SOIL STRUCTURE AND METHODS FOR ITS IMPROVEMENT

by

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INTRODUCTION

Physical conditions of soils are known to affect crop growth and yield. Reductions in rate of growth and in final crop yield are brought about directly as a result of the influence of physical condition on seed germination, seedling emergence, root elongation, and plant respiration. Indirectly, physical conditions affect plant growth by influencing rates of aeration, water infiltration and percolation, and by controlling moisture storage capacity. Since the amount of erosion is influenced by soil physical condition, reduced plant growth and development caused by erosion may result indirectly from poor soil physical condition.

Structure is one of the very important physical properties of the soil as far as plant growth is concerned. Soil structure is defined as "the arrangement of the soil particles, both primary (sand, silt, and clay), and secondary (aggregates)". A soil which is well aggregated and whose aggregates are stable, usually will provide satisfactory conditions for germination and emergence of the crop, and for good root development. A well aggregated soil will provide conditions which are favorable for necessary chemical and biological activities also.

Structural deterioration results from long cropping, and from various physical and chemical manipulations of the soil. Surface crusting, which may reduce seedling emergence, also may result from the breakdown of structural units (aggregates) and the formation of sealed soil surfaces.

Since the early days of agriculture, attempts have been made to improve the structure of the soil, or to maintain the natural good structure, which resulted from the growth of native plants, and from the activities of microorganisms, and from freezing and thawing and wetting and drying. Different organic materials such as manure and plant residues, were added to soils and their effects on structure noted.

Organic matter additions have pronounced effects on ease of tillage, but these may not appear immediately. These materials need to be decomposed partially in order to be useful in aggregation. As decomposition continues the benefits from organic additions may become less apparent or may disappear altogether.

Soil scientists have studied the decomposition products of crop residues and other organic materials in order to find out what types of compounds promote aggregate formation. The plant compounds responsible for aggregation appear to be large or complex polysaccharide molecules. The discovery that specific chemical compounds promoted aggregation led to the development of synthetic soil conditioners. The better conditioners have some advantages over natural organic materials. Their addition is accompanied quickly by a high degree of aggregation. These materials also resist the destructive action of microorganisms for a long time. However, conditioners do not produce a high degree of aggregation on all kinds of soils. Their cost is too high for practical application in normal field scale operations.

In spite of the beneficial effects of synthetic soil conditioners, little effort has been made to compare the relative effectiveness of soil conditioners and of organic materials on the same soils and under the same conditions.

The first part of the present study was designed to compare the effect of a soil conditioner with that of different organic materials on soil structure and to try to determine whether the relatively inexpensive organic materials will provide as good soil aggregation as the very expensive synthetic conditioner.

The second part of this study was designed to find out the effect of different salts on crust strength and to correlate the strength of soil crust with wheat seedling emergence.

A salt affected soil with a silty clay loam texture was selected from the Kansas State College Agronomy Farm, northwest of Manhattan. This soil was known to have extremely poor physical conditions. It was used in all phases of the experiments reported in the following pages.

REVIEW OF LITERATURE

Soil structure is commonly defined as the arrangement of the naturally occurring soil particles (Russell, 37). Soil structure usually is assessed in terms of one or more of its related properties. A few of these properties are degree of aggregation, size distribution of aggregates, permeability of soil to air and water, porosity, and resistance of aggregates to breakdown in air or under water.

Aggregate formation results from the binding or cementing together of the primary particles (Bayer, 6). In order to be well aggregated a soil usually needs to have a moderate clay content and needs to have its colloidal material in a flocculated state. In subsequent pages the factors responsible for aggregate formation are grouped and discussed in the following order:

1. Cations and anions.
2. Amount and nature of clay.
3. Irreversible iron and aluminum oxides.

4. Vegetation.
5. Microorganisms.
6. Climate.
7. Organic matter.
8. Complex synthetic chemicals.

The noticeable effect of the calcium ion on the flocculation of soil particles led many people to believe that calcium was the principal ion contributing to aggregate formation and stability (6, 36). Baver (6), Browning and Milam (7), and Russell (36) have presented evidence that proved the calcium ion had only an indirect effect on granulation. Hubbell and Stubblefield (17) studied the effect of other ions in addition to calcium and they found that none of the following amendments $CaSO_4$, $Ca(NO3)_2$, CaO, $CaCO_3$, $(NH_4)_2 SO_4$, H_2SO_4 and sulfur, had any significant effect on the formation of water stable aggregates regardless of quantity used. Ackerman and Myers (1) suggested that if the calcium ion was added with the organic matter to the soil, the calcium had an indirect effect on soil aggregation.

Baver (6) and Russell (36) stated that the soil colloidal phase or fraction was responsible for cementing primary particles into stable aggregates. Baver (6) observed that clay had a greater aggregating effect when the organic matter content of the soil was low than when it was high. Allison and Moore (5) found that clay content had a direct effect on the formation of aggregates. Hedrick and Mowry (15), on the other hand, reported that there was no correlation between soil aggregation and clay content. Hide and Metzger (16) found that clay was high in highly aggregated soils.

Bayer (6) in discussing the effect of iron and aluminum compounds on aggregation, emphasized the importance of these two ions in aggregate formation, especially in lateritic soils. These soils are known to have large iron contents as well as high degrees of aggregation. Russell (36) was in agreement with this idea. Lutz (22) also claimed the high iron content caused the good state of granulation of lateritic and semilateritic soils.

The effect of different kinds of crops on soil aggregation has been recognized by a great number of workers. Russell (36) observed that permanent grass promotes better structure than successive annual crops. Alderfer and Merkle (2) found that a rotation of corn, oats, wheat and clover over a period of 58 years caused a breakdown of soil aggregates as compared with sod land. Elson (12) found that large aggregates were formed when soil was left under sod for several years. Myers and Myers (28) reported that a legume rotation had a greater effect on total aggregation than a non-legume rotation had. Hide and Myers (16), on the other hand, reported that grass resulted in a decrease of aggregation. Bayer (6) mentioned the favorable effect of roots on aggregation. This favorable effect, he believed, was caused in the following ways:

1. Small groups of particles were pressed together by root pressure to form aggregates.

2. Granules were formed when clods shrank as plant roots removed water.

3. Root secretions bound soil particles into aggregates.

4. Plants added organic matter to the soil. Intermediary products, formed when the organic matter decayed, bound the soil particles together.

