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FACTORS THAT INFLUENCE CLOD STRUCTURE AND ERODIBILITY OF SOIL BY WIND: IV. SAND, SILT, AND CLAY

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In a previous study (2) data were obtained from 112 fields, chosen at random in Kansas and Nebraska, showing the relationship between the various textural soil classes and erodibility by wind. A considerable scatter of individual values of erodibility around an average for the different soil classes was obtained, probably because of great variation in cropping and tillage practices and in climatic conditions throughout the region. Studies were undertaken, therefore, to verify the relationship under more uniform conditions. This paper summarizes the results of these experiments and indicates more specifically than in the initial study the influence of sand, silt, and clay on some phases of clod structure and erodibility by wind.

PROCEDURE

Quartz sand (0.84 to 0.05 mm.), silt (0.05 to 0.005 mm.), and clay (<0.002 mm.) were extracted from three different soil materials. Quartz sand was extracted from fine dune sand obtained near Great Bend, Kansas; silt from silty material found near St. George, Kansas; and clay from the parent material of Geary silty clay loam.

Dune sand used in this study was highly erodible and contained not more than 1 per cent of grains greater than 0.84 mm. in diameter. Grains larger than this were removed by sieving. The sand was then washed on a 0.05-mm. sieve to remove all traces of silt and clay.

To extract silt, each 5-pound sample of silty material was first dispersed with *N* sodium hexametaphosphate in about 25 gallons of water. A paint mixer was used for dispersion. The dispersed material was passed through a 0.044-mm. sieve, and particles remaining on the sieve were discarded. The suspension containing the silt and clay was thoroughly mixed, allowed to settle, and the clay particles less than 0.005 mm. in diameter were removed by siphoning. The process of mixing, settling, siphoning, and subsequent dilution was repeated 15 to 20 times until all clay particles were removed. A microscope was used to check the size of particles that had settled. A portion of the purified silt was separated into three different size-fractions, 0.005–0.01, 0.01–0.02, and 0.02–0.05 mm., by repeated mixing in water, settling, siphoning, and dilution. Finally the suspensions containing the different silt fractions were allowed to settle, most of the water was siphoned off, and the sediment was dried and rubbed gently to break the particles apart.

To obtain clay particles, the silty clay loam material was first worked into a paste, diluted with 1 liter of distilled water for each 50 g. of soil, mixed thoroughly, and the dilute suspension allowed to settle. The top portion of the suspension containing the clay was siphoned off and evaporated to a thick paste. The paste was then placed in an air-tight container to be used as required.

Dry sand and silt and moist clay were mixed thoroughly in various proportions. To

[1] Contribution 517, department of agronomy, Kansas Agricultural Experiment Station, Manhattan, and the U. S. Department of Agriculture. Cooperative research in the mechanics of wind erosion.

another identical series of mixtures 10 per cent by weight of ground wheat straw was added and thoroughly mixed. The mixtures, equal to about 1 pound of oven-dry material, were then covered with a ¼-inch wire screen to prevent any erosion that might have occurred otherwise.

The mixtures were left in the field for 1.5 years. From time to time throughout the next 1.5 years they were thoroughly air-dried and sieved on a rotary sieve to determine the proportion and mechanical stability of soil fractions greater than 0.84 mm. in diameter (2). It was shown previously that dry soil fractions greater than 0.84 mm. in diameter, such as clods, blocks, or coarse grains, are essentially nonerodible by wind and that the proportion of these fractions in soils can be used as an approximate index of relative erodibility (1). Consequently, the proportion of these fractions, determined by dry-sieving, was used in this study as a measure of erodibility, a uniform residue-roughness factor of 100 being assumed (5). The proportion of dry soil fractions greater than 0.84 mm. in diameter is referred to as cloddiness, and the fractions are considered clods.

On two occasions near the end of the 3-year period, size distribution of water-stable particles was determined by the method of Yoder (7).

Modulus of rupture of dry briquets of clay and of three different size-fractions of silt was determined according to the method of Richards (6), except that the clay paste was formed into briquets, then dried slowly in a semiairtight container at room temperature to avoid cracking. Drying of clay briquets was continued for several weeks until constant weight was reached. Briquets showing signs of cracking were discarded.

