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FACTORS THAT INFLUENCE CLOD STRUCTURE AND ERODIBILITY OF SOIL BY WIND: III. CALCIUM CARBONATE AND DECOMPOSED ORGANIC MATTER

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Hopkins (8) observed in Canada that soils high in organic matter and $CaCO_3$, or lime, have been eroded severely by wind and suggested that these factors may be responsible for the development of a loose, fine soil structure susceptible to erosion by wind. Initial laboratory studies (2) on some soils of Canada substantiated, in general, the observations of Hopkins. Hardt (7) concluded from his investigations of muck soils in Bavaria, however, that organic matter or humus has little influence on erosion of soil by wind but that the high content of lime, particularly in the clay fraction, increases erodibility appreciably.

This paper presents information on the influence of $CaCO_3$ and decomposed organic matter on structure and erodibility of some soils of the High Plains area of the United States. Lime, where mentioned in this paper, refers to $CaCO_3$ contained naturally in soil.

MATERIALS AND METHODS

Precipitated $CaCO_3$ was applied in October 1948 to 6-pound samples of five different soil types of the chernozem, chestnut, reddish chestnut, and brown soil zones of Kansas. After being shaken in water the $CaCO_3$ particles settled out readily. Only 0.4 per cent of the particles in water were smaller than 0.002 mm. in diameter (table 1).

The treated soils were kept for 2 years in a moist condition in glazed earthenware pots in the greenhouse. They were then transferred into porous-bottom trays and kept in the field until the end of the experiment in 1953. The trays were covered with a ¼-inch mesh screen to prevent erosion.

In another experiment, initiated in the greenhouse in 1950 and later transferred to the field, precipitated $CaCO_3$ with and without ground wheat straw was applied. One soil from the brown soil zone, one from the reddish chestnut, and one from the chernozem were used (table 2).

Two groups of high- and low-lime soils of the reddish chestnut soil zone, one group from near Portales, New Mexico, and the other from near Lubbock, Texas, were chosen for study. The high- and low-lime soils were similar in texture but differed in $CaCO_3$ content.

The soils treated with differed amounts of $CaCO_3$ were analyzed for structural characteristics and erodibility by wind at approximately 1-year intervals throughout the experiments. The high- and low-lime soils from Texas and New

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TABLE 1

*Size distribution of particles of precipitated calcium carbonate**

DISPERSION MEDIUM	PARTICLE SIZE DISTRIBUTION				
	> 0.05 mm.	0.05–0.02 mm.	0.02–0.01 mm.	0.01–0.002 mm.	< 0.002 mm.
	%	%	%	%	%
Water alone	5.5	15.5	71.5	7.1	0.4
Water and dispersing agent	8.0	18.0	71.0	2.6	0.4

* Determined essentially by the Bouyoucos hydrometer method. Ten grams of $CaCO_3$ was dispersed in 1 liter of water, and 10 ml. of *N* sodium hexametaphosphate used as dispersing agent. Duration of stirring 10 minutes.

