Reprinted from Soil Science
Vol. 69, No. 5, May, 1950

PROPERTIES OF SOIL WHICH INFLUENCE WIND EROSION: II. DRY AGGREGATE STRUCTURE AS AN INDEX OF ERODIBILITY[1]

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Received for publication November 9, 1949

A simple method of estimating the relative erodibility of soils by wind is of considerable practical value to agriculturists in dry-land areas. The size and stability of soil aggregates at the surface of the ground is one of the main factors that influence the erodibility of the soil by wind. Since this factor can be altered by various tillage and cropping methods, and by other means, it is important to know what type of soil structure is necessary to reduce the erodibility by wind to the practical minimum. There is likewise a need for some simple method for estimating the relative susceptibility of a soil to wind action, particularly for estimating the value of various tillage implements and cropping practices that have possibilities of use for wind erosion control.

Experiments conducted previously in a wind tunnel[2] showed an intricate relationship between the dry clod structure and erodibility by wind. Because of a relatively large number of size-fractions into which the soils were divided for detailed study, the mathematical expressions for estimating erodibility were extremely complicated. An attempt was made to incorporate the several derived expressions into a simplified general form applicable to the average range of erosive wind velocity.[3] Experimental tests proved that the general form was valid within specific limits on a large variety of soils of western Canada, but the computations were too elaborate for practical use.[4]

To achieve a simpler solution for the expression of erodibility based on the dry aggregate structure of a soil, a series of experiments were undertaken. The results of these tests and a simple method of estimating the erodibility of different soils are presented herein. Two aspects of the problem not investigated previously are included in this study: first, the possible effect of the apparent specific gravity of different soil fractions on erodibility; second, the possible degree of breakdown of soil structure during the sieving process.

PROCEDURE

The soils selected for study were all reasonably free from undecomposed crop residues, such as stubble or straw. To avoid undue breakdown of structure, the soils to be tested for erodibility were taken from the field only when in a reason-

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[1] Contribution No. 414 from the department of agronomy, Kansas Agricultural Experiment Station, Manhattan, Kansas, and the Soil Conservation Service, U. S. Department of Agriculture. Cooperative research in the mechanics of wind erosion.

[2] Chepil, W. S. Relation of wind erosion to the dry aggregate structure of a soil. *Sci. Agr.* 21: 488–507. 1941.

[3] Chepil, W. S. Measurement of wind erosiveness of soils by dry sieving procedure. *Sci. Agr.* 23: 154–160. 1942.

[4] Chepil, W. S. Relation of wind erosion to the water-stable and dry clod structure of soil. *Soil Sci.* 55: 275–287. 1943.

ably dry condition. A square-cornered spade was pushed under a layer of surface soil 1 inch thick, and the soil was placed in a suitable tray and brought to the laboratory for thorough air-drying.

After drying, the soils were placed in air-tight containers for subsequent use. Portions of some soils were passed through a specially designed rotary sieve,[5] and the various soil fractions were stored in air-tight containers to be used as required. The different fractions into which the soils were sieved were as follows: A, <0.42 mm. in diameter; B, 0.42 to 0.84 mm.; C, 0.84 to 6.4 mm.; D, >6.4 mm.

To test the erodibility of the various soils, or mixtures of the various soil fractions, use was made of a closed-circuit type wind tunnel described previously.[6] The soils were subjected to a wind equivalent to 25 miles per hour under standard temperature and pressure at a 6-inch height. The soil samples were placed in a trough 5 feet long, 8 inches wide, with open ends. The soil surface was leveled by hand. Some differences in the degree of surface roughness existed on the different soils, but these were due to differences in the size of the fractions and not to differences in the treatment. The trough with the soil was placed on the leeward end of the test chamber parallel to the direction of the wind and level with the remaining floor area. The remaining floor area of the test chamber was covered with gravel 2.0 to 6.4 mm. in diameter.

Erosion continued for a relatively short time on all soils tested and ceased as soon as the surface became stabilized with fractions too large to be moved by wind. The quantity of soil eroded up to the time when movement ceased constituted a measure of erodibility. The time required for movement to cease varied considerably with soil structure—the range being approximately 10 to 60 minutes.

