Ecological Effect of a Clay Soil's Structure on Some Native Grass Roots[1]

E. M. WHITE AND J. K. LEWIS

Professor of Agronomy and Associate Professor of Animal Science, South Dakota State University, Brookings.

Highlight

Dense Clay Range soils have larger structure peds or groups of smaller peds in the upper part of the soil when moisture is at the wilting point than do Clayey Range soils of the same moisture and clay content. Large peds, which are bordered by cracks when dry, apparently constrict roots as they dry and hold the roots so that they are stretched across the bordering cracks. Blue grama and buffalograss grow on the Clayey Range soils and have a fine, spreading root system near the soil surface. However, these grasses do not grow on Dense Clay Range soils where presumably their fine roots are not strong enough to withstand the constricting and stretching forces. Western wheatgrass and green needlegrass have larger, more deeply placed roots which are more vertically oriented than the short grasses and are able to utilize subsoil moisture and grow on the Dense Clay soils.

The range site concept is an essential part of the basic resource inventory of rangeland (Dyksterhuis, 1949, 1958; Aandahl and Heerwagen, 1964). In the Northern Great Plain, range sites have been designated by range soil groups, precipitation zone, and geographical location, for example; Silty, 15 to 19 inch precipitation belt, Mound City to Rosebud, South Dakota. Range soil groups were described by Dyksterhuis (1964) but are continually being revised as better criteria are established.

In the Northern Great Plains, some clay soils support an understory of short grasses and midgrasses (Clayey Range Soil Group) while others do not have the short grasses (Dense Clay Range Soil Group). The separation of these range soil groups is important since overgrazing deteriorates the Clayey site to shortgrasses and the Dense Clay site to a thin stand of western wheatgrass (*Agropyron smithii*)[2] and green needlegrass (*Stipa viridula*) with annuals, except during dry years when the ground is nearly bare of cover. Attempts to separate these soil groups on the basis of textures or dispersion have not been very satisfactory. This paper considers the use of soil structure to differentiate these fine-textured soils into the Dense Clay and Clayey groups.

[1] South Dakota Agricultural Experiment Station Journal Series 809. Received April 14, 1968; accepted for publication April 10, 1969.

[2] Nomenclature follows Chase (1951).

Methods

Five soil profiles on gently sloping uplands were studied. All were in the Chestnut-Chernozem transition zone of southwest central South Dakota with 16 to 17 inches average annual precipitation. All were in ranges in upper good or lower excellent range condition (Dyksterhuis, 1949), usually distant from water. The profile are typical of many observed in the field.

Laboratory and field data are from studies on soil structure (White, 1967), on volume changes in clay soils (White, 1962), and from other soils to complete the data. Methods used were reported earlier (White, 1962, 1967). The vegetation reported for the soils was restricted to perennial grasses. Forbs and annual grasses were not abundant.

Results

The Dense Clay and Clayey Range soils studied have different structure and vegetation. In the following order, Profiles 1, 2 and 3 have proportionately more blue grama (*Bouteloua gracilis*) and buffalograss (*Buchloe dactyloides*) and less western wheatgrass (*Agropyron smithii*) (Table 1). However, the texture of Profiles 1 and 3 are nearly identical and finer textured than Profile 2 (Table 2), so texture probably does not cause the difference in the composition of the grasses.

Soil structure[3] appears to be the controlling factor. Profile 1 has a cloddy surface and parallelepipeds in the subsoil. Profile 2 has granular structure in the coarse clay surface layer and irregular subsoil prisms. Profile 3 has a granular to subangular blocky surface structure and weak subsoil prisms that contain a few parallelepiped faces. The increase in bulk density (Table 1), caused by the drying and shrinking of moist clods, is least for Profile 2, intermediate for Profile 3, and greatest for Profile 1.

Profile 4, a Clayey Range soil, has about equal amounts of blue grama and western wheatgrass. In comparison to Profiles 1, 2, and 3, Profile 4 has more organic matter and consequently the prisms are relatively better developed than the blocks and parallelepipeds. In contrast to the preceding four clay soils, Profile 5 has a silty upper part and a coarse clay in the 13- to 20-inch layer. This soil had dominantly western wheatgrass vegetation with a sparse understory of blue grama. The vegetation is comparable to that of the Clayey Range soils although the upper soil layers are silty. On the adjacent silty soils without a clay subsoil, western wheatgrass was less abundant so there was relatively

[3] Individual structure units or peds have different shapes and sizes. A ped may be composed of smaller peds of the same kind or a different kind. Ped shapes are: angular blocks = cubical, subangular blocks = cubical with some rounded corners, granules = spherical, plates = tabular in horizontal direction, prisms = polygonal prism elongated vertically, and parallelepiped = tabular but oblique to the horizontal plane.

