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Shrink-Swell and Other Characteristics of Five Benchmark Soils of Western Oklahoma

OKLAHOMA STATE UNIVERSITY ● AGRICULTURAL EXPERIMENT STATION

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Shrink-Swell and Other Characteristics of Five Benchmark Soils of Western Oklahoma

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INTRODUCTION

Shrink-swell data are needed for Benchmark soils of Oklahoma for accurate engineering interpretations (16). This soil quality influences tillage management, excavation, construction and maintenance of many soils involved in engineering projects.

Particle size distribution and clay mineralogy influence shrink-swell more than any other properties. The coefficient of linear extensibility (COLE) should vary with textural families and clay mineralogy. Five soils retaining textural family classifications ranging through coarse-loamy, fine loamy, fine silty and fine with mixed mineralogy were chosen for this study. These soils were chosen with respect to the central concept of each series. The selections anticipate a general application of information to other closely related and similar soils.

Very little recorded data exist pertaining to COLE values for Oklahoma soils. Land use interpretations and classification of vertic subgroups require more data than presently available for such purposes. Thus, the premises for this study exist.

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REVIEW OF LITERATURE

Soil Forming Factors

The soils selected for this study are developed from two resource regions of Oklahoma (Figure 1). The Central Rolling Red Prairies and the Central Rolling Red Plains occupy an area from north and south central Oklahoma through western Oklahoma. Mixed grasses, which are found on Permian Redbed formations under a warm, temperate and subhumid climate, dominated the original vegetation.

Climate

The pedons studied occur in two adjacent climatic areas of Oklahoma. An indistinct boundary exists between the two based on a gradual climatic change (15). In the Central Rolling Red Prairies, the average annual precipitation reaches 35″ per year and decreases to 28″ at its boundary with the Central Rolling Red Plains. The western Central Rolling Red Plains experiences average annual precipitation as low as 22″ per year. The prevailing wind in both areas is southerly and both experience long dry summer periods accompanied by hot dry winds from the south. The growing season ranges from 190 days in the north to 225 days in the south (11).

The climatic change influences other soil forming factors. The vegetation of the Central Rolling Red Plains is sparser, more adaptive to dryer climates, and the topography shows more evidence of physical

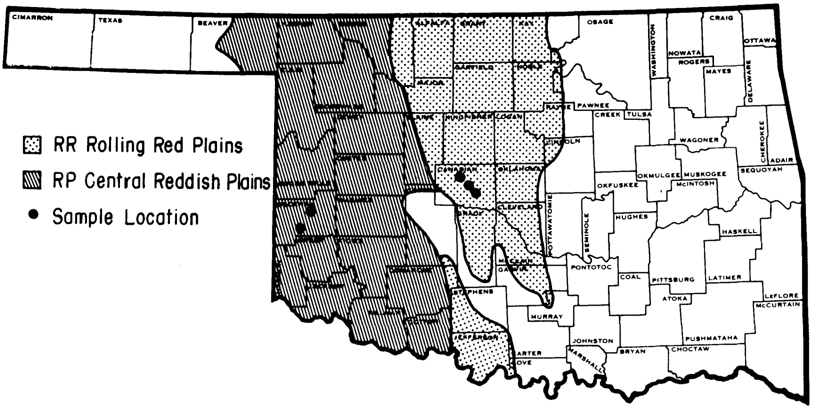

Figure 1. The Rolling Red Plains and Central Reddish Prairie Resource Areas of Oklahoma.

weathering. Lower amount of rainfall developed concentrations of calcium carbonates near the surface of the heavy texture soils in this area.

Parent Material

Pedons occurring in the Central Rolling Red Prairies and Rolling Red Plains developed in materials of Permian and post-Permian geologic periods (15). Permian formations extend westward in north-south bands from central Oklahoma to the Oklahoma-Texas border (22). Clay beds and shales dominate the stratified Permian formations giving rise to vast areas of clayey soils. The clay mineralogy of these soils is generally mixed with high proportions of 2:1 type clay minerals which have a high potential for engineering problems.

Post-Permian materials (Pleistocene) overlay vast areas adjacent to major western Oklahoma rivers. These deposits involve younger, coarser, less weathered soils than the surrounding Permian exposures resulting in different management and engineering problems (30).

Vegetation

Grasses climax the vegetation of Oklahoma prairies (8, 26). Original climax grass species combined with the other soil forming factors have developed the classical dark fertile soils of the prairies (32). Climax grass species reflect the clayey drought-prone evolution of the prairie soils (36). In central Oklahoma tall grasses climaxed the vegetation on loamy soils and midgrasses dominated vegetation on finer soils. In the drier western areas, tall grasses dominate loams and sands while short grasses dominate finer textured soils.

Scrub oak dominates the coarser Pleistocene deposits along the rivers. The deep, coarse, and duney material near major western rivers, vegetated by trees, produce lighter colored forest type soils (30).

Relief

General relief patterns change gradually, but often distinctly, from central to western Oklahoma. Topographic differences result from gradual climatic change and sparser vegetation density toward the west. Subdued changes of relief characterize the Reddish Prairie landscape. Broad interstream divides and wide shallow valleys form a smooth to rolling topography with convex slopes (15, 29). The smooth, broad surfaces combined with slowly permeable clays produce poor drainage and enhance the formation of deep profiles with well developed B2t horizons.

Relief frequently acquires a less subdued attitude in the Rolling Red Plains. A dryer climate and sparser vegetation result in a higher degree of physical weathering. Steep gradients and the changing course of rivers in this dry environment have caused the evolution of a scarred rough topography. Rivers flow through the area in narrower valleys than to the east. These rivers supply coarse materials for larger areas of undulating, dunes sand deposits. The relatively short time of existence of these materials combined with a drier climate and sparse vegetation result in the genesis of less well developed soils (15, 16, 29).

Time

Evolution of soil individuals gradually occurs as dynamic forces of soil formation act through time (32, 36, 38). Chemical, physical, and biological processes produce results over a long period of time. Pedological observations and measurements merely express changes that have occurred through the life of a soil.

Soil individuals pass through stages of development; youth, maturity, and old age. Thorp and Smith (36) suggest the formation of minimal, medial and maximal subgroups based on increasing textural differences between A and B horizons. Young soils exhibit no textural change between A and B horizons while old soils exhibit far more clay in the B horizons than in A horizons.

Soil pedons of this study fall into the mature age brackets. Three pedons formed in Permian aged parent material and exhibit well developed B horizons but have not yet begun to deteriorate into old age. Two pedons developed in sandy Pleistocene deposits of western Oklahoma and exhibit development of the B horizon but still retain characteristics of the parent material (16).

Previous Work

Some soil properties are of special interest to engineers because they affect the construction and maintenance of roads, building foundations, water storage facilities, erosion control, drainage systems, and sewage disposal systems. The most important soil properties are permeability to water, Atterberg limits, soil drainage, shrink-swell characteristics, texture, and reaction. Topography, depth to water table, and depth to bedrock are also important (23).

Atterberg limits are of major importance to engineering interpretations for soils. They indicate the desirability and stability of a soil for various engineering purposes.

