Reprinted from SOIL SCIENCE SOCIETY OF AMERICA PROCEEDINGS
Vol. 18, No. 1, January 1954

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Seasonal Fluctuations in Soil Structure and Erodibility of Soil by Wind[1]

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ABSTRACT

The objective of this investigation was to elucidate the effects of seasons on soil structure and erodibility by wind.

Little change in soil structure and erodibility occurred during a mild, dry winter near Lubbock, Tex., in 1952–53, but considerable change occurred during several consecutive winters in some areas of the Prairie soil zone of Kansas where the soils were usually moist.

Under moist conditions, frost action tended to break down the coarse water-stable aggregates and at the same time tended to consolidate the finest fractions to an intermediate size, especially between 0.05 and 0.42 mm. in diameter. The probable mechanism of frost action on soil structure is described.

Secondary aggregates and clods tended to break down during the winter to a size erodible by wind (<0.84 mm. in diameter). Soil erodibility was in most cases much higher in spring than in fall. The greatest increase in erodibility occurred in finest textured soils, the least in coarsest. Seasonal fluctuations in soil structure and erodibility seldom exceeded 3 inches in depth. Below this depth, the structure and erodibility changed little from season to season.

During the summer there was usually an increase in the coarsest and the finest water-stable soil fractions. It was concluded that the finest water-stable fraction (<0.02 mm.) contains materials essential for the building of primary and secondary soil aggregates.

IN regions of humid and sub-humid climate, land is often plowed in the autumn to utilize the action of frost for improving soil tilth. Farmers in such areas have long recognized that intractible fall-plowed clays become friable and easily tilled in spring. Alternate freezing and thawing of the soil when moist cause a granulating action on soil clods (6).

In semi-arid regions where soils naturally assume a satisfactory tilth, fall plowing exposes a bare soil to excessive freezing and thawing, causes undue destruction of clods, and makes the soils more susceptible to erosion by wind (7).

The effects of frost on soil structure, although understood in broad outline, have not received much detailed study. Jung (9) found from laboratory experiments that slow cooling at –10°C., comparable in many cases to speed of cooling in the field, had an aggregating action on the soil, as measured by an increase in soil permeability after thawing. Aggregation under slow cooling increased with moisture content of the soil up to about 50% saturation. Decreases were then experienced until the soil reached 100% saturation. Beyond this point aggregation remained constant up to 200% saturation. Quick freezing at –190°C. had effects opposite to those of slow freezing and generally caused soil dispersion, as indicated by a decrease in soil permeability. It is doubtful whether results similar to those of quick freezing are obtainable under natural conditions in the field.

From the experiments of Jung it is difficult to determine the effects of slow and quick freezing on the size distribution of soil aggregates. Studies conducted by Slater and Hopp (8, 11, 12) under field conditions indicated that freezing and thawing of bare, moist soil tend to destroy water-stable aggregates greater than 0.5 mm. in diameter, but no information was obtained on the effect of frost on other sizes of soil aggregates.

Materials and Methods

The present study was conducted in an attempt to clarify the action of frost on the various phases of soil structure and on erodibility by wind. Cass fine sandy loam, Cass loam, Wabash silt loam, Geary silty clay loam, and Sutphen clay were chosen from the Prairie soil zone near Manhattan and Salina, Kans. Starting in 1950 and continuing into 1953, samples of soil were taken from different depths from the same locations in the field in early fall and early spring. In addition, samples were taken from two soil types (see table 1) of the Reddish Chestnut soil zone near Lubbock, Tex., in the fall of 1952 and in the spring of 1953. The samples were transported to the laboratory, dried, and analyzed for structural characteristics and erodibility by wind. In all cases, the fields were undisturbed by cultivation between the times of sampling in fall and spring. The soils in most cases were completely or partly covered with crop or crop residue, although in a few cases they were bare.

Soils from near Manhattan and Salina, Kans., were generally moist during the winters. Average annual rainfall in these two areas during 1950 through 1952 was 37.46 and 31.94 inches, and the average semi-annual rainfall, October through March, was 6.74 and 4.81 inches. Freezing and thawing were common during this period. The winter of 1952–53 near Lubbock, Tex., on the other hand, was unusually mild and dry. The 1952 annual precipitation for Lubbock was 14.54 inches and the semi-annual precipitation, October 1952 through March 1953, was 2.06 inches.