TABLE 2

*Effect of calcium carbonate on soil structure and erodibility by wind**

SOIL TYPE	AMOUNT OF $CaCO_3$ ADDED	WATER-STABLE AGGREGATES			DRY AGGREGATES			MECHANICAL STABILITY OF DRY CLODS	ERODIBILITY BY WIND
		>0.84 mm.	0.84–0.02 mm.	<0.02 mm.	>6.4 mm.	6.4–0.84 mm.	<0.84 mm.		
	%	%	%	%	%	%	%	%	*t./A.*
Hastings silt loam	0	2.0	72.1	25.9	57.8	17.5	24.7	90.6	0.11
	1	2.1	72.2	25.7	42.0	15.7	42.3	82.1	0.61
	3	2.2	72.7	25.1	42.7	14.4	42.9	84.9	0.62
	10	2.1	67.9	30.0	45.3	18.3	36.4	89.5	0.38
Keith silt loam	0	1.6	73.1	25.3	50.3	13.0	36.7	84.4	0.42
	1	1.5	71.8	26.7	41.2	15.4	43.4	75.5	0.64
	3	1.3	72.5	26.2	40.0	14.7	45.3	77.8	0.80
	10	1.4	68.1	30.5	50.5	16.1	33.4	85.8	0.29
Baca silt loam	0	1.6	76.3	22.1	49.5	17.8	32.7	87.7	0.27
	1	2.2	77.9	19.9	49.3	19.3	31.4	86.7	0.24
	3	1.8	76.8	21.4	46.7	19.7	33.6	89.3	0.30
	10	2.1	71.7	26.2	47.4	19.5	33.1	89.4	0.29
Dalhart fine sandy loam	0	0.9	85.7	13.4	45.1	12.6	42.3	83.5	0.62
	1	1.2	87.0	11.8	42.1	10.7	47.2	82.2	0.86
	3	1.0	85.4	13.6	41.0	10.6	48.4	80.4	1.00
	10	0.9	80.5	18.6	44.9	12.4	42.7	83.2	0.63
Pratt loamy fine sand	0	1.2	94.9	3.9	8.6	2.4	89.0	31.2	16.4
	1	0.8	95.7	3.5	10.4	3.1	86.5	31.4	14.0
	3	1.6	92.7	5.7	16.9	3.6	79.5	49.7	7.0
	10	0.9	88.6	10.5	31.0	8.4	60.6	68.1	2.1

* Experiment started October 1948. Data represent averages for determinations made in October 1949, September 1950, April 1952, and February 1953. Properties of soils at start of experiment:

SOIL TYPE AND ZONE	ORGANIC MATTER	$CaCO_3$	MECHANICAL COMPOSITION		
			Sand >0.05 mm.	Silt 0.05–0.002 mm.	Clay <0.002 mm.
	%	%	%	%	%
Hastings silt loam (chernozem)	3.25	0.41	18.4	56.5	25.1
Keith silt loam (chesnut)	2.77	0.45	23.9	57.4	18.7
Baca silt loam (brown)	2.18	0.86	27.1	46.8	26.1
Dalhart fine sandy loam (brown)	1.08	0	54.5	31.1	14.4
Pratt loamy fine sand (reddish chesnut)	0.85	0.27	87.4	9.6	3.0

Mexico were analyzed only once. Soil analyses in all cases included (*a*) size distribution of water-stable aggregates by the modified method of Yoder (12), (*b*) size distribution of dry aggregates or clods by the method of Chepil (3), (*c*) mechanical stability of dry clods, that is, their resistance to breakdown by mechanical forces, by the method of Chepil (3), and (*d*) erodibility by wind estimated from the proportion or erodible soil fractions (5). Erodibility of some high- and low-lime soils was tested in a portable wind tunnel (13). Moreover, some determinations were made of soil organic matter by the chromic acid titration method of Walkley (11) and of mechanical composition by the method of Bouyoucos (1). Proportion of $CaCO_3$ in soils was determined by treating 5 g. of soil with 0.5 N H_2SO_4 solution till evolution of CO_2 ceased and then titrating the soil suspension with 0.5 N NaOH, using phenolphthalein as an indicator.

RESULTS

Influence of calcium carbonate

In most soils, addition of $CaCO_3$ in amounts not exceeding 3 per cent decreased soil cloddiness and mechanical stability of clods and increased erodibility by wind (table 2). The greatest reductions in cloddiness and increases in erodibility of silt loam soils were in Hastings, followed by Keith and Baca series, respectively. The effects of all amounts of $CaCO_3$ on Baca series were insignificant.

On silt loam and sandy loam soils, except on Baca series, 1 and 3 per cent of added $CaCO_3$ caused a substantial disintegration of soil cloddiness and an increase in erodibility (table 2). Addition of 10 per cent $CaCO_3$ showed a slight, varied effect, depending on the soil. In most soils, cloddiness increased and erodibility decreased when $CaCO_3$ was increased from 3 to 10 per cent. On Pratt loamy fine sand the more $CaCO_3$ added, the greater was the increase in soil cloddiness and mechanical stability of clods and the greater the decrease in erodibility by wind. This soil is inherently highly erodible and adding 10 per cent $CaCO_3$ left it in a condition still much more erodible than any of the other treated and untreated soils (table 2).