As moisture evaporates soil volume decreases in direct proportion to moisture loss until the shrinkage limit is reached. After reaching the shrinkage limit soil volume remains the same with moisture loss. The volume of dry soil divided by the loss of moisture gives the shrinkage ratio. In general the lower the shrinkage limit and the higher the shrinkage ratio the greater the clay content will be.

Volume change is the change in volume from the field moisture equivalent to the shrinkage limit, expressed as a percentage of the dry volume. Soil moisture content reaches the field moisture equivalent when moisture fills all pores in sands and cohesive soils approach saturation (1, 25).

Liquid limit and plastic limit indicate the effect of water on soil consistence. Soil changes from a semisolid to a plastic state as percent moisture increases from a dry state to plastic limit. Further moisture increases eventually change the soil from a plastic state to a liquid state, the liquid limit. The plastic index indicates the moisture content range within which a soil is plastic and is the numerical difference between the liquid limit and the plastic limit (7, 15).

Shrink-swell properties generate volume changes, referred to as extensibility, within a profile. The measurement of this soil quality is called linear extensibility. Many researchers have conducted field experiments attempting to determine linear extensibility under natural soil conditions (17, 20, 37). However, due to lack of moisture standards these measurements have limited use in soil characterization. Engineering procedures call for the unnatural disruption of soil aggregates and destruction of soil fabric (17, 18). Now, however, recent developments of saran resin allow preservation of natural soil organization (4, 14).

General predictions for shrink-swell potential of mapping units are made using the coefficient of linear extensibility (COLE) (37). COLE employs the bulk density of natural soil clods desorbed to ⅓ bar and oven dry. Once determined, the bulk densities are used to calculate COLE and linear extensibility (L. E.) (4,17).

Bulk density, COLE and L.E. measurements are affected by exchangeable ions, composition of the soil solution, particle size distribution, particle arrangement, mineralogy, and water retention properties (35). Bulk density is a direct result of particle size and arrangement in soils. Kaolinite in a sand matrix tends to form a laminated structure and montmorillonite tends to form a sponge-like structure (24). Flat pieces of clay orient parallel to one another with attractive forces between negatively charged surfaces and intervening exchangeable cations (35).

The type of clay present directly affects COLE and L.E. The 2:1 clays swell appreciably but 1:1 clays do not exhibit such a pronounced effect. The structure of 2:1 clays results in weaker bonds between units allowing movement of water into the structure. The absorption of water into the interlayer of a 2:1 clay mineral is the main mechanism of soil shrink-swell (4, 35). The resulting swelling pressure and COLE are influenced by mineralogy of the clay fraction.

MATERIALS AND METHODS

Important Benchmark soils, Nobscot, Grandfield, Bethany, Kirkland, and Norge, were chosen for this investigation. They extend over large areas of old alluvial deposits of the Central Rolling Red Plains and eroded uplands of the Central Red Prairies. Sites for the Nobscot and Grandfield pedons were located in Beckham County and sites for the Bethany, Kirkland and Norge pedons were located in Canadian County. Collection of bulk and block samples followed the detailed description of each pedon. After air drying in the laboratory the samples remained stored until used.

Nobscot-like Fine Sandy Loam

The sampling site occurs on undulating to hummocky or hilly, wind modified upland formed from reddish alluvial sand. Soil development occurs under the influence of midgrasses and scrub oak and the site is currently used as pasture. It is a well drained soil with moderately rapid permeability and very slow runoff. The surface horizon is a little too loamy for typical Nobscot. Pedon location is 600 feet E. and 90 feet N. of the SW corner of Sec. 35, T9N, R23W, Beckham County, of about six miles south and two and a quarter miles east of Sayre, Oklahoma.

Norge-like Silt Loam

The site occurs on nearly level to gently sloping upland of old alluvial origin. Soil development occurs under the influence of tall grasses and the site is currently part of an extremely large city park area. It is a well drained soil with slow permeability and slow runoff. This soil is a little too clayey for typical Norge. Pedon location is 2800 feet S. and 2300 feet W. of the NE corner of Sec. 13, T12N, R8W, Canadian County, about one mile west and one and one half miles south of El Reno, Oklahoma.

Kirkland-like Silt Loam

The site occurs on nearly level to very gently sloping uplands weathered from Permian shale and clay beds. Soil development occurs under the influence of tall grasses and the site is currently part of an extremely large city park area. It is a well drained soil with very slow permeability and slow to medium runoff. This soil contains more expanding clays than typical Kirkland. Pedon location is 200 feet S. and 350 feet W. of the NE corner of Sec. 13, T12N, R8W, Canadian County, Oklahoma, about one mile west and one and one half miles south of El Reno, Oklahoma.

Grandfield-like Loamy Sand

The site occurs on nearly level to gently sloping uplands formed in old alluvial and aeolian sediments. Soil development occurs under the influence of tall to midgrasses and the site is currently an old abandoned gravel pit. This is too sandy for typical Grandfield. It is a well drained, moderately extensive soil of west Texas and Oklahoma. Pedon location is 1650 feet S. and 823 feet W. of the NE corner of Sec. 28, T11N, R22W, Beckham County, about six miles west and one half mile south of Elk City, Oklahoma.

Bethany Silt Loam

The sampling site occurs on nearly level to very gently sloping upland formed in weathered shale and claybeds capped with loess. Soil development occurs under the influence of tall grasses and the site is currently used as pasture. It is well drained soil with slow permeability and slow runoff. Pedon location is 150 feet N. of the SW corner of Sec. 4, T12W, R8W, Canadian County which is about four and one half miles west of El Reno, Oklahoma.

The morphological descriptions of the soils studied have been abbreviated according to the Soil Survey Manual, and are shown in Table 1 of Results and Discussions.

Chemical analysis of the study pedons employed standard Soil Conservation Service procedures as outlined below. Organic carbon determination followed grinding of the sample to pass a 60 mesh sieve. Sample digestion occurred after the addition of 10 ml of 0.4 N potassium dichromate, 15 ml of concentrated sulfuric acid, and heating of the sample solution to 161°C. After cooling and the addition of 100 ml distilled water the sample was titrated with 0.2 N ferrous ammonium sulfate solution. The organic matter was calculated by multiplying organic carbon by I.72 (31). Soil reaction was measured on a 1:1 mixture of soil with distilled water (31). The percent calcium carbonate was determined by the acid-neutralization method (3). Fifty ml of standardized 0.5 N HC1 added to the sample reacted with carbonates when boiled gently for five minutes. After filtration through retentive paper, several washings with distilled water removed excess acids. The HC1 filtrate was then titrated to end point using phenolphthalein as an indicator and 0.25N NaOH. Cation exchange capacity and extractable cations were determined by methods of NaAC, pH 8.2 and NH_4AC, pH 7.0 respectively (31). Extractable aluminum was measured by KC1 extraction, and extractable H^+ by $BaC1_2$- triethanolamine procedure (31).