Susceptibility to abrasion by wind-blown sand of dry blocks or different separates was determined by the method previously described (1). Susceptibility to abrasion is expressed by a coefficient of abrasion A, which is the amount of soil abraded off a block per unit weight of abrader blown against the block by a 25-mph. windstream. The coefficient of abrasion may be determined by using any wind velocity. As the amount of abrasion varies as the square of wind velocity, coefficient A may be determined from the expression $a\left(\frac{25}{v}\right)^2$ in which a is the weight abraded per unit weight of abrader blown at wind velocity v, expressed in miles per hour.

Analyses of variance were made in cases where significance of difference was in doubt.

RESULTS

Marked differences in cloddiness and erodibility were obtained between soil samples receiving straw and corresponding samples not receiving straw. Superimposed on these differences was the effect of the different mechanical separates, sand, silts, and clay. The relative effects of these separates were generally the same in samples receiving and not receiving straw. To avoid inclusion of superfluous data, only the averages of straw-treated and corresponding untreated cases are presented.

In samples containing any one of the mechanical separates, the greatest degree of cloddiness was obtained with silt ranging from 0.005 to 0.01 mm. in diameter (fig. 1). Degree of cloddiness decreased for separates smaller and larger than this size. Virtually no cloddiness was obtained with very fine sand (0.05 to 0.1 mm.). Cloddiness obtained with clay was only 57 per cent that of fine silt.

Modulus of rupture, a measure of cohesive strength of dry briquets, varied inversely with diameter of mechanical separate from which a briquet was formed (fig. 2). No simple expression was found governing this relationship. The clay particles possessed the greatest value of modulus of rupture, and very fine sand exhibited virtually none. Grains of very fine sand (0.05–0.1 mm.) cohered

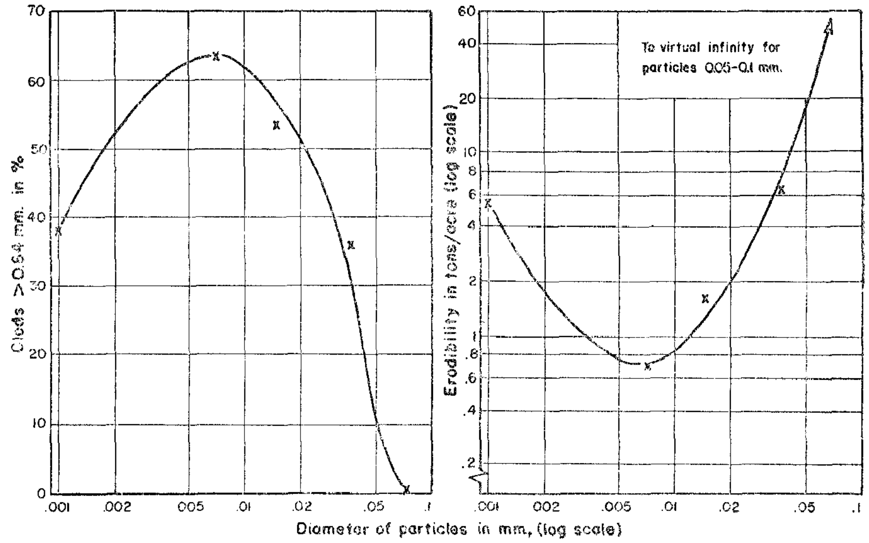

FIG. 1. RELATION OF SOIL CLODDINESS AND ERODIBILITY TO DIAMETER OF MECHANICAL SOIL PARTICLES

slightly after forming briquets by wetting and subsequent drying, but a mere touch caused the briquets to crumble into a heap of loose grains. The silt particles exhibited some coherence but not nearly to the same degree as did clay. The physical behavior of silt was entirely different from that of clay. Though briquets of clay cracked badly after repeated wetting and drying and finally