Adding $CaCO_3$ to soils had virtually no effect on the size distribution of water-stable aggregates except to increase the proportion of water-stable particles < 0.02 mm. in diameter (table 2). The increases in this fine fraction were due apparently to the lime particles added rather than to dispersion of the soil.

The foregoing results remained essentially the same from 6 months after the start of the experiment in 1948 until its termination in 1953. Table 2 indicates only the averages for that period.

Influence of combinations of calcium carbonate and decomposed organic matter

The amounts of $CaCO_3$ and organic matter found in soils 2½ years after the start of the second experiment are shown in table 3. In the 2½-year period the average loss of $CaCO_3$ was 14 per cent. This loss was caused apparently by eluviation and leaching.

The wheat straw started to decompose immediately after it was added to

TABLE 3

*Some properties of soils 2½ years after application of calcium carbonate and ground wheat straw**

AMOUNT AND KIND OF MATERIAL ADDED	$CaCO_3$	ORGANIC MATTER	MECHANICAL STABILITY OF DRY CLODS	ERODIBLE DRY SOIL FRACTION < 0.84 mm.	ERODIBILITY BY WIND
	%	%	%	%	*t./A.*
None	0.67	2.53	62.6	34.3	0.33
3% $CaCO_3$	3.13	2.57	59.6	43.0	0.61
3% $CaCO_3$ and 3% straw	3.41	2.78	50.6	55.3	1.60
10% $CaCO_3$	9.10	2.43	59.1	46.2	0.84
10% $CaCO_3$ and 10% straw	9.08	4.09	53.1	64.6	2.95
1% straw	0.67	2.63	56.9	40.0	0.54
6% straw	0.67	3.33	55.5	46.5	0.90

* Averages of results obtained with Baca silt loam, Larned sandy loam, and New Cambria clay of the brown, reddish chesnut, and chernozem soil zones, respectively.

the soils, and at the end of the 2½-year period virtually no evidence of it remained except for a somewhat darker color of the soils. The organic matter content 2½ years after the straw and $CaCO_3$ were added was 2.53, 2.63, 2.78, 3.33, and 4.09 per cent in soils receiving 0, 1, 3, 6, and 10 per cent of straw, respectively (table 3). The organic matter remaining in the soil 2½ years after straw was applied was considered decomposed. Further decomposition would continue, no doubt, but at an appreciably lower rate.

The results of the second experiment, on the influence of $CaCO_3$, generally confirmed those of the first. In addition, decomposed wheat straw and $CaCO_3$ had similar effects on soil structure and erodibility (table 3). Both increased the proportion of dry erodible soil fractions, decreased the mechanical stability of clods, and increased erodibility by wind. The only difference observed was with respect to their influence on the size distribution of water-stable aggregates. Cal-

TABLE 4

Size distribution of water-stable aggregates 2½ years after application of different amounts of ground wheat straw

SOIL TYPE	PROPORTION OF STRAW APPLIED	WATER-STABLE AGGREGATES				
		>0.84 mm.	0.84–0.42 mm.	0.42–0.05 mm.	0.05–0.02 mm.	<0.02 mm.
	%	%	%	%	%	%
Hastings, Keith, and Baca silt loam	0	1.8	2.9	26.9	40.7	27.6
	1	1.3	3.0	36.6	37.6	24.8
	6	3.4	7.6	37.7	32.1	19.3
Dalhart fine sandy loam	0	0.5	4.7	48.6	30.6	15.6
	1	0.7	6.3	57.4	23.6	12.0
	6	1.1	9.8	61.1	20.0	8.0
Pratt loamy fine sand	0	0.9	9.5	76.4	9.6	3.6
	1	0.8	8.8	84.2	3.0	3.2
	6	1.2	9.9	83.2	3.5	2.2