The effects of microorganisms have attracted great attention also because of their apparent direct and indirect effects on soil aggregation. Martin and Waksman (23) and Waksman and Martin (41) observed a relationship between the activity of microorganisms and aggregation. They believed that both the mycelia and the gelatinous by-products the organisms released bound soil particles together, thus increasing soil aggregation. Myers and McCalla (29) found that bacteria played a role in soil aggregation. However, they found no simple direct relationship between number of bacteria and degree of aggregation. Baver (6) showed that the aggregating effects of materials produced by microorganisms were many times greater than the direct binding effect of microbial cells. The binding materials produced by microorganisms were polysaccharides, levans, and dextrans.

Baver (6), Chepil (8), Russell (36), and Willis (42) believed that natural climatic cycles of freezing and thawing and of wetting and drying were the major factors in the formation of soil aggregates. Under moist conditions frost action broke down coarse water stable aggregates and, at the same time, bound the finest fractions into intermediate sized granules. Chepil (8) observed that during summer the coarsest and the finest water stable fractions usually increased but that during the winter the larger aggregates were broken down. Baver (6) in discussing the effect of wetting and drying attributed increased aggregation to unequal strains and stresses that result from shrinkage and swelling. In addition the entrapped air had a disruptive action on the aggregates as they were wet. Baver (6) and Russell (36) believed that rapid freezing of wet soil brought about fine aggregates. On the other hand, slow freezing of wet soil tended to form large aggregates.

The beneficial effect of organic matter on soil aggregation has been recognized for a long time. Baver (6) found a very high correlation between organic matter content and aggregation. Klute and Jacob (20) observed that adding 20 tons of manure per acre per year for a 25-year period increased the stability of aggregates but did not increase percentage of aggregation. Lynch, Barczewski and Cotnoir, Jr., reported that aggregation was significantly increased by the addition of two per cent of plant materials to the soil.[1]

Martin and Waksman (23) observed that manure and peat greatly increased the aggregation of the soil. However they showed that the effect of alfalfa was greater than peat. Quastel (31) found that the addition of manure and horse dung greatly improved the air-water relationships and the aggregate stability of soils.

Baver (6) stated that the mechanics of the binding effect of organic matter is not completely understood. Rennie, Truog, and Allen (33) believed that organic matter was effective in increasing aggregation because of the gums produced as the residues were decomposed. Sideri (38) suggested that humus was adsorbed by clay through the process of orientation of organic molecules on the surface of clay particles. Myers (30) in his discussion of the physicochemical properties of a mixture of organic and inorganic colloidal materials pointed out that polar adsorption took place between the clay and organic matter. Robinson and Page (34) observed that organic matter associated with clay was largely responsible for aggregate

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[1] D. L. Lynch, J. K. Barczewski, and L. J. Cotnoir, Jr. The Effect of Residue and Related Materials and Environmental Factors on the Production of Microbial Gums and Soil Aggregation. Paper presented at Annual Meetings of Am. Soc. Agronomy, Atlanta, Ga., Nov., 1957.

stability. They listed the beneficial effects of organic matter as follows:

1. Organic matter reduced the degree of swelling.
2. Organic matter reduced wetability of soil.
3. Organic matter tended to strengthen the aggregates.

Baver (6) also found that organic matter content increased aggregation. However, the effects of organic matter depended in part on the clay content. When the clay content was high, organic matter was not very effective, but when only a small amount of clay was present, organic matter appeared to be very influential.

The increase in aggregation caused by organic matter additions was transitory. Myers and McCalla (29) observed that aggregation declined after the 8th day of incubation. Quastel (31) pointed out that organic matter loses its improving properties as the rate of decomposition increases.

Rennie, et al. (33) in their study pointed out that the effect of alfalfa decreased after 12 days and the effect of straw decreased after 24 days. Their soils were stored at room temperature and kept at field capacity.

From the above discussion, it is obvious that organic matter does affect soil aggregation, but to insure a lasting effect, organic materials must be added frequently.

Because the effect of organic matter on soil aggregation is transitory, a search for synthetic materials that brought fast and lasting effects on aggregation was conducted. This effort led to the discovery of complex electrolytes which were effective in aggregating soils. One of the first of these chemicals that was available commercially was called "Krilium".[1]

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[1] Krilium-Trade mark, Monsanto Chemical Co.

Allison (3) working with saline soils found that the application of 0.025 per cent and 0.1 per cent of synthetic polyelectrolytes (of the Krilium type) overcame the dispersive effect of sodium ions. He also found that permeability markedly increased and in proportion to the rate of treatment.

Allison and Moore (5) found that the application of soil conditioners decreased soil crusting. However, they stated that the addition of a modified vinyl acetate maleic acid compound (VAMA) gave better aggregation on eight of 11 soils than hydrolyzed polyacrylonitrile (HPAN) when added to dry soil. When added to moist soil the two types of conditioners produced comparable results. Allison and Moore (5) found that the amount of conditioners needed was directly related to both specific surface and clay content. They even mentioned that the amount of conditioners required could be estimated by knowing the clay content of the soil.

Hedrick and Mowry (15) found that aggregate stability, aeration, and percolation rate were increased by the addition of polyelectrolytes. They observed that the degree of response did not correlate with the pH of the soil, or with the clay content. They reported that seedling emergence was increased from 32 per cent on an untreated soil to 63 per cent on the soil treated with 0.05 per cent HPAN. Chepil (10) found that granulation and permeability were increased by conditioner addition but that resistance to erosion by wind was decreased.

Duley (11) observed that synthetic soil conditioners increased water intake and reduced runoff and erosion. However, the application of 2.5 tons of straw per acre was more effective in reducing runoff than the HPAN treatment was.

Martin,et al. (24) found that the addition of polyelectrolytes to Paulding clay was noticeable within an hour after incorporation. Conditioners increased the percentage of large aggregates of size 2 to 5 m.m. Rennie et al. (33) found the addition of 0.5 per cent of Krilium increased aggregation significantly. Applications greater than 0.5 per cent caused additional small but non-significant increases in aggregation.

Baver (6) found that subtropical soils of Hawaii were not affected significantly by polyelectrolyte applications. Laws (21) found that soil conditioners acted differently on different soils. Consequently the result obtained from conditioner application on one soil would not necessarily be obtained on other soils.

