Reprinted from SOIL SCIENCE
Vol. 75, No. 6, June, 1953
Printed in U.S.A.

FACTORS THAT INFLUENCE CLOD STRUCTURE AND ERODIBILITY OF SOIL BY WIND: I. SOIL TEXTURE

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Received for publication August 14, 1952

Erodibility of soil by wind depends primarily on the structure of the soil in a dry condition. This structure is generally referred to as the dry aggregate or the clod structure. Erodibility has been estimated successfully from the dry aggregate soil structure (7).

The dry aggregate structure is governed by a number of secondary factors, the nature and the relative importance of which are not altogether understood. The most important of these factors are as follows:

1. Soil texture, or the relative proportion of sand, silt, and clay.
2. Water-stable structure and degree of dispersion in water.
3. Organic matter, bacteria and fungi, and various products of decomposition.
4. Soil moisture and raindrop effects.
5. Calcium carbonate or lime concentration layers common to arid and semiarid regions.
6. Alkali and other water-soluble salts.
7. Nature of colloidal fraction.

The purpose of this paper is to present some information on the effect of soil texture as one of the secondary factors influencing erodibility of soil by wind.

PROCEDURE

Soil samples were obtained in April 1951 from 112 wheat fields chosen at random from black, chestnut, and brown soil zones of western Nebraska and central and western Kansas. The samples ranged in texture from sand to clay. They were taken to a 1-inch depth when the land was dry. Samples from saline or highly calcareous areas were avoided. The samples were placed in shallow trays to minimize breakdown of structure. Five individual samples from each field were combined to form composite samples. The fields had not been cultivated or disturbed in any way since they were seeded to wheat in the fall of 1950. The wheat plants, which at the time of sampling were not more than 3 inches high, were excluded from the soil samples.

Laboratory analyses consisted of the following determinations: mechanical composition by the method of Bouyoucos (1), moisture equivalent by the usual method (2), dry aggregate structure by the method of Chepil and Bisal (6), relative erodibility measured in a wind tunnel. This last determination consisted of placing the soil in a tray 5 feet long and 8 inches wide and exposing it in

[1] Contribution 462, department of agronomy, Kansas State College, Manhattan, and the Soil Conservation Service, U. S. Department of Agriculture. Cooperative research in the mechanics of wind erosion. Grateful acknowledgment is due J. I. Northam for some mathematical interpretations connected with this study, and to D. A. Russ and C. S. Parsons for assistance with various phases of analytical work.

a laboratory tunnel to a wind having a drag velocity of 61 cm. per second for 5 minutes. Erosion usually ceased within this period.

RESULTS

There was a definite relationship between the amount of erosion in the wind tunnel, the amount of soil fraction < 0.42 mm. in diameter, known as fraction A, and the percentage of clay contained in the soil (fig. 1). The soils containing 20 to 35 per cent of clay were least erodible and had the smallest percentage of fraction A. Erodibility and the percentage of fraction A increased as the per-