Soil analyses included (a) size distribution of water-stable aggregates by the modified method of Yoder (13), (b) size distribution of dry aggregates and their mechanical stability by the method of Chepil (3), and (c) erodibility by wind as indicated by the proportion of dry erodible fractions contained in the soil (4, figure 6). All determinations were made in duplicate. Analyses of variance between fall and spring measurements of erodibility and some phases of soil structure were made.

Results

To avoid superfluity, detailed data based on averages of duplicate tests are presented only for Cass loam (table 1). These data represent approximately the average seasonal fluctuations in structure and erodibility of a group of five soils of the Prairie soil zone of Kansas. Figures 1 to 4 have been prepared to show more clearly the fluctuations in some phases of structure and erodibility of the five soils.

SEASONAL VARIATION OF WATER-STABLE AGGREGATE STRUCTURE

In soils studied from the Prairie soil zone of Kansas the proportion of the finest and the coarsest water-stable fractions (<0.02 mm. and >0.84 mm. in diameter) was generally higher in fall than in spring (figure 1, left side). The greatest change occurred at or near the surface of the ground, and little or no change occurred below the 3-inch depth (table 1). It is apparent that the action of freezing and thawing during the winter when the soil was generally moist tended to break down the coarsest water-stable fractions and at the same time tended to consolidate the finest fraction to an intermediate size of water-stable fraction, especially between 0.05 and 0.42 mm. in diameter (table 1). This fraction, if unconsolidated into larger secondary aggregates, is highly erodible by wind, whereas fractions above and below this size offer re-

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[1] Contribution 493, Department of Agronomy, Kansas Agr. Exp. Sta., Manhattan, Kans., and the BPISAE, U. S. Dept. of Agriculture. Cooperative investigations in the mechanics of wind erosion. Received for publication Sept. 25, 1953.

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Table 1.—The influence of seasons on state and stability of soil structure and erodibility by wind.

Soil No.*	Date	Depth	Water-stable aggregates					Dry aggregates				Mechanical stability	Erodibility
			>0.84 mm.	0.84–0.42 mm.	0.42–0.05 mm.	0.05–0.02 mm.	<0.02 mm.	>6.4 mm.	6.4–0.84 mm.	0.84–0.42 mm.	<0.42 mm.		
	Mo. Yr.	In.	%	%	%	%	%	%	%	%	%	%	Tons per acre
1	Sept. 50	0–1	3.9	3.6	39.9	42.2	10.4	47.3	18.2	1.5	33.0	93.0	0.3
	Mar. 51	0–1	1.4	1.7	40.1	50.2	6.6	29.9	22.4	9.2	38.5	87.6	1.0
		1–3	0.6	2.8	45.8	43.0	7.8	28.6	23.6	6.5	41.3	84.4	1.0
		3–6	0.8	2.4	40.8	48.0	8.0	53.6	18.7	3.5	24.2	92.8	0.2
	Sept. 51	0–1	2.0	1.7	23.7	56.0	16.6	44.5	25.7	5.0	24.8	92.5	0.2
		1–3	1.0	1.4	21.9	65.7	10.0	53.7	25.9	3.2	17.2	90.9	0.07
		3–6	0.4	1.0	27.0	58.0	13.6	61.7	17.4	1.8	19.1	88.0	0.07
	Mar. 52	0–1	0.1	1.2	40.3	48.0	10.4	29.6	18.4	3.4	48.6	76.0	1.3
		1–3	0.3	1.0	42.7	47.2	8.8	41.2	23.6	3.7	31.5	82.3	0.8
		3–6	0.2	0.6	18.4	64.0	16.8	68.9	17.7	1.6	11.8	90.5	0.02
	Aug. 52	0–1	2.1	1.1	27.2	54.0	15.6	38.6	20.6	4.4	36.4	78.0	0.6
		1–3	2.1	1.9	26.4	55.0	14.6	42.3	21.8	3.6	32.3	84.7	0.4
		3–6	2.4	1.6	26.4	55.0	14.6	62.8	19.0	2.2	16.0	89.6	0.04
	Mar. 53	0–1	0.2	1.0	34.6	53.0	11.2	21.4	18.4	3.5	56.7	53.9	2.2
		1–3	0.2	1.3	36.0	51.5	11.0	30.6	26.6	4.8	38.0	73.4	0.7
		3–6	0.1	1.0	34.1	53.5	11.3	57.7	24.8	1.7	15.8	88.4	0.04
2	Nov. 52	0–1	1.1	4.2	58.9	23.1	12.7	15.5	21.8	7.7	55.0	75.0	2.5
	Apr. 53	0–1	0.5	3.0	70.5	15.5	10.5	20.3	21.5	7.0	51.2	72.4	1.9
3	Nov. 52	0–1	2.6	6.5	54.3	22.6	14.0	29.2	22.5	9.6	38.7	87.5	1.0
	Apr. 53	0–1	1.0	6.8	54.8	23.2	14.2	29.3	19.5	10.2	41.0	71.0	1.2

