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Soil Strength and Porosities Associated with Cropping Sequences[1]

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ABSTRACT

The effects of cropping sequences on the strength and porosity of the Portneuf silt loam soil were studied in south-central Idaho under normal field conditions. Undisturbed soil cores were collected from the surface 20 cm of seven fields with cropping histories ranging from continuous pasture to contínous beans (*Phaseolus vulgaris* L.). The soil in all fields was a uniform silt loam developed under arid conditions. The pore size distribution and soil hardness were measured on the undisturbed cores as well as on bulk samples collected from each site. The results indicated that both the pore size distribution and the hardness are rather independent of cropping history. While both these parameters can be changed by mechanical manipulation, the soil soon reverts back to a stable range of values under field conditions.

Additional Index Words: **soil structure, crop rotations, tillage, soil stability, soil hardness.**

GOOD SOIL STRUCTURE is a prerequisite for maximum plant growth. Though the term "soil structure" is poorly defined and ambiguous, past research has led to the often quoted postulates that wetting and drying, freezing and thawing, moderate tillage, and increasing the organic matter all benefit soil structure (Gradwell and Arlidge, 1971; Smukalski, 1968; and Williams and Cooke, 1961). On the other hand, continuous row cropping, intensive tillage, and mechanical compaction have been cited as causes for soil structure deterioration (Shaw, 1952). Aside from these generalities, many practical questions concerning soil management and the resulting physical conditions have not been answered.

The term "soil structure" should really be used in the same broad sense as "soil fertility." Specific procedures might then be devised to evaluate soil structure in the same way that soil tests for available nutrients are used to evaluate fertility. So far as plant growth is concerned, we do know that soil hardness and pore size distribution in the root zone are important properties. In a previous paper, we developed an index for characterizing the pore size distribution and suggested a compatible method for measuring soil hardness (Cary and Hayden, 1973). The porosity index is a dimensionless number with values ordinarily falling between one and ten. Formally defined as the arithmetic mean change in water content as the soil water tension increases from 1 cm of water to 1.5 bars, the index characterizes the pore size groups which are most important for maximum plant growth through their association with aeration and readily available water. A small index number indicates few pores with a radius greater than 1 μm, while a large index indicates an increase in the number of large pores and generally more favorable conditions for plant growth.

Soil hardness, also an important aspect of soil structure, may be independent of pore size distribution. Because hardness is a sensitive function of water content, we suggested making penetrometer measurements at a known soil moisture tension of 1.5 bars. This measurement is compatible with the procedure for measuring the porosity index and should signal the onset of any hardness problem in the moist soil range where one strives to achieve maximum plant growth. Penetrometer measurements have, of course, been correlated with root growth (Taylor, 1971).

The work reported here uses these indices to explore the effects of seven different cropping sequences on the hardness and pore size distribution of a silt loam soil. The effects of simulated tillage and the subsequent stability of the soils from the seven fields were also studied.

METHODS

Seven small fields on or near the USDA and Idaho Experiment Station farms in south-central Idaho were chosen for the study. The fields were of the same soil type and had received normal tillage and fertilizer management, but had different cropping histories. Each field was divided into four quarters, and one core taken at random in each quarter at the end of the cropping season. The sampling sites were preirrigated so that the cores could be obtained with negligible compaction by pushing a split stainless steel cylinder 20 cm into the soil surface. After removing the split cylinder, brass retaining rings (2-cm high and matching the 4.2-cm diam of the cylinder) were slipped over the outside of the core and the ends were discarded. The remainder of the core was sliced, leaving eight rings filled with undisturbed samples. Four of these samples were brought to equilibrium under ⅓ bar on the pressure plate and loaded with 3.4 kg/cm^2 (50 psi). The samples were compressed between a jack and the platform of a scale until the scale reading was constant for 15 to 20 sec at the desired load level.