cium carbonate had little influence on the water-stable soil aggregates (table 2), but decomposed wheat straw had an appreciable influence (table 4). Decomposed straw increased the proportion of water-stable aggregates > 0.84 mm. in diameter and decreased the proportion of water-stable particles < 0.02 mm. Both of these fractions tend to decrease erodibility about equally (6). The increases in the proportion of water-stable fraction > 0.84 mm. were small compared with the decreases in the proportion of fraction < 0.02 mm. Consequently, the net effect from decomposed wheat straw, as may be expected, was to increase substantially the erodibility by wind (table 3). The decomposed wheat straw, as indicated by the amount of organic matter in soil 2½ years after the straw was applied, increased soil erodibility much more than did like amounts of $CaCO_3$ (table 3). Moreover, it increased the erodibility of soils containing a high proportion of $CaCO_3$ more than of soils containing a low proportion. The highest erodibility was recorded for soils receiving the highest quantity of both straw and $CaCO_3$.

Field studies on the influence of calcium carbonate

The percentage of erodible soil fraction < 0.84 mm. in diameter was substantially higher in the high-lime than in the low-lime soils of similar texture and similar content of organic matter (tables 5 and 6). Mechanical stability of clods was considerably lower in the high-lime soils than in the low-lime soils.

TABLE 5

Some structural conditions and erodibility of low- and high-lime soils near Portales, New Mexico

Data based on surface to 1-inch depth, April 1952

SOIL CLASS	NUMBER OF FIELDS	$CaCO_3$	DRY FRACTION <0.84 mm.	MECHANICAL STABILITY OF DRY CLODS	ERODIBILITY BY WIND
		%	%	%	*t./A.*
Loam and clay loam	6	0.3	75.7	76	1.3
	1	1.4	85.5	71	6.2
Sandy loam	7	tr.	74.5	71	5.6
	4	4.7	87.3	57	12.1

TABLE 6

Some structural conditions and erodibility of low- and high-lime soils near Lubbock, Texas

Data based on surface to 1-inch depth, November 1952 and April 1953

SOIL TYPE	NUMBER OF FIELDS	$CaCO_3$	DRY FRACTION <0.84 mm.	MECHANICAL STABILITY OF DRY CLODS	ERODIBILITY BY WIND
		%	%	%	*t./A.*
Amarillo fine sandy loam	1	0.14	59.0	76.8	2.1
	1	0.23	62.1	72.0	2.5
Mansker fine sandy loam	1	0.32	64.4	78.5	2.8
	1	0.73	71.8	67.4	4.3

Erodibility of the high-lime soils was likewise substantially higher in comparable cases. The greater the proportion of lime in the soil up to about 5 per cent, the greater was the erodibility. Erodibility was comparatively low where the lime content did not exceed 0.3 per cent.

DISCUSSION AND CONCLUSIONS

The effects of precipitated $CaCO_3$ on sand and loamy sand are similar in some respects to the effects of quartz silt. This is due probably to the fact that the crystals in precipitated $CaCO_3$ when shaken in water are predominantly of the size of silt. Silt is a mild cementing agent and is partly responsible for the formation of fragile secondary aggregates or clods. As shown in previous study (5), small initial amounts of silt are very effective in reducing erodibility of sand. Addition of 10 per cent $CaCO_3$ to Pratt loamy fine sand raised the proportion of soil particles of the size of silt and clay from 12.6 to 22.0 per cent and reduced erodibility by 87 per cent (tables 1 and 2). This reduction in erodibility was virtually the same as would have been obtained from an equal increase in the proportion of quartz silt (5).

On other than sand and loamy sand the action of precipitated $CaCO_3$ is considerably different from quartz silt. In soils containing an appreciable proportion of clay, $CaCO_3$ appears to weaken the cementing strength of the clay and causes the clods to soften and granulate. It has little influence on the state of the primary or water-stable aggregates. It primarily weakens the bonds that hold the water-stable aggregates together to form clods. This action is probably basically due to the flocculation phenomenon, which may be observed clearly when precipitated $CaCO_3$ is shaken in water.