*Soil No. 1 is Cass loam from the Prairie soil zone near Manhattan, Kans., and soils No. 2 and 3 are Zita sandy clay loam and Pullman clay loam from the Reddish Chestnut soil zone near Lubbock, Tex., respectively.

sistance to erosion by wind (2). Decreases in the proportion of the coarsest water-stable fraction during the winter were associated with approximately equal decreases in the proportion of finest water-stable fraction. Conversely, increases in the proportion of the coarsest fraction during the summer were associated with about equal increases in the proportion of the finest fraction. The differences in water-stable aggregates > 0.84 plus < 0.02 mm. in diameter between fall and spring measurements were not significant for Cass fine sandy loam, significant at a 5% level for Geary silty clay loam, and significant at a 1% level for Cass loam, Wabash silt loam, and Sutphen clay.

The water-stable structure of soils near Lubbock, Tex., during the unusually dry and mild winter of 1952–53 remained about the same from fall to spring (last 2 soils of table 1).

In a previous study (4) it was found that increases in the coarsest and the finest water-stable fractions tend to result in a reduction of the proportion of dry fraction < 0.84 mm. in diameter and to cause a reduction in erodibility of soil by wind. Since, in this study, both of the water-stable fractions varied directly with each other, it was decided that the sum of the two would serve as a convenient index of the dry aggregate structure and erodibility by wind.

SEASONAL VARIATION OF DRY AGGREGATE STRUCTURE AND ERODIBILITY BY WIND

Soil cloddiness was reduced from fall to spring in all cases where the soil was moist occasionally during the winter (figure 1, right side). If the soil was dry during the winter little change in cloddiness occurred (last 2 soils of table 1). The greatest reduction in cloddiness of moist soils occurred in the finest-textured soils and the least in those of coarsest texture. The visible change in cloddiness of moist soils from fall to spring may be observed from photographs of figure 2.

The proportion of dry fraction < 0.84 mm. in diameter in all Kansas soils increased from fall to spring

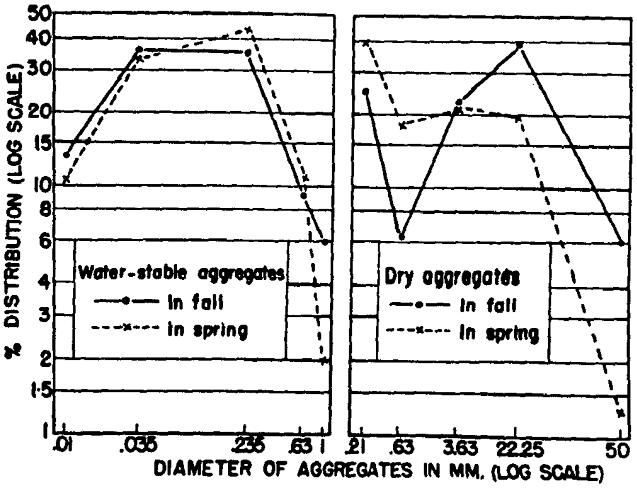

FIG. 1.—Size-distribution of water-stable and dry aggregates in soils from surface to 1-inch depth in fall and spring. Data are based on averages of 5 soils from the Prairie soil zone of Kansas from September 1950 to March 1953.