The apparent specific gravity or volume weight of the soil grains of each size-fraction separated by sieving was determined by dividing the weight of a definite volume of the fraction by the weight of an equal volume of quartz sand containing the same sized grains as the soil fraction and multiplying the quotient by 2.65. The quartz grains used were uniform in composition, entirely devoid of pore spaces, and had a specific gravity of 2.65. The apparent specific gravity thus determined represented the volume weight of the individual soil grains or aggregates and not the volume weight of the soil body or bed composed of these grains. The apparent specific gravity of soil clods greater than 6.4 mm. in diameter was determined by the usual liquid displacement method after the clods were coated with a thin, impermeable film of paraffin wax.

RESULTS

Erodibility of mixtures of different soil aggregates

Figure 1 indicates the quantities of soil removed by wind when the highly erodible fraction A, separated from three widely different soil classes by sieving,

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[5] Chepil, W. S., and Bisal, F. A rotary sieve method of determining the size distribution of soil clods. *Soil Sci.* 56: 95–100. 1943.

[6] Zingg, A. W. and Chepil, W. S. Aerodynamics of wind erosion. (To be published in Agr. Eng.)

is mixed with different amounts of similar textured, nonerodible fractions C and D. When the amount of fractions C and D is plotted against the logarithm of the amount eroded, the resultant curves are nearly straight. Evidently, each increment of the nonerodible fraction C or D added to the synthetic mixture with fraction A reduces the logarithm of the amount eroded almost equally. With very low concentrations of C or D, the logarithm of the amount eroded deviates slightly upward from the linear relationship, and with very high concentrations, slightly downward. The plotted curves thus assume a slight "S" curvature.

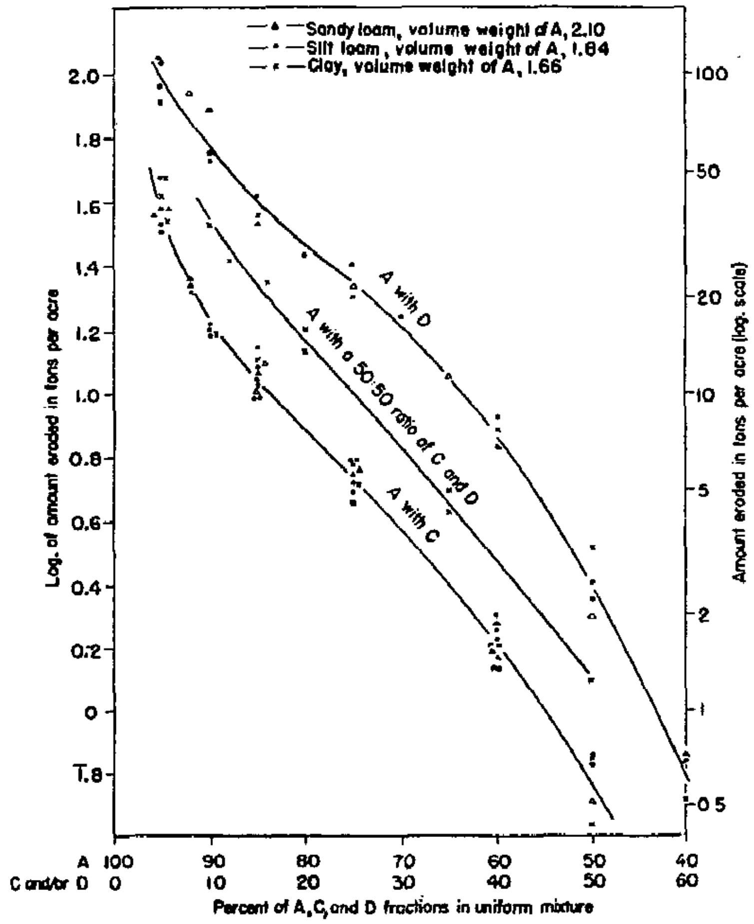

FIG. 1. EFFECT OF FRACTIONS C AND D ON ERODIBILITY OF FRACTION A

The experimental data in figure 1 show the erodibility of any mixture of A with C, A with D, and A with C and D. An equal proportion of C and D mixed with A gives the logarithmic values of erodibility half way between the values where only C or D alone is mixed with A. These data, and especially those of figure 2, show that the logarithm of the amount eroded varies directly and proportionately with the ratio of C to D contained in the soil. Thus, if the soil is composed of 20 per cent of C mixed with A, the logarithm of the amount eroded in tons per acre is shown to be 0.9; and if it is composed of 20 per cent of D mixed with A the logarithm of the amount of erosion is 1.5. On the other hand,. if it contains a mixture of C and D amounting to 20 per cent of the total, the logarithm of the amount eroded varies directly with the relative proportion of C and D and is equal to

$$\frac{0.9\,C + 1.5\,D}{C + D},$$

where C and D are the percentages of fraction C and D. The actual erodibility of the whole range of uniform mixtures of fractions A, C, and D applicable to the conditions of the wind and the soil under which the tests were conducted can thus be determined by interpolation or direct reading of experimental values in figures 1 and 2. These values are presented in rather broad increments in table 1. Erosion values less than 0.1 ton per acre are considered too small to be of any significance and are, therefore, omitted from table 1.