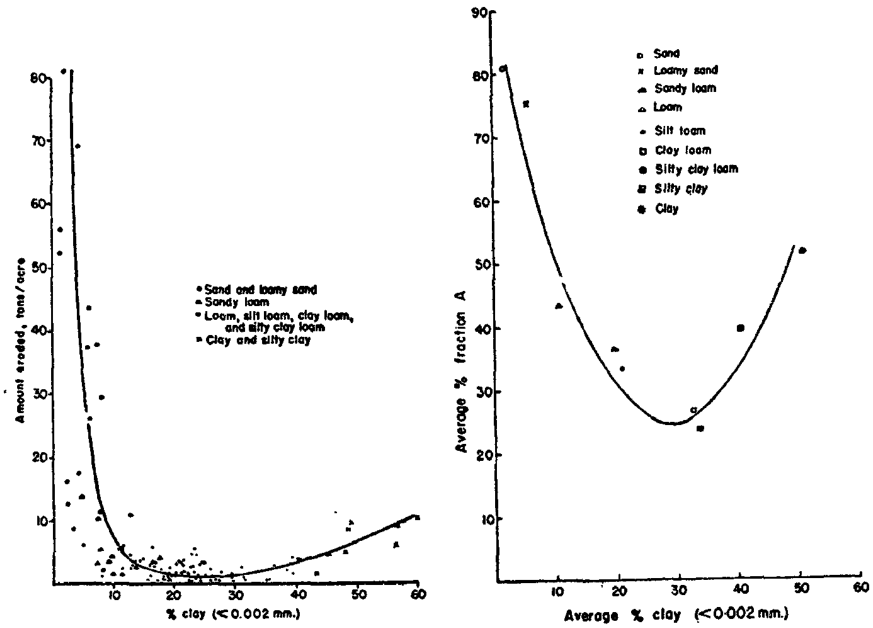

FIG. 1. RELATION OF PERCENTAGE OF CLAY TO SOIL ERODIBILITY AND TO PROPORTION OF ERODIBLE FRACTION A

centage of clay increased or decreased from 27 per cent. Clay up to about 15 per cent of the weight of the soil was extremely important in lowering the quantity of erodible soil fractions and, consequently, the amount of erosion by wind. On the other hand, clay above 40 per cent was highly important in increasing the proportion of erodible fractions and the erodibility.

The relationship between erodibility and the amount of clay, on the average, conformed with the equation

$$q = ax^b c^x \tag{1}$$

where q is the amount of eroded soil in tons per acre and x is the percentage of clay. For the units used, the constants a, b, and c have values of 4.8, -5.1, and 0.09, respectively. The curve on the left hand side of figure 1 is drawn in conformance with equation (*1*).

Soil erodibility was likewise closely associated with moisture equivalent. The moisture equivalent of the soil is the percentage of water that it can retain against a centrifugal force 1,000 times that of gravity. The water-retaining component of the soil is mainly clay; hence, the value of the moisture equivalent is an indirect measure of the amount of clay. The moisture equivalent can be determined readily and serves, therefore, as a convenient index of the amount of clay and also as an indirect index of erodibility.

The effects of moisture equivalent on erodibility (fig. 2) parallel very closely the effects of clay (fig. 1). The soils with the lowest erodibility had a moisture equivalent of about 23 per cent. Erodibility increased as moisture equivalent increased or decreased from 23 per cent.

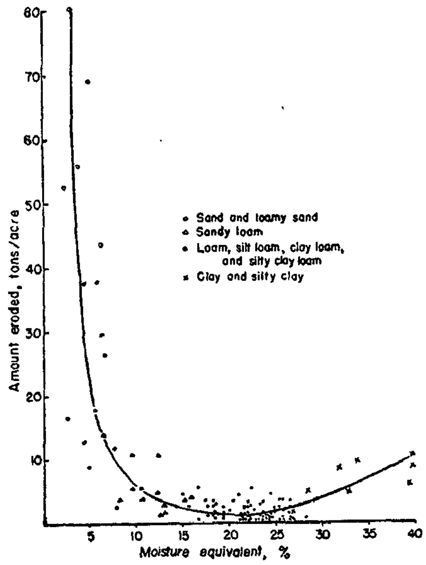

FIG. 2. RELATION OF SOIL ERODIBILITY TO MOISTURE EQUIVALENT

There was a less definite relation between percentage of sand and erodibility than between percentage of clay and erodibility, especially for soils containing less than 20 per cent of sand (fig. 3). For soils containing more than 20 per cent of sand, erodibility varied more or less with the porportion of sand in the soil; but the relationship even here does not fit any simple exponential equation, as does that of erodibility *versus* percentage of clay. In these soils an increase in sand was generally accompanied by a proportional decrease in clay, so that one or the other served as an indicator of erodibility. For other soils, however, the proportion of sand was not a sole criterion of erodibility. Thus, silty clay and clay soils had about as much sand as many of the other soils but their erodibility was considerably higher, principally because of their high clay content. As in the previous case, soil erodibility was positively associated with the percentage of fraction A in the soil.