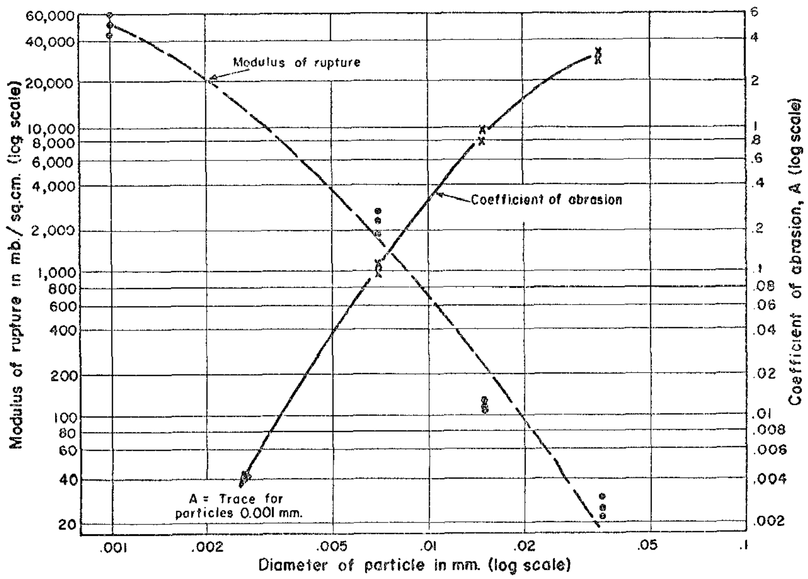

FIG. 2. RELATION OF MODULUS OF RUPTURE AND COEFFICIENT OF ABRASION TO DIAMETER OF MECHANICAL SOIL PARTICLES

crumbled into small more or less water-stable aggregates, briquets of silt dispersed each time they were wetted, and repeatedly formed single massive blocks when dried. These silt blocks did not erode under a wind velocity as high as 40 mph. at 6-inch height but abraded in a variable degree when a stream of fine sand was ejected against them.

Coefficient of abrasion, a measure of susceptibility of dry soil blocks to abrasion by wind-borne grains of sand, varied inversely with cohesive strength of the blocks, as indicated by the modulus of rupture (fig. 2). But the high coherence of blocks of clay and their resistance to abrasion by blown sand were not an indication of their resistance to wind erosion, for under the influences of weather, especially under freezing and thawing, blocks of clay disintegrated into a substantial proportion of grains too small to resist the erosive force of wind. Blocks of fine silt did not granulate, but after drying always remained as a compact mass that resisted the direct force of wind exceedingly well and resisted abrasion from wind-blown sand to a moderate degree (fig. 2). Fine sand grains exhibited no coherence, whereas medium and coarse silt (0.01–0.05 mm.) possessed characteristics intermediate between fine sand and clay.

Mechanical stability of clods, that is, the relative resistance of clods to breakdown by mechanical forces such as tillage or abrasion by wind-blown soil materials, increased directly with the proportion of silt and clay (table 1). The clay fraction evidently offered a much greater resistance to breakdown of clods than did silt.

In mixtures of clay and fine sand, clay up to about 5 per cent was extremely effective in creating cloddiness and reducing erodibility by wind, but succeeding

TABLE 1

The influence of sand, silt, and clay on size of water-stable particles and mechanical stability of clods

Mechanical Composition			Water-Stable Particles			Mechanical Stability of Clods
Sand	Silt	Clay	>0.84 mm.	0.84–0.02 mm.	<0.02 mm.	
%	%	%	%	%	%	%
100	0	0	0	100	0	0
99	1	0	1	96	3	42
75	25	0	2	91	7	47
52	48	0	1	87	12	45
29	71	0	3	78	19	51
0	100	0	7	68	25	57
0	84	16	3	74	23	70
0	63	37	9	79	12	71
0	39	61	12	79	9	85
0	21	79	12	80	8	82
0	0	100	6	86	8	79
24	0	76	7	86	7	75
47	0	53	5	90	5	74
71	0	29	4	90	6	70
100	0	0	0	100	0	0

