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FACTORS THAT INFLUENCE CLOD STRUCTURE AND ERODIBILITY OF SOIL BY WIND: V. ORGANIC MATTER AT VARIOUS STAGES OF DECOMPOSITION

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General observations in Canada have indicated that high organic matter content of soil is conducive to high fertility and good tilth but facilitates erosion by wind (10, 11). Initial experiments undertaken to verify these observations showed that wheat straw in the process of decomposition increased soil cloddiness and decreased erodibility by wind (2). These trends were reversed after the straw was decomposed. Under identical treatment the black soils contained more wind-erodible fractions than did the brown or dark brown soils and were more susceptible to wind erosion. The influence of decomposed wheat straw was magnified in soils containing a high proportion of calcium carbonate (5).

This paper presents results of studies on the influence of decomposing and decomposed organic matter on structure and erodibility of some soils of the high plains area of the United States.

PROCEDURE

Dry wheat straw, chopped into about 1-inch lengths or finely ground, and freshly cut alfalfa hay, chopped into about 1-inch lengths, were mixed with 6-pound duplicated samples of soil in October 1948, in June 1949, and again in January 1950 in amounts each time equal to 0.333 and 2 per cent on the basis of oven-dry weight. Controls, without straw or hay, were also duplicated. Five soil types, one each from the chernozem, chestnut, and reddish-chestnut soil groups of Kansas and two from the brown group, also of Kansas, were used. The treated soils were placed in porous-bottomed trays and maintained in the field. The trays are covered with a ¼-inch mesh screen to prevent any possibility of erosion by wind.

In a similar experiment initiated in September 1951, ground wheat straw was mixed with previously described soils of various textures prepared synthetically (7). The amount of added straw was equal to 10 per cent on the basis of oven-dry weight.

The soils were analyzed at irregular intervals for years for some structural characteristics and erodibility by wind. Soil analyses in all cases included (*a*) size distribution of water-stable particles or aggregates by the modified method of Yoder (23), (*b*) size distribution of dry aggregates or clods by the method of Chepil (3), and (*c*) erodibility by wind estimated from the proportion of dry

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TABLE 1

Influence of organic matter on soil structure and erodibility by wind at different periods

Averages of five soil types in duplicate

Organic Matter Added	Water-Stable Aggregates			Dry Aggregates			Relative Erodibility
	>0.84 mm.	0.84–0.02 mm.	< 0.02 mm.	< 0.84 mm.	0.84–0.42 mm.	< 0.42 mm.	
	%	%	%	%	%	%	
September 1950							
None	1.4	82.3	16.3	38.1	6.9	55.0	100
1% straw (1 inch long)	2.1	84.0	13.9	40.3	7.3	52.4	82
6% straw (1 inch long)	4.7	84.1	11.2	42.7	9.8	47.5	99
1% straw (ground)	1.8	86.5	11.7	39.7	7.5	52.8	84
6% straw (ground)	7.0	84.4	8.6	41.7	12.7	45.6	78
1% alfalfa	2.0	83.9	14.1	37.4	7.3	55.3	104
6% alfalfa	3.6	82.4	14.0	46.8	8.6	44.6	60
L.S.D. 1% level	1.2	N.S.	1.7	6.7	0.9	6.8	N.S.
L.S.D. 5% level	0.9	N.S.	1.3	5.1	0.7	5.1	N.S.
April 1952							
None	1.5	78.2	20.3	56.8	5.0	38.2	100
1% straw (1 inch long)	1.4	80.5	18.1	53.7	5.8	40.5	149
6% straw (1 inch long)	2.3	81.7	16.0	51.4	6.9	41.7	198
1% straw (ground)	1.1	81.0	17.9	51.3	5.8	42.9	190
6% straw (ground)	2.5	83.9	13.6	43.8	8.5	47.7	412
1% alfalfa	1.4	80.5	18.1	55.0	4.9	40.1	150
6% alfalfa	1.9	81.0	17.1	52.9	6.4	40.7	199
L.S.D. 1% level	N.S.	1.1	0.9	3.1	0.8	5.8	132
L.S.D. 5% level	N.S.	0.8	0.7	2.3	0.6	4.3	99
February and July 1953							
None	1.1	78.1	20.8	44.6	8.5	46.9	100
1% straw (1 inch long)	0.8	81.0	18.2	38.0	9.8	52.2	212
6% straw (1 inch long)	1.4	82.9	15.7	35.7	11.4	52.9	256
1% straw (ground)	1.1	81.0	17.9	38.6	8.5	52.9	191
6% straw (ground)	0.9	84.0	15.1	32.3	11.9	55.8	342
1% alfalfa	0.8	79.6	19.6	38.1	9.3	52.6	209
6% alfalfa	1.1	82.4	16.5	38.1	10.9	51.0	225
L.S.D. 1% level	N.S.	0.6	0.6	2.6	1.1	2.3	136
L.S.D. 5% level	N.S.	0.4	0.4	1.9	0.8	1.7	102
April 1954							
None	0.9	87.6	11.5	48.8	7.5	43.7	100
1% straw (1 inch long)	0.7	88.1	11.2	46.6	8.9	44.5	134
6% straw (1 inch long)	1.5	88.6	9.9	43.9	10.2	45.9	171
1% straw (ground)	0.7	88.8	10.5	46.9	7.4	45.7	118
6% straw (ground)	1.0	90.5	8.5	37.2	10.4	52.4	351
1% alfalfa	0.9	88.1	11.0	49.4	8.1	42.5	102
6% alfalfa	1.2	89.1	9.7	46.6	9.6	43.8	325
L.S.D. 1% level	0.3	1.4	1.5	3.7	1.3	5.1	180
L.S.D. 5% level	0.2	1.0	1.1	2.8	1.0	3.9	136

