SOIL SCIENCE SOCIETY OF AMERICA

PROCEEDINGS

VOL. 31 | JULY–AUGUST 1967 | No. 4

DIVISION S-1—SOIL PHYSICS

Layer Thickness Changes in a Clay-Rich Soil in Relation to Soil Water Content Changes[1]

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ABSTRACT

Changes in soil water content and layer thickness of a soil with clay-enriched horizons will depend upon the rooting depth and seasonal growth characteristics of the plant cover, as well as the nature of the soil itself. Soil anchors fitted with sleeves were turned to different depths in Mexico silt loam under bluegrass and alfalfa. Elevation measurements were made at each location with respect to benchmarks consisting of 3.7-meter, sleeve-fitted rods driven into the soil. Soil water measurements were made with a neutron meter. High corre'ations were found between water content and layer thickness of the clay-rich layers. Alfalfa (*Medicago sativa*) proved to be much more effective in water removal from the claypan and deep subsoil than bluegrass (*Poa pratensis*). Disregarding expansion in the surface layer due to freezing, the greatest shrinking-swelling effects were in the claypan. About one-fourth of the magnitude of soil water change in the claypan of Mexico silt loam was manifested as a change in soil layer thickness.

Additional Key Words for Indexing: soil shrinkage or swelling, claypan soil.

SINCE HAINES (3) studied the shrinkage of clay soils with water content reduction, considerable attention has been given to the water-soil volume relationships in clay-rich soils and clay materials (1, 2, 5, 9). Soil horizons that are rich in clay minerals of the expanding lattice type often exhibit large volume changes with wetting and drying. In the midwestern USA, such horizons have developed in parent materials consisting of till or of fine loess over till. Woodruff (9), in 1934, found that large decreases in elevations of the different horizons in the Shelby loam profile were caused by soil water losses during the prevailing severe drought. The Shelby soi has developed in till. Field measurements of this type have not been reported for the claypan soils of the midwestern USA.

The conversion of grassland to cultivated land for the growth of row crops, either year after year or in rotation with sod crops, may be expected to alter soil water relationships. Water withdrawal from deep subsoil layers should be greater by deep-rooted legumes than by shallow-rooted grasses. Knowledge of the magnitude of soil layer thickness changes in the profile with water withdrawal by plants will be of value to planners and engineers in designing conservation structures and establishing of elevation controls on clay soils or soils with clay layers exhibiting appreciable shrinking-swelling properties. The objectives of this study were to determine soil layer thickness changes in a layered claypan soil in association with soil water changes and to evaluate the effect of variations in water withdrawal patterns by different crop plants.

SOIL DESCRIPTION

This experiment was conducted at McCredie, Missouri, on Mexico silt loam. This soil, because of large amounts of clay in the subsoil, has been described as a claypan soil and classified as a Planosol (4). In the new system (8), the Mexico series is classified as Aeric Mollic Albaqualf, fine, montmorillonitic, mesic. The soil developed from loess on a slope of about 3% in a landscape position below the nearly level Putnam series and above the steeper Gara, a soil developed from glacial till. The thickness of loessal deposits varies from 46 cm at the Gara boundary to more than 1.5 m at the tops of slopes.

The Ap horizon, or plow layer (0 to 18 cm), of the profile at a location near the experimental site is a very dark grayish-brown friable silt loam . The A3 horizon (18 to 28 cm) is dark grayish-brown fine silt loam. The Ap and A3 have weakly developed, fine-to-weak granular structure. The upper part of the claypan, or the B21 (28 to 40 cm), is dark grayish-brown silty clay, highly mottled with yellowish-red concretions. It has a very fine, moderately developed, angular, blocky structure. The lower part of the claypan, the B22 (40 to 64 cm), is dark grayish-brown silty clay with fine reddish-brown mottling. It is plastic when wet and breaks into fine, angular aggregates when dry. The transitional B3 layer (64 to 86 cm) is brown silty clay of massive structure. The C horizon (86 to 127 cm) is grayish-brown silty clay loam of

[1] Contribution from the North Central Watershed Research Center, Corn Belt Branch, Soil and Water Conservation Research Division, ARS, USDA, in cooperation with the Missouri Agr. Exp. Sta., Columbia, Missouri Journal no. 3088. Received Dec. 19, 1966. Approved March 27, 1967.

