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Microorganisms and Soil Structure¹

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Soil structure has an important influence on soil erosion, water intake, and crop growth. A dispersed or compact soil has a low infiltration rate. A stable, granulated soil will permit rapid water intake, drainage, aeration, and beneficial microbial activity; crops grown in it will respond well to favorable moisture, fertility, and good cultural practices. Among the most effective aids to good management in maintaining or improving granulation are microorganisms and their decomposition products.

Growing plants and microorganisms constitute the living phase of the soil. In it are living and non-living bacteria, viruses, phages, fungi, algae, protozoa, earthworms, nematodes, and insects. These organisms have numerous enzymatic systems which are capable of producing available nutrients for the growing plants by breaking down some of the many organic compounds in the soil.

Physically, a good mineral soil is made up of about five per cent organic and 95 per cent inorganic materials by weight. The influence that the organic matter in most soils exerts is out of proportion to its weight and is more directly related to the volume it occupies. This organic fraction of the soil is made up of plant and animal remains in all stages of decomposition. Chemically it is composed of sugars, starches, celluloses, proteins, lignins, vitamins, pigments, fats, oils, and myriads of compounds in all sorts of configurations and combinations.

The mineral portion of the soil is made up of sand, silt and clay mixture in different combinations to make specifically a clay, silt loam, or soil of some other texture. Chemical elements of the inorganic fraction are composed largely of oxides, silicates, and phosphates of calcium, potassium, magnesium, etc., and the number of compounds ranges into the hundreds.

Usually the sand, silt, and clay in the soil do not remain as individual particles but become organized into groups, which are called aggregates or structural units. These units are formed largely by physical forces such as wetting and drying or freezing and thawing. They may be of various sizes and shapes and in the same soil may follow a definite pattern. United by chemical, physical, and biological forces (2, 3, 4, 5), they are held together specifically by materials such as silica, clays, iron oxides, and constituents of

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organic matter. The latter include plant roots, soil organisms of various types, and organic cements of resins, gums, waxes, fats, and lignins.

One of our recent projects at Nebraska has been to study the influence of microorganisms and their decomposition products and organic substances on soil structure stability against falling water drops and percolating water.

METHODS

Soil Used

Peorian loess was taken from a road cut near Plattsmouth, Nebraska, at a depth of 10 to 15 feet. It has 0.2 per cent oxidizable material by the chromic acid method and 14 per cent sand, 66 per cent silt, and 20 per cent clay by the hydrometer method. This material was used because it was low in organic matter and clay. The air-dry soil was broken into small lumps and then units of desired size were separated by screening.

Laboratory Procedure

Water drop test. A soil lump weighing approximately 0.15 g. was placed on a 1-mm. screen, and drops of distilled water 4.7 mm. in diameter, falling 30 cm. from a burette, were allowed to strike it. When a lump was broken down and at the point of being washed through the screen, it was considered destroyed. Three sets of determinations with air-dry soil were made, with 20 individual determinations in each.

Method of measuring percolation. A square metal container 23.5 cm. on a side and 28 cm. in height, with a drainage tube in one corner, was filled to a depth of 4 inches with first a layer of gravel and then about 2 inches of coarse sand. On top of this was placed a two-layer thickness of cheesecloth and then a 6-inch layer of the soil to be tested. Packing was accomplished by dropping a 2- by 3-inch board 3 feet long a distance of 6 inches 36 times on each 3-inch layer of the soil. Water was applied to a cheesecloth pad in one corner of the container from an automatic discharge tube which maintained a constant head. This method of application would be somewhat similar to the application of irrigation water. Percolation was measured every hour for a 3-hour period on two successive days. The results reported as inches of water per hour are the mean of triplicate tests, unless otherwise stated.

RESULTS

Water Drop Test

Organic substances. Carbohydrates, proteins, and gums were dissolved in distilled water and added to lumps of Peorian loess; waxes, oils, fats, resin, and paraffin were dissolved in an alcohol-benzene mixture and added. After the alcohol-benzene mixture had evaporated, the lumps were dried immediately at 105° C. and determinations made, as shown in Table 1.