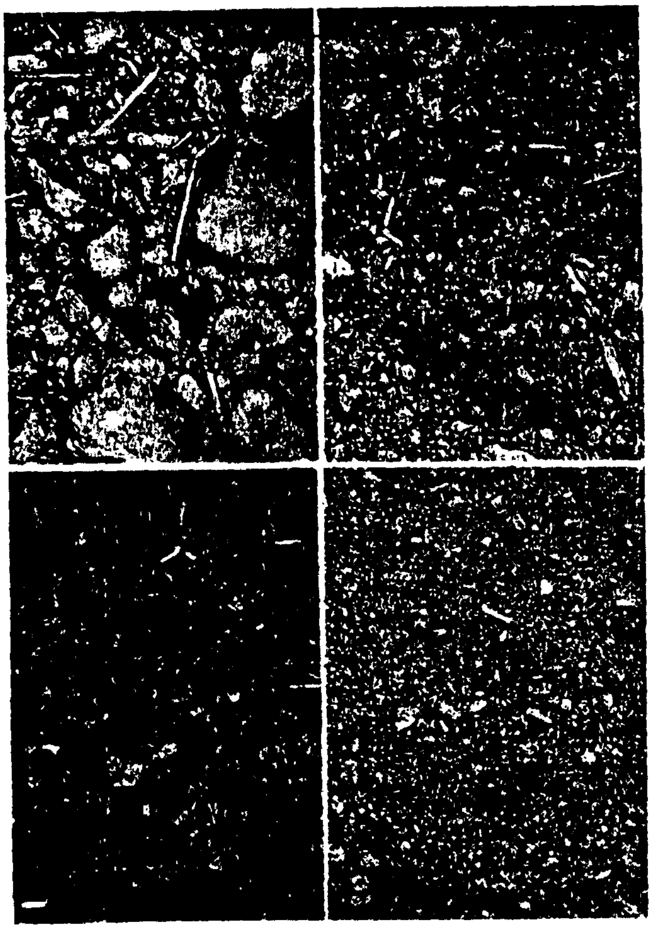

FIG. 2. — Appearance of soil from surface to 1-inch depth after sampling, drying and thorough mixing. Top row, left to right: Wabash silt loam in fall, 1951; Wabash silt loam in spring, 1952. Bottom row, left to right: Sutphen clay in fall, 1951; Sutphen clay in spring, 1952.

(figure 3). The increases were all significant at a 1% level. This fraction is erodible by wind and serves as an approximate index of erodibility (4). An increase in dry fraction < 0.84 mm. in diameter always accompanied a decrease in the water-stable fraction < 0.02 mm. and > 0.84 mm. in diameter.

Erodibility was higher in the spring than in the previous fall in all cases where the soil was moist occasionally during the winter, but the increases in erodibility were not of the same magnitude in all soils (figure 3). The greatest increase in erodibility from fall to spring occurred in the finest textured soil, the least in the coarsest. The increases in erodibility were all significant at a 1% level except for the coarsest soil (Cass fine sandy loam).

Mechanical stability of dry aggregates, that is, the resistance of dry aggregates to breakdown by mechanical forces, was usually greater in fall than in spring (figures 3 and 4). Most of the differences were not significant, however. Significant differences might have been obtained if more replicates were used.

Much greater seasonal fluctuations in soil structure and erodibility occurred near the surface than at a depth range of 1 to 3 inches (figure 4). At a third level, from 3 to 6 inches in depth, the fluctuations were even less perceptible and in some cases apparently did not exist.

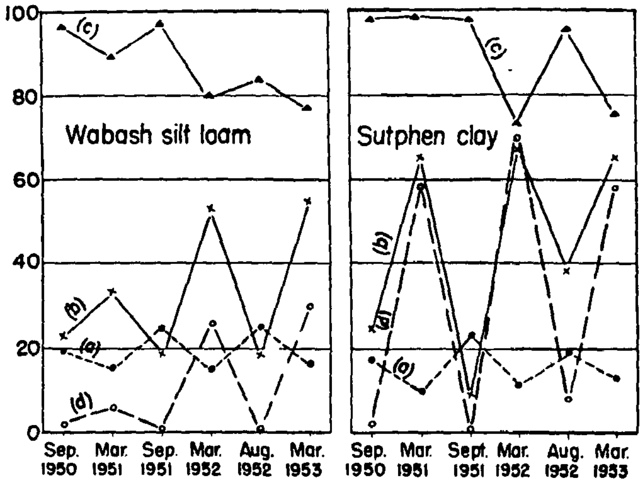

FIG. 3. — Seasonal fluctuation in water-stable and dry soil structure and erodibility by wind: (a) percent water-stable particles < 0.02 mm. and > 0.84 mm. in diameter; (b) percent dry particles < 0.84 mm. in diameter; (c) percent mechanical stability of dry clods; and (d) erodibility in hundredweights per acre. All measurements based on soil from surface to 1-inch depth.