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Table 1—Mechanical composition, bulk densities and organic matter content of samples of Mexico silt loam from the experimental site

Horizon	Depth	Moist bulk density*	Organic matter	Mechanical analyses			
				Sand	Coarse silt	Fine silt	Clay
	cm	grams/cc	%	(> 50μ) %	(50–20μ) %	(20–2μ) %	(< 2μ) %
Ap	0–18	1.50	2.3	1	41	46	12
A3	18–28	1.30	1.9	2	20	50	28
B21	28–40	1.03	1.7	4	9	37	50
B22	40–64	1.22	1.7	4	13	35	48
B3	64–86	1.48	.9	18	10	36	36
C	86–127	1.62	.7	5	22	44	29

* At 0.33-bar suction.

massive structure, having brown and dark red concretions. This horizon is underlain by glacial till 2 or 3 m thick. The upper part of the till is highly weathered clay.

The mechanical composition and moist bulk densities of the Mexico silt loam profile are shown in Table 1. All horizons are mostly fine silt and clay. Only the B3 has more than 5% sand, and the C and Ap horizons have more than 20% coarse silt. The clay content of the claypan (B21 and B22) is about 50%, the minerals being dominantly of the expanding lattice type (6). Samples of the B22 horizon will shrink to about two-thirds of the initial volume when dried from 0.33- to 15-bar suction.

PROCEDURE

The first plot was established in a native bluegrass area (*Poa pratensis*) in March 1959. The study was expanded in 1960 and 1961 to include a plot in alfalfa (*Medicago sativa*) with some native grasses. Each plot was 8 meters wide and 12 meters long.

Screw-type soil anchors such as those used for guy-wire anchoring of fence posts or power poles were turned into the various transition zones between the horizons in the soil profile and an additional depth of 213 cm in the till layer (Fig. 1). The anchor screws were 10 cm in diameter, with 16-mm shanks. The shanks were

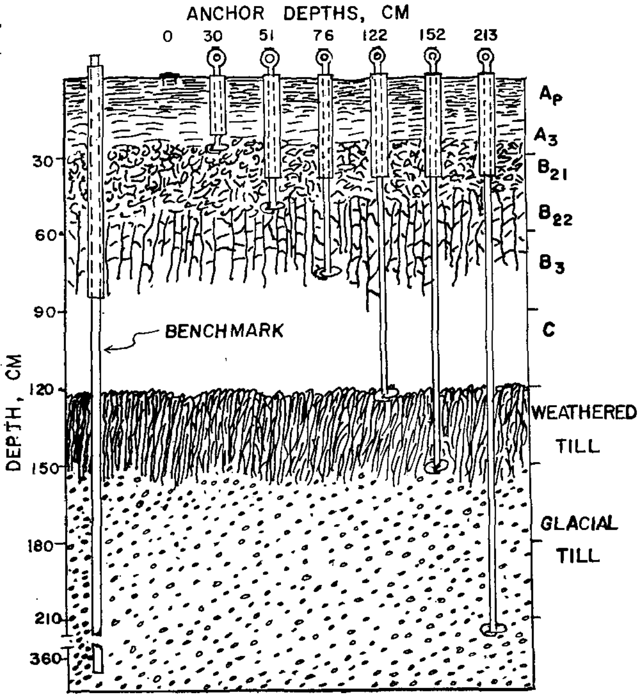

Fig. 1—Mexico silt loam profile showing benchmark and anchor used for elevation measurements.

fitted with 30-cm lengths of 19-mm pipe sleeves. Each anchor was turned into a 25-mm soil auger hole to the desired depth, with the screw penetrating a few centimeters beyond the hole. About 5 cm of the sleeve and 10 cm or more of the shank extended above the soil surface. The sleeve was intended to prevent frost heaving of the anchors.

An elevation benchmark was installed at each site This benchmark consisted of a 3.7-m length of 19-mm steel rod fitted with a 90-cm sleeve of 19-mm pipe. Each rod was driven through a 85-cm-deep, 25-mm-diameter auger hole to a depth of 3.6 m, so 10 cm of rod and 5 cm of pipe sleeve extended above the soil surface (Fig. 1).

Three aluminum plates were placed in each plot for surface elevation measurements. The plates were pinned to the surface by aluminum nails inserted into the soil about 5 cm through holes drilled in the plates.