None of the carbohydrates and few of the proteins were effective in increasing the structure stability of Peorian loess to water drops. Egg albumin and casein, however, were highly effective. The lumps treated with these materials seemed to wet rather quickly but did not swell and disintegrate from the pounding of the water drops except after a long time. The oils, fats, waxes, resin, and paraffin in the concentrations used increased the stability of the soil structure to water drops. These lumps became wet slowly and did not appear to swell.

In another test different organic substances were dissolved in distilled water and dropped on lumps of Peorian loess with the results shown in Table 2.

Table 1. Influence of carbohydrates, proteins, oils, waxes and gums on the stability of Peorian loess to water drops.

Substance added*		Concentration		
		0.25%	0.50%	1.00%
		Drops per 0.1 g. of soil		
Carbohydrates	{ Dextrose	4.3	4.5	4.4
	{ Sucrose	4.0	4.2	4.3
	{ Dextrin	4.3	4.1	4.2
	{ Salicin	4.7	4.8	4.6
	{ Starch	4.2	4.5	4.4
Proteins	{ Urea	4.4	4.0	4.2
	{ Tryptone	4.3	4.1	4.3
	{ Asparagine	4.2	4.1	4.3
	{ Peptone	4.2	4.2	4.2
	{ Egg Albumin	270.0	1060.0	4000.0
Gums	{ Casein	31.4	224.0	1369.0
	{ Arabic	4.2	4.2	4.3
Oils	Vegetable	14.4	13.4	14.9
Fats	Vegetable	13.5	13.9	15.4
Waxes	{ Ceresin	5.7	12.5	30.4
	{ Beeswax	6.5	9.4	11.9
Resin		11.6	16.3	17.6
Paraffin		12.7	20.2	23.9

*When no substance or alcohol and benzene were added to Peorian loess, the stability was 4.4 drops per 0.1 gram of soil.

Table 2. The influence of some organic materials dissolved in water drops on stability of Peorian loess.

Material dissolved in distilled water	P.p.m.				
	0	10	100	1000	10,000
Drops per 0.1 gram of soil					
2, 4-D	5.2	5.7	5.4	5.9	5.2
Organic matter	5.2	6.3	6.1	6.9	7.9
Vinsol	5.2	5.2	5.9	7.1	16.1
Dodecyl dimethylamine sulfate 10%	5.2	5.9	5.7	9.0	9.9
Dodecyl dimethyl benzyl ammonium chloride 20%	5.2	5.5	6.2	7.7	13.1

The 2, 4-D dissolved in the water did not affect the stability of the structure. A longer time was required to break down the soil structure with water drops containing organic matter or Vinsol. The effect was less with the organic matter. Previous results (3) showed that decomposing organic matter, added to the Peorian loess and dried before sprinkling, increased stability. This may be the result of the organic substance changing the surface tension or wetting ability of the water.

The more concentrated the solution, the more effective were the treatments in stabilizing soil structure.

Dodecyl dimethylamine sulfate and dodecyl dimethyl benzyl ammonium chloride increased the stability of the structure. These substances were used because of their surface-active properties.

Microbial Groups. Since the bacteria in the soil make up a large numerical portion of the total microbial populations, the influence of some bacterial types on soil structure stability was determined. Soil bacteria of various kinds were used to inoculate lumps of Peorian loess treated with a solution of energy materials. The aqueous solution used for the *Azotobacter* and legume bacteria contained 4 per cent mannitol; for the *Actinomycetes*, 3 per cent glycerin and 1 per cent proteose-peptone; and for the spore formers, 3 per cent dextrose and 1 per cent proteose-peptone. The nutrient solutions were added in sufficient quantity to give 27 per cent moisture and energy material in a concentration of 1.6 per cent of the soil.