* Dry wheat straw, chopped in 1-inch lengths or finely ground, and freshly cut alfalfa hay chopped in 1-inch lengths were used. These materials were mixed with soil in October 1948 at the start of the experiment, in June 1949, and again in January 1950, in amounts each time equal to ⅓ per cent and 2 per cent of the oven-dry weight of soil.

Analysis of variance is based on duplicate samples of five soils and seven treatments, or $N = 70$.

clods greater than 0.84 mm. in diameter, a residue-roughness factor of 100 being assumed (6). Determinations of soil organic matter were made by the chromic acid titration method of Walkley (22).

RESULTS

During the time of rapid decomposition of vegetative matter, in the form of either dry wheat straw or green alfalfa, an increase was noted in the proportion

TABLE 2

*Influence of decomposing and decomposed wheat straw on some phases of soil structure and erodibility by wind**

Averages of duplicated tests

Soil Type and Zone	Straw Added	Water-Stable Aggregates			Dry Aggregates			Relative Erodi-bility
		> 0.84 mm.	0.84–0.02 mm.	< 0.02 mm.	> 0.84 mm.	0.84–0.42 mm.	< 0.42 mm.	
September 1950 when straw was decomposing rapidly								
	%	%	%	%	%	%	%	%
Hastings silt loam (chernozem)	0	2.3	74.5	23.2	59.6	5.5	34.9	100
	6	11.4	76.4	12.2	58.1	10.6	31.3	114
Keith silt loam (chestnut)	0	1.3	74.5	24.2	46.0	4.7	49.3	100
	6	5.4	85.0	9.6	43.2	9.2	47.6	72
Baca silt loam (brown)	0	1.5	79.7	18.8	48.2	7.2	44.6	100
	6	8.2	82.4	9.4	58.4	11.8	29.8	62
Dalhart fine sandy loam (brown)	0	1.2	87.6	11.2	34.6	7.8	57.6	100
	6	5.7	85.7	8.6	37.1	16.6	46.3	131
Pratt loamy fine sand (reddish	0	0.9	95.1	4.0	2.4	9.2	88.4	100
chestnut)	6	4.2	92.6	3.2	11.4	15.4	73.2	77
L.S.D. 1% level		4.8	N.S.	12.0	N.S.	3.7	13.0	N.S.
L.S.D. 5% level		2.9	N.S.	7.2	N.S.	2.1	7.8	N.S.
Average of Apr. 1952, July 1953, and Apr. 1954 when decomposition slowed								
Hastings silt loam (chernozem)	0	1.2	74.1	24.7	64.5	7.0	28.5	100
	6	1.5	78.7	19.8	55.1	10.9	34.0	299
Keith silt loam (chestnut)	0	1.5	74.1	24.4	55.5	5.5	39.0	100
	6	2.1	80.8	17.1	44.3	6.1	49.6	418
Baca silt loam (brown)	0	1.0	77.7	21.3	64.5	5.1	30.4	100
	6	1.9	84.4	13.7	48.9	9.1	42.0	192
Dalhart fine sandy loam (brown)	0	0.6	86.1	13.3	55.5	7.9	36.6	100
	6	0.8	91.3	7.9	36.3	13.8	49.9	497
Pratt loamy fine sand (reddish	0	1.3	94.7	4.0	10.2	9.8	80.0	100
chestnut)	6	1.0	95.3	3.7	4.1	11.5	84.4	285
L.S.D. 1% level		N.S.	5.2	6.0	10.6	4.3	8.1	107
L.S.D. 5% level		N.S.	3.1	3.6	6.4	2.6	4.9	78