Two samples of loamy sand exhibited a comparatively low degree of erodibility (2.1 and 8.8 tons per acre) for this soil class. The samples contained 81.4 and 88.4 per cent of sand, much of which, unlike that of the other soils, was coarse and gravellike. This coarse sand was nonerodible and served as an excellent protection for the finer erodible soil fractions. After some removal of the finer ingredients by the wind, a gravelly pavement was formed which stabilized the surface and protected the soil from further erosion by the wind. Of the 112 samples chosen, these were the only ones capable of forming a gravelly pavement when subjected to wind erosion.

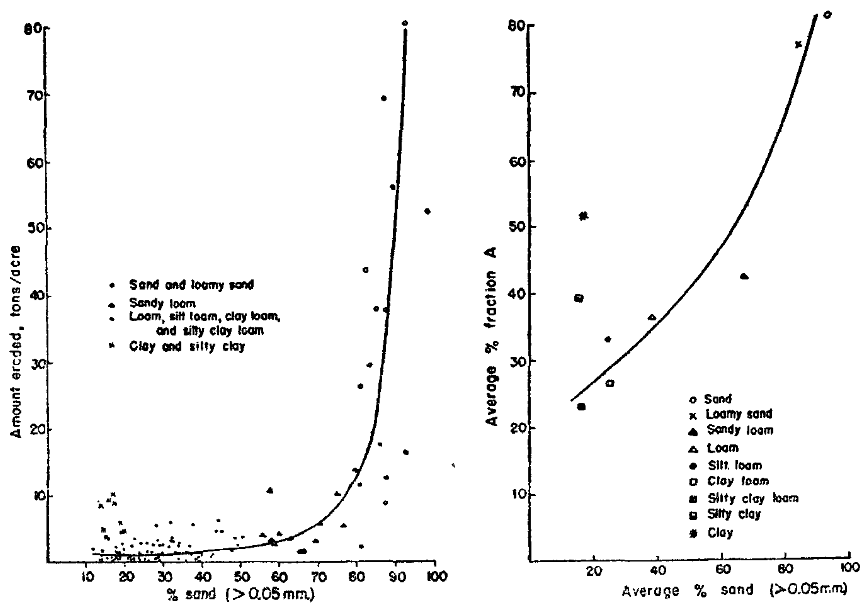

FIG. 3. RELATION OF PERCENTAGE OF SAND TO SOIL ERODIBILITY AND TO PERCENTAGE OF ERODIBLE FRACTION A

In general, the higher the proportion of silt in the soil, the lower were the percentage of fraction A and the soil erodibility (fig. 4). The curve on the left side of figure 4 conforms to the expression

$$q = 1420\ S^{-1.80} \qquad (2)$$

where q is the amount of eroded soil in tons per acre and S is the percentage of silt contained in the soil.

Expression (*2*) does not, however, apply to all soil classes. Clay and silty clay soils showed a higher level of erodibility than some other soils with a similar proportion of silt; hence, the average value of erodibility shown for these soils in figure 4 falls considerably above the general average. In these fine-textured soils clay, rather than silt, was a predominant factor influencing erodibility by wind. Nevertheless, silt was also a factor that tended to lower the erodibility in all soils. Soils with an erodibility less than 1 ton per acre were all of a medium texture containing more than 38 per cent of silt. Soil erodibility again was positively associated with the proportion of fraction A.

There was a close association between the degree of cloddiness, the proportion of highly erodible fraction A, the proportion of highly and semierodible fractions A and B, and the measured erodibility of nine soils classes analyzed (table 1). It was evident that clod structure was a primary factor governing erodibility by wind. The summarized data of table 1 show that silty clay loam was most