For particle size distribution the pipette method was utilized as out-

Table 1 Morphology and Classification of the Soils Sampled for Study

Horizon	Depth inches	Color (moist)	Texture	Structure	Consistence (moist)	Boundary	Others
Norge-like silt loam, Fine, mixed, thermic, Udic Paleustolls							
A1	0-8	5 YR 3/2	sil	1fgr	mfr	gs	
B1	8-17	5 YR 3/3	sil	2f & mgr	mfr	gs	
B21t	17-25	5 YR 3/4	sicl	2f & msbk	mfr	gs	Few pebbles
B22t	25-42	5 YR 3/4	C	2mpr-2mbk	mfi	gs	Few pebbles
B23t	42-53	2.5 YR 3/6	C	2mpr-2mbk	mfi	Cs	Few iron and manganese concretions and stains; few pebbles
B3	53-75	2.5 YR 4/6	sic	2mpr-2cbk	mfi		Few $CaCO_3$, iron and manganese concretions.
Nobscot-like fine sandy loam Coarse loamy, mixed, thermic Udic Paleustalfs							
A1	0-5	7.5 YR 4/2	fsl	lfgr	mvfr	gw	
A2	5-23	7.5 YR 6/4	ls	0	ml	cw	
B21t	23-36	2.5 YR 3/6	sl	lcpr	mfr	gs	Few ¼″ thick bands of dark red heavy sandy loam.
B22t	36-53	2.5 YR 4/6	ls	lcpr	mvfr	gs	Thin bands of dark red sandy loam, spaced 4-6″ apart.
B23t	53-71	2.5 YR 5/6	ls	lcpr	mvfr	ds	Red sandy loam bands, spaced 2-5″ apart.
B3	71-80	5 YR 5/6	sl	0	mvfr		Few thin bands of red sandy loam.
Kirkland-like silt loam Fine, montmorillonitic Pachic Argiustolls							
Ap	0-9	10 YR 3/2	sil	lfgr	mfr	cs	
Al	9-13	10 YR 3/2	sil	lfgr	mfr	as	
B21t	13-30	10 YR 3/2	sicl	2mabk	mfi	cs	

Table 1 Morphology and Classification of the Soils Sampled for Study (Continued)

Horizon	Depth inches	Color (moist)	Texture	Structure	Consistence (moist)	Boundary	Others
B22t Ca	30-45	10 YR 3/2	sicl	2mabk	mfi	gs	Soft powdery masses of CaCO$_3$, and CaSO$_4$, few fine concretions of CaCO$_3$
B32t Ca	45-54	10 YR 4/2	sicl	lf & msbk	mfi	gs	Soft masses of CaCO$_3$ and CaSO$_4$.
B32 Ca	54-72	10 YR 4/2	sil	lf & msbk	mfi		Soft masses and threads of CaCO$_3$ and CaSO$_4$; few fine iron and manganese concretions.
Grandfield-like loamy sand Fine-loamy, mixed, thermic Udic Haplustalfs							
Ap	0-8	5 YR 3/4	ls	lvfgr	mvfr	as	Few pebbles
B1	8-12	5 YR 3/3	scl	lvf & msbk	mvfr	cs	″ ″
B21t	12-20	2.5 YR 3/4	scl	2m & cpr	mfr	cs	″ ″
B22t	20-31	2.5 YR 3/6	l	2m & cpr	mfr	cs	″ ″
B23t	31-45	2.5 YR 4/6	l	2m & cpr	mfr	cs	″ ″
B24t	45-51	2.5 YR 4/6	sl	2m & cpr	mfr	cs	″ ″
B31	51-64	5 YR 5/6	sl	lmsbk	mfr		Many irregular bands of red sandy loam, spaced 1-3″ apart.
B32	64-80	5 YR 5/8	sl	0	mfr	gs	
Bethany, silt loam Fine, mixed, thermic Udic Paleustolls							
A11	0-6	10 YR 2/2	sil	2mgr	mfr	cs	
B11	6-12	10 YR 2/2	sil	2mgr	mfr	cs	
B12	12-18	10 YR 3/2	sil	1fsbk	mfi	cs	
B21t	18-38	10 YR 3/2	sicl	3mabk	mvfi	gs	
B22t	38-54	10 YR 4/3	sicl	2cabk	mvfi	gs	Few fine faint mottles; CaCO$_3$ concretions.
B23t	54-71	10 YR 4/2	sicl	2cabk	mvfi	gs	Many coarse distinct mottles, fine vertical lime streaks.
B3	71-80	5 YR 4/6	sicl	1mabk	mvfi		Many fine lime concretions.

lined in Methods of Soil Analyses: Part I (2). The sample was passed through a sieve column collecting the very coarse, coarse, medium fine and very fine sand fractions.

Atterberg limit measurements required the use of standard ASTM procedures for liquid limit, shrinkage limit, plastic limit and plastic index (1).

Bulk density was determined using clods coated with saran resin before transfer to the laboratory and again in the laboratory for protection during measurement. The next step employed a tension table for moisture equilibrium of the clod before removal to a tension plate. A ⅓ bar atmosphere was maintained on the tension plate until the clod equilibrated. Weight in air and volume displacement in water were measured before oven drying to constant weight. After oven drying to constant weight the clods were again weighed in air and the volume displacement measured (4, 17, 31). The weights in air were then adjusted for the weight of saran resin and wires. The bulk densities moist and dry were then calculated using the following formulas:

$$\text{Dbe} = \frac{\text{WCod}}{\text{VCe}} \qquad \text{Dbod} = \frac{\text{WCod}}{\text{VCod}}$$

where: Dbe = bulk density of the equilibrated clod, WCod = weight of the clod oven dry, VCe = volume of the clod equilibrated, Dbod = bulk density of the clod oven dry and VCod = volume of the clod oven dry.

The % water by weight and % water by volume at ⅓ bar tension may be calculated as follows:

$$\text{WWE} = \frac{\text{WCe-WCod}}{\text{WCod}} \text{ X } 100 \qquad \text{VWe} = \frac{\text{WCe-VCod}}{\text{VCod}}$$

where: WWE = the % water by weight, WCe = weight of the clod equilibrated and VWe = the % water by volume.

COLE values were calculated using the bulk density figures:

$$\text{COLE} = {}^{3}\,\frac{\text{Dbod}}{\text{Dbe}} - 1$$

It is assumed that dimensional changes per unit of length along the axis are equal. The COLE values are then multiplied by horizon thickness to obtain the vertical linear extensibility. The sum of the vertical linear extensibility for each horizon yields the cumulative vertical linear extensibility.

Clay samples for x-ray diffraction received three 50 ml washings of either 1.0 N $CaCl_2$ or 1N KCl. After saturation, three washings with distilled water removed excess salts and dispersed the sample. Aliquots of the calcium saturated samples received glycerol solvation by the Jackson method for differentiation between vermiculite and montmorillonite peaks (19).

Cation exchange capacity was determined on the fine and coarse clay fraction of selected profile horizons. Ca saturated samples were washed 3 times with 1N NaCl and the supernate saved. The supernate was buffered with 10 ml of NH_4Cl-NH_4OH buffer and 10 drops of Eriochrome Black T indicator was added. The supernate was then titrated to a bright blue end point with EDTA.