Table 1. Range soil group and composition (percent by weight) of 5 profiles studied.

Profile Number	Range Soil Group	Major Grasses: Species	Major Grasses: Composition
1	Dense clay	Western wheatgrass	85
		Green needlegrass	5
2	Dense clay	Western wheatgrass	80
		Green needlegrass	5
		Blue Grama	5
3	Clayey intergrading to thin clayey	Western wheatgrass	50
		Blue grama	10
		Sideoats grama	10
		Buffalograss	10
		Green needlegrass	5
4	Clayey	Western wheatgrass	45
		Blue grama	35
		Buffalograss	5
		Green needlegrass	10
5	Silty intergrading to clayey	Western wheatgrass	70
		Blue grama	10
		Sand dropseed	5

more blue grama and considerable needleandthread (*Stipa comata*). The blocky, clay subsoil of Profile 5 apparently favors the dominance of western wheatgrass over blue grama. Thus, subsoil as well as surface soil properties are important in defining range soil groups.

Discussion

The Dense Clay soil structure seems to be detrimental to roots of blue grama and buffalograss but not to those of western wheatgrass and green needlegrass (*Stipa viridula*). Roots of blue grama and buffalograss, in contrast to the two taller grasses, are finer, grow more profusely in the soil surface layer, and less profusely vertically into the subsoil (Weaver, 1958; Weaver, 1919; Coupland and Johnson, 1965). Root distribution is influenced also by soil profile properties (Weaver and Darland, 1959) and by grazing intensity (Weaver, 1950; Schuster, 1964). In contrast to the fibrous roots of the short grasses, western wheatgrass has rhizomes at a depth of 1 to 4 inches below the soil surface (Weaver, 1919). Roots from the rhizomic nodes extend nearly vertically into the subsoil. They are less affected by soil surface properties than the shortgrass roots which grow from the base of the plant at the soil surface. Sideoats grama (*Bouteloua curtipendula*), with a root distribution intermediate between western wheatgrass and the short-grasses, has some vertically and obliquely oriented roots and others which spread horizontally at a depth of 2 to 4 inches before they turn down (Weaver, 1920). Green needlegrass has a similar but deeper root system than sideoats grama. Thus, the mid-grasses growing on the soils studied are less dependent on the soil surface layer than the short-grasses.

The Dense Clay soils have larger and more com-

Table 2. Bulk densities, clay content, and structure for five range soils studied.

Profile Number and Soil Horizon	(Inches) Depth	Bulk Density Measurements (gm/cm³): Field	Dry Clod	Wet Clod	(%) Clay	Structure
Profile 1						
A	0-1	0.96	1.66	0.96	64.0	Vesicular; irreg. c. crumb-gran. in blocky clods
B2	1-11	1.18	1.79	0.99	69.7	v. wk., m. bl.; obliq.; v. wk. irreg. pris.
B3	11-18	1.17	1.77	0.99	67.1	v. wk., m. bl.; obliq.
Profile 2						
A	0-1	n.d[2]	1.56	1.17	50.2	wk., v. f. gran.
B21	1-7	n.d	1.85	1.35	56.3	wk., v. f. subang. & bl.; v. wk. irreg. pris.
B22	7-14	n.d	1.71	1.37	60.8	wk., v. f. bl.; wk. irreg. pris.
B3ca	14-18	n.d	1.67	1.43	58.0	bl. in partially weathered mudstone
Profile 3						
A	0-1	1.26	1.54	1.01	62.7	v. wk. gran. -subang.
B2	1-10	1.24	1.79	1.07	68.7	wk., v. f. subang.; v. wk., m. & c. pris.; few obliq.
B3	10-18	1.29	1.89	1.03	69.7	wk., v. f. subang.; obliq.; v. wk., m. & c. pris.
Profile 4						
A	0-1	n.d.	n.d.	n.d.	50.6[3]	wk., v. f. gran. with platy orientation
B21	1-7	1.12	1.92	1.30	60	wk., m. pris.; wk., v. f. subang.; few obliq.
B22	7-15	1.44	1.93	1.28	60	wk., m. pris.; wk., v. f. subang.; obliq.
B31	15-22	1.60	2.01	1.31	60	wk., m. pris.; v. wk., v. f. subang.; obliq.
B3-C	22-30	1.63	1.97	1.38	60	v. wk., m. pris.; v. wk., v. f. subang.; obliq.
Profile 5						
A-C	0-4	n.d.	1.52	1.38	18.2	v. wk., v. f. gran.
A1	4-6	n.d.	1.44	1.38	19.5	wk., m. & f. prism.; v. wk., m. & f. gran.
B2	6-8	n.d.	1.47	1.36	18.6	wk., f. & m. pris.; (very porous peds)
B3	8-13	n.d.	1.55	1.35	28.4	wk., m. pris.; wk., f. subang.
B-C	13-20	n.d.	1.63	1.51	42.2	mod. & wk., f. bl.; wk., m. pris.