Synthetic soil conditioners apparently are stable under field conditions. Hedrick and Mowry (15) found that these chemicals resisted the action of bacteria for at least 32 months at 76° F. Mortensen and Martin (26) also found that HPAN and VAMA were resistant to bacterial action. Laws (21) found that oxidation of organic matter decreased the effectiveness of soil conditioners. The presence of free $CaCO_3$ in the soil appeared to reduce the effectiveness of conditioner applications. Willis (42) found that freezing and thawing generally decreased percentage of aggregates >0.25 m.m. more in conditioned soil than in the control. He mentioned that this was also true with wetting and drying but to a lesser degree. Jones and Martin (19) found that the presence of ions affected the stability of aggregates induced by HPAN applications as follows:

Cations - $K^+ > Na^+ > H^+ \cong NH_4^+ > Ca^{++} \cong Mg^{++}$

Anions - $OH^- > H_2PO_4^- > SO_4^= > Cl^- > NO_3^-$

Mortensen (27), on the other hand, found that HPAN was adsorbed on a kaolinitic type of clay in the presence of cations and anions in the following order:

Cations - $Th^{4+} > Ca^{2+} > Ba^{2+} > H^{+} > NH_4^{+} > K^{+} > Na^{+}$

Anions - $F^{-} > OH^{-} > H_2PO4^{-} > Cl^{-} > CH_3COO^{-} > NO_3^{-} >$ HPAN

Ruehrwein and Ward (35) studied the effect of different polyelectrolytes on different clay minerals and concluded that the increase in soil aggregation was effected by the formation of "chemical bridges" between soil particles. Thus they believed that clay particles played a prominent role in aggregate formation of soils.

Soil structure also had a great influence on soil crusting. The soil that had a poor structure frequently formed a crust. The number of seedlings that will emerge was controlled in part by crust strength. A number of soil scientists have studied the various factors that influence soil crusting.

Jamison (18), in studying the effect of synthetic chemicals on soil crusting, found that these chemicals decreased the crust strength. He also found that spraying conditioner on the soil surface was accompanied by surface sealing. Allison (4) also found that application of soil conditioners reduced soil crusting. He also stated that calcium probably reduced soil crusting. Allison and Moore (5) listed the factors affecting soil crusting: sodium content, other exchangeable cations, texture, structure, kind of clay, and salinity. Reeve et al. (32) found that the permeability ratio of air to water and the modulus of rupture increased markedly with increasing exchangeable sodium percentage. Potassium had little effect. There seems to be no extensive quantitative study of effect of different salts on crust strength.

Hanks and Thorp (13, 14) found that crust strength of 200 to 500 millibars limited seedling emergence. They found that crust strength decreased as the amount of available moisture at which the crusts were formed decreased.

METHODS AND PROCEDURE

The research reported in this treatise can be divided into two parts. (1) The effect of different organic materials and HPAN on soil structure as measured by size distribution of water stable aggregate, size distribution of dry aggregates, mechanical stability of dry aggregates, and permeability to water. (2) The effect of different salts on crust strength and per cent seedling emergence. These studies will be referred to in this sequence throughout this manuscript.

Effect of Different Organic Materials and HPAN on Soil Structure

The soil from an area of the Kansas State College Agronomy Farm at Manhattan, known for its poor physical conditions, was selected for study. The soil from this area had a silty clay loam texture, natural bulk density of 1.4, and a mechanical composition of 10 per cent sand, 36.5 per cent clay, and 53.5 per cent silt. The per cent moisture at field capacity (1/3 atmosphere percentage) and permanent wilting percentage (15 atmospheres percentage) were 39 per cent and 26 per cent respectively. The soil can store very little moisture that is available to plants. The lower plastic limit was 29.6 per cent moisture and the upper plastic limit was 53 per cent moisture. Accordingly this soil cannot be tilled at moisture much above the wilting point. Surface soil from this area was collected, air dried, and passed through 4.6 m.m. sieve. Four replicates with each of the following treatments added were prepared:

(1) 2.5 per cent wheat straw

(2) 2.5 per cent dried alfalfa leaves

(3) 2.5 per cent fresh manure (dry basis)

(4) 0.1 per cent HPAN

(5) No added material (control)

Wheat straw and alfalfa leaves were ground very finely in a hammer mill. The manure was dried first and then crushed. The soil for each of the four replicates was mixed separately in a cement mixer with the material used to insure good mixing. Then the soil for each replicate was divided equally into two 2-gallon crocks. The HPAN was dissolved first in water in a paint sprayer and sprayed on the soil while the mixer was turning.

The pots were taken to the greenhouse and enough distilled water was added to bring the soil to field capacity. The pots were alternately dried and wet until three cycles of wetting and drying were finished at room temperature. One of the pots from each of the four replicates of the different treatments and the control were taken for analysis at the end of this period. A representative sample for water permeability was taken out of the soil and the rest of the soil was dried at 75° C. After drying the soil was passed through a rotary sieve described by Chepil (9), to determine dry aggregates distribution and mechanical stability. After dry sieving a sample was taken of that fraction between 2 and 6.4 m.m. diameter for the determination of water stability of aggregates. This analysis was carried out according to the Yoder method (43) as modified by Nichols.[1] The method for permeability was essentially the same as the one mentioned in U.S.D.A. Agricultural Handbook, No. 60 (40).

The same analyses were made on the duplicate pots after three additional cycles of wetting and drying in order to determine the effect of time on the effects of organic materials and HPAN.

Effect of Different Salts on Soil Crusting

A large sample (10 kilograms) of the same soil which was used for the foregoing study and which had an exchange capacity 23 per cent saturated with sodium, 45 per cent saturated with magnesium and only 28 per cent saturated with calcium, was washed thoroughly with calcium choride solution in order to replace the native cations with calcium. Leaching was continued until the calcium content of the leachate was similar to that of the leaching solution. Then the soil was washed with distilled water until the leachate was free of chlorides. The exchange complex after leaching was found to be saturated with only eight per cent sodium, 12 per cent magnesium, and 78 per cent calcium. The soil was left to dry, then ground to pass a 2 m.m. sieve. A similar weight of soil in its original form (sodium and magnesium dominated) was also ground to pass a 2 m.m. sieve. The following treatments were set up on both the original sodium and magnesium dominated soil and the new calcium dominated soil: (1) check: (2) 0.5 per cent KCl; (3) 0.5 per cent $CaCl_2$; (4) 0.5 per cent NaCl and (5)

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[1] M. L. Nichols. Tentative Method of Determining Water-stable Aggregates. Submitted to all project supervisors and cooperators Research Division, Soil Conservation Service, U.S.D.A. September 17, 1943.