* 2% ground wheat straw was mixed with soil in October 1948, June 1949, and January 1950.

Analysis of variance is based on averages for water-stable and dry aggregate analyses, or $N = 10$.

Analysis of variance is based on duplicates for erodibility, or $N = 20$.

of coarse water-stable aggregates greater than 0.84 mm. in diameter, a decrease in the proportion of fine water-stable particles less than 0.02 mm. in diameter, a slight average increase in soil cloddiness (expressed by percentage of dry aggregates greater than 0.84 mm. in diameter), a decrease in highly wind-erodible particles less than 0.42 mm. in diameter, and a slight average decrease in erodibility by wind (table 1, data for September 1950). The differences, except for erodibility by wind, were all statistically significant.

These effects generally were more pronounced with the higher than with the lower quantity of added vegetative matter. Wheat straw and green alfalfa chopped into 1-inch lengths were about equally effective, but finely ground wheat straw was considerably more effective, especially in increasing the proportion of water-stable aggregates greater than 0.84 mm. in diameter.

Three to five years after the last addition of vegetative matter, the relative condition of the treated and untreated soils was drastically different from its condition near the beginning (table 1, data for 1952–54). The treated soils generally showed no significant difference from the untreated soils in the proportion of coarsest water-stable aggregates, but had a significantly higher proportion of medium-sized water-stable aggregates and a significantly lower proportion of water-stable particles less than 0.02 mm. in diameter. On the basis of previous study (4), the relatively low proportion of the coarsest and the finest water-stable particles in the soil should decrease soil cloddiness and increase erodibility by wind. This proved to be the case. Soil cloddiness was reduced markedly in the treated soils, and erodibility by wind was increased, in some cases by more than

TABLE 3

Total organic matter in soils at two periods after addition of vegetative materials

Soil Type	Total Vegetative Matter Added	Organic Matter	
		Sept. 1950	Aug. 1953
	%	%	%
Hastings silt loam	0	2.73	2.26
	1	3.05	2.64
	6	4.04	3.12
Keith silt loam	0	2.19	2.05
	1	2.64	2.34
	6	3.54	2.71
Baca silt loam	0	1.48	1.52
	1	1.75	1.68
	6	2.69	2.19
Dalhart fine sandy loam	0	0.86	0.84
	1	1.09	1.09
	6	2.18	1.68
Pratt loamy fine sand	0	0.49	0.40
	1	0.84	0.66
	6	1.94	1.26

* The vegetative materials were dry wheat straw and freshly cut alfalfa. Equal increments were added in October 1948, June 1949, and January 1950.

300 per cent. These differences were pronounced in all five soil types tested (table 2).

At the end of 3 years the vegetative matter was presumed to be decomposed. Analyses indicated, however, that considerable quantities of organic residue remained in the soil (table 3). Further decomposition undoubtedly continued, but at a low rate. Analyses of total organic matter are being made periodically to determine the rate of decomposition with time after addition to the soil.