[1] Abbreviations used: bl. = angular blocks; c. = coarse; f. = fine; gran. = granules; irreg. = irregular; m. = medium; mod. = moderate; obliq. = parallelepiped faces; pris. = prisms; subang. = subangular blocks; v. = very; wk. = weak.
[2] Not determined
[3] Determined for 0-6 inch layer and estimated for lower layers

pact structure units or peds, when the soil is nearly dry, than do the Clayey soils. The larger peds usually contain smaller peds which are not distinct in Dense Clay soils. In nearly dry Clayey soils, the smaller peds are more distinct and are separated by narrow cracks. Thus, the average size of the ped, which is unattached to an adjacent ped, is smaller in the Clayey soils than in the Dense Clay soils. In addition, prisms are more distinct, have a more uniform size, and smoother faces in the Clayey soils than in the Dense Clay soils. Vertical cracks surrounding prisms in nearly dry Clayey soils have a more uniform width than those in Dense Clay soils. Parallelepipeds and blocks jut out from the prisms in nearly dry Dense Clay soils so the prism faces are irregular and the cracks are not uniform in width. The kind of structure is caused mainly by changes in the soil volume due to wetting and drying. Volume-change forces tend to be largest if parallelepipeds form, intermediate if blocks form, and least if prisms form (White, 1967). Thus, soil structure is indicative of the shrink-swell forces to which roots are subjected.

A root removes moisture from the adjacent enclosing cylinder of moist soil first before the soil farther away is dried. As this surrounding cylinder is dried and contracts, the root is compressed radially. Root constriction was reported for cotton plants which had roots growing through a thin, compact clay layer (Taubenhaus et al., 1937). In addition to simple radial compression, longitudinal compression occurs because a soil contracts in all directions. Wheat yields from pots in the greenhouse where soil self-compaction during the experiment increased the soil density from about 1.08 to 1.35 were less than from pots with a constant bulk density of about 1.35 (Abroe and Pathok, 1967). Longitudinal compression may have been a factor in this study. Barley (1963) and Gill and Miller (1956) found corn radicals could not elongate if sufficient pressure were placed on a surrounding artificial soil.

The pressure a functioning mature root can withstand apparently has not been measured. However, grass roots with deciduous cortices (Weaver, 1958) would be less affected than normal roots by soil contraction because the living stele can bend in the space left after the cortex disintegrates. Deciduous cortices have been observed for roots of western wheatgrass, green needlegrass, and indistinctly for sideoats grama. Thus, these grasses may be able to withstand soil contraction more effectively than blue grama and buffalograss which apparently do not have distinct deciduous cortices. The root tensile strength may decrease when the cortex slough but it apparently is a function of root diameter (Troughton, 1957) regardless of the species.

Cracks which form between soil peds may transect and break roots (Thorp, 1948) if the root is anchored securely by lateral roots in the soil on the two sides of the cracks. Western wheatgrass and green needlegrass apparently have fewer lateral roots than many common grasses (Coupland and Johnson, 1965) which may be a factor in their survival in Dense Clay soils. Hubbard (1950) reported crowns of blue grama were disrupted by cracks in clay soils although this disruption has not been observed on South Dakota soils. Soil cracks affect western wheatgrass less than blue grama (Hubbard, 1950) because a new plant may grow from a node on a rhizome fragment broken from a parent plant. In addition, western wheatgrass roots stretch considerably before breaking (Weaver and Darland, 1949, fig. 10).

A root would be stretched most frequently along the prisms where a vertically oriented crack forms. Horizontal cracks usually are very narrow because the weight of the overlying soil counteracts their formation. Thus, roots of western wheatgrass and green needlegrass that tend to grow vertically downward would cross fewer cracks than the shortgrass roots that grow more obliquely or horizontally. Other factors must be involved because the shortgrasses, which do not grow as abundantly on silty soils with a clay subsoil as on one with a silty subsoil, have lower subsoil roots oriented vertically. Constriction or pinching of the fine roots may occur in the clay subsoil as it dries. But this root damage by constriction or by breaking apparently would require large clods or ped aggregates.