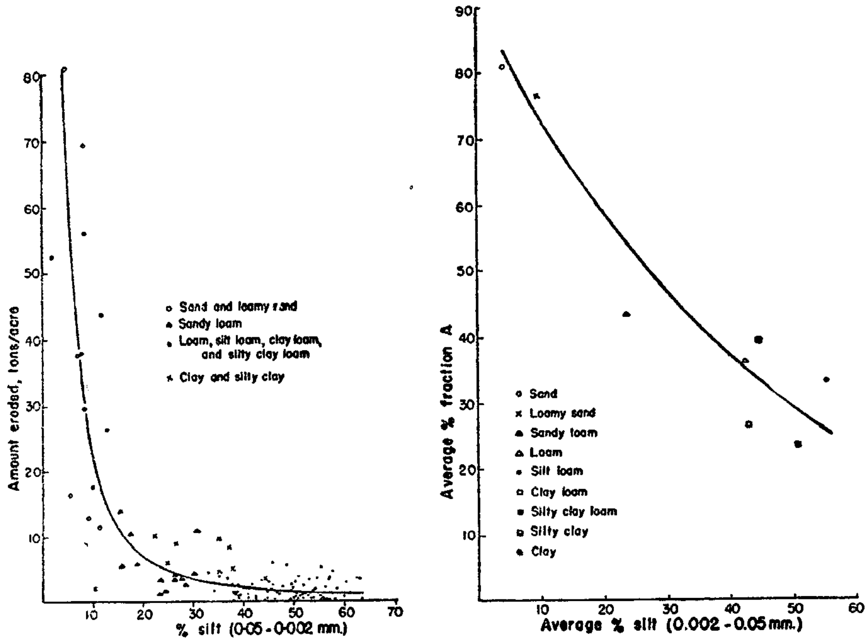

FIG. 4. RELATION OF PERCENTAGE OF SILT TO SOIL ERODIBILITY AND TO PERCENTAGE OF ERODIBLE FRACTION A

cloddy, had the lowest proportion of fraction A, and therefore was least erodible. A progressively lesser degree of cloddiness, greater proportion of fraction A, and greater degree of erodibility followed for clay loam, silt loam, loam, silty clay, sandy loam, clay, loamy sand, and sand. The intermediate-textured soils were most cloddy and least erodible. Erodibility increased for soils finer or coarser than silty clay loam. The erodibility was positively associated with the proportion of fraction A, but no simple expression was found to fit the whole relationship. When fraction A comprised 15 to 60 per cent of the weight of soil, erodibility varied approximately as A^3, where A is the percentage of fraction A. When A comprised 61 to 90 per cent of the soil, erodibility varied on the average as A^5 (fig. 5). But the value of the exponent was never constant. It deviated little from 3 for soil containing less than 60 per cent of fraction A, but for soils containing more than 60 per cent of fraction A it was highly variable. The curve drawn

TABLE 1

State of dry aggregate structure and erodibility of various soil classes

SOIL CLASS	NUMBER OF FIELDS	DISTRIBUTION OF DRY AGGREGATES*				APPARENT DENSITY OF FRACTIONS A AND B	AMOUNT ERODED IN WIND TUNNEL
		D	C	B	A		
		> 6.4 mm.	6.4–0.84 mm.	0.84–0.42 mm.	< 0.42 mm.		
		%	%	%	%		*tons/A.*
Sand	3	0.6	2.7	15.7	81.0	2.54	49.8
Loamy sand	12	1.3	5.6	16.6	76.5	2.36	29.4
Sandy loam	13	19.9	16.7	20.1	43.3	2.02	5.4
Loam	25	24.3	20.1	19.3	36.3	1.81	2.2
Silt loam	35	26.7	21.9	18.3	33.1	1.76	1.9
Clay loam	5	17.5	26.1	29.8	26.6	1.75	1.5
Silty clay loam	10	25.1	24.3	27.3	23.3	1.74	1.2
Silty clay	1	2.3	16.9	41.4	39.4	1.60	3.4
Clay	8	2.5	17.7	28.2	51.6	1.65	6.7

* Fraction A, highly erodible; fraction B, semierodible; fraction C, nonerodible; fraction D, nonerodible.