Actinomycetes are intermediate in morphological characteristics between the bacteria and molds. Some have branching cells which may be active in binding soil particles. About half of the total count of bacteria of most soils by the plate method is composed of *Actinomycetes*. Three isolates from field soils were used to inoculate lumps treated with an aqueous solution of 3 per cent glycerin, 1 per cent proteose-peptone, and soil extract.

Yeasts are more highly developed morphologically than bacteria, but they do not produce the extent of branching that fungi or *Actinomycetes* do. However, in the soil the yeast cells and their products of decomposition may be effective in structure stabilization. Three isolates of yeast were used to inoculate lumps of Peorian loess moistened with an aqueous solution of 3 per cent dextrose and 1 per cent proteose-peptone.

Table 3. The influence of some bacteria, *Actinomycetes*, yeast and fungi on soil structure stability against falling water drops.

Culture	Days of incubation					
	0	1	5	10	20	30
		Drops per 0.1 g. of soil				
Soybean	5.1	5.3	6.7	6.9	13.2	20.3
Alfalfa	5.1	6.7	6.0	6.1	5.7	8.8
<i>Azotobacter</i>	5.8	7.2	7.9	8.5	9.6	6.0
Spore former	5.1	8.7	7.2	7.4	8.0	8.8
<i>Trichobacteria</i>	5.3	6.5	25.0	32.9	36.3	21.0
Gum former	5.0	5.4	5.6	28.5	28.2	17.4
Viscous	5.3	9.7	51.8	54.2	52.6	49.2
<i>Actinomycetes</i> 1	5.4	6.6	32.3	40.4	51.8	51.7
2	5.4	6.9	30.7	45.5	50.5	52.2
3	5.4	7.0	22.9	20.5	43.4	33.8
Yeast 1	5.2	13.0	13.9	12.9	12.3	12.0
2	5.2	11.0	12.6	11.0	8.7	14.7
3	5.2	10.7	22.8	20.5	14.0	20.7
Fungi 1	5.1	9.4	52.2	48.0	41.9	36.8
2	5.1	49.9	50.4	46.7	50.1	42.1
3	5.1	48.5	21.2	38.4	20.3	20.7

Since fungi produce numerous threads during growth, their mycelium may be effective in binding the soil particles together. To determine the influence of fungi on soil structure stability, three isolates were used to inoculate lumps of Peoria loess moistened with an aqueous solution of 3 per cent glucose and 1 per cent proteose-peptone. The stability of the Peorian loess lumps resulting from the growth of some bacteria *Actinomycetes*, yeast and fungi for different time intervals is shown in Table 3.

The spore formers, the *Azotobacter*, and a few other bacterial groups increased the stability at least one-third more than in the untreated soil. Also the soybean culture increased stability of the soil against falling water drops. The trichobacteria, gum formers, and bacteria-forming viscous colonies on plates produced a marked stability of the lumps of Peorian loess. These and related organisms may be of considerable importance in producing and maintaining the stability of sods and other types of soil structures in the field.

The *Actinomycetes* cultures were highly effective in stabilizing lumps of Peorian loess. About 5 days were required for the maximum stability to be reached, which was maintained throughout a 30-day test period.

There was considerable increase in the stability of the soil produced by different cultures of yeast. Although they were not as effective as the *Actinomycetes*, they were more effective than some groups of bacteria.

The fungi produced a high stability of the Peorian loess lumps against falling water drops that remained throughout the 30-day test period. Toward the end of the period stability declined slightly.

Percolation Tests

Undisturbed Peorian loess. Solid blocks of Peorian loess, cut slightly smaller than the size of the percolator and 6 inches in depth, were put into each container. Finely screened Peorian loess was packed lightly around the margins. Blocks were watered for 13 hours. Following this treatment they were sprinkled for 13 hours from a height of 6 feet and at a rate just to equal the intake of the soil. Results of duplicate tests are reported in Table 4. The water moved slowly through the undisturbed Peorian loess regardless of whether it was by sprinkling or surface flooding. The mean percolation rate was 0.20 inch per hour for the sprinkled and 0.29 inch per hour for the surface flooded treatments during a 13-hour period.