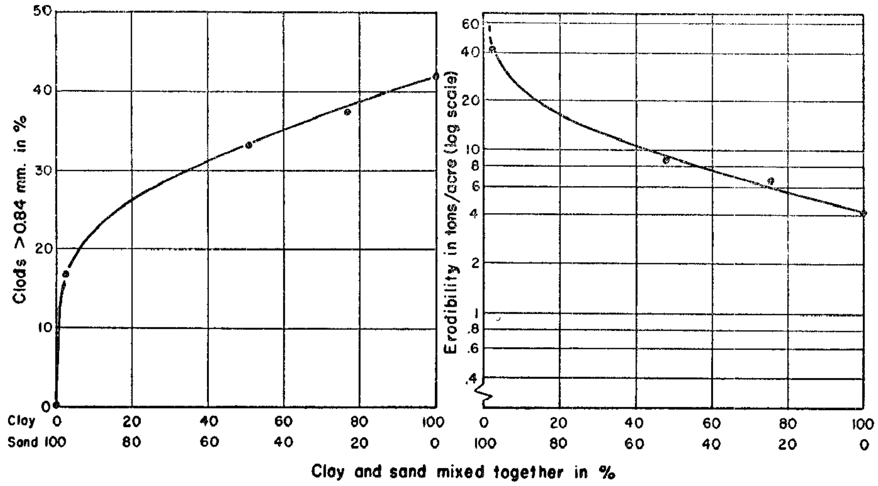

FIG. 3. RELATION OF SOIL CLODDINESS AND ERODIBILITY TO RELATIVE PERCENTAGES OF CLAY AND SAND

increments of clay were progressively less effective (fig. 3). Thus, the first 5 per cent of clay increased the cloddiness by as much as the next 75 per cent. The 5 per cent of clay constituted a mere coating of the clay particles over the sand grains.

In mixtures of silt and sand, silt up to 5 per cent of the total weight of mixture was about as effective in creating clods as was clay (fig. 4). From this point onward, the silt was, on the average, more than 1.5 times as effective as clay.