0.5 per cent $MgCl_2$. About 1300 grams of each soil was taken and sprayed with enough water containing the required amount of salt to bring the soil to its wilting point (26 per cent moisture). The treated soils were stored in plastic bags for 24 hours to insure good moisture distribution. Samples of each soil were formed into 7x7x0.5 inch crusts of 1.5 bulk density as described by Hanks and Thorps (14). These crusts were placed on top of a seed germinating bed in an 8x8x2 inch aluminum pan. The germinating bed consisted of a 1 1/4 inch deep layer of fine sandy loam soil. The crust and germinating bed were separated by a piece of 1/2 inch hardware cloth and a piece of 10-mesh screen. Thirty-six wheat seeds were placed at one inch intervals and were covered with one-half inch of soil. The germinating bed was moistened so that it contained two-thirds of the water available at field capacity. The crusts prepared as described above were transferred to the pan containing the seeds. Sand was added around the crust and the crust sealed to the edges of the pan with melted paraffin. The soil was then put into a germinator.

A portion of each soil treated with salts in the above manner was used to make briquets in order to find the modulus of rupture. The method used was essentially that of Richards (40) modified slightly by Hanks and Thorp (14).

The results obtained in all these studies were subjected to statistical analyses using the methods outlined by Snedecor (39).

RESULTS AND DISCUSSION

Effect of Different Organic Materials and HPAN on Soil Structure

The appearance of all treatments except wheat straw indicated that most crop residue and Krilium had a marked effect on the physical condition of the soil. The appearance of these pots after six cycles of wetting and drying is shown in Plate I.

A summary of the per cent of water stable aggregates > 0.5 m.m. in diameter is presented in Table 1. Detailed data on water stable aggregates after three cycles and six cycles of wetting and drying respectively are given in Table 10 and Table 11 (Appendix).

Statistical analysis of these data showed that treatments caused highly significant differences to develop. Similarly the number of wetting and drying cycles caused differences. Accordingly a table of means and differences was prepared (Table 2). HPAN and alfalfa caused the development of significantly larger aggregates than did the check in both cycles. Manure produced significantly larger aggregates than the check after six cycles only. This indicated that HPAN and alfalfa influence aggregation more quickly than manure. Apparently manure needed more time to become effective. Straw did not cause the development of large aggregates. Actually straw decreased the per cent of aggregates > 0.5 m.m.

These results show that the relatively cheap organic materials are as effective as the very expensive synthetic soil conditioners in producing water stable aggregates. These results show also that the effect of these organic materials may last for a good length of time.

The geometric mean diameter data for the dry sieving study, for both

EXPLANATION OF PLATE I

The effect of different organic materials and HPAN on the surface condition of a silty clay loam soil.

M - 2.5 per cent manure

A - 2.5 per cent alfalfa

CH - check (no added organic material)

K - 0.1 per cent Krilium (HPAN)

S - 2.5 per cent wheat straw

PLATE I

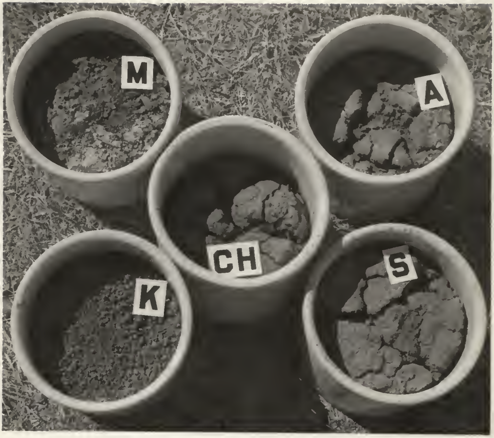

Table 1. The effect of treatment and wetting and drying cycles on the per cent of stable soil aggregate > 0.5 m.m.

Treatment	Water stable aggregates 0.5 m.m. in diameter				
	Replicate				Average
	1	2	3	4	
	%	%	%	%	%
	3 Cycles of Wetting and Drying				
Check	21.3	23.7	17.8	20.9	20.9
Straw	14.3	14.9	18.1	24.0	17.8
Alfalfa	25.6	29.8	27.8	28.4	27.9
Manure	22.6	23.9	25.8	20.7	23.3
Krilium	32.0	34.5	32.4	28.5	31.9
	6 Cycles of Wetting and Drying				
Check	25.1	21.5	19.3	18.3	21.0
Straw	14.6	14.4	23.6	23.2	18.9
Alfalfa	36.3	33.0	33.8	36.4	34.9
Manure	28.1	25.8	24.3	28.1	26.6
Krilium	35.6	42.8	36.5	35.2	37.5

Table 2. Means and differences for water stable aggregates > 0.5 m.m.

Treat	S-6	C-3	C-6	M-3	M-6	A-3	K-3	A-6	K-6
Mean:	18.9	20.9	21.0	23.3	26.6	27.9	31.9	34.9	37.5
S-3 17.8	1.1	3.1	3.2	5.5*	8.8**	10.1**	14.1**	17.1**	19.8**
S-6 18.9		2.0	2.1	4.4	7.7**	9.0**	13.0**	16.0**	18.6**
C-3 20.9			0.1	2.4	5.7*	7.0**	11.0**	14.0**	16.6**
C-6 21.0				1.3	5.6*	6.9*	10.9**	13.9**	16.5**
M-3 23.3					3.3	4.6*	8.6**	11.6**	14.2**
M-6 26.6						1.3	5.3*	8.3**	10.9**
A-3 27.9							4.0	7.0**	9.6**
K-3 31.9								3.0	6.6**
A-6 34.9									2.6

L.S.D. (p = 0.05) = 4.6
L.S.D. (p = 0.01) = 6.2
C = Check
S = Straw
A = Alfalfa
M = Manure
K = Krilium
3 = 3 cycles
6 = 6 cycles

cycles, are given in Table 3. Detailed results for three cycles and six cycles of dry aggregate distribution, and geometric mean diameters are given in Tables 12 and 13 respectively (Appendix). Statistical analysis showed that treatments caused the development of significant differences in dry clod size.