Table 4. Percolation through a 6-inch block of Peorian loess sprinkled or irrigated.

Method of applying water to Peorian loess blocks	Percolation during certain hours—Inches per hour				Mean percolate Inches per hour	Total percolate for 13 hours, Inches
	4	7	10	13		
Sprinkled	0.25	0.21	0.17	0.20	0.20	2.57
Irrigated	0.26	0.30	0.29	0.31	0.29	3.77

On bare cultivated Knox silt loam surface soil located on first bluffs

at Blair, Nebraska, Duley and Kelly (1) found the infiltration rate to be 0.63 inch per hour after 3.5 hours of artificial sprinkling, and 0.16 inch after 12.74 hours. At the end of 11, 11.50, and 12.25 hours the intake was 0.25, 0.22, and 0.20 inch, respectively. After prolonged sprinkling of either the surface soil at Blair, Nebraska, or the Peorian loess blocks in the laboratory, the final rate of intake was approximately the same—0.16 and 0.20 inch per hour, respectively. The surface soil at Blair (1), cultivated and protected with a straw mulch, had an intake rate of 1.64 inches per hour after 7.25 hours of sprinkling, while the block of Peorian loess in the laboratory, although protected, had a percolation rate of only 0.29 inch per hour. These various results show that with the well-aggregated surface soil a protective cover of residue permitted rapid infiltration, but when the soil was not so protected, its rate of intake rapidly declined. The Peorian loess, low in organic matter, gave a low intake regardless of whether the surface was protected with residues.

Organic substances. In the handling of large or small areas devoted either to general or truck crops, organic substances may be returned to the land in different quantities and different mechanical and chemical conditions. It seemed probable that these substances either in the initial state or some stage of decay might influence water penetration. To test this point, both soluble and insoluble organic substances were mixed with air-dry Peoria loess in concentrations ranging up to 4 per cent. Percolation rates were determined immediately as shown in Table 5.

Soluble organic substances did not increase the percolation rate. However, these substances can be transformed into microbial tissue or decomposition products that greatly increase the percolation rate under certain conditions (3).

Insoluble organic materials were mixed with Peorian loess to make 4 per cent concentration. The straw, cornstalks, and soybean straw increased percolation rates considerably. Even though the Peorian loess was not aggregated, the water was able to pass through the soil layer rapidly by following channels made by the plant material.

When sawdust was added to air-dry Peorian loess to make 4 per cent concentration, the percolation rate was not increased. In this instance the lumps or aggregates of Peorian loess disintegrated around the small sawdust particles.

Wheat straw mixed with soil at the rate of 2 tons per acre did not increase percolation. However, wheat straw at the rates of 4 and 8 tons per acre increased the percolation rate slightly.

Straw decay. To test the effect of decomposition, wheat straw and ammonium nitrate, at the rate of 8 tons and 200 pounds per acre,

respectively, were added to Peorian loess. The samples were incubated at room temperature and 27 per cent moisture. The percolation rate was determined as shown in Table 6.

Table 5. Influence of undecayed organic substances mixed with the soil on water percolation through a layer of Peorian loess.

Treatment	Tons per acre	Percolate, inches per hour						Total for 6 Hrs.
		1 Hr.	2 Hrs.	3 Hrs.	4 Hrs.	5 Hrs.	6 Hrs.	
None		0.00	0.43	0.43	0.22	0.37	0.42	1.87
		CONTROL						
Sucrose	40	0.05	0.41	0.40	0.26	0.40	0.38	1.90
Starch	40	0.00	0.24	0.35	0.25	0.30	0.30	1.44
		SOLUBLE MATERIALS						
		INSOLUBLE MATERIALS						
Straw	2	0.00	0.33	0.43	0.31	0.36	0.37	1.80
Straw	4	0.35	0.42	0.36	0.90	0.37	0.36	2.76
Straw	8	0.40	0.55	0.56	0.56	0.44	0.42	2.93
Straw	40	52.50	19.40	16.20	14.80	15.30	13.40	131.60
Xylene	40	0.00	0.18	0.28	0.22	0.26	0.26	1.20
Oil	40	0.07	0.41	0.41	0.28	0.33	0.35	1.85
Lignocellulose	40	0.00	0.12	0.59	0.43	0.50	0.52	2.16
Sawdust (fine)	40	0.00	9.33	0.54	0.55	0.50	0.44	2.36
Wood shavings	40	0.29	1.01	1.22	1.00	1.49	1.05	6.06
Soybean straw	40	39.57	17.75	23.93	24.35	18.49	14.73	138.82
Cornstalks	40	23.78	20.66	16.51	15.22	10.71	10.25	97.13