RESULTS AND DISCUSSION

Particle Size Distribution

The particle-size analysis of the Nobscot exhibits maximum clay accumulation in the B21t or argillic horizon with dwindling amounts of clay further down in the profile (Table 2). After initial clay increase, the B horizon rapidly decreases in percent clay and exhibits skeletal sand grains throughout. The coarse texture of the profile is indicative of high infiltration and permeability rates which increase leaching and weathering processes.

The particle size determination of the Grandfield pedon exhibits maximum clay accumulation in the B21t and decreases thereafter (Table 2). The clay increase of the B21t, and lamellae in the lower horizons are evidence of a developing argillic horizon. The sand content of the B horizon and the presence of pebble lines in the profile indicate deposition in rapid moving water. The rapid permeability and infiltration rates lead to increased leaching processes.

An intensive clay accumulation within the Norge profile is shown in Table 2. Clay accumulation exceeds a 1.2 increase within the first 20 cm of the B horizon and reaches its maximum within the B22t horizon. These data lend support to the field observation of an argillic horizon. The field description notes a firm, sticky, very plastic consistence and blocky structure in the B2t horizon along with continuous clay films on ped faces. The profile possesses clay contents and morphological characteristics indicative of a strongly developed agrillic horizon.

The particle-size analysis for the Bethany profile exhibits high clay accumulation within the B horizon (Table 2). Clay content continually increases with depth in the profile. These data support the recognition

Table 2 Physical and Chemical Analyses of the Soils

	Depth	%			CEC Meq	Ext. Cations meq/100 g						
Horizon	cm	sand	silt	clay	100 g	H	Ca	Mg	K	Na	% B.S.	pH 1:1 H_2O
Grandfield												
Ap	0-20	85.5	4.2	10.3	12.4	0.9	6.5	2.9	0.7	0.1	92.2	7.3
B1	20-31	82.2	16.2	11.6	12.6	0.3	6.7	3.3	0.4	0.1	96.9	6.9
B21t	31-51	61.8	10.0	28.2	21.2	3.5	9.9	6.3	0.5	0.1	82.7	6.4
B22t	51-79	48.8	36.1	15.1	13.7	2.1	7.7	4.4	0.3	0.1	85.8	6.3
B23t	79-114	62.0	21.9	16.1	11.0	0.7	5.8	4.6	0.2	0.1	94.0	6.3
B24t	114-130	64.9	19.2	15.9	7.9	0.7	6.7	5.0	0.2	0.1	94.3	6.2
B31	130-163	70.4	16.7	12.9	7.2	0.9	4.8	4.6	0.1	0.1	91.8	6.3
Nobscot												
A1	0-13	63.6	33.0	3.4	3.5	0.0	4.3	0.5	0.1	0.1	100.	8.1
A2	13-58	79.0	18.9	2.1	1.3	0.0	1.6	0.5	0.1	0.1	100.	7.3
B21t	58-91	75.9	16.0	8.1	7.9	0.9	5.2	2.6	0.1	0.1	90.3	6.6
B22t	91-135	76.3	18.3	5.4	5.5	1.2	3.0	2.5	0.1	0.1	82.5	6.3
B23t	135-180	83.9	11.7	4.4	6.0	0.3	2.3	2.0	0.1	0.1	93.0	6.4
B3	180-203	64.6	32.2	3.2	3.7	0.0	1.3	2.1	0.1	0.1	100.	6.5
Bethany												
A11	0-15	20.9	61.7	17.4	18.2	3.2	11.9	4.9	1.0	0.2	84.8	6.4
B11	15-31	18.2	58.5	23.3	17.7	2.1	11.5	6.2	0.8	0.4	90.1	6.7
B12	31-46	18.5	56.1	25.4	20.4	2.8	12.2	8.7	0.7	1.2	89.2	6.6
B21t	46-97	14.4	54.6	31.0	28.9	1.1	17.7	15.3	0.7	2.3	97.2	7.7
B22t	97-137	13.1	52.3	34.6	29.1	0.0	43.6	20.1	0.7	5.6	100.0	8.5
B23t	137-80	20.3	43.2	36.5	26.3	0.1	42.3	17.5	0.7	5.8	99.9	7.7
B3	80-203	21.8	39.7	38.5	29.6	1.3	23.6	14.1	0.5	5.3	97.2	7.6

Table 2 Physical and Chemical Analyses of the Soils (Continued)

	Depth	%			CEC Meq	Ext. Cations meq/100 g						
Horizon	cm	sand	silt	clay	100 g	H	Ca	Mg	K	Na	% B.S.	pH 1:1 H_2O
						Kirkland						
Ap	0-23	18.0	65.5	16.5	12.8	2.9	7.4	5.7	0.6	0.3	83.0	6.4
A1	23-33	12.4	66.8	20.8	13.8	2.1	10.3	6.0	0.5	0.7	89.4	6.6
B21t	33-76	8.4	53.8	37.8	33.2	1.7	21.8	17.1	0.7	3.5	96.2	7.0
B22r	76-114	8.1	52.1	39.8	30.9	0.0	42.6	25.0	0.7	5.2	100.0	7.6
B31	114-137	6.3	58.8	34.9	30.1	0.0	46.5	16.6	0.7	4.9	100.0	7.5
B32	137-183	10.0	65.8	24.2	30.1	0.6	60.9	15.8	0.7	6.0	99.4	7.4
						Norge						
A1	0-20	31.3	51.4	17.3	10.7	2.3	11.5	4.4	1.0	0.4	88.3	6.6
B1	20-43	23.0	51.5	25.5	12.3	2.8	8.0	9.8	0.5	0.1	86.8	6.5
B21t	43-64	16.4	50.4	33.2	16.0	3.5	11.2	10.1	0.3	0.1	86.0	6.6
B22t	64-107	17.9	39.9	44.2	18.9	3.5	12.5	11.3	0.5	0.3	97.7	6.6
B23t	107-135	20.2	35.2	44.6	18.3	2.9	13.1	11.4	0.6	0.5	90.0	7.1
B3	135-191	15.8	43.6	40.6	27.5	0.0	21.2	11.7	0.6	1.0	100.0	8.3

of an argillic horizon from the field description. The field description acknowledges a very hard, very firm, sticky consistence and blocky structure with clay films on ped faces in the B2t horizons.

Clay accumulation within the Kirkland profile is shown in Table 2. Clay accumulation exceeds a 1.2 increase within the first 20 cm of the B horizon and reaches its maximum within the B22t horizon. These data verify the field observation of an argillic horizon. The profile also retains an abrupt transition between A and B horizons and pressure faces in the B2t horizons indicating extensive profile development with a high concentration of 2:1 clays. The profile possesses high clay contents and morphological characteristics pointing to a well developed argillic horizon.

Bulk Density

Soil bulk densities indicate the presence of certain morphological properties and genetic processes. Due to the coarse nature and decreased intra ped void spaces of the fine earth fraction in loamy soil, the Nobscot and Grandfield pedons have high bulk densities (Table 3). The dry bulk densities range up to 1.83 g/cm^2 but indicate nothing other than the influence of texture.