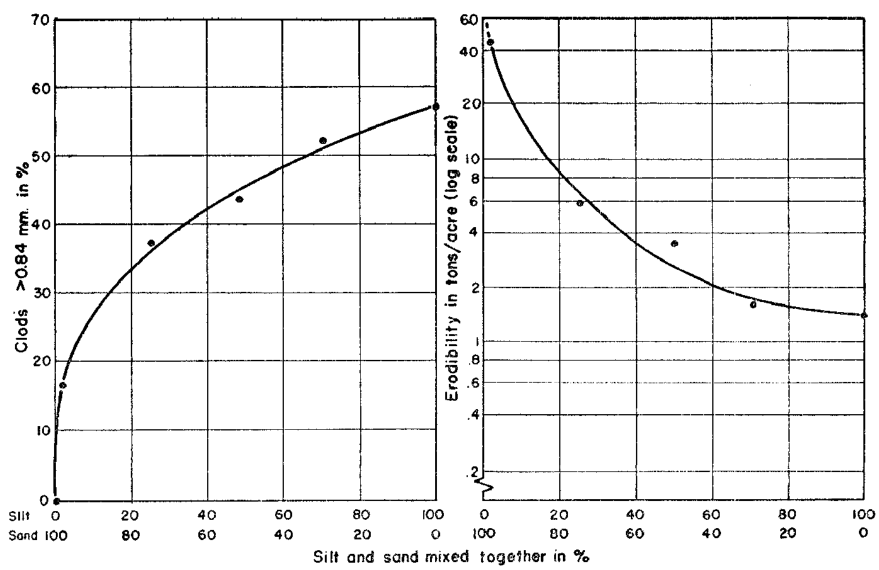

FIG. 4. RELATION OF SOIL CLODDINESS AND ERODIBILITY TO RELATIVE PERCENTAGES OF SILT AND SAND

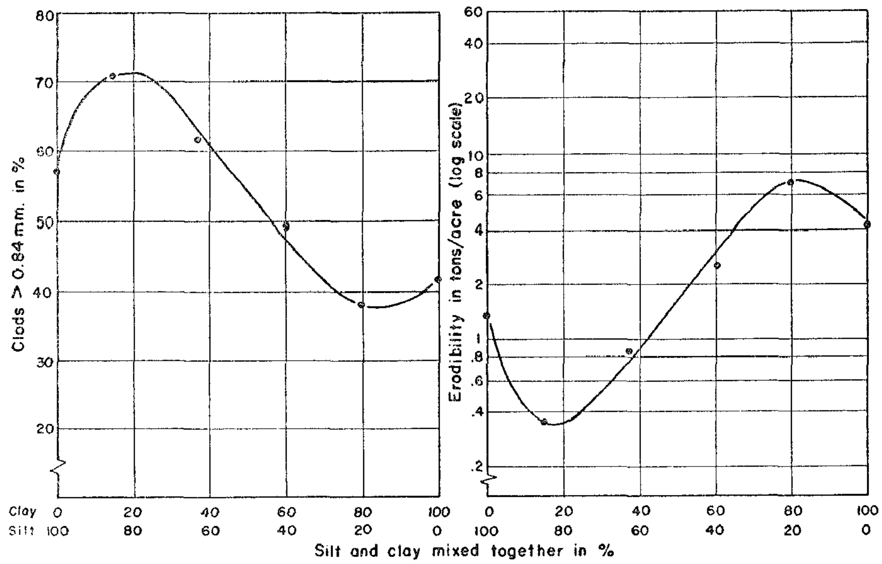

Fig. 5. Relation of Soil Cloddiness and Erodibility to Relative Percentages of Clay and Silt

A soil composed entirely of silt had, on the average, 37 per cent more clods than did a soil composed entirely of clay and had an erodibility only 36 per cent that of clay. The differences were highly significant. Cloddiness of clean sand, on the other hand, was zero, and, consequently, its erodibility was infinite. "Infinite" erodibility means that erosion would continue indefinitely if depth were unlimited.

For mixtures of silt and clay, a peculiar S-shaped surve was obtained (fig. 5). Cloddiness increased with clay content up to about 20 per cent, then it decreased as the clay was increased to 80 per cent, and increased again when the clay was increased to 100 per cent. Of the different mixtures used in these experiments, the greatest degree of cloddiness and the lowest erodibility were obtained from a mixture containing 20 per cent clay and 80 per cent silt. Analysis of variance indicated that differences in individual values marking the different trends shown in figure 5 were statistically significant.

The clay fraction of the soil tended to increase especially the water-stable aggregates greater than 0.84 mm. in diameter, and the silt fraction tended to increase especially the water-stable particles less than 0.02 mm. in diameter (table 1). A previous study (4) indicated that both of these sizes of water-stable particles tend to reduce erodibility by wind—the former by the fact that their size is resistant to movement by wind, and the latter by their tendency to form clods.

DISCUSSION

The data indicate that sand particles have little or no cohesive property, are readily loosened by force of impact of wind-blown materials, and, except the coarse particles, are easily carried by the wind. Silt and clay, on the other hand, exhibit a cohesive property and, therefore, seldom exist as individual particles but act as a binding agent in the formation of wind-resistant clods. It is difficult to say which of the two is a more effective binding agent for sand, for their effectiveness depends somewhat on their proportion to each other and to the sand fraction. The first 5 per cent of silt and clay mixed with sand was about equally effective in creating cloddiness, but the quality of clods was different in the two cases. Those formed with clay and sand were harder and less subject to abrasion by wind-blown sand than were those formed from silt and sand. For proportions greater than about 5 per cent and up to 100 per cent the silt fraction created more clods, though the clods tended to be somewhat softer than those formed from clay and sand.

An entirely different regimen of cloddiness was obtained from mixtures of silt and clay. Data in this paper show that about 20 per cent of clay, when mixed with silt, formed the greatest degree of cloddiness and resistance to wind erosion. Amounts of clay considerably beyond this limit were detrimental in that under the influence of wetting and drying, and especially freezing and thawing, clay formed a substantial proportion of small granules as erodible as fine grains of sand. In a study of 31 western Canada soils, the greatest degree of cloddiness and resistance to wind erosion was found for intermediate-textured soils having about 20, 38, and 42 per cent of clay, silt, and sand, respectively.[2] Results obtained from Kansas and Nebraska, on the other hand, showed that the lowest average erodibility was obtained on soils having about 27, 51, and 22 per cent of clay, silt, and sand, respectively (3). The reason for this discrepancy is not known definitely. Of interest is the fact that in both cases the soils with the lowest erodibility had a moisture equivalent of about 23 per cent. The two soil groups, the first developed predominantly from glacial till, and the second from loess, no doubt differed in size-distribution of silt and clay fractions and in amount and nature of the organic matter. All of these factors probably influence cloddiness and erodibility by wind. At least the size-distribution of silt, as shown from this study, has considerable influence.