Thompson (10) asserts that the presence in soils of large amounts of calcium, usually present in the form of $CaCO_3$, tends toward the development of a granular soil structure. If the granules are small enough they will be eroded readily by wind. More often than not, granulation of dryland soils tends to induce wind erosion (9).

Decomposed organic matter also tends to induce soil granulation and wind erosion. It aggregates a substantial proportion of dispersed silt and clay, but unfortunately the aggregates formed are generally too small to resist erosive winds common in dryland regions. Organic matter is essential for maintenance of soil fertility. What must be done to maintain a high level of organic matter and at the same time prevent the accelerated erosion of soil by wind? The answer probably is to be found from the condition of dryland soils recently broken out of virgin sod. Some of the newly broken dryland soils contain a relatively large amount of organic matter but are potentially highly susceptible to erosion by wind (4). Their stability against wind is facilitated, however, by their ability to produce relatively large quantities of crop residue, which may be left anchored at the surface of the ground. The results of this study emphasize indirectly the fundamental importance of vegetative cover as a factor in wind erosion control. The creation of soil structure resistant to wind erosion probably should be of secondary importance.

Calcium carbonate in soils containing a high proportion of decomposed organic matter increases erodibility by wind more than in soils containing a lower proportion of decomposed organic matter. Flocculation of the unaggregated particles of the size of clay is facilitated apparently by presence of decomposed organic matter. In the present study of soils relatively low in organic matter, addition of $CaCO_3$ had little influence in reducing the proportion of water-stable particles < 0.02 mm. in diameter, thus indicating little aggregating effect. In a previous study of soils higher in organic matter (2) addition of $CaCO_3$ decreased substantially the proportion of water-stable particles < 0.02 mm., indicating a greater aggregating effect. In both studies, however, increased aggregation was generally limited to the formation of granules erodible by wind.

In semiarid regions, soils are characterized generally by a layer of $CaCO_3$ accumulation, which normally lies just below the solum. This layer is often brought up to the surface by tillage implements, especially where some of the soil has been removed by erosion. Exposure of the $CaCO_3$ layer increases the hazard of wind erosion. Higher ground, such as a knoll, commonly is eroded to expose this layer. Knolls frequently cause erosion of adjacent lands by serving as focuses from which $CaCO_3$ may be spread. Such areas are a serious erosion hazard to surrounding lands and should be protected specially, as with grass.

In humid regions, applications of lime are required sometimes to correct soil acidity. The amounts of ground limestone applied in such cases range from 2 to 5 tons an acre, according to the degree of soil acidity. As shown from this study, these amounts are too small to have an appreciable effect on soil structure and erodibility by wind. Moreover, the favorable soil moisture conditions in these regions almost preclude the hazard of wind erosion.

SUMMARY

On silt loam and sandy loam soils, 1 to 5 per cent $CaCO_3$ caused a substantial disintegration of soil cloddiness, a decrease in mechanical stability of clods, and an increase in erodibility by wind. Additions of 0.3 and 10 per cent had only a slight but variable effect on cloddiness and erodibility, according to the soil.

On loamy sand, the greater the amount of $CaCO_3$ added, the greater was the increase in soil cloddiness and mechanical stability of clods and the greater the decrease in erodibility by wind.

Addition of $CaCO_3$ alone to soil had little effect on the size distribution of water-stable aggregates. The effects of decomposed organic matter were similar to those of $CaCO_3$, with one exception. Whereas $CaCO_3$ had little influence on the water-stable aggregates, decomposed organic matter increased somewhat the proportion of water-stable aggregates > 0.84 mm. in diameter and decreased appreciably the proportion of water-stable particles < 0.02 mm.

Decomposed organic matter increased the susceptibility of soils to wind erosion. Decomposed organic matter increased soil aggregation, but aggregation was limited, as a rule, to the formation of granules erodible by wind. These influences were amplified in soils containing a high proportion of $CaCO_3$. The

highest erodibility was recorded, consequently, for soils containing a high proportion of both $CaCO_3$ and decomposed organic matter.

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