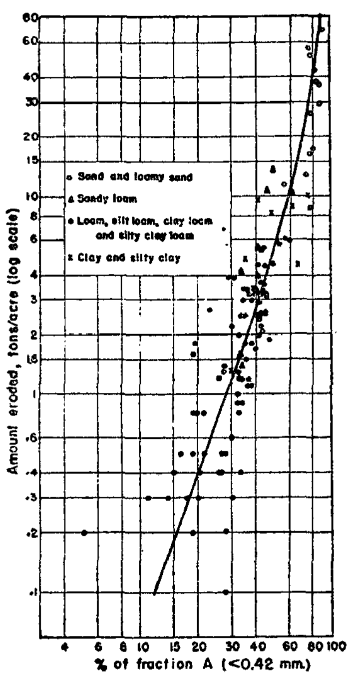

FIG. 5

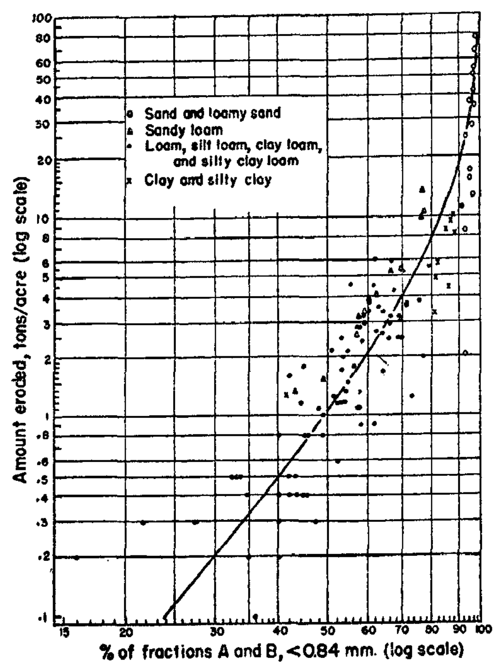

FIG. 6

FIG. 5. RELATION OF SOIL ERODIBILITY TO PROPORTION OF FRACTION A IN VARIOUS SOIL CLASSES

Drag velocity of the wind equal to 61 cm. per second

FIG. 6. RELATION OF SOIL ERODIBILITY TO PERCENTAGE OF FRACTIONS A AND B

Drag velocity of the wind equal to 61 cm. per second through an average of the individual measurements in figure 5 conforms to the expression

$$q = a\,A^b + cd^A \tag{3}$$

in which the constants a, b, c, and d have values of $4.37(10^{-5})$, 3, 0.0016, and 1.11, respectively, for the units used. Expression (3) or the curve of figure 5 can be used to estimate the approximate erodibility based on the amount of fraction A in the soil.

Figure 6 indicates the relationship between erodibility and the proportion of fractions A and B. The magnitude of deviation of individual values of erodibility from the mean values is about the same as where erodibility was plotted against fraction A (fig. 5). Evidently, either the amount of fraction A alone or the amount of fractions A and B together can be used as an index of erodibility.

DISCUSSION AND CONCLUSIONS

It is recognized that tillage and cropping methods have a profound influence on the dry aggregate structure and erodibility of soil by wind. Hence, to avoid, so far as possible, variable effects of such methods, field samples for this study were chosen in spring only from undisturbed wheat fields. The action of freezing and thawing and wetting and drying tends to break down the clod structure near the soil surface, the degree of breakdown depending in some measure on soil texture. This breakdown of structure by the forces of weather is partly responsible for the relatively high rate of wind erosion that occurs during late winter and spring.

The variable effects of cropping and tillage persist under some conditions beyond the spring of the year, and this variation may have been partly responsible for a considerable scatter of individual experimental values of erodibility around the average values. This scatter was undoubtedly due to other factors as well, notably a wide range of climatic, topographic, and vegetative conditions throughout the extensive region where the samples were obtained. In addition, some variation in erodibility was attributed to variation in size of sand and gravel in the soils. The samples chosen represent, it is believed, a range of structural and erosional variation for several major soil textural classes over the central Great Plains region.