The Bethany, Kirkland and Norge soils are finer and thus expected to have lower bulk densities unless altered by some morphological property. These three soils possess horizons with dry bulk densities in excess of 1.80 gm/cm^3 and clay percentages greater than 35% (Table 4). These horizons also include structures of medium to coarse size blocks indicating the prevalent action of shrinking and swelling. Shrinking and swelling action in fine soils results in a compaction effect thus increasing dry bulk densities.

COLE

COLE values of the Nobscot and Grandfield generally fall short of any significant value, except in the B21t horizon of the Nobscot (Table 3). Pedon clay fractions are insufficient to dominately influence physical properties (Table 2).

COLE values of the Bethany, Kirkland and Norge are much higher. Values exceed 0.03 indicating the presence of substantial amounts of smectite (Table 4). The Bethany profile has COLE values up to 0.095 and a cumulative linear extensibility of 11.19 cm. The Kirkland profile has COLE values up to 0.090 and a cumulative linear extensibility of 12.41 cm. The Norge profile has COLE values up to 0.066 and a cumulative linear extensibility of 9.22 cm (Table 4). The shrink-swell of these

Table 3 Bulk Density and Extensibility of the Grandfield and Nobscot Pedons

Horizon	Depth Centimeters	% Water by Weight Equilibrated	% Water by Volume Equilibrated	Bulk Density Equilibrated	Bulk Density Oven Dry	Linear Extensibility		
						COLE	Vertical Centimeters	Cumulative Vertical
				Grandfield				
Ap	0-20	–	–	–	–	–	–	1.47
B1	20-31	–	–	–	–	–	–	1.47
B21t	31-51	19	30	1.59	1.83	0.019	0.39	1.47
B22t	51-79	15	26	1.64	1.78	0.022	0.62	1.08
B23t	79-114	12	21	1.72	1.83	0.013	0.46	0.46
B24t	114-130	–	–	–	–	–	–	–
B31t	130-163	–	–	–	–	–	–	–
				Nobscot				
A1	0-13	–	–	–	–	–	–	3.75
A2	13-58	–	–	–	–	–	–	3.75
B21t	58-91	13	21	1.56	1.65	0.050	1.65	3.75
B22t	91-135	11	17	1.52	1.62	0.027	1.17	2.13
B23t	135-180	8	13	1.59	1.65	0.021	.98	.96
B3	180-203	–	–	–	–	–	–	–

Table 4 Bulk Density and Extensibility of the Bethany, Kirkland and Norge Pedons

Horizon	Depth Centimeters	% Water by Weight Equilibrated	% Water by Volume Equilibrated	Bulk Density Equilibrated	Bulk Density Oven Dry	Linear Extensibility		
						COLE	Vertical Centimeters	Cumulative Vertical
			Bethany					
A11	0-15	23.3	30.3	1.30	1.38	0.020	0.31	11.19
B11	15-31	29.0	36.3	1.25	1.37	0.030	0.46	10.88
B12	31-46	28.2	36.1	1.28	1.39	0.028	0.43	10.42
B21t	46-97	25.0	35.0	1.43	1.88	0.095	4.83	9.99
B22tca	97-137	23.8	37.0	1.52	1.81	0.060	2.44	5.16
B23t	137-180	20.2	30.7	1.54	1.76	0.063	2.72	2.72
			Kirkland					
Ap	0-23	26.8	35.4	1.32	1.38	0.016	0.37	12.41
A1	23-33	26.8	36.8	1.37	1.47	0.024	0.24	12.04
B21t	33-76	26.9	39.4	1.46	1.90	0.090	3.89	11.80
B22tca	76-114	25.8	37.7	1.46	1.82	0.076	2.90	7.91
B31	114-137	31.2	44.3	1.42	1.79	0.081	1.85	5.01
B32	137-183	28.3	42.0	1.49	1.81	0.069	3.16	3.16
			Norge					
A1	0-20	25.6	27.5	1.22	1.28	0.014	0.28	9.22
B1	20-43	26.3	32.2	1.23	1.34	0.029	0.66	8.94
B21t	43-64	24.6	32.9	1.34	1.55	0.050	1.02	8.28
B22t	64-107	24.6	36.6	1.49	1.81	0.066	2.85	7.26
B23t	107-135	24.1	37.2	1.65	1.95	0.058	1.62	4.41
B3	135-191	22.2	36.4	1.64	1.90	0.050	2.79	2.79

three profiles gives a strong indication of severe limitations for many engineering projects.

Organic Matter

Organic matter content has a recognized effect on soil physical properties. High organic matter percentages decrease the bulk density (Table 3 and 4) and reduce Atterberg limits (Table 8 and 9). This is especially evident in the A horizon of the Kirkland. The effects of organic matter on physical properties of the Nobscot and Grandfield are minor due to low organic matter percentages (Table 5) and the coarse texture of the soil.

The effects of organic matter on the physical properties of the Norge, Kirkland, and Bethany are much greater. These three pedons were sampled at virgin or nearly virgin sites. Thus organic matter content of the A horizons is exceptionally high and bulk densities are much less than in lower horizons (Table 6). The Atterberg limits are also noticeably depressed, but large amounts of organic matter present make the A horizons unstable for engineering purposes that involve compaction and filling. Furthermore the COLE values of these horizons with more than 1.5% organic matter are noticeable depressed. This is due to the loss of some clay by translocation and most importantly the flocculating effect of organic matter on clay particles.

Table 5 Organic Matter and Calcium Carbonate Equivalent

Horizon	Depth Centimeters	% Organic Matter	Calcium Carbonate Equivalent
	Grandfield		
Ap	0-20	1.63	0.8
B1	20-31	1.30	2.2
B21t	31-51	1.53	3.1
B22t	51-79	0.62	1.8
B23t	79-114	0.26	2.3
B24t	114-130	0.25	2.3
B31	130-163	0.20	1.8
	Nobscot		
A1	0-13	1.54	0.0
A2	13-58	0.47	0.0
B21t	58-91	0.68	0.0
B22t	91-135	0.44	0.0
B23t	135-180	0.43	0.0
B3	180-203	0.22	0.0

Total Carbonates

The total soil carbonates are a measure of translocation within a soil profile. The Nobscot pedon produced no measurable amounts of carbonates. Total carbonates in the Grandfield are very low in the A horizon and the increase in the B horizons are a sign of some translocation in the profile (Table 5).

The Norge soil shows some translocation of carbonates downward in the profile though no large concentrations have developed (Table 6). Due to a geologically young age, less weathering and translocations have occurred than in older soils of this study.

Kirkland has heavy concentrations of carbonates in its B horizons indicating active translocation and soil development over a long period of time (Table 6). Carbonate concentrations exceed 15 percent in the B22t horizon qualifying it as a calcic horizon. The high concentration may have depressed linear extensibility to some degree.