Three anchors were turned to each selected depth in each plot. They were set at selected random locations within each plot so that no adjacent anchors were turned to the same depth. Elevation readings for each of the anchors, with reference to the benchmark, were made at least once each month. When weather conditions were such that an appreciable change in soil water content could be expected, more frequent readings were made. Attention was given to a possible error due to the expansion and contraction of the anchor shanks with temperature changes. From the thermal coefficient of linear expansion of steel, the rod would increase 3 mm per meter of length for each 25C increase in temperature. Since both anchor shanks and benchmark rods were of steel, this small error should be considered as compensated so it would be within the range of error with a surveyor's level.

Access tubes for a neutron soil water probe were installed to a depth of 183 cm in the center of each plot. Each time elevations were determined, soil water readings were made at depth intervals so that each value was intended to represent the soil horizon or layer between two anchor depths.

The elevation reading for each anchor and plate was recorded by date. The last anchor was installed and the first complete set of readings taken on May 11, 1961. For the analysis of the data, the reading of each anchor on this date was chosen as a reference. Thereafter, the deviation of each reading from the corresponding reference reading was recorded. The average deviations for replicate anchors on each date were used to calculate the changes in thickness with respect to the reference date of the various soil layers under the different plant covers. Each change was calculated as a percentage of the thickness of the given layer on the reference date.

RESULTS

The percentage changes in soil layer thickness under the two different plant covers were plotted against time (Fig. 2 and 3). Freezing of the surface layers during some winter months caused large increases in thickness which can be attributed to ice crystal formation. Increases above the reference line during freezing weather are assumed to be due, in part, to freezing of the soil. A decrease below the reference line is interpreted as soil shrinkage due to drying of the soil.

The results for the bluegrass cover are shown in Fig. 2. The thickness of each of the upper layers, including the claypan, has shown decreases, but there has been little change in the thickness of any of the deeper layers. The changes in soil water content (P_v) are shown for comparison. The water content and layer thickness changes are expressed on percentage scales so the relative magnitude of changes in bulk volume with changes in moisture content can be seen. Even though the L_t scale is expanded twice the P_v scale, the graphical variations in the moisture curves are still greater than those of the corresponding layer thickness curves.

Table 2—Comparison of soil water volume percentages in deep subsoil layers under bluegrass and alfalfa at annual maximal points of soil water recharge under alfalfa

Date	91-cm depth		122-cm depth		183-cm depth	
	Bluegrass	Alfalfa	Bluegrass	Alfalfa	Bluegrass	Alfalfa
9-29-61	36.0*	24.3	32.8	20.7	33.0	24.0
6-27-62	35.2	28.3	33.3	25.5	38.3	25.9
3-25-63	34.5	18.8	30.2	18.3	34.4	26.7
11- 5-64	30.5	18.8	30.5	19.7	27.5	22.5
7-29-65	34.4	28.2	30.0	30.3	29.8	28.5
7- 5-66	34.7	35.7	31.7	31.5	33.0	26.7

* Overall peak values for each crop are underscored.

There have been long periods of low water content and reduced layer thickness in the subsoil layers under alfalfa during the experiment (Fig. 3). Removal of water and soil shrinkage have continued, with infrequent periods of partial recovery. It is clear that water recharge to "field capacity" in the deep subsoil under alfalfa was never achieved during the 6-year period of measurement. During this time, the water content of the deep subsoil layers under alfalfa was generally lower than for the same layers under bluegrass. The annual maximal values for the subsoil layers under alfalfa are shown in comparison with those under bluegrass on the same dates in Table 2. The values for alfalfa at the 183-cm depth were 1.3 to 12.4 percentage points lower than for bluegrass at the same depth. It can be assumed that maximum layer thickness was not achieved in the deep layers under alfalfa.

Table 3—Correlation coefficients for relationship between water content and layer thickness for different soil layers of Mexico silt loam under different plant covers

Soil Layer	Ap	B21	B22–B3	C	C-D	D
			Bluegrass Plot			
Depth, cm	0–30	30–51	51–76	76–107	107–152	152–213
Coefficient	+0.365	+0.502	+0.644	+0.038	+0.063	+0.027
Prob. Level†	.02	.01	.01	NS	NS	NS
			Alfalfa Plot			
Depth, cm	0–30	30–46	46–76	76–122	114–152	152–213
Coefficient	+0.156	+0.717	+0.809	+0.850	+0.386	+0.160
Prob. Level†	NS	<0.01	<0.01	<0.01	.03	NS

† Probability levels of 0.05 or less are considered as significant and those of 0.01 or less as highly significant (7). Values for frozen soil are excluded.