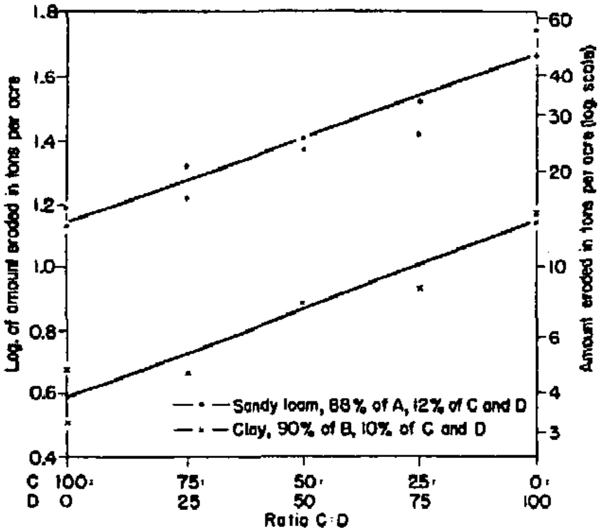

FIG. 2. EFFECT OF DIFFERENT MIXTURES OF FRACTIONS C AND D ON ERODIBILITY OF FRACTIONS A AND B

Some consideration was given to the possible effect of apparent specific gravity of the different fractions on erodibility. In the soils used, the range of apparent specific gravity of fractions C and D, which was between 1.46 and 1.66, was too narrow to determine what effect it might have on erodibility.

The apparent specific gravity of fraction A varied considerably more, that is, from 1.66 to 2.10. Figure 1 shows that this range of variation for fraction A has little, if any, effect on erodibility. Further studies are undertaken to obtain information on the possible effects of a wider range of apparent specific gravity of the various soil fractions on erodibility.

TABLE 1

Erodibility x *in tons per acre for any proportion of fractions C and D in mixture with A**