A bulk soil sample from the upper 20 cm was also taken near each core site. These were air-dried and passed through a 2-mm sieve. The sieved soil was divided to receive four different treatments. One treatment involved the complete dispersal of a subsample in distilled water with a high-speed mechanical mixer and allowing it to dry before passing it through a 2-mm sieve and into the brass retaining rings. The second subsample was subjected to 10 wetting and drying cycles at 65C. The third was treated by bringing its water content to ⅓ bar on the pressure plate and then loading it with 3.4 kg/cm^2 (50 psi). The remaining sieved soil samples were left untreated for controls and subsampled for mechanical analysis by the hydrometer method (Day, 1965). None of the soil samples were packed or otherwise encouraged to consolidate as they were poured into their brass retaining rings.

After the undisturbed and sieved samples were prepared, they were placed with their rings on a pressure plate and submerged in water so that the level was even with the top of the rings. After soaking several hours, the water level was lowered, leaving just a small amount of free liquid on the surface of the pressure plate. After a few minutes, each sample was removed with a lightweight spatula from the pressure plate for weighing. The combined weight of the spatula, ring, and sample was recorded. The ring and sample were then slipped off the spatula onto the plate and brought to equilibrium with 0.2 bar in the pressure chamber. Each sample was then reweighed and rewet for several hours with free water on the surface of the pressure

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Table 1—Average porosity index (I) and penetrometer reading in bars (Pen) for soils from seven fields with different cropping sequences. The most recent crop is listed first

Field no., cropping history, and soil texture				Undisturbed core samples				Treated bulk soil samples									
				Field		Loaded		Control samples sieved		Dispersed		Sieved, wet and dried		Sieved, loaded		LSD	
	Sand	Silt	Clay	I	Pen	I	Pen	I	Pen	I	Pen	I	Pen	I	Pen		
1. First seedbed prepared after 15 year continuous pasture	20	61	19	2.8	7.5	2.8	14.7	6.1	3.8	7.3	6.7	5.0	3.5	2.9	15.2	0.6	2.8
2. 15 year continuous beans	19	62	19	3.1	9.1	3.2	14.1	6.1	5.2	6.7	7.8	5.1	4.8	3.7	13.5	0.3	2.4
3. 3 grain, 2 beets, 1 potato	21	61	18	2.8	7.2	2.9	15.7	6.3	4.8	7.1	7.1	5.5	3.9	3.7	13.2	0.5	3.3
4. potato, grain, beans, 2 alfalfa, grain	21	60	19	2.6	6.9	2.8	14.0	6.0	4.5	7.9	7.4	4.9	3.9	3.5	12.3	0.3	1.1
5. beans, 2 alfalfa, grain, fallow grain	20	61	19	2.6	9.0	2.6	18.6	7.0	4.4	7.7	7.2	5.1	3.2	4.5	12.2	0.7	2.3
6. grain beans, 2 alfalfa, grain, beans	18	62	20	2.4	7.2	2.5	17.3	6.8	3.5	6.6	7.5	5.0	4.1	3.6	15.2	0.5	2.5
7. potatoes, 4 alfalfa, beans	19	61	20	2.9	5.7	2.6	15.5	6.0	3.8	8.1	8.0	5.1	2.9	3.1	13.2	0.8	2.6
LSD 5% level				NS	NS	NS	NS	0.4	1.0	0.8	NS	0.3	0.8	0.5	2.1		

plate before applying 1.5 bars in the pressure chamber. After reaching equilibrium, the samples were weighed again and three penetrometer readings were made. A cylindrical penetrometer with an end surface area of 0.32 cm^2 was pressed 0.5 cm into the sample (Davidson, 1965). The soil was then oven dried to determine dry weights and the moisture contents were calculated.

During all of the experimental work, the pressure plate and samples were kept in a plastic bag whenever they were not in the pressure chamber since even a small amount of evaporation can cause significant errors. A standard sample from a bulk soil stock was also run on each pressure plate to detect any anomalies in the procedure.

The results were used to calculate the porosity index according to the relation

$$I = \frac{\theta_1 - \theta_3 - 1.5}{17.3 \log_{10}\left[\frac{\theta_1 - \theta_3 - 1.5}{\theta_2 - \theta_3 - 1.3}\right]} + 0.75 \qquad [1]$$

where θ_1, θ_2, and θ_3 are the water contents on a percent dry weight basis at pressure plate settings of 0, 0.2, and 1.5 bars (Cary and Hayden, 1973).