It also showed a significant interaction between treatments and numbers of cycles. However, averages for the two cycles were not sufficiently different to be significant. Table 4 contains the averages and differences between geometric mean diameters of dry clods. All treatments decreased the size of clods after the sixth cycle significantly. HPAN was most effective treatment after three cycles but manure became the most effective after six cycles. This is probably because manure became more influential in the formation of medium size aggregates as it was decomposed. HPAN showed less effect after the sixth cycle than after the third.

A study of Tables 12 and 13 will show that organic additions reduced large clods to a smaller size. In areas where wind erosion is a serious menace to agriculture, reduction of clod size is associated with increased susceptibility to wind erosion. However the sizes of aggregates developed in this study are not erodable by wind.

The mechanical stability data for the dry sieving study, at the end of both cycles, are given in Table 5. Detailed results after three and six cycles of the mechanical stability of dry aggregates are given in Tables 12 and 13 (Appendix) respectively. Statistical analysis showed that stability levels after the two cycles of wetting and drying were not different but that organic treatments caused the production of significant differences in dry aggregate mechanical stability. Table 6 contains the averages and

Table 3. Effect of treatment and wetting and drying cycles on the size distribution of dry aggregates.

Treatment	Geometric Mean Diameter				
	Replicates				Average
	1	2	3	4	
	m.m.	m.m.	m.m.	m.m.	m.m.
	3 Cycles of Wetting and Drying				
Check	20.0	22.2	21.0	23.0	21.6
Straw	20.0	25.7	21.0	6.8	18.4
Alfalfa	7.6	12.5	7.9	19.0	11.8
Manure	8.5	9.8	6.6	8.8	8.4
Krilium	3.8	2.5	3.2	7.4	4.2
	6 Cycles of Wetting and Drying				
Check	25.0	27.0	26.0	50.7	32.2
Straw	23.0	17.0	21.5	28.0	22.4
Alfalfa	4.0	7.1	4.1	5.2	5.1
Manure	2.0	6.0	7.4	4.0	4.8
Krilium	6.8	3.8	4.5	6.5	5.4

Table 4. Means and differences for geometric mean diameter (m.m.) of dry clods.

Treat		S-6	C-3	S-3	A-3	M-3	K-6	A-6	M-6	K-3
	Mean:	22.4	21.6	18.4	11.8	8.4	5.4	5.1	4.8	4.2
C-6	32.2	9.8*	11.6*	13.8**	20.4**	23.8**	26.8**	27.1**	27.4**	28.0**
S-6	22.4		0.8	4.0	10.6**	14.0**	17.1**	17.3**	17.6**	18.2**
C-3	21.6			3.2	9.8*	13.2**	16.2**	16.5**	16.8**	17.4**
S-3	18.4				5.6	10.0*	13.0**	13.3**	13.6**	14.2**
A-3	11.8					3.4	6.4	6.7	7.0	7.6*
M-3	8.4						3.0	3.3	3.6	4.2
K-6	5.4							0.3	0.6	1.2
A-6	5.1								0.3	0.9
M-6	4.8									0.6

L.S.D. (p = 0.05) = 7.6
L.S.D. (p = 0.01) = 10.3
C = Check
S = Straw
A = Alfalfa
M = Manure
K = Krilium
3 = 3 cycles
6 = 6 cycles

Table 5. Effect of treatment and wetting and drying cycles on the mechanical stability of dry aggregates.

Treatment	Mechanical Stability of Dry Clods				
	Replicate				Average
	1	2	3	4	
	%	%	%	%	%
	3 Cycles of Wetting and Drying				
Check	95.0	98.0	93.6	94.6	95.3
Straw	90.5	94.7	94.3	96.7	94.0
Alfalfa	90.3	74.6	90.1	88.4	85.8
Manure	92.9	92.4	94.0	94.5	93.3
Krilium	97.4	92.0	93.3	94.6	94.3
	6 Cycles of Wetting and Drying				
Check	88.9	96.3	97.1	97.8	95.0
Straw	98.5	97.2	97.0	96.5	97.3
Alfalfa	92.3	92.4	91.9	92.9	92.4
Manure	95.8	92.0	92.9	93.4	93.5
Krilium	96.9	90.0	95.9	97.5	95.1

Table 6. Means and difference for mechanical stability of dry aggregate.

Treat		C-3	K-6	C-6	K-3	S-3	M-6	M-3	A-6	A-3
	Mean:	95.3	95.1	95.0	94.3	94.0	93.5	93.3	92.4	85.8
S-6	97.3	2.0	2.2	2.3	3.0	3.3	3.8	4.0	4.9	11.5**
C-3	95.3		0.2	0.3	1.0	1.3	1.8	2.0	2.9	9.5**
K-6	95.1			0.1	0.8	1.1	1.6	1.8	2.7	9.3**
C-6	95.0				0.7	1.0	1.5	1.7	2.6	9.2**
K-3	94.3					0.3	0.8	1.0	1.9	8.5**
S-3	94.0						0.5	0.7	1.6	8.2**
M-6	93.5							0.2	1.1	7.7**
M-3	93.3								0.9	7.5**
A-6	92.4									6.6**

L.S.D. ($p = 0.05$) = 5.1
L.S.D. ($p = 0.01$) = 6.6
C = Check
S = Straw
A = Alfalfa
M = Manure
K = HPAN
3 = 3 cycles
6 = 6 cycles

differences of mechanical stability between treatments and cycles. Only alfalfa after the third cycle showed a significant decrease in mechanical stability. Alfalfa after the sixth cycle as well as other treatments after both cycles did not cause significant changes in stability.

The data for soil permeability to water after the fifth hour for both cycles are given in Table 7. Statistical analysis showed no significant differences were brought about by treatments. This may be due to the breakdown under water of the aggregates formed by organic materials and HPAN. Some of the particles released from weak aggregates at the surface of the columns may have been moved into the pores by the downward moving water.

Effect of Different Salts on Soil Crusting

The average of two replicates of the wheat seedling emergence data on each of two soils and five salt treatments are given in Table 8, along with the crust strength data on the same soils and treatments. Detailed data on seedling emergence are given in Table 14 (Appendix). Seedling emergence was limited under all treatments. Statistical analysis of the data showed no significant differences between the plants emerging under the different treatments. The bulk density (1.5) of this soil with attending high crust strength limited seedling emergence regardless of the kind of soil or the kind of salt added. All per cent seedling emergences were far below those satisfactory for the establishment of a good crop.