Of the different silt fractions, silt of 0.005 to 0.01 mm. in diameter appeared to be the least wind-erodible. Its resistance to wind erosion was due to its ability to form clods that exhibited considerable cohesion, substantial resistance to abrasion by wind-blown materials, and a high degree of stability against the disintegrating forces of wetting and drying and freezing and thawing. Larger silt fractions had a lower degree of coherence, were more readily separated by the disintegrating force of wind-blown materials, and were more readily picked up by the wind. Coarse silt of 0.02 to 0.05 mm. had virtually no coherence and no resistance to abrasion and was easily picked up by the wind. Its physical properties were similar to those of very fine sand.

A certain proportion of clay, ranging from 20 to 30 per cent, appears to be essential for the greatest stability of soil against wind. The actual proportion of

[2] Chepil, W. S. The relation of wind erosion to some physical soil characteristics. 1940. [Unpublished Ph.D. thesis. Copy on file University of Minneapolis, Minnesota.]

clay required for greatest stability may be influenced somewhat by the physical and chemical nature of the clay and by the relative proportion of other constituents in the soil. No information is presently available on the effects of different types of clay. This study gives some information of the effects of two-constituent mixtures of silt and clay, silt and sand, and clay and sand, but no information is available on the specific influence of triple-constituent mixtures of sand, silt, and clay.

SUMMARY

Where a soil sample was composed of only one mechanical constituent, sand, silt, or clay, the greatest degree of cloddiness and resistance to wind erosion was obtained with silt ranging from 0.005 to 0.01 mm. in diameter. An extremely high erodibility was obtained with fine sand, and a moderate degree of erodibility was obtained with clay.

Modulus of rupture varied inversely and coefficient of abrasion varied directly with diameter of soil particles consolidated in blocks by wetting and drying. These coefficients served as a measure of only one phase of erodibility by wind—the phase of resistance of clods to disintegrating forces of tillage and abrasion from wind-eroded materials. The coefficients had no general bearing to soil cloddiness or to size distribution of water-stable particles.

The greater the proportion of silt and the lesser the proportion of sand, the lower was the soil erodibility, as indicated by the degree of soil cloddiness. The function of clay was variable. Additions of clay to silt decreased erodibility, but only if the clay did not exceed 20 per cent. Further additions of clay to silt increased the erodibility substantially. No proportion of clay to silt produced a greater erodibility than that of mixtures containing more than 75 per cent fine sand.

Clay tended to increase especially the water-stable particles greater than 0.84 mm. in diameter, and silt tended to increase especially the water-stable particles less than 0.02 mm. in diameter. A previous study indicated that both of these water-stable fractions tend to decrease erodibility by wind.

REFERENCES

(1) Chepil, W. S. 1951 Properties of soil which influence wind erosion: V. *Soil Sci.* 72: 465–478.

(2) Chepil, W. S. 1952 Improved rotary sieve for measuring state and stability of dry soil structure. *Soil Sci. Soc. Amer. Proc.* (*1951*) 16: 113–117.

(3) Chepil, W. S. 1953 Factors that influence clod structure and erodibility of soil by wind: I. *Soil Sci.* 75: 473–483.

(4) Chepil, W. S. 1953 Factors that influence clod structure and erodibility of soil by wind: II. *Soil Sci.* 76: 389–399.

(5) Chepil, W. S., and Woodruff, N. P. 1954 Estimations of wind erodibility of field surfaces. *J. Soil and Water Conserv.* 9: 257–265, 285.

(6) Richards, L. A. 1953 Modulus of rupture as an index of crusting of soil. *Soil Sci. Soc. Amer. Proc.* 17: 321–323.

(7) Yoder, R. E. 1936 A direct method of aggregate analysis and a study of the physical nature of erosion losses. *J. Am. Soc. Agron.* 28: 337–351.