The 4 porosity index numbers and 12 penetrometer readings from each sampling site were then averaged and treated as single measurements for statistical analysis. The four sampling sites in each field were considered as replications in a random block design and analysis of variance was carried out to determine significance by the F test.

RESULTS AND DISCUSSION

Undisturbed cores from the seven fields did not differ significantly in their average porosity indices or penetrometer measurements (Table 1). The seven soils did not even respond differently to loading at ⅓ bar water content under 3.4 kg/cm^2 (50 psi). While the loading did increase the hardness of all these soils, their pore size distributions remained nearly constant.

It is possible that differences due to the past cropping sequences were masked by recent tillage and harvest operations. To explore the possibility that the soils from the seven fields might still be potentially different, the effects of simulated tillage and the subsequent stability were studied. Mechanically dispersing the soil simulates excess tillage without compaction from the weight of the tillage machinery. Dry-sieving the soil simulates a more realistic level of noncompacting tillage. Wetting and drying the sieved soils shows what types of change one might expect from irrigation cycles during the following season; loading them while moist indicates what responses may follow future traffic on the soils.

While the penetrometer measurements were not significantly different from the dispersed samples, some of the pore size distributions were. This might be attributed to differences in organic matter or particle size distribution, but the average percentages of sand, silt, and clay (Column 1, Table 1) do not suggest any changing pattern in texture which might explain the differences. Variations in particle size distributions from field to field (Fig. 1) may have contributed to the differences found in the index for dispersed samples. Specific conclusions concerning these effects will require a better understanding of the relationship between particle size, organic matter content, and pore size distributions.

When the bulk soil samples from the seven fields were sieved—wet and dried, or moistened and loaded—significant differences among fields did occur in both pore size distribution and hardness (Table 1). In general, however, these differences were not large and do not appear to fall into a pattern which correlates with the cropping histories of the seven fields. Because these fields were all the same at the end of the cropping season, it appears that the differences are not of much practical importance. These differences do suggest voids in the theory relating physical processes to soil structure development.

When one considers the six different physical states of the soil from any single field (Table 1), the effect of loading on soil hardness is striking. While the undisturbed cores showed no change in pore size distribution due to loading, the hardness increased significantly. Dispersion of these soils tended to increase their hardness compared to simply passing the soil through a 2-mm sieve. Wetting and drying the sieved soil decreased the number of large pores and tended to decrease the hardness. Of course, loading moist

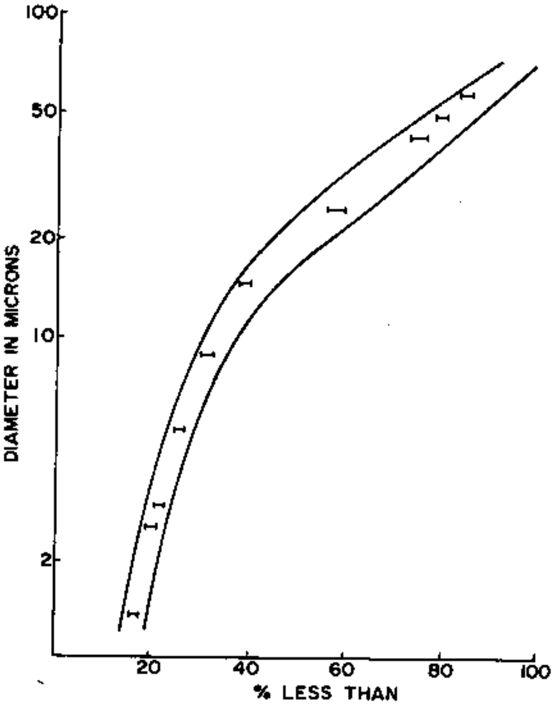

Fig. 1—Particle size distribution of the silt loam soil. Bars indicate typical range of measurements from 4 sites on a single field, while the curves were drawn to enclose the data points from all 28 sites studied.

soil with a large pore size index decreased the number of large pores and drastically increased its hardness. These data do show what trends may be expected in the field as a result of increasing intensity of mechanical manipulation. They also indicate that recent tillage may have a greater effect on the porosity index and soil hardness than the past cropping sequences.