In the second experiment, in which a greater quantity of vegetative matter (wheat straw) was added at one time, marked influences were obtained (table 4). The initial results confirmed strikingly the results of the first experiment (table 4, 7 months and 17 months after treatment). In all soils tested, ranging from loamy sand to clay, additions of 10 per cent of ground wheat straw substantially increased soil cloddiness and decreased erodibility by wind for at least 17 months

TABLE 4

Influence of ground wheat straw at different stages of decomposition on dry aggregate distribution and erodibility by wind

Straw added September 27, 1951; determinations not replicated

Soil Class	Straw Added	Dry Aggregates			Relative Erodibility	Dry Aggregates			Relative Erodibility
		>6.4 mm.	6.4–0.84 mm.	<0.84 mm.		>6.4 mm.	6.4–0.84 mm.	<0.84 mm.	
	%	%	%	%	%	%	%	%	%
		7 months after treatment				*17 months after treatment*			
Loamy sand	0	0	9.1	90.9	100.	13.5	2.4	84.1	100.
	10	60.3	7.5	32.2	0.33	36.9	5.8	57.3	7.4
Sandy loam	0	18.9	6.7	74.4	100.	45.0	8.8	46.2	100.
	10	87.7	4.2	8.1	0.08	69.9	8.5	21.6	10.1
Silt loam	0	21.9	8.7	69.4	100.	55.9	10.3	33.8	100.
	10	83.7	7.0	9.3	0.17	72.3	8.8	18.9	20.2
Clay	0	29.3	47.0	23.7	100.	11.9	37.9	50.2	100.
	10	64.8	24.1	11.1	15.4	40.8	35.3	23.9	9.6
L.S.D. 1% level		13.4	N.S.	72.4	14.1	15.2	N.S.	16.3	10.6
L.S.D. 5% level		7.3	N.S.	39.4	9.3	8.3	N.S.	8.9	7.0
		29 months after treatment				*39 months after treatment*			
Loamy sand	0	12.3	3.8	83.9	100.	10.9	7.8	81.3	100.
	10	5.4	4.8	89.8	238	0	14.8	85.2	157
Sandy loam	0	30.4	7.4	62.2	100	35.5	11.8	52.7	100
	10	18.8	11.5	69.7	200	5.2	18.6	76.2	827
Silt loam	0	53.2	6.5	40.3	100	42.3	13.7	44.0	100
	10	34.5	13.0	52.5	255	10.1	22.4	67.5	712
Clay	0	29.8	23.2	47.0	100	41.8	26.6	31.6	100
	10	14.0	33.5	52.5	156	11.0	34.9	54.1	651
L.S.D. 1% level		15.0	N.S.	8.9	82	29.6	2.8	28.2	548
L.S.D. 5% level		8.2	N.S.	4.9	54	16.1	1.5	15.3	362

Analyses of variance are based on data shown.

TABLE 5

Influence of ground wheat straw on size distribution of water-stable aggregates

Single determinations

Soil Class	Straw Added	Water-Stable Aggregates					
		>0.84 mm.	0.84–0.02 mm.	<0.02 mm.	>0.84 mm.	0.84–0.02 mm.	<0.02 mm.
	%	%	%	%	%	%	%
		17 months after treatment			*24 months after treatment*		
Loamy sand	0	0.1	94.9	5.0	0.1	97.4	2.5
	10	3.1	91.9	5.0	0.7	98.2	1.1
Sandy loam	0	0.1	83.7	16.2	0.2	90.9	8.9
	10	1.7	83.9	14.4	2.9	90.7	6.4
Silt loam	0	0.2	68.2	31.6	0.2	85.3	14.5
	10	12.0	68.8	19.2	0.9	89.4	9.7
Clay	0	2.3	84.1	13.6	0.2	92.0	7.8
	10	28.7	62.1	9.2	18.0	76.7	5.3
L.S.D. 1% level		N.S.	N.S.	N.S.	N.S.	N.S.	4.2
L.S.D. 5% level		N.S.	N.S.	N.S.	N.S.	N.S.	2.3

after treatment. But the effects 17 months after treatment were smaller than the effects 7 months after treatment, indicating that the beneficial influences of decomposition were only temporary.

Twenty-nine months after treatment, the trends with respect to cloddiness and erodibility were reversed (table 4). At this time, cloddiness of the treated soils was significantly lower and erodibility by wind was significantly higher than in the untreated soils. These effects were even more pronounced 39 months after treatment.

The influence of 10 per cent ground wheat straw on the water-stable structure (table 5) was of less consequence than its effect on cloddiness and erodibility by wind. The straw caused a decrease in the proportion of water-stable particles smaller than 0.02 mm. Otherwise, the differences were not significant statistically, possibly because of insufficient replications. As in the first experiment, the effects on the coarse water-stable aggregates appeared to be transitional, becoming less pronounced with length of time after treatment.