The Bethany also has heavy concentrations of carbonates in the B horizons indicating active translocation and soil development over a long period of time (Table 6). Carbonate concentrations exceed 15 percent in

Table 6 Organic Matter and Calcium Carbonate Equivalent

Horizon	Depth Centimeters	% Organic Matter	Calcium Carbonate Equivalent
	Bethany		
A11	0-15	4.13	3.3
B11	15-31	2.28	3.3
B12	31-46	1.78	3.0
B21t	46-97	1.01	4.7
B22tca	97-137	0.70	17.2
B23t	137-180	0.53	7.4
B3	180-203	0.18	5.0
	Kirkland		
Ap	0-23	1.88	2.4
A1	23-33	1.58	5.4
B21t	33-76	1.38	7.4
B22t	76-114	1.07	16.3
B31	114-137	0.78	10.9
B32	137-183	0.72	6.7
	Norge		
A1	0-20	3.42	2.1
B1	20-43	2.15	3.2
B21t	43-64	1.59	4.6
B22t	64-107	1.08	4.6
B23t	107-135	0.41	3.2
B3 ca	135-191	0.55	6.2

the B22t horizons qualifying it as a calcic horizon. The calcium carbonate concentrations of the lower horizons may have depressed natural shrinking and swelling tendencies.

X-Ray Diffraction Analysis

Clay minerals of the coarse, 2-0.2 micron, and fine clays, less than 0.2 micron, of A and B horizons of Norge, Bethany and Kirkland were identified by the x-ray diffraction analysis (Table 7).

Coarse clays contain mainly a mixture of illite and montmorillonite. Small amounts of kaolinite and quartz are usually present. Fine clays are dominantly montmorillonitic. However, little amounts of illite, kaolinite and quartz are generally found.

Cation Exchange Capacity of Fine and Coarse Clays

The cation exchange capacity of the coarse and fine clay fractions was determined to indicate the dominate clay minerals. The cation exchange capacity of the fine clays were higher than the exchange capacity of the coarse clays due to higher content of montmorillonite, particularly in B22t horizon of Kirkland and Bethany (Table 7). In B22t horizon of Norge, the CEC of coarse and fine clays have almost the same values. The low exchange capacity of the Kirkland coarse clay indicates the illite is the dominant clay mineral (Table 7).

Atterberg Limits

Atterberg limits indicate the desirability of a soil for various engi-

Table 7
Cation Exchange Capacity and Mineralogy of Coarse and Fine Clays

		CEC Meq/100 g		Mineralogy (x-ray diffraction)	
	Horizon	Coarse clay	Fine clay	Coarse clay	Fine clay
Norge	A1	31.4	67.0	$I_1M_2K_3Q_3$	$M_1I_2K_3Q_3$
	B1	52.4	63.9	$I_2M_2K_3Q_3$	$M_1I_2K_3Q_3$
	B22t	50.7	55.3		
Kirkland	Ap	30.8	79.3	$I_1M_2K_3Q_3$	$M_1I_3K_3Q_3$
	B22t	38.5	85.0	$I_1M_2K_3Q_3$	$M_1I_3K_3Q_3$
	B31	35.4	84.4		
Bethany	A11	45.7	77.3	$I_2M_2K_3Q_3$	$M_1I_2K_3Q_3$
	B1	68.9	63.1		
	B22t	62.1	94.1	$M_1I_2K_3Q_3$	$M_1I_3K_3Q_3$

mineralogy code I-Illite, M-Montmorillonite, K-Kaolinite, Q-Quartz, 1-more than 40%, 2-between 20-40%, 3 less than 20%.

neering purposes. Data for Atterberg limits measured by the Oklahoma State Highway Department are presented in Tables 8 and 9. The tests were made for the purpose of determining shrinkage, volume change, liquid limit, and plasticity index.

When samples have textures of sand, sandy loam and loamy sand the clay content is considered too small to be effective regardless of its properties. Coarse soils such as the Grandfield and Nobscot have little or no plasticity. However, clay percentages of the Grandfield exceed twenty eight percent of the B21t and 10% in all other horizons making it a desirable precaution to test for Atterberg limits (Table 8). The plastic indices fall in the low to medium range and liquid limits, except in the B21t are far below the significant 35% value. Plotting plastic index vs. liquid limit (Figure 2) shows the effect of 2:1 type clays on engineering properties to be minimal.

The liquid limits of the Norge profile exceed thirty percent and the plastic indexes of the B horizon fall in the medium to high range. However, the shrinkage ratios exceed 15% which is low, indicating some shrinking and swelling properties for this soil (Table 9). The high clay content produces high liquid limits and plastic indices, however, this soil is relatively low in swelling type clays. The plotting of plastic index vs. liquid limit shows the effect of swelling type clays on engineering properties as low to moderate.

Table 8 Some Engineering Properties of the Grandfield and Nobscot Pedons[1]

Horizon	Depth Centimeters	Thickness Centimeters	Liquid Limit	Plastic Index	Shrinkage Limit	Shrinkage Ratio	Volume Change
			Grandfield				
Ap	0-20	20	22	5	14	1.86	10
B1	20-31	10	23	7	14	1.86	14
B21t	31-51	20	42	22	13	1.91	46
B22t	51-79	28	31	16	14	1.90	33
B23t	79-114	36	28	11	18	1.75	17
B24t	114-130	15	32	14	16	1.80	27
B31	130-163	33	25	6	18	1.74	10
			Nobscot				
A1	0-13	13	NP[2]	NP	NP	NP	NP
A2	13-58	46	NP	NP	NP	NP	NP
B21t	58-91	33	NP	NP	NP	NP	NP
B22t	91-135	43	NP	NP	NP	NP	NP
B23t	135-180	46	NP	NP	NP	NP	NP
B3	180-203	23	NP	NP	NP	NP	NP

[1] Oklahoma Highway Department Soils Laboratory
[2] Nonplastic

Table 9 Some Engineering Properties of the Bethany, Kirkland and Norge Soils

Horizon	Depth Centimeters	Thickness Centimeters	Liquid Limit	Plastic Limit	Shrinkage Limit	Shrinkage Ratio	Volume Change
			Bethany				
A1	0-15	15	34	8	21	1.62	19
B11	15-31	16	32	11	17	1.72	23
B12	31-46	13	39	18	15	1.83	35
B21t	46-97	51	47	27	11	1.98	57
B22tca	97-137	40	47	27	10	2.02	66
B23t	137-180	43	46	26	11	2.00	61
B3	180-203	23	47	28	11	2.02	51
			Kirkland				
Ap	0-23	23	26	4	15	1.80	17
A1	23-33	10	26	6	16	1.80	17
B21t	33-76	43	52	30	9	2.07	68
B22t	76-114	38	53	32	9	2.09	68
B31	114-137	23	53	31	9	2.10	71
B32	137-183	46	53	31	10	2.06	73
			Norge				
A1	0-20	20	33	7	20	1.67	20
B1	20-43	23	33	12	17	1.76	26
B21t	43-64	21	38	17	15	1.86	42
B22t	64-107	43	47	26	13	1.94	51
B23t	107-135	28	50	29	15	1.86	46
B3 ca	135-191	56	48	28	12	2.00	51

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[1] Oklahoma State Highway Department Soils Laboratory.