Table 6. Percolation rate of Peorian loess as influenced by the decomposition of straw added at the rate of 8 tons per acre.

Days after addition of straw	Percolate, Inches per hour						Total for 6 hrs.
	1 hr.	2 hrs.	3 hrs.	4 hrs.	5 hrs.	6 hrs.	
0	0.05	0.81	0.76	0.38	0.44	0.37	2.81
10	0.76	2.39	1.84	0.93	0.93	0.87	7.72
20	0.81	3.00	2.21	0.96	1.10	0.76	8.84
26	0.46	2.63	2.76	1.17	1.26	1.26	9.54
46	0.00	1.31	1.53	0.64	0.79	0.81	5.08

Percolation increased with the time of decay, and then decreased. During the decomposition of plant material, the by-products of decomposition increased in quantity for a time and then eventually decayed. While these decomposition products and microbial tissue were present, the percolation rate was increased above that of the untreated parent material.

Sucrose decay. It is conceivable that if organic substances were allowed to decompose in the soil, the decomposition products and microbial tissue might plug up the soil pores and reduce water penetration. If this mass of soil with microorganisms and decomposition products were stirred into a lumpy mixture, the water penetration might be rapid.

To test these points, sucrose was added to air-dry Peorian loess to equal 4 per cent concentration. This mixture was inoculated with a pinch of soil and incubated in a shallow pan. After 5 days of incubation at room temperature of 28° C. and 26 per cent moisture, the material was mixed and packed into the percolators. In another test air-dry Peorian loess inoculated with a pinch of surface soil was packed directly into the percolator. Sucrose to equal 4 per cent concentration of the soil and ammonium nitrate at the rate of 200 pound per acre were dissolved in

sufficient water to wet the layer of Peorian loess. After incubation for 5 days, percolation tests were made as shown in Table 7.

When the soil and sucrose were incubated and stirred prior to testing, the percolation rate was increased from 3.17 inches for the untreated to

Table 7. Influence of sucrose decomposition on the percolation rate of disturbed and undisturbed samples of Peorian loess.

Treatment of Peorian loess	Percolate, inches per hour								Total for 8 hours
	1 hr.	2 hrs.	3 hrs.	4 hrs.	5 hrs.	6 hrs.	7 hrs.	8 hrs.	
None	0.00	0.46	0.46	0.58	0.58	0.37	0.36	0.36	3.17
4% sucrose (undisturbed)	0.04	0.14	0.14	0.14	0.12	0.15	0.16	0.18	1.07
4% sucrose (disturbed)	18.37	12.68	5.36	4.26	10.18	9.26	6.41	2.78	69.30

69.30 inches percolation for an 8-hour period. Where the soil and sucrose were incubated in the percolator and not stirred, the percolation for the 8-hour period dropped from 3.17 inches for the untreated to 1.07 inches.

The microorganisms and their decomposition products may coat the soil particles so that the surface will not become wet. Under some soil conditions, such as on the surface of the soil with plenty of oxygen, or in deeper layers in the absence of oxygen, microorganisms may produce slimes or other substances that will clog the pores of the soil and reduce water transmission.