DISCUSSION AND CONCLUSIONS

A thorough review and analysis of literature dealing with the relationships among organic matter, soil aggregation, and biological activity has been made by Stallings (20, 21). The literature reveals that numerous cementing substances produced by soil microorganisms as they attack the vegetative matter bind soil particles to form aggregates. The cementing substances may be divided into three major categories: (*a*) lyophylic and lyophobic colloids consisting of decomposition products of plant residues (12, 17), (*b*) the microorganisms themselves and their secretory products such as mucus, slime, or gum (13, 15, 18), and (*c*) polysaccharides synthesized by some microorganisms (12, 16).

The aggregating effects of the initial products of decomposition are temporary (1, 12). Aggregation declines as the products are destroyed by other microorganisms (15). Incorporating the vegetative matter into the soil is not so effective as leaving it on the surface, where it decomposes less rapidly and, therefore, continues to replenish the cementing products for much longer periods (8, 12). Improved aggregation persists long after the bacterial population has declined (19) but remains only as long as the initial decomposition products exist (13). The products concentrate in and around the soil aggregates (9).

Although many initial cementing substances persist in the soil only a short time, others, like the soil polysaccharides, persist for long periods. It is likely that their persistence is due to combination with other soil constituents that render them resistant to decomposition (16). In such a combination they probably contribute to the so-called "stable" soil structure.

The present study substantiates, in general, the results of previous studies on the effects of decomposition of vegetative matter on soil aggregation. Increases in soil aggregation in this study were not discernible until after decomposition of vegetative matter began. The aggregating effects apparently were due to the products of decomposition and not particularly to the binding action of vegetative fibers in the soil. These sticky products of decomposition increased the size of both the water-stable aggregates and the dry (secondary) aggregates, or clods. These products apparently were not entirely water-soluble, otherwise water-stable aggregates would not be formed. Many of the aggregates formed from decomposition of the vegetative matter were of a size resistant to erosion by wind.

Gradually, the initial cementing materials appeared to lose their sticky property or to be destroyed and replaced by secondary materials. Mechanical forces of expansion and contraction of the soil by wetting and drying and especially by freezing and thawing during the third and subsequent winters after the vegetative matter was added to the soil apparently caused the secondary cements to break up and the coarse primary and secondary aggregates to disintegrate to a more or less granulated condition. The secondary cements apparently were more brittle and caused more granulation than the initial products. The resultant granules were essentially water-stable. They formed a friable, mellow soil but one more erodible by wind. In the present study, soil granulation and increased wind-erodibility resulting from decomposed vegetative matter persisted from about 2 to at least 5 years after the last increment of vegetative matter was added to the soil.

High organic matter levels are essential for maintenance of soil fertility. Vegetative matter, therefore, must be added to the soil continually. Continual additions of vegetative matter should tend to produce wind-resistant aggregates and should tend to counterbalance excessive granulation and increased wind-erodibility caused by the secondary products of decomposition. On the basis of information derived from this study, the benefits obtained from the primary products of decomposition in augmenting resistance of soil to wind erosion are small compared to the detrimental effects from the secondary products of decomposition. A far greater benefit, no doubt, would be derived by leaving as much of the vegetative matter as possible anchored on top of the ground to protect the soil surface from wind.

SUMMARY AND CONCLUSIONS

Decomposing vegetative matter in the form of wheat straw or green alfalfa mixed into the soil increased the proportion of water-stable aggregates greater than 0.84 mm. in diameter, decreased the proportion of water-stable particles smaller than 0.02 mm., slightly increased the proportion of dry soil clods greater than 0.84 mm., and slightly decreased erodibility of soil by wind. The effects were more pronounced with larger quantities of added vegetative matter.

The results were entirely different after the vegetative matter was decomposed (2 to 5 years after treatment). The decomposed vegetative matter or the products resulting from decomposition had little or no influence on the proportion of water-stable aggregates greater than 0.84 mm., but increased the proportion of medium-sized water-stable aggregates, decreased the proportion of water-stable particles or aggregates less than 0.02 mm., decreased soil cloddiness, and increased erodibility by wind. It was concluded that far greater protection from wind erosion would be derived from maintenance of vegetative materials on top of the ground than from mixing them into the soil to increase soil aggregation during the initial stage of their decomposition.

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