The average of five determinations of the crust strength data (modulus of rupture) from soils treated with different salts were given in Table 8. Detailed data on crust strength are reported in Table 15 (Appendix). Statistical analysis of the crust strength data showed that

Table 7. Effect of treatments and wetting and drying cycles on water permeability during the fifth hour.

Treatment	Water permeability				
	Replicate				Average
	1	2	3	4	
	cm/hr	cm/hr	cm/hr	cm/hr	cm/hr
	<u>3 Cycles of Wetting and Drying</u>				
Check	0.000	0.000	0.000	0.010	0.002
Straw	0.000	0.000	0.000	0.005	0.001
Alfalfa	0.020	0.032	0.043	0.025	0.030
Manure	0.024	0.020	0.020	0.010	0.018
Krilium	0.017	0.010	0.000	0.000	0.007
	<u>6 Cycles of Wetting and Drying</u>				
Check	0.000	0.000	0.000	0.000	0.000
Straw	0.000	0.013	0.004	0.000	0.004
Alfalfa	0.051	0.043	0.010	0.763	0.217
Manure	0.043	0.043	0.034	0.043	0.040
Krilium	0.004	0.003	0.006	0.000	0.003

Table 8. The effect of 0.5 per cent concentration of salts on seedling emergence and on crust strength.

Salt Added	Crust strength in millibar and per cent seedling emergence			
	Calcium dominated		Na - Mg dominated soil	
	Crust strength**	% seedling emergence*	Crust strength**	% seedling emergence*
Check	363	4.1	494	12.6
KCl	308	1.4	369	11.1
$CaCl_2$	277	4.1	320	7.0
NaCl	403	1.4	249	14.0
$MgCl_2$	439	7.1	375	2.7

**Each value is the average of five determinations
*Each value is the average of two replicates

adsorbed cations and treatments did not cause significant differences. However, a highly significant interaction between adsorbed cations and treatments was found. Accordingly a table of treatment means and differences was prepared (Table 9). All added cations showed highly significant decreases in the crust strength when added to the soil which contained sodium and magnesium ions as major adsorbed cations. Potassium and calcium decreased significantly the crust strength of the soil that had calcium as the major cation on the exchange complex. On the other hand, magnesium and sodium added to this soil caused significant increases in crust strength. It appeared that magnesium and sodium had dispersive effects on the soil thus causing the increase in crust strength. Plant seedlings might be expected to emerge less easily through the soils with the greater crust strengths.

Table 9. Means and differences for crust strength with the addition of different salts.*

Treat	Ca-Mg	Ca-Na	Na-Mg	Na-K	Ca-O	Na-Ca	Ca-K	Ca-Ca	Na-Na
Mean	439	403	375	369	363	320	308	277	249
Na-O 494	55**	91**	119**	125**	131**	174**	186**	217**	245**
Ca-Mg 439		36**	64**	70**	76**	119**	131**	162**	190**
Ca-Na 403			28**	34**	40**	83**	95**	126**	154**
Na-Mg 375				6	12	55**	67**	98**	126**
Na-K 369					6	49**	61**	92**	120**
Ca-O 363						43**	55**	86**	114**
Na-Ca 320							12	43**	81**
Ca-K 308								31**	69**
Ca-Ca 277									28**

L.S.D. $(p = 0.05) = 14.9$
L.S.D. $(p = 0.01) = 19.4$

*When Na is present as the first element it indicates the unleached soil. When Ca is the first element listed it denotes the leached soil. The second chemical element listed in each treatment denotes the cation added as the chloride.

CONCLUSIONS

In evaluating the effects of different organic materials and HPAN on soil structure, it must be kept in mind that these data are drawn from an experiment on a soil with extremely poor structure. These organic materials and HPAN might cause more improvement on soils which are not in as bad physical condition.

On the basis of the first study, the following conclusions may be drawn:

1. Organic materials and HPAN will result in significant improvement of structure on soils similar to the one used in these studies.

2. The organic materials, especially alfalfa and manure after sufficient time, gave comparable improvement in physical condition to that caused by the very expensive synthetic soil conditioners.

3. The natural organic materials were still increasing the per cent of aggregates > 0.5 m.m. after eight months.

4. Straw was the only organic material tested that did not bring any improvement in physical condition. This material appeared to resist destruction and was not as well decomposed after eight months as was the alfalfa and manure.

5. In spite of the improvements in aggregation brought about by organic matter and soil conditioner additions, no significant improvement in soil permeability was noted by the method used.

6. The alfalfa and manure treatments decreased to a degree the state of cloddiness. A decrease in cloddiness is desirable for good seed bed. However, a decrease in dry clod size sometimes is associated with an increase in wind erosion susceptibility.

The following conclusions were drawn from the seedling emergence and crust strength study:

1. Both soils tested, regardless of treatment, limited seedling emergence.

2. Soils that had sodium and magnesium ions as the major adsorbed cations on the exchange complex formed the toughest crusts encountered in this study.

3. The presence of appreciable amounts of salts tended to offset the bad effect of sodium and magnesium ions but this did not increase seedling emergence.

4. Soils that had calcium as the major adsorbed ion on the exchange complex did not form as tough crusts as the ones found on the sodium and magnesium dominated soil.

5. The addition of calcium and potassium salts decreased the strength of the crust on the calcium dominated soil.

6. Magnesium and sodium salts offset the beneficial effect of calcium on crust strength.

7. The effect of salts on crust strength should be studied further.

SUMMARY

The effects of different organic materials and HPAN on the development of better soil structure were studied. The influences of treatments on water stability of aggregates, dry clod size distribution, mechanical stability of dry clods and permeability to water were investigated. A salt affected soil with a silty clay loam texture was selected. Treatments on this soil included: check, the addition of 2.5 per cent by weight of straw, alfalfa, manure, and 0.1 per cent HPAN.

The effects of salts on seedling emergence and their influence on crust strength were also studied. The same silty clay loam soil, with a preponderance of either calcium or sodium and magnesium on the exchange complex and to which 0.5 per cent sodium, potassium, calcium, or magnesium was added as the chloride, was formed into 1 3/8 x 2 3/4 inch briquets and 7 x 7 inch blocks under pressure. These crusts were tested for their resistance to wheat seedling emergence and for their modulus of rupture.