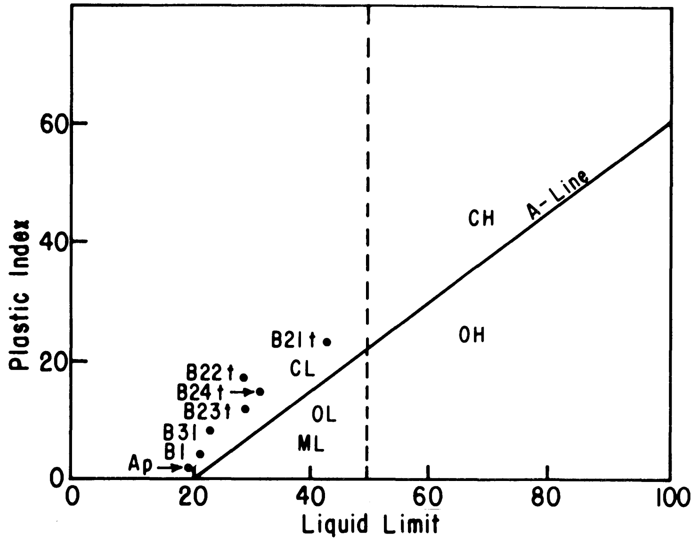

Figure 2. Plasticity Chart for the Grandfield Pedon. (ML), Inorganic Silts and Fine Sands with Slight Plasticity. (CL), Inorganic Clays of Low to Medium Plasticity. (OL), Organic Silts and Organic Silty-Clays of Low Plasticity. (CH), Inorganic Clays of High Plasticity, Fat Clays. (OH), Organic Clays of Medium to High Plasticity.

Liquid limits of the Kirkland B horizon exceed fifty percent and plastic indices are high. The shrinkage ratio is less than eleven in all horizons indicating high shrink-swell clays (Table 9). A plotting of plastic limit versus liquid limit (Figure 3) shows larger amounts of the swelling clay. The engineering properties confirm the undesirability of this soil for most engineering purposes.

The liquid limits and plastic indices of the Bethany pedon are about medium. The shrinkage ratios are also about medium indicating appreciable but not extreme amounts of swelling clays (Table 9). The plotting of plastic limit vs. liquid limit shows the effect of swelling clays to be significant.

Interpretations of Engineering Qualities

The Benchmark soils studied were rated for various engineering purposes based on field descriptions and laboratory data from representative pedons presented in this report. Interpretations and ratings were made using data in Tables 8, 9, and 10. Table 10 include USDA re-

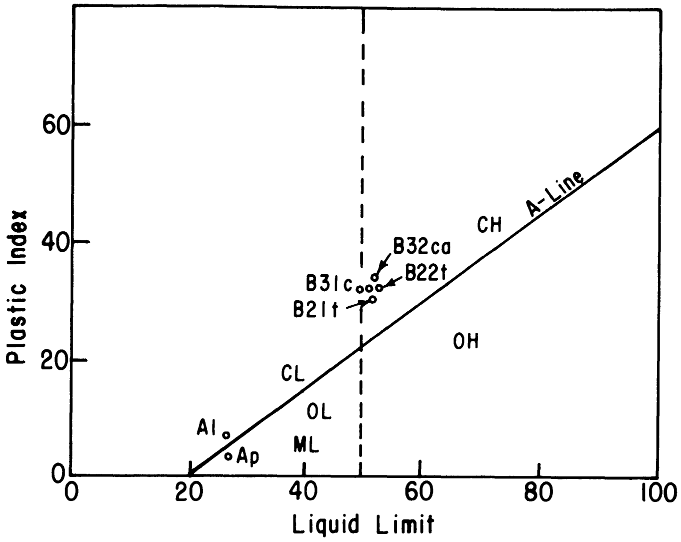

Figure 3. Plasticity Chart for the Kirkland Pedon. (ML), Inorganic Silts and Fine Sands with Slight Plasticity. (CL), Inorganic Clays of Low to Medium Plasticity. (OL), Organic Silts and Organic Silty-Clays of Low Plasticity. (CH), Inorganic Clays of High Plasticity, Fat Clays. (OH), Organic Clays of Medium to High Plasticity.

action and ratings for shrink-swell potential. These tables and the field descriptions were the bases for engineering interpretations and ratings found in Tables 11, 12, 13, and 14.

In Table 11, the soils are rated for suitability as sources of topsoil, select material and roadfill. The Bethany, Kirkland and Norge are good to fair sources of topsoil while the Grandfield and Nobscot are good sources of select material and roadfill.

Table 12 gives ratings and indicates features affecting suitability as sites for highways, farm ponds, drainage, irrigation systems, waterways, terraces and diversions. All soils have some limitations for highway locations, embankments, irrigation or terraces and diversions. The Bethany, Kirkland and Norge soils have features most suited for reservoir areas and waterways.

Interpretive ratings for specific soil uses are given in Tables 13 and 14. The soils are rated for septic tank filter fields, sewage lagoons, sanitary land fill, sites for low buildings, roads and streets, lawns, shrubs and tree gardens, golf fairways, picnic areas, intensive play areas, paths and trails, camping areas, and parks. The ratings are for soils in place.

Table 10 Engineering Properties and Qualities of Five Benchmark Soils

Soil Name	Depth From Surface (cm)	USDA Texture	Available Water Capacity[1]	Reaction	Shrink-Swell Potential
Bethany silt loam	0-30	Silt loam	0.15-0.17	6.4-6.7	Low
	30-137	Silty clay loam	0.15-0.17	6.6-8.5	Moderate
	137-203	Clay loam	0.15-0.17	7.6-7.7	Moderate
Grandfield loamy sand	0-30	Loamy sand	0.05-0.10	6.9-7.3	Low
	30-51	Sandy clay loam	0.10-0.15	6.4-6.4	Low
	51-163	Sandy loam	0.05-0.10	6.2-6.3	Low
Kirkland silt loam	0-33	Silt loam	0.15-0.17	6.4-6.6	Low
	33-137	Silty clay loam	0.15-0.17	6.6-8.0	High
	137-183	Silt loam	0.15-0.17	7.4-7.4	High
Nobscot fine sandy loam	0-58	Sandy loam	0.05-0.10	7.3-8.1	Low
	58-135	Sandy loam	0.05-0.10	6.3-6.6	Low
	135-203	Loamy sand	0.03-0.07	6.4-6.5	Low
Norge silt loam	0-43	Silt loam	0.15-0.17	6.5-6.6	Low
	43-64	Silty clay loam	0.15-0.17	6.6-6.6	Moderate
	64-191	Clay	0.10-0.15	6.6-8.3	Moderate

[1] Inches per inch of soil

The sandy Nobscot and Grandfield soils have severe to moderate limitations for uses requiring slow permeability, high fertility or trafficability. The Bethany and Norge soils generally have moderate to severe ratings for those uses requiring high permeability and low shrink-swell. However, they are only slightly limited for most recreational uses. Due to high clay content, clay mineralogy, and resulting engineering properties the Kirkland soil has limitations for every use except ponding water.