Superimposed on the influences of the aforementioned factors is the influence of soil texture. This study shows that variations in soil texture in the central Great Plains region cause a variation in erodibility from virtual zero to virtual infinity (fig. 6). "Zero" erodibility, in such units as tons per acre, occurs on soils in which the erodible fractions are wholly protected from wind by the sheltering effect of the nonerodible fractions. "Infinite" erodibility means that 100 per cent of the soil is composed of erodible fractions and that such a soil will continue to erode indefinitely, if depth is unlimited. Obviously, soil texture influences erodibility essentially by the type of dry aggregate structure that it is capable of producing.

This study confirms general observations made in other regions with respect to erodibility of soil by wind, namely, that the coarsest- and the finest-textured soils are, on the average, more erodible than the medium-textured soils (9, 11). There is, however, a considerable variation in clod structure and erodibility from season to season and from year to year (5). Hence, a somewhat different level of clod structure and erodibility from that indicated in this study may be present in another season or another year. There is also a seasonal variation in the relative erodibility of the various soil classes. Clays are notably nonerodible in fall but relatively highly erodible in spring. Since by far the greatest amount of wind erosion occurs during late winter and spring, soil erodibility measured in these seasons is, therefore, a better criterion of relative erodibility.

Coarse-textured soils apparently lack sufficient amounts of silt and clay to bind individual sand particles together. Consequently, such soils form a "single grain" structure usually extremely susceptible to erosion by wind, or they may form weakly cemented clods that are readily broken down and eroded by the wind. The fine-textured soils, on the other hand, have too much clay and produce clods which under the action of wetting and drying and freezing and thawing readily disintegrate to a finely granulated, erodible condition. On medium-textured soils, such as silty clay loam, the proportion of silt and clay appears to be sufficient to bind the sand grains together, yet not so high as to cause excessive cracking and consequent granulation. Further studies are necessary to determine the exact function of sand, silt, and clay in soils with respect to clod structure and erodibility by wind.

The soil that appears to be least erodible contains about 27 per cent of clay or has a moisture equivalent of 23. This conclusion confirms the results of an initial study on a group of widely different soils.[2] However, there is relatively little increase in erodibility if the clay is increased or decreased as much as 10 per cent above or below this optimum amount. The soils that fall within this category include loam, silt loam, clay loam, and silty clay loam, which on the basis of this and other studies (9, 11) are relatively resistant to wind erosion. But they are by no means immune to wind erosion. Under extreme conditions of drought these soils, if not properly managed, may move readily with the wind. Wind erosion can be controlled much more easily on these soils because wind-resistant clods are more available and can be brought up to the surface by tillage much more readily than on the other soils (11).

The first increment of clay in the soil is the most effective in reducing erodibility by wind. Clay up to 15 per cent of the weight of the soil is extremely important in reducing erodibility. Additional amounts are less and less effective until in the vicinity of 27 per cent of the weight of the soil a maximum reduction in erodibility occurs. Still greater amounts of clay produce a reversal of the initial trend and become increasingly effective in increasing the erodibility. Amounts of clay greater than 40 per cent are especially detrimental in that they increase the erodibility by wind.

[2] Chepil, W. S. Relation of wind erosion to some physical soil characteristics. [Unpublished Ph.D. thesis. Copy on file Univ. Minn., Minneapolis.]

Silt reduces erodibility of soil very appreciably. It is responsible in part for the formation of soil clods and surface crust that resist erosion by wind. Previous studies have shown that some degree of cohesion is exhibited between fine silt particles after wetting and drying and that the cohesive force is sufficient to withstand the erosive force of a strong wind (4). Unlike clay, however, silt particles do not swell and contract when wetted and dried. Hence clods composed predominantly of silt do not form so many definite cleavage planes when dried after a rain and, consequently, do not disintegrate into fragments small enough to be eroded by the wind.

