In most soils, however, the relative volume and the relative weight of each soil fraction vary proportionately to each other, and one or the other can be used in estimating the relative erodibility. The weight of any soil fraction can be determined more readily than its volume. Hence, estimation of erodibility based on weight is a more convenient procedure.

Perhaps the greatest source of error in this method might be due to subdivision of the erodible soil fractions into two categories only—the highly erodible (less than 0.42 mm. in diameter) and the semierodible (0.42 to 0.84 mm. in diameter). Actually, the erodibility is not dependent on the diameter so much as on the equivalent diameter, including that within the silt size or dust range. It is difficult to separate fine soil dust by sieving. Fine dust affects the erodibility, however.

Because of these limitations, an attempt was made to estimate erodibility from results of elutriation and only in limited degree from results of dry-sieving (13).

Method 2: Estimation of erodibility based on the equivalent diameter of erodible fractions

In this simplified method, the percentage weight of fraction D (that portion of the soil remaining on a 6.4-mm. sieve) is determined first. The relative amount of erodible soil fractions with equivalent diameters of < 0.05 mm., 0.05 to 0.30 mm., and 0.30 to 0.59 mm. in the portion of the soil that passed through the 6.4-mm. sieve then is determined on the air elutriator (13). The fraction remaining in the elutriator, known as fraction C, is weighed and expressed in percentage of total weight of soil. The weighted mean equivalent diameter of erodible fractions is determined as indicated in table 2.

The relative erodibility, as influenced by the proportionate weight of the two nonerodible fractions is read from table 1 of the previous publication (10). The

TABLE 3

Comparison of computed with determined erodibility of soils under a drag velocity of 61.5 cm. per second

Method 1: Based on dry-sieving and apparent-density determinations

SOIL NO.	SOIL TEXTURE	DRY AGGREGATE DISTRIBUTION BY WEIGHT BASED ON ACTUAL DIAMETER				APPARENT DENSITY OF FRACTION 0.42–0.84 mm.	ERODIBILITY COMPUTED BY METHOD 1*	AMOUNT ERODED IN WIND TUNNEL
		<0.42 mm.	0.42–0.84 mm.	0.84–6.4 mm.	>6.4 mm.			
		%	%	%	%		*tons/A.*	*tons/A.*
1	Sandy loam	46.4	9.2	15.2	29.2	1.80	3.4	2.7
2	Clay	35.0	18.3	21.2	25.5	1.69	1.5	0.5
3	Silty clay loam	57.3	24.7	6.6	11.4	1.61	13.8	11.8
4	Silt loam	40.3	2.9	14.2	42.6	1.62	1.1	0.8
5	Loamy sand	80.0	4.2	9.3	6.6	1.81	16.6	15.8
6	Muck	48.2	13.2	28.4	10.2	0.85	3.0	3.1

Method 2: Based on elutriation and dry-sieving

SOIL NO.	SOIL TEXTURE	DRY AGGREGATE DISTRIBUTION BY WEIGHT						ERODIBILITY COMPUTED BY METHOD 2	AMOUNT ERODED IN WIND TUNNEL
		Equivalent diameter				Actual diameter			
		<0.05 mm.	0.05–0.30 mm.	0.30–0.59 mm.	Weighted mean†	0.59 equivalent to 6.4 actual mm.	>6.4 mm.		
		gm.	*gm.*	*gm.*	*mm.*	%	%	*tons/A.*	*tons/A.*
1	Sandy loam	14.5	158.6	39.0	.24	15.7	29.2	2.8	2.7
2	Clay	9.2	112.4	59.7	.29	24.3	25.5	0.9	0.5
3	Silty clay loam	18.3	140.5	74.7	.28	6.0	11.4	13.5	11.8
4	Silt loam	26.7	161.4	14.4	.22	11.6	42.6	1.0	0.8
5	Loamy sand	12.0	205.4	17.4	.21	5.7	6.6	22.0	15.8
6	Muck	51.5	125.6	39.2	.27	18.2	10.2	4.5	3.1

* As proposed in a previous publication (10).

† Counterpart of equivalent diameter of fraction <0.05 mm. was taken as 0.34 mm.

erosion values in this table are based on the weighted mean equivalent diameter of erodible fractions of 0.18 mm. and on a drag velocity of 61.5 cm. per second. Let it be assumed that the soil in question (soil 1 of table 3) contains by weight 16 per cent of fraction C and 29 per cent of fraction D. Then (10, table 1) the erodibility of the soil is 3.7 tons per acre if the equivalent diameter of erodible fractions is 0.18 mm. But the weighted mean equivalent diameter of the erodible fractions in this soil is 0.24 mm. instead of 0.18 mm. According to figure 5, the erodibility of the soil in question is, therefore, 2.8 tons per acre when the drag velocity of the wind is 61.5 cm. per second. The erodibility of this soil computed by method 1 for the same drag velocity was found to be 3.4 tons per acre and that determined in the wind tunnel 2.7 tons per acre.

COMPARISON OF COMPUTED WITH DETERMINED ERODIBILITY

Six soils of widely different texture were chosen for comparison of erodibility computed by simplified methods 1 and 2 with that determined in the wind tunnel. In every case, the amount of soil eroded in the tunnel was somewhat less than the computed amount (table 3). This was to be expected, since the erodibility determined in the wind tunnel is based on that portion of the soil which was not sieved, elutriated, or disturbed appreciably in any other way. The computed erodibility, on the other hand, is based on sieving and elutriation which break up the soil structure to some degree. On the basis of the total amount eroded from the six soils, sieving and elutriation evidently caused an average increase in computed erodibility of about 12 per cent. Methods 1 and 2 gave virtually the same results. The order of computed and determined erodibility was virtually the same irrespective of which of the two methods was used. It is evident, therefore, that erodibility as computed by either of the methods can be used as an approximate index of the relative erodibility of freshly cultivated soils.

SUMMARY

The relationships between the various dry structural conditions of the soil and erodibility by wind have been described and evaluated. These relationships fall into four main categories: (*a*) relation of wind velocity to proportion of erodible and nonerodible fractions; (*b*) influence of volume of nonerodible fractions on erodibility; (*c*) relationship of wind velocity to erodibility; (*d*) influence of equivalent diameter distribution of erodible fractions on erodibility.

Tables and graphs evaluating each of these relationships give a general insight into what constitutes an erodible or a nonerodible soil. The relative erodibility of any soil of which the dry aggregate structure is known can be estimated from the table and graphs. In addition, two simplified methods of estimation are presented. On six widely different soils each of these methods gave, for all practical purposes, the same order of erodibility as that determined directly by wind tunnel tests. The estimated and determined erodibility was based on certain specified conditions of the wind and conditions of the soil not connected with soil structure.

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