Since loading the undisturbed samples increased their hardness but did not change their porosity index, a closer inspection of these data is of interest. Table 2 shows the average water contents of both the undisturbed samples and those following loading. Statistical analysis of these data showed differences among fields only in the case of saturated undisturbed samples after loading, though differences were nearly significant at the 5% level before loading. Field 1, which had just come out of pasture, is the most interesting of these, since its saturated water content suggested a greater soil porosity. Its 1.5-bar water content also tended to be higher, causing the porosity index to be about the same as in the other fields. Because of plant growth considerations, the index is defined to include only pores larger than those filled with water at 1.5 bars. Field 7 also showed an initially high saturated water content which is believed to have been a residual effect from spring tillage. Particular care was taken on this field to develop a loose seedbed and then avoid compaction during the growing season.

While statistical analysis did not confirm many real differences among fields, there are trends in the water content data (Table 2). The loading treatment generally decreased the total porosity, as shown by the saturated water contents, while the 0.2 and 1.5 bars water contents tended to show an increase in the total volume of small pores with the difference between paired means statistically significant at the 5% level according to the t test. While the direction of these changes in pore sizes is reasonable, they are small compared to simulated tillage effects and do not explain the large increase in penetrometer readings which accompanied loading. For example, in Field 7 penetrometer readings rose 10 bars with loading—which decreased the saturated water content 11.5%, while the changes in Field 2 were 5 bars with only a 1% water content change. Such results, as well as the reversals shown in Table 1 (under the headings "dispersed" and "sieved" and "wet and dried" where the hardness decreased as the porosity index fell), suggest that hardness is affected by at least one mechanism that is not closely associated with changes in pore size distribution.

Table 2—Average water contents of undisturbed samples from the seven fields at saturation, 0.2 bar, and 1.5 bar in their normal states and after loading

Field no.	Saturated		0.2 bar		1.5 bars	
	Normal	Loaded	Normal	Loaded	Normal	Loaded
	% water					
1	47.1	42.8	27.4	28.3	21.0	20.9
2	39.6	38.5	24.0	25.4	16.4	16.5
3	38.4	36.2	23.9	24.8	17.3	17.8
4	36.9	33.5	22.4	23.6	16.4	17.2
5	41.1	38.7	23.7	25.3	17.9	18.6
6	36.9	33.8	23.2	24.4	17.8	18.4
7	48.0	36.5	24.0	24.9	17.7	18.5
Significance						
at 1%		4.1				
at 5%	NS		NS	NS	NS	NS

The response of the silt loam soil to any given set of physical operations depends upon the state of the soil at the beginning of the operations. An example was observed in a growth chamber study with beans (*Phaseolus vulgaris* L.). A sieved sample of the soil was potted and compressed so that its porosity index was 1.6 and its penetrometer reading 22.4 bars. The control pots which were not compacted had a porosity index of 4.3 and a penetrometer hardness of 7.6 bars. After the pots had been cropped with beans for 6 weeks, the porosity index in the compacted soil rose to 1.9, and the hardness fell to 12.6 bars, while the control soil suffered a decrease in its porosity index to 3.4 and an increase in hardness to 10.2 bars.

The soil pore size distribution changes in the field, too, as a result of weather and farming practices. For example, measurements of the pore distribution index in the seed zone of the soil in the spring were greater than 3 for both normally tilled plots prepared for planting beans and for nontilled plots under grain stubble. On the other hand, the index was generally less than 3 following the cropping season in the fall.

It appears that the pore size distribution and soil hardness are rather independent of cropping history on this silt loam soil. While alfalfa (*Medicago sativa* L.) and pasture in the cropping sequence did not result in a large benefit to soil structure insofar as it is defined by the indexes we used for pore size distribution and hardness, this does not mean that cropping sequences will not affect such things as surface crusting, water infiltration, erosion resistance, fertility, and plant diseases. Tillage may have a large effect on both pore size distribution and soil strength, but it appears that at least the Portneuf silt loam reverts rather quickly to a stable range of values for these parameters under field conditions.

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