A ped or ped aggregate must be at least a minimum size before it can constrict or compress the root rather than break into smaller fragments. The nearly dry ped or ped aggregate size determines the width of the desiccation cracks in the soil. With small peds, the cracks are more numerous and have a narrower width than if the peds were larger. Thus, the size of the finest ped or ped-aggregate is an important factor as far as root growth is concerned. The large peds or ped aggregates bordered by irregular cracks in the Dense Clay soils will cause more root damage than the smaller peds in the Clayey soils. The distance between cracks is larger and the width of the cracks is less uniform in clay soils with parallelepipeds in comparison to those with prisms.

The roots of western wheatgrass and green needlegrass, sideoats grama, and blue grama and buffalograss decrease in this general order in size and also in abundance with increasing soil depth. The soils with blue grama and buffalograss in comparison to those of the other species had more stable structure and/or smaller volume-change with drying so that the roots are not damaged. This relationship between grass species and soils supports the contention that soil structure determines the distribution of these species on the clay soils because it permits better utilization of soil water which is the limiting factor. In support of this hypothesis, western wheatgrass is most abundant in the more mesic or moist site of an area of silty soils where it can compete with the shortgrasses for the more abundant supply of water. Less water is available for western wheatgrass on clays in comparison to silty soils because: (1) less plant available water is stored (Black, 1968), (2) more water is usually lost by runoff, and (3) more water is needed to wet an air-dry soil surface layer to a content where moisture is available to a plant. Thus, summer showers are less beneficial for the clays than for the silty soils. Paradoxically, soil structure, or rather the lack of it, permits the more mesic species to compete with more xeric species for soil moisture in a clay soil which is effectively drier than the silty soils where these mesic species are relatively less abundant.

LITERATURE CITED

Aandahl, A. R., and A. Heerwagon. 1964. Parallelism in the development of soil survey and range site concepts. (In) Forage plant physiology and soil-range relationships. Am. Soc. Agron. Spec. Publ. 5:137–146.

Abrol, I. P., and B. S. Pathak. 1967. Self compaction as a factor influencing crop growth in pot studies. Plant and Soils 27:151–152.

Barley, K. P. 1963. Influence of Soil strength on growth of roots. Soil Sci. 96:175–180.

Black, C. A. 1968. Soil-plant relationships. Second Edition. John Wiley, New York.

Chase, Agnes. 1951. Manual of the grasses of the United States. Second Edition. U.S. Dep. Agr. Misc. Publ. 200.

Coupland, R. T., and R. E. Johnson. 1965. Rooting characteristics of native grassland species in Saskatchewan. J. Ecol. 53:475–507.

Dyksterhuis, E. J. 1949. Condition and management of range land based on quantative ecology. J. Range Manage. 2:104–115.

Dyksterhuis, E. J. 1958. Ecological principles in range evaluation. Bot. Rev. 24:253–272.

Dyksterhuis, E. J. 1964. My rangelands: What kinds? How good? S. Dak. Agr. Ext. Serv. F.S. 224.

Gill, W. R., and R. D. Miller. 1956. A method for study of the influence of mechanical impedance and aeration on growth of seedling roots. Soil Sci. Soc. Am. Proc. 20: 154–157.

Hubbard, W. A. 1950. The climate, soils, and soil-plant relationships of an area in southwestern Saskatchewan. Sci. Agr. Canada 30:327–342.

Schuster, J. L. 1964. Root development of native plants under three grazing intensities. Ecology 45:63–70.

Taubenhaus, J. J., W. N. Ezekiel, and H. E. Rea. 1931. Strangulation of cotton roots. Plant Physiol. 6:161–166.

Thorp, J. 1948. How soils develop under grass. U.S. Dep. Agr. Yearbook. 1948:55–66.

Troughton, A. 1957. The underground organs of herbage grasses. Commonwealth Bur. of Pastures and Field Crops Bul. 44.

Weaver, J. E. 1919. The ecological relations of roots. Carnegie Instit. Wash. Publ. 286.

Weaver, J. E. 1920. Root development in the grassland formation. Carnegie Instit. Wash. Publ. 292.

Weaver, J. E. 1950. Effects of different intensities of grazing on depth and quantity of roots of grasses. J. Range Manage. 3:100–113.

Weaver, J. E. 1958. Summary and interpretation of underground development in natural grassland communities. Ecol. Monogr. 28:55–78.

Weaver, J. E., and R. W. Darland. 1949. Soil-root relationships of certain native grasses in various soil types. Ecol. Monogr. 19:303–338.

White, E. M. 1962. Volume changes in some clay soils. Soil Sci. 94:168–172.

White, E. M. 1967. Soil age and texture factors in subsoil structure genesis. Soil Sci. 103:288–298.

23rd Annual Meeting

American Society of Range Management

February 9–12, 1970

Denver Hilton Hotel

Denver, Colorado

See preview and tentative program beginning on page 436.