Table 11 Engineering Interpretations of Five Important Soils Suitability as a Source

Soil Name	Topsoil	Selected Materials	Road Fill
Bethany silt loam	Good to fair to a depth of 1½ feet: easily eroded on steep slopes.	Unsuitable	Poor: moderate shrink-swell potential, unstable
Grandfield loamy sand	Poor: low fertility easily eroded.	Good	Good if entire profile is used
Kirkland silt loam	Good to fair to a depth of 1 foot: easily eroded on steep slopes.	Unsuitable	Very poor: unstable, high shrink-swell potential
Nobscot fine sandy loam	Poor: low fertility easily eroded.	Good	Good
Norge silt loam	Fair to good: somewhat easily eroded on steep slopes.	Poor: elastic	Fair to poor: unstable

Table 12 Engineering Interpretations of Five Important Soils—Soil Features Affecting—

Soil Name	Highway Location	Farm Ponds		Agricultural Drainage	Irrigation	Terraces and Diversions	Waterways
		Reservoir Area	Embankment				
Bethany silt loam	Moderate shrink-swell potential; very slow internal drainage; unstable	Features favorable	Susceptible to cracking when dry; low shear strength	Good drainage	Slow rate of intake; slow permeability	Susceptible to ponding in channels	Features favorable
Grandfield loamy sand	Erodible soils	High rate of seepage	High erodibility	Good drainage	Undulating topography; wind erosion	Susceptible to wind erosion	Susceptible to wind and gully erosion
Kirkland silt loam	High shrink-swell potential; unstable	Features favorable	Cracks when dry	Very slow internal drainage	Very slow rate of intake; cracks when dry	Ponded water in channels	Features favorable
Nobscot fine sandy loam	Erodible soils	High rate of seepage	High erodibility	Good drainage	Wind erosion; hummocky topography	Hummocky topography; subject to wind erosion	Susceptible to wind and gully erosion
Norge silt loam	Moderate shrink-swell potential; very slow internal drainage; unstable	Features favorable	Susceptible to cracking when dry; low shear strength	Good drainage	Slow rate of intake; slow permeability	Susceptible to ponding in channels	Features favorable

Table 13 Degree and Kind of Limitation to Non-Farm Uses of Five Important Soils

Soil Name	Septic tank filter field	Sewage Lagoons	Sanitary Landfill	Sites for low buildings	Roads and Streets	Lawn Shrubs and Trees
Bethany silt loam	Severe: slow percolation	Slight	Moderate: material difficult to excavate	Moderate: moderate shrink-swell potential	Moderate: moderate shrink-swell potential	Slight
Grandfield loamy sand	Slight	Severe: rapid percolation	Slight	Slight	Slight	Moderate: low fertility
Kirkland silt loam	Severe: slow percolation	Slight	Moderate: material difficult to excavate	Severe: high shrink-swell potential	Severe: high shrink-swell potential	Severe: droughtiness; clayey
Nobscot fine sandy loam	Slight	Severe: rapid percolation	Slight	Slight	Slight	Moderate: low fertility
Norge silt loam	Severe: slow percolation	Slight	Slight	Moderate: moderate shrink-swell potential	Moderate: moderate shrink-swell potential	Slight

Table 14 Degree and Kind of Limitation to Non-Farm Uses of Five Important Soils

Soil Name	Gardens	Golfways	Picnic Area	Intensive Play Area	Paths and Trails	Camping Areas	Parks
Bethany silt loam	Slight	Slight	Slight	Slight	Slight	Slight	Slight
Grandfield loamy sand	Moderate: low fertility	Severe: sandy surface low water holding capacity, low productivity	Severe: trafficability	Severe: sandy surface	Moderate: sandy surface layers	Severe: trafficability	Moderate: trafficability
Kirkland silt loam	Severe: droughtiness, clayey	Severe: droughtiness, clayey, soil cracks when dry	Moderate: clayey	Moderate: very slow permeability	Moderate: very slow permeability	Moderate: very slow permeability	Moderate: very slow permeability
Nobscot fine sandy loam	Moderate: low fertility	Severe: sandy surface, low water-holding capacity, low productivity	Severe: trafficability	Severe: sandy surface	Moderate: sandy surface	Severe: trafficability	Moderate: trafficability
Norge silt loam	Slight	Slight	Slight	Slight	Slight	Slight	Slight

Summary and Conclusions

The purpose of this study was to obtain a more complete characterization of five Benchmark soils of Oklahoma in order to make better engineering interpretations. The soils selected occur under an ustic moisture regime in two major Land Resource Areas of Oklahoma. Study of the soils encompassed morphological, physical, chemical and mineralogical investigations from selected, representative sites with emphasis on particle size distribution, clay mineralogy, shrink-swell and plasticity.

The Grandfield and Nobscot soils have somewhat similar characteristics and properties resulting in similar interpretations. Both, relatively young soils, developed in wind-reworked Pleistocene materials. Due to youth and parent material the sand fraction dominates textures and the low clay content has little effect on chemical and physical properties. Moisture variations have little effect on engineering properties, as stable plasticity limits and low shrink-swell potentials indicate. These soils make good building sites and sources of construction materials. However, they possess low suitabilities for any purpose requiring water retention. They are coarse, have rapid permeability, and little or no natural binding of soil particles.

The Bethany, Kirkland, and Norge soils also have somewhat similar characteristics and properties, resulting in similar interpretations. Clay content of the B horizons and mixed clay mineralogy with significant amounts of montmorillonite make the soils unstable for many engineering purposes. Moderate to high plasticities and moderate to high shrink-swell make them unstable soils restricted for uses requiring soil disturbance or a more rapid permeability. They have limitations as sources of building materials, as sewage filter fields, and as building sites. They are however, excellent sites for reservoirs, water retention areas, and water diversions. They are best for those engineering projects requiring little manipulation, light use, or a slow permeability.

The Kirkland soil is inherently unstable soil. This instability results from high clay contents dominated by the montmorillonite. The soil is very plastic and highly expansive restricting its use for most engineering purposes. Projects requiring displacement, more rapid permeability, low shrink-swell and heavy use *in situ* encounter heavy restrictions. They are best adapted to those purposes requiring ponding or restriction of water movement.

The results of this study will allow a more exact interpretation of properties associated with these five important soils. Furthermore, results may be extrapolated to closely related soils not yet as thoroughly characterized. Special land use management interpretations and recommendations may be found for each soil in published county Soil Surveys.

Definitions of the Terms

Coefficient of linear extensibility (COLE) — The volume change of soil with change in water content defined as:

$$\text{COLE} = \frac{Lm - Ld}{Ld} = \frac{Lm}{Ld} - 1 = \sqrt[3]{\frac{Dbod}{Dbm}} - 1$$

where Lm = length of moist sample, Ld = length of dry sample.

Dbod = bulk density of the dry clod, Dbm = Bulk density of the moist clod.

Cumulative vertical linear extensibility — Summation of the vertical linear extensibilities for the horizons.

Extensibility — Increase in volume of the soil fabric with increased water content.

Linear Extensibility — The linear increase of the soil fabric with increased volume.

Liquid Limit — That water content expressed as a percentage of the dry weight of a soil at which the soil mass just starts to become fluid under the influence of a series of standard shocks.

Plastic index — The difference between the liquid and plastic limits, representing the range of moisture within which the soil is plastic.

Plastic limit — That water content expressed as a percentage of the dry