The relationships between moisture content and layer thickness for the plots are shown in Table 3. The correlation coefficients are high and are considered significant (7) for the claypan and layers below the claypan where appreciable soil water changes occurred. The values for the surface soil under bluegrass, even though significant, were lower than for the claypan layers. The ranges and standard deviations from means of soil water percentages and layer thickness changes for the soil under the two crop covers are shown in Table 4. The ratios of the range of layer thickness changes to those

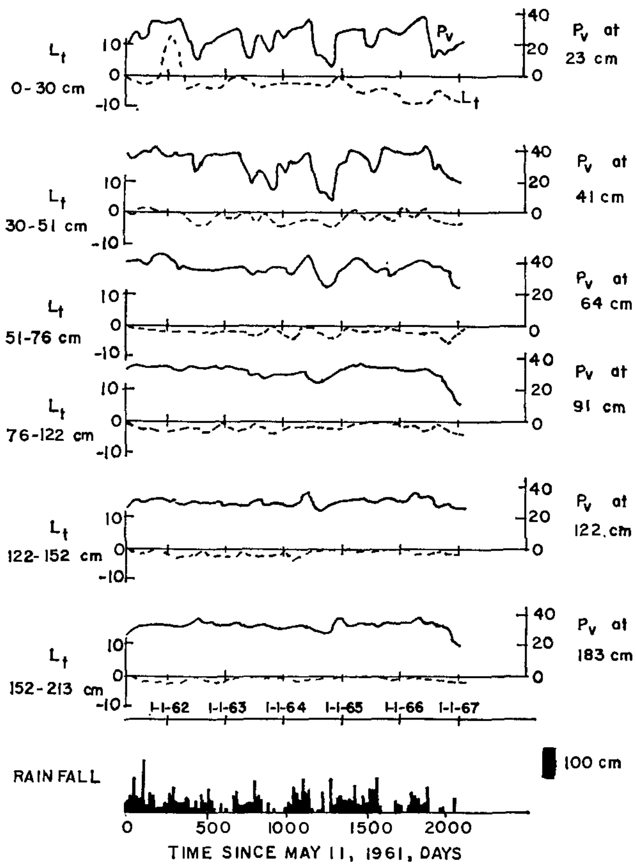

Fig. 2—Changes in soil water volume percentage (P_v) and layer thickness percentage (L_t) relative to that on May 11, 1961, for the different soil layers under bluegrass.

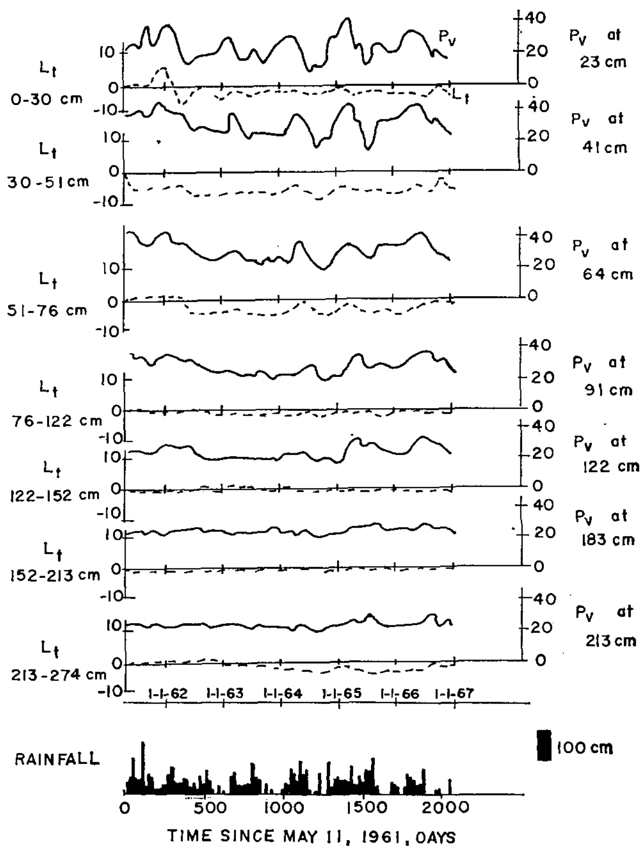

Fig. 3—Changes in soil water volume percentage (P_v) and layer thickness percentage (L_t) relative to that on May 11, 1961, for the different layers under alfalfa.