DISCUSSION

The soils derived from Peorian loess cover a considerable portion of the better farming area of Nebraska and states adjoining. At the present rate of erosion of row cropland, the parent material will be exposed eventually at the surface in many fields. Since erosion is related to the amount of water running over the soil, increasing water intake will decrease erosion and store moisture for crops. **When the parent material becomes exposed, something can be done to improve water penetration. If crop waste is allowed to decay in the soil, water percolation through the Peorian loess can be increased.**

Microorganisms and their decomposition products may decrease as well as improve percolation by clogging the pores of the soil. The mechanical state of the soil after microbial growth will largely determine whether the percolation rate will be increased or decreased. If the growth of microbial tissue or by-products occurred in the surface soil, it would be possible to stir the soil with tillage implements to form mechanical soil units. If the growth occurred at greater depths in the soil, it might be difficult to form mechanical units even though the soil contained stabilizing microbial tissue and decomposition products. These products of microbial growth under such conditions might restrict water movement at lower depths.

A bare soil, as a result of plowing, is exposed to the beating action of

raindrops. However, there are two ways of controlling its erosion. It may be kept covered with a growing crop or with a plant residue mulch. The stability of the structure may be maintained to withstand the impact of water drops. At the present time, however, it is impractical to maintain a structure sufficiently stable to withstand indefinitely the beating action of falling raindrops. A covered soil should be sufficiently granulated and stable to allow the water to penetrate rapidly.

One effective way of maintaining or improving the stability of soil structure is by the decomposition of crop residues and green manures by soil organisms. The fungi and *Actinomyces* were more effective than other microbial groups in producing stability of Peorian loess lumps against falling water drops. Some bacterial groups were highly effective, while others were not.

If there is sufficient moisture, nutrients, and ample aeration with a cultural system, fungi grow readily. For example, in a system of stubble mulch culture, fungi decompose crop residues at the surface of the soil. Such plant residues also aid in moisture conservation, which may favor microbial growth. Since the fungi and *Actinomyces* were the most effective in soil stabilization, conditions that enhance their activity will increase soil stabilization.

Organisms and their metabolic products are active in the formation and stabilization of soil structure, although they probably play a greater role in stabilization than in formation. A good soil structure is essential for the smooth integration and performance of the multi-groups of organisms in the soil. The beneficial organisms decay plant and animal residues, liberate plant nutrients, and produce soil-structure-stabilizing substances. A deterioration of soil structure results in suppressing the activities of the beneficial groups and promoting the growth of microbial groups that render nutrients unavailable.

SUMMARY

Laboratory tests were made to determine the effectiveness of different compounds and microbial groups in increasing the stability of Peorian loess lumps against the action of falling water drops. The influence of these on percolation tests in the laboratory was also determined.

Many organic substances—dextrose, sucrose, starch, peptone, cellulose, and gum arabic—did not themselves contribute directly to soil-structure stability, though these substances do furnish energy material for soil microorganisms, which can convert them readily into either microbial tissue or decomposition products that increase soil-structure stability. Lignin, proteins, oils, fats, waxes, resin, and paraffin increased the stability of lumps of Peorian loess to water drops. Organic matter, Vinsol, dodecyl

dimethylamine sulfate, and dodecyl dimethyl benzyl ammonium chloride increased stability.

The order of descending effectiveness of different microbial groups for soil lump stabilization against the beating action of water drops was: (1) Fungi, (2) Actinomycetes, (3) certain bacteria, (4) yeasts, and (5) the majority of bacteria used.

The percolation rate of Peorian loess material was increased by certain organic substances, especially if these were in the process of decaying. Water-soluble organic substances like starch and sugar were not immediately effective in increasing percolation.

Coarse organic substances such as straw, cornstalks, and soybean straw in sufficient concentration increased the percolation rate of the Peorian loess by holding up the soil lumps so that the water could run down between them. Organic substances such as sawdust or lignocellulose, added in a finely divided mechanical state, did not increase the percolation rate.

Microorganisms grown at the surface of Peorian loess plugged up the pores, provided the soil was not stirred, so that the percolation rate was decreased. If the soil was treated with microorganisms and then stirred into a lumpy condition, the percolation rate was increased. As microorganisms act upon organic matter in the soil, they tend to stabilize the soil structure units.

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