The great majority of silt loam and silty clay loam samples were taken from soils of loessal origin, that is, from soils formed from depositions of silty materials laid down by the wind. These soils are relatively resistant to wind erosion. The question immediately arises why they were transported by wind in the first place. Studies of the dynamics of wind erosion have indicated that deposition of silty materials is but one phase of the process of erosion. The movement of soil by wind is initiated by the movement of very fine sand and coarse silt, both of which are highly erodible by wind. These fractions are eroded in saltation, that is, by movement in jumps. Silt and clay particles smaller than 0.02 mm. in diameter are resistant to direct force of a strong wind, but are readily lifted into the atmosphere by impacts from saltation of larger fractions. When lifted into the air, fine silt and clay particles may be carried great distances before they settle with the rain or after wind velocity has abated considerably.

Silt particles are removed from eroding soil and carried into the atmosphere in much greater quantity than is clay.[3] Clay particles are generally cemented into stable aggregates which, although erodible, are too large to be carried high in the air. The clay particles once lifted into the air are carried faster and farther than any other component of the soil, but in relatively small concentration. Silt particles, on the other hand, are generally unaggregated and therefore constitute the bulk of the atmospheric load. Apparently, this helps to explain the predominance of silt in loessal soils.

Sand is an inactive component of soil so far as its ability to form aggregates is concerned. In excessive amounts it forms a "single-grain" structure, which, in effect, is a complete lack of structure. Sandy soils are usually highly erodible, but a predominance of coarse sand may lower the erodibility somewhat. At least two cases in this study showed that some sandy soils exhibit some resistance to wind erosion because the size of the sand is too large to be moved readily. Such cases are exceptions rather than the rule. Soils containing more than 80 per cent of fine sand are, on the average, far more erodible than other soils, including the highly erodible clay soils.

The results show that the proportions of fraction A alone or of fractions A and B together serve as approximate indexes of erodibility by wind. These simplified

[3] Chepil, W. S., and Englehorn, C. L. Report of causes and effects of wind erosion in east-central Kansas in March, 1950. Kans. Agr. Exp. Sta. and U. S. Dept. Agr. Soil Conserv. Serv. Contrib. 444. (mimeographed). 1951.

indexes have been used in previous evaluations of erodibility (3, 8, 10, 12). The proportions of fractions A and B are not the only factors that determine erodibility, however, although they appear to be the major ones. The apparent density of the erodible units and the size distribution of all fractions were found previously to influence erodibility (7). The individual data obtained in this study show that the relative proportion of soil fractions and the apparent density of erodible units are variable in some degree, depending on soil texture (table 1). Positive relationships between erodibility and proportions of fractions A and B were obtained for all soil classes. Obviously, the influence of factors other than fractions A and B was more or less canceled by opposing trends.

SUMMARY

Soil texture had a profound influence on erodibility by wind. The coarsest- and the finest-textured soils were more erodible than the medium-textured soils because they had a less developed clod structure. The coarse-textured soils lacked sufficient cementing material (silt and clay) to bind the individual sand grains together; the fine-textured soils, on the other hand, had too much clay, which under the action of the weather caused the soil clods to disintegrate into a finely granulated, erodible condition. The most cloddy and the least erodible soils, other factors being equal, contained about 27 per cent of clay and the greatest possible proportion of silt and had a moisture equivalent of about 23.

Clay in amounts equal to 15 per cent of the weight of the soil was extremely important in increasing cloddiness and in reducing erodibility by wind. Amounts considerably greater than 27 per cent were detrimental. Notably in clay and silty clay soils, the clay fraction was a predominant factor in decreasing cloddiness and increasing erodibility, although silt was also an important factor tending to increase cloddiness and to reduce erodibility.

Fine and very fine sand increased erodibility very appreciably. Gravel and medium and coarse sand reduced erodibility, depending on the relative weight of these fractions. Soils that contained more than 80 per cent of fine sand were, on the average, far less aggregated and more erodible than any other soil.

Erodibility varied directly with percentage of fraction less than 0.42 mm. or less than 0.84 mm. in diameter and with proportions of sand, silt, and clay in the soil. Simple algebraic expressions were found to denote these relationships.

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