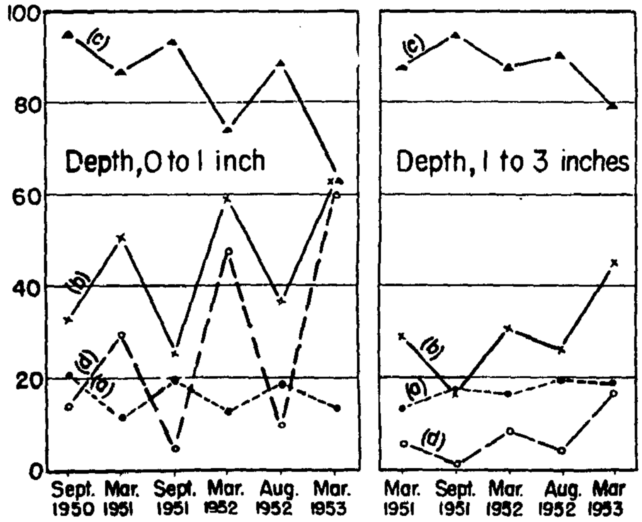

FIG. 4. — Seasonal fluctuation in dry and water-stable soil structure and erodibility by wind: (a) percent water-stable particles < 0.02 mm. and > 0.84 mm. in diameter; (b) percent dry particles < 0.84 mm. in diameter; (c) percent mechanical stability of dry clods; and (d) erodibility in hundredweights per acre. Data are based on averages of 5 soils from the Prairie soil zone of Kansas.

Discussion and Conclusions

So far as the author is aware, this study shows for the first time that frost action tends to break down the coarse water-stable aggregates and at the same time tends to aggregate the fine water-stable particles to an intermediate size of water-stable aggregates. In every case a decrease of the coarsest fraction during the winter is accompanied by a decrease of the finest fraction. In every case, also, an increase in the proportion of the coarsest water-stable fraction during the summer is accompanied by an increase in the proportion of the finest fraction. Thus, aggregation of one phase of water-stable structure, winter or summer, is accompanied by deaggregation or dispersion of the other phase. It is possible that some factors may affect a change in the proportion of the coarsest fraction without affecting a change in the finest, but as far as the effect of seasons is concerned, a change in one phase has been always accompanied by a change in the other.

The breakdown of coarse aggregates during the winter is apparently due to expansion of ice crystals within the aggregates. If the aggregates are dry, no crystals are formed and no breakdown occurs. Whenever the breakdown of coarse aggregates occurs, there is always an accompanying aggregation of the fine soil particles. Apparently the formation of ice crystals also is responsible for the aggregation of the fine soil particles. Baver (1) has described the possible causes of aggregation of fine soil particles during the freezing process, but has not recognized the simultaneous breakdown of the coarser soil aggregates.

The increase in the proportion of the coarsest water-stable fraction during the summer is always accompanied by the increase in the proportion of the finest water-stable fraction. It is probable that the increase of the coarsest fraction is caused by the increase of cementing substances contained in the finest fraction (2, 5). This finest fraction apparently contains materials of either mineral, organic, or biologic origin necessary for the building of both primary and secondary aggregates. The cementing substances appear to be somewhat dispersible in water initially but tend to coagulate and form rather large water-stable aggregates. Assisted by freezing temperatures, more of these cementing substances are coagulated during the winter, resulting in the formation of additional water-stable aggregates. But the formation and growth of ice crystals within the aggregates cause many to break down to smaller, intermediate sizes of aggregates. Moreover, dry aggregates or clods built during the summer likewise tend to break down to smaller fractions during winter. The degree of breakdown of soil aggregates during the winter is, however, far less drastic than that of soil dispersion.

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