Additions of alfalfa, manure and HPAN to the test soil caused a highly significant increase in the stability of aggregates $>$ 0.5 m.m., reduced the cloddiness, and preserved the mechanical stability of the dry soil clods. The natural materials apparently became more effective as they decomposed because their influence increased through an eight month period. The HPAN, on the other hand, became less effective with time. Straw which did not decompose rapidly did not bring about any increase in water stable aggregates and did not increase the stability of dry clods. None of the treatments had a significant effect on permeability to water.

Seedling emergence was limited by all treatments. Apparently the cohesion of the particles of this soil at the wilting point and at a bulk density of 1.5 was so great that small differences in crust strength caused by salt treatment could not increase emergence of seedlings.

The presence of salts in the soil that had sodium and magnesium as major adsorbed cations on the exchange complex, offset the bad effect of the adsorbed ions and decreased the crust strength. For the calcium dominated soil, only calcium and potassium salts brought about significant decreases in crust strength. Sodium and magnesium salts caused a significant increase in crust strength. This was probably due to the dispersive effect of the sodium and magnesium ions on soil.

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APPENDIX

Table 10. The effect of treatment on the size distribution of water stable aggregates after three cycles of wetting and drying.

Treatment	Replicate	Size of water stable aggregates in m.m. > 2	2-0.84	0.84-0.5	0.5-0.25	0.25-0.05	0.05-0.02	< .02
		%	%	%	%	%	%	%
Control	1	0.7	9.7	10.9	12.8	36.4	10.0	19.5
	2	0.4	11.2	12.1	15.7	24.4	14.3	21.9
	3	1.1	7.4	9.3	12.2	44.6	8.4	16.9
	4	2.0	9.0	10.0	11.1	37.6	8.3	22.1
Straw	1	0.8	6.9	6.6	9.1	50.9	6.2	19.5
	2	0.3	7.3	7.3	8.2	49.9	6.2	20.8
	3	2.2	8.4	7.5	9.8	47.6	3.8	20.8
	4	1.8	11.3	11.0	10.3	41.5	4.7	19.5
Alfalfa	1	2.5	10.3	12.9	13.9	39.0	3.9	17.5
	2	2.9	14.8	12.2	14.1	36.1	6.7	13.2
	3	4.0	10.2	13.7	14.5	36.6	9.5	11.6
	4	2.9	12.9	12.5	13.6	38.8	4.7	14.6
Manure	1	2.1	8.8	11.8	14.8	38.2	7.0	17.4
	2	2.3	11.3	10.3	13.6	38.1	8.4	16.0
	3	4.6	10.3	10.9	13.9	38.4	11.2	10.7
	4	3.4	7.9	9.4	9.8	49.1	7.0	13.5
Krilium	1	5.7	15.7	10.7	9.6	38.2	7.8	12.4
	2	11.6	15.8	7.2	8.5	44.3	4.0	8.7
	3	9.6	14.6	8.2	9.5	35.7	7.2	15.2
	4	6.1	13.6	8.8	9.8	36.1	13.3	12.3

Table 11. The effect of treatment on the size distribution of water stable aggregatesafter six cycles of wetting and drying.

Treatment	Replicate	Size of water stable aggregates in m.m.						
		> 2	2-0.84	0.84-0.5	0.5-0.25	0.25-0.05	0.05-.02	< .02
		%	%	%	%	%	%	%
Control	1	1.3	10.9	12.8	12.6	34.0	9.7	18.6
	2	1.4	7.8	12.3	14.2	36.3	9.6	18.5
	3	0.8	7.3	11.2	13.4	35.3	13.0	19.1
	4	0.4	7.8	10.1	8.7	45.1	10.0	18.0
Straw	1	1.8	8.5	4.3	5.1	41.8	11.2	27.8
	2	2.2	6.5	5.7	7.1	46.7	8.0	23.9
	3	2.8	12.4	8.4	9.1	29.8	9.1	28.4
	4	2.0	8.8	12.5	12.0	34.1	7.1	23.6
Alfalfa	1	4.6	15.5	16.2	13.7	20.5	9.7	19.9
	2	6.0	13.3	13.8	13.9	24.0	11.0	18.0
	3	5.7	16.0	11.9	11.5	20.0	12.8	21.9
	4	7.4	16.6	12.4	11.7	18.9	11.5	21.6
Manure	1	3.5	11.6	13.0	13.3	22.8	11.3	24.5
	2	2.4	10.2	13.1	14.5	22.3	19.3	18.1
	3	1.8	10.4	12.1	13.8	23.8	15.7	22.5
	4	3.3	12.2	12.7	13.9	22.9	9.8	25.2
Krilium	1	7.2	16.2	12.2	11.5	24.3	8.4	20.2
	2	12.5	20.8	9.6	9.8	17.0	9.9	20.5
	3	9.9	15.7	10.9	10.5	20.8	9.1	23.0
	4	8.0	15.9	11.4	11.5	23.6	8.1	21.6

Table 12. The effect of treatment on dry aggregate distribution and mechanical stability of aggregates > 2 m.m. after 3 cycles of wetting and drying.

Treatment	Replicate	Size distributions of dry sieving in m.m.						Geometric mean diameter	Mechanical Stability
		>12.7	12.7-6.4	6.4-2.0	2.0-.84	.84-.42	<.42		
		%	%	%	%	%	%	m.m.	%
Control	1	61.3	7.5	17.3	7.7	2.7	3.7	20.0	95.0
	2	62.5	5.9	15.2	8.1	3.5	4.8	22.2	98.0
	3	67.5	5.6	14.6	6.9	2.4	3.2	21.1	93.6
	4	67.6	7.0	13.1	6.9	2.3	3.1	23.0	94.6
Straw	1	61.0	11.6	16.7	6.7	2.1	1.9	20.0	90.5
	2	70.2	7.8	13.0	5.9	1.5	1.6	25.7	94.7
	3	62.3	9.5	15.9	7.2	2.7	2.4	21.0	94.3
	4	40.8	9.8	26.9	12.8	4.9	4.8	6.8	96.7
Alfalfa	1	43.4	6.1	29.9	12.5	3.8	4.3	7.6	90.3
	2	49.2	5.3	29.5	9.0	3.1	3.9	12.5	74.6
	3	50.7	4.7	22.5	12.4	4.3	5.4	7.9	90.1
	4	60.1	7.5	17.9	8.5	2.9	3.1	19.0	88.4
Manure	1	43.6	9.7	24.2	12.7	4.6	5.2	8.5	93.0
	2	47.6	8.8	22.5	11.9	4.3	4.8	9.8	92.4
	3	41.8	7.3	26.6	13.7	5.1	5.7	6.6	93.5
	4	46.2	9.6	21.8	12.4	5.0	5.0	8.8	94.6
Krilium	1	14.7	12.6	47.0	18.9	5.0	1.7	3.8	97.4
	2	1.5	10.7	53.4	25.8	7.1	1.6	2.6	92.0
	3	5.8	12.5	55.0	20.8	4.7	1.3	3.2	93.3
	4	35.6	13.6	33.0	13.4	3.3	1.1	7.4	99.6