Table 4—Soil water and layer thickness changes under different covers on Mexico silt loam during the period of measurements*

Soil Layer	Ap	B21	B22–B3	C	C-D	D
			Bluegrass Plot			
Depth, cm	0–30	30–51	51–76	76–107	107–152	152–213
Layer thickness:						
Range, L_t points	4.3	4.8	4.8	1.5	2.7	1.8
Standard Dev., ±	1.3	1.4	1.0	0.4	0.5	0.6
Soil water:						
Range, P_v points	30.0	27.0	21.0	18.0	10.0	12.0
Standard Dev., ±	8.8	6.2	4.4	3.4	2.9	2.5
Ratio of ranges†	0.14	0.18	0.23	0.08	0.27	0.15
			Alfalfa Plot			
Depth, cm	0–30	30–46	46–76	76–114	114–152	152–213
Layer thickness:						
Range, L_t points	4.7	9.0	7.0	3.7	1.3	0.7
Standard Dev., ±	1.4	1.6	2.3	0.9	0.3	0.0
Soil water:						
Range, P_v points	30.0	28.0	25.0	18.0	14.0	9.0
Standard Dev., ±	7.8	6.9	7.3	5.3	3.9	1.9
Ratio of ranges†	0.15	0.32	0.28	0.21	0.09	0.08

* The values for frozen soil are excluded.
† Ratio of range of variation of layer thickness percentage (L_t points) to the range in variation of moisture percentage (P_v points).

of soil water content were generally higher for the claypan layers than for the surface or loessal horizons beneath the alfalfa.

The average ratio of the range of layer thickness changes to those for soil moisture for the claypan (B21 and B22-B3) was 0.25. If the changes in layer thickness of the claypan are interpreted as changes in bulk volume of the soil, then about 25% of the magnitude of variation in soil water was manifested in the amplitude of variation of bulk volume. The remainder must be attributed to air-water exchange in the soil matrix and to the opening and closing of vertical cracks.

DISCUSSION

The shrinkage of the soil in the claypan layers, as measured by changes in layer thickness, is probably less than would be exhibited by clay material with no overburden. Overburden pressure would reduce swelling, even at full saturation. With the very first water withdrawal from clay saturated with no overburden, the reduction in volume should be equal to the water removal. With overburden pressure, particle-to-particle contact increases so as to reduce swelling. Also, as the soil gets drier, air enters the soil and shrinkage is "residual," rather than "normal," in the terminology of Haines (3). Crack formation in dry soil, especially in the vertical direction, is caused by shrinkage not directly measurable by elevation differences between layer boundaries.

The difference between water withdrawal from the soil by shallow-rooted and deep-rooted plants is of some significance to agronomists, engineers, and hydrologists. Bluegrass used the water within the upper 30 to 60 cm of soil and then wilted and lapsed into dormancy until soil water content and temperature were again favorable for renewed growth. Alfalfa continued to extract water from deeper layers in the soil during long periods of drought. Reduction in soil water to greater depths under alfalfa during the experiment, with only partial recharge during rainfall periods, can be partly attributed to relatively low precipitation. Saxton found the average annual deficit in rainfall since 1958 to be 14.9 cm below the 75-year average recorded at this location (Unpublished data furnished by Keith E. Saxton, Hydraulic Engineer, North Central Watershed Research Center, USDA ARS SWC, Columbia, Mo.). It is clear that the deep loess and till layers beneath alfalfa never recharged with water to near full storage capacity during the duration of the experiment (Table 2). The greater withdrawal from the deep subsoil for alfalfa in comparison with bluegrass can be attributed to its deeper root system and longer active growing season, as well as to the prolonged period of relatively low rainfall.

Particular attention should be given to the effect of deep-rooted plants on soils subject to shrinking and swelling. Since some deep-rooted plants are considered an aesthetic requirement or are needed as shade for homes and many public buildings, precautions must be taken to counteract the effects of soil volume changes. For a structure on clay soil that will be growing deep rooted plants, the foundation should be below the zone of shrinkage, or based on piers that rest on firm, constant-volume soil or bedrock material.

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