PER CENT FRACTION D	PER CENT FRACTION C																					
	0	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20	24	28	32	36	40	44
0	∞	—	—	69.0	48.0	38.4	30.9	25.7	22.1	19.5	17.4	14.4	12.1	10.2	8.9	7.8	5.8	4.4	3.2	2.3	1.5	1.1
1	—	—	77.5	61.3	46.1	37.8	30.5	25.7	22.1	19.5	17.4	14.3	12.0	10.1	8.8	7.7	5.7	4.2	3.0	2.1	1.4	1.0
2	—	82.0	69.0	57.5	44.3	36.5	30.0	25.5	22.0	19.4	17.4	14.3	11.9	10.0	8.6	7.6	5.5	4.0	2.7	2.0	1.4	1.0
3	117.0	77.0	63.0	53.6	41.6	35.0	29.4	25.2	21.8	19.4	17.4	14.2	11.8	9.9	8.5	7.5	5.3	3.9	2.5	1.9	1.3	0.9
4	106.0	72.3	57.8	49.5	39.0	33.5	28.7	24.7	21.6	19.1	17.1	13.9	11.6	9.8	8.4	7.4	5.1	3.7	2.4	1.8	1.2	0.8
5	95.5	69.0	53.3	46.0	37.5	32.0	27.9	24.1	21.3	18.8	16.8	13.6	11.4	9.6	8.2	7.3	4.9	3.5	2.3	1.7	1.2	0.8
6	85.3	63.8	50.3	42.6	35.2	30.7	27.0	23.5	20.9	18.4	16.4	13.3	11.1	9.5	8.1	7.1	4.8	3.3	2.2	1.6	1.1	0.7
7	77.1	58.8	47.5	39.8	33.8	29.5	26.0	22.9	20.5	18.1	16.1	13.0	10.9	9.4	8.0	6.9	4.7	3.1	2.1	1.5	1.0	0.7
8	70.8	55.0	44.8	37.1	32.0	28.3	25.1	22.2	20.1	17.7	15.8	12.7	10.7	9.2	7.8	6.6	4.6	3.0	2.0	1.4	1.0	0.6
9	64.8	52.0	42.2	34.7	30.6	27.2	24.2	21.6	19.6	17.3	15.6	12.4	10.4	9.0	7.6	6.4	4.5	2.8	1.9	1.3	0.9	0.6
10	59.9	49.0	39.7	33.0	29.0	26.0	23.3	21.0	19.0	17.0	15.3	12.1	10.1	8.7	7.3	6.2	4.3	2.7	1.8	1.2	0.9	0.5
12	52.4	42.7	35.1	29.5	26.4	23.7	21.5	19.5	17.7	16.0	14.4	11.6	9.7	8.3	6.9	5.8	4.0	2.4	1.6	1.1	0.7	0.4
14	46.8	37.2	31.7	26.6	23.9	21.7	19.7	18.0	16.4	15.0	13.5	11.0	9.2	7.8	6.4	5.4	3.6	2.2	1.4	0.9	0.5	0.3
16	41.2	32.8	27.9	24.0	21.6	19.8	18.1	16.5	15.1	14.0	12.6	10.4	8.6	7.2	6.0	4.8	3.2	1.9	1.2	0.8	0.4	0.2
18	35.9	28.6	24.9	22.0	19.8	18.0	16.5	15.1	14.0	13.0	11.8	9.8	8.1	6.8	5.4	4.2	2.8	1.7	1.1	0.7	0.4	0.1
20	30.7	25.3	22.4	20.1	18.2	16.5	15.1	13.8	12.9	12.0	11.0	9.2	7.7	6.4	5.0	3.6	2.4	1.5	1.0	0.6	0.3	
22	25.7	22.3	20.1	18.2	16.4	14.9	13.6	12.6	11.7	10.9	10.1	8.5	7.1	5.9	4.5	3.2	2.2	1.3	0.9	0.5	0.2	
24	22.1	19.9	18.0	16.2	14.7	13.3	12.2	11.3	10.5	9.9	8.9	7.7	6.5	5.4	4.1	3.0	2.0	1.1	0.7	0.3	0.1	
26	19.7	17.7	16.0	14.3	13.1	11.9	11.0	10.2	9.5	8.8	8.1	6.9	5.9	4.8	3.7	2.8	1.7	1.0	0.6	0.2		
28	17.7	15.9	14.2	12.8	11.6	10.7	9.9	9.2	8.5	7.9	7.2	6.1	5.3	4.2	3.3	2.6	1.5	0.8	0.4	0.1		
30	15.8	14.1	12.7	11.4	10.5	9.6	8.8	8.2	7.6	7.0	6.4	5.4	4.6	3.8	2.9	2.3	1.3	0.6	0.2			
34	12.2	10.7	9.5	8.5	7.7	7.0	6.4	5.8	5.3	4.9	4.6	3.9	3.1	2.5	1.9	1.5	0.8	0.3	0.1			
38	8.8	7.4	6.4	5.7	5.1	4.5	4.1	3.7	3.4	3.1	2.9	2.5	2.1	1.7	1.3	1.0	0.4	0.1				
42	6.0	5.0	4.2	3.8	3.3	2.9	2.6	2.4	2.2	2.1	1.9	1.6	1.3	1.1	0.9	0.6	0.2					
46	3.9	3.3	2.8	2.6	2.2	2.0	1.8	1.6	1.4	1.3	1.2	1.0	0.8	0.7	0.5	0.2						
50	2.5	2.1	1.8	1.6	1.4	1.3	1.2	1.1	1.0	0.9	0.8	0.6	0.4	0.2	0.1	0.1						
54	1.6	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1								
58	1.0	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.2	0.1	0.1										
62	0.6	0.5	0.4	0.3	0.2	0.1	0.1	0.1														

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* Erodibility for a 5-foot length of exposed area; a wind blowing from one direction at 25 m.p.h. at a 6-inch height; an apparent specific gravity of 1.5 to 1.7 for fractions C and D and 1.6 to 2.1 for fraction A.

The effect of the semierodible fraction B remains to be clarified. Figures 3, 4, and 5 show the results obtained when this fraction is mixed with the nonerodible fractions. The curves correspond in slope and shape approximately to those in which A instead of B is the erodible fraction. Only the position of the curves is altered. Figures 3 and 4 show that when A of any apparent specific gravity and mixed with any quantity of C or D is replaced by B of 1.6 apparent specific gravity the logarithm of the amount eroded is decreased by approximately 0.55.

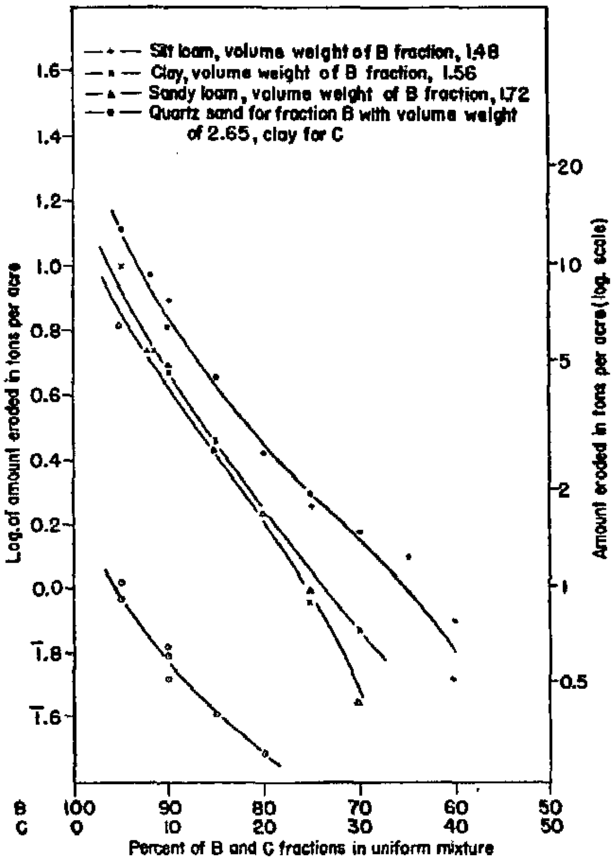

FIG. 3. EFFECT OF FRACTION C ON ERODIBILITY OF FRACTION B

In other words, the replacement of A by B of 1.6 apparent specific gravity reduces the amount of erosion x to $\frac{x}{3.55}$. Figure 5 indicates further that if only a part of fraction A is replaced by B, the logarithm of the amount eroded is decreased in proportion to the part displaced. Thus, let it be assumed that the amount of erosion for any mixture of A, C, and D, such as shown in table 1, is x, then the amount of erosion when A is replaced by B of 1.6 apparent specific gravity is antilog $(\log x - 0.55)$. If only part of A is replaced by B, the amount of erosion is antilog

$$\left(\log x - 0.55 \frac{\%\mathrm{B}}{\%\mathrm{A} + \%\mathrm{B}}\right).$$

The apparent specific gravity of fraction B, contrary to that of A, has a considerable influence on the amount of erosion. As shown in figures 3 and 4, the logarithm of the amount eroded is inversely proportional to the apparent specific gravity of B, irrespective of whether B is mixed with C or D. It will be seen that for every 0.1 decrease in the apparent specific gravity of B, mixed with C or D, there is approximately a 0.1 decrease in the logarithm of the amount eroded.

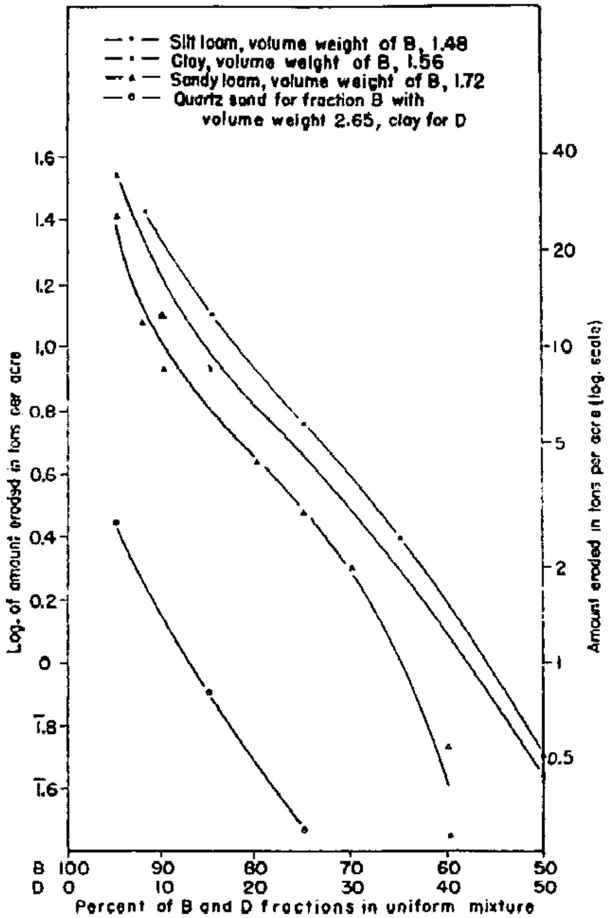

FIG. 4. EFFECT OF FRACTION D ON ERODIBILITY OF FRACTION B

The effect of the total or partial replacement of A by B and the effect of the apparent specific gravity of B on erodibility may be indicated from the data available by the expression:

$$q = \operatorname{antilog}\left[\log x - (0.55 + \sigma_{\mathrm{B}} - 1.6)\frac{\%\mathrm{B}}{\%\mathrm{A} + \%\mathrm{B}}\right]$$

or

$$q = \frac{x}{\text{antilog}\left[(0.55 + \sigma_B - 1.6)\,\dfrac{\%B}{\%A + \%B}\right]}$$

where q is the ultimate amount of erosion, x is the amount of erosion for a soil in which the erodible fractions are composed entirely of fraction A, and σ_B is the apparent specific gravity of fraction B.

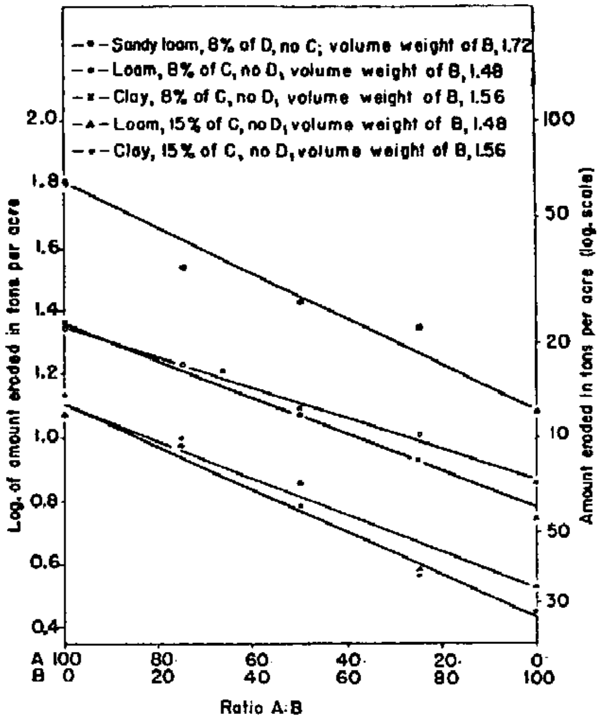

FIG. 5. EFFECT OF FRACTIONS C AND D ON ERODIBILITY OF DIFFERENT MIXTURES OF A AND B

The values of the divisor, antilog

$$(0.55 + \sigma_B - 1.6)\,\frac{\%B}{\%A + \%B},$$

for the whole working range of apparent specific gravity of B and of proportion of B to A are prepared in table 2 by interpolation of the experimental data obtained. By determining the proportions of soil fractions A, B, C, and D by sieving, the erodibility of any soil reasonably free from stubble, straw, or other types of organic residue, may thus be readily determined from tables 1 and 2. To avoid superfluity, the values of erodibility are presented in rather broad increments in tables 1 and 2. More detailed tables were prepared, however, for greater convenience in practical use.

Comparison of computed with determined order of erodibility

To check the validity of tables 1 and 2 for estimating the erodibility of different soils by the sieving method, a series of wind tunnel tests were conducted.

TABLE 2

Divisors for erosional values in table 1, as influenced by proportion and apparent specific gravity of fraction B contained in the soil

RATIO $\frac{\% B}{\% A + \% B}$	APPARENT SPECIFIC GRAVITY OF FRACTION B								
	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
.02	1.00	1.01	1.02	1.03	1.04	1.05	1.05	1.06	1.07
.04	0.99	1.01	1.03	1.05	1.07	1.09	1.10	1.13	1.15
.06	0.99	1.02	1.05	1.08	1.10	1.14	1.17	1.21	1.23
.08	0.99	1.03	1.07	1.11	1.15	1.19	1.23	1.27	1.32
.10	0.99	1.04	1.09	1.13	1.19	1.25	1.30	1.37	1.43
.12	0.99	1.04	1.10	1.17	1.23	1.30	1.37	1.45	1.53
.14	0.98	1.05	1.12	1.20	1.27	1.36	1.45	1.55	1.64
.16	0.98	1.06	1.14	1.23	1.32	1.42	1.53	1.65	1.77
.18	0.98	1.07	1.16	1.26	1.37	1.48	1.61	1.75	1.90
.20	0.98	1.07	1.18	1.29	1.42	1.55	1.70	1.86	2.03
.22	0.98	1.08	1.20	1.32	1.47	1.62	1.79	1.98	2.18
.24	0.97	1.09	1.21	1.36	1.51	1.69	1.89	2.11	2.35
.26	0.97	1.09	1.23	1.39	1.57	1.77	1.99	2.24	2.53
.28	0.97	1.10	1.25	1.42	1.62	1.85	2.10	2.39	2.71
.30	0.97	1.11	1.27	1.46	1.68	1.93	2.22	2.54	2.91
.32	0.96	1.12	1.29	1.50	1.74	2.02	2.34	2.71	3.14
.34	0.96	1.13	1.32	1.54	1.80	2.10	2.46	2.88	3.38
.36	0.96	1.13	1.34	1.58	1.86	2.20	2.59	3.06	3.61
.38	0.96	1.14	1.36	1.62	1.93	2.30	2.74	3.26	3.87
.40	0.96	1.15	1.38	1.66	2.00	2.40	2.88	3.46	4.15
.42	0.95	1.16	1.40	1.70	2.06	2.50	3.04	3.70	4.48
.44	0.95	1.16	1.43	1.74	2.14	2.62	3.20	3.93	4.81
.46	0.95	1.17	1.45	1.79	2.22	2.74	3.38	4.18	5.17
.48	0.95	1.18	1.48	1.83	2.30	2.86	3.56	4.45	5.55
.50	0.94	1.19	1.50	1.88	2.38	2.98	3.76	4.73	5.96
.52	0.94	1.20	1.52	1.93	2.46	3.12	3.96	5.04	6.40
.54	0.94	1.20	1.54	1.98	2.54	3.26	4.18	5.36	6.88
.56	0.94	1.21	1.57	2.03	2.63	3.40	4.41	5.70	7.38
.58	0.94	1.22	1.59	2.08	2.72	3.56	4.65	6.06	7.93
.60	0.93	1.23	1.62	2.14	2.82	3.71	4.90	6.45	8.52

The erodibility of 15 widely different soils and composites of these soils from central and western Kansas was determined directly in the wind tunnel (table 3). Portions of the same soils not exposed to the wind in the tunnel were passed inherent erodibility but rather as a measure of the relative erodibility at the time the determinations are made. The dry aggregate structure, as well as the erodibility, varies from season to season and virtually from day to day, depending on weather conditions and on tillage and cropping practices.

The apparent specific gravity of the different soil fractions affects the erodibility in a variable degree. The major effects of the apparent specific gravity have been determined in this investigation and incorporated into the computation method. More details are necessary, however, for a thorough understanding of the relationship of this factor to erodibility by wind.

The computed erosion values are expected to apply particularly to soils that have been recently cultivated, such as the ones on which these experiments were based. A previous study showed, however, that the computed erodibility based on the dry aggregate structure of soils is a reliable index of the actual erodibility of less recently cultivated soils as well as of freshly cultivated soils.

In determining the relative erodibility from the dry aggregate soil structure, care must be taken to avoid undue breakdown of soil aggregates and undue segregation of the finer fractions from the coarser ones. Since dry-sieving is responsible for some breakdown of the soil aggregates, it is important that a uniform sieving technique be followed in all comparable cases. The rotary sieve was found most suitable for this purpose.

SUMMARY

A simple method of computing the erodibility of cultivated soils by wind is presented. The computed erosion values are based on soils with a smooth surface free from organic residues. After determination of the apparent specific gravity and of the proportions of dry soil fractions by sieving, the relative erodibility of any soil reasonably free from organic residues can be readily computed from the tables presented. Similar but more detailed tables, not presented, have been prepared for greater ease and accuracy of computing the erodibility.