Table 13. The effect of treatment on dry aggregate distribution and mechanical stability of aggregates > 2 m.m. after six cycles of wetting and drying.

Treatment	Replicate	Size distribution of dry sieving in m.m.						Geometric mean diameter	Mechanical Stability
		> 12.7	12.7-6.4	6.4-2.0	2.0-.84	.84-.42	< .42		
		%	%	%	%	%	%	m.m.	%
Control	1	66.8	15.4	7.4	2.9	4.0	3.6	25.0	88.9
	2	74.4	6.9	9.8	4.6	1.8	2.6	27.0	96.3
	3	63.7	8.4	13.2	7.5	2.9	4.3	26.0	97.1
	4	71.5	7.4	9.7	6.0	2.1	3.3	50.7	97.2
Straw	1	63.0	13.0	15.5	5.2	1.6	1.7	23.0	98.5
	2	56.2	11.4	19.1	9.8	2.6	2.8	17.0	97.2
	3	60.9	13.0	15.7	6.1	1.9	2.5	21.5	97.1
	4	68.6	12.0	12.6	4.1	1.3	1.3	28.0	96.5
Manure	1	18.8	18.0	21.9	9.4	3.5	28.5	2.0	95.8
	2	36.7	12.0	27.5	13.1	4.7	6.1	6.0	92.0
	3	42.9	10.5	22.8	12.5	5.2	6.1	7.4	92.9
	4	13.4	29.8	31.6	14.6	5.3	5.3	4.0	93.4
Alfalfa	1	24.6	8.8	32.9	18.7	6.7	8.4	4.0	92.3
	2	38.4	8.0	24.4	15.8	6.4	6.9	7.1	92.4
	3	24.0	7.9	35.6	18.7	6.2	7.5	4.1	91.9
	4	33.6	9.4	27.0	15.2	6.5	8.3	5.2	92.9
Krilium	1	34.8	14.8	34.1	11.6	2.8	1.9	6.8	96.9
	2	6.8	16.4	55.1	15.6	4.0	2.1	3.8	90.1
	3	20.4	13.9	40.1	18.9	4.5	2.3	4.5	95.9
	4	32.2	16.8	34.8	11.9	2.4	1.9	6.5	97.5

Table 14. The effect of 0.5 per cent concentration of salts on seedling emergence.

Soil	Salt added	Seedling emergence in per cent	
		Replicate	
		1	2
Calcium dominated	0.0	5.5	2.8
	KCl	0.0	2.8
	$CaCl_2$	8.3	0.0
	NaCl	2.8	0.0
	$MgCl_2$	8.3	6.0
Sodium Magnesium dominated	0.0	0.0	25.2
	KCl	5.5	16.8
	$CaCl_2$	11.2	2.8
	NaCl	0.0	28.0
	$MgCl_2$	5.5	0.0

Table 15. The effect of salts on crust strength as measured by modulus of rupture.

Treatment*	Crust strength in millibars	Treatment*	Crust strength in millibars
Ca-O	343	Na-O	628
	356		475
	422		412
	343		528
	354		428
Ca-K	304	Na-K	428
	353		343
	304		422
	290		312
	290		343
Ca-Ca	238	Na-Ca	327
	253		370
	280		238
	301		312
	312		354
Ca-Na	412	Na-Na	296
	317		264
	438		201
	457		211
	391		275
Ca-Mg	380	Na-Mg	354
	502		375
	449		327
	380		449
	475		370

*The first letter indicates the major ion on the exchange complex and the second letter indicates the added cation.

SOIL STRUCTURE AND METHODS FOR ITS IMPROVEMENT

by

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Soil structure as defined by the "arrangement of soil particles" has great influence on soil productivity. A deteriorated soil structure will influence root development and penetration, will reduce soil aeration and decrease the infiltration capacity and water permeability of the soil. A soil in poor physical condition also will tend to form a tough surface crust that will prevent seedling emergences.

The present study was designed to determine quantitatively some of the influences of different organic material and synthetic soil conditioner (HPAN) additions on the soil structure properties. The organic materials were added at the rate of 2.5 per cent and HPAN at 0.1 per cent by weight to a salt affected soil with a silty clay loam texture. Water stable aggregates, dry aggregates size distribution, mechanical stability, and permeability to water were studied.

These characteristics were studied after two periods: after three cycles and after six cycles of wetting and drying, at room temperature.

The effects of different salts on crust strength as measured by modulus of rupture and wheat seedling emergence were studied also. The chloride of sodium, potassium, calcium or magnesium was added at the rate of 0.5 per cent by weight to the sodium and magnesium dominated silty clay loam soil and to its leached and calcium dominated counterpart.

HPAN and organic materials, except straw, increased the percentage of water stable aggregates > 0.5 m.m. They also decreased the size of dry clods. They kept the mechanical stability of soil high. Permeability was not influenced significantly by any treatment.

Seedling emergence was limited by all treatments. The tenacity of the soil at a bulk density of 1.5 and at the wilting point appeared to

restrict emergence regardless of kind of salt added. The effects of salts on crust strength and emergence should be studied further under a range of bulk density and moisture conditions.

Salts decreased the crust strength when added to soil that had sodium and magnesium ions as major cations on exchange complex. Only calcium and potassium significantly decreased crust strength on calcium dominated soil. Magnesium and sodium salts had adverse effect on calcium dominated soil and brought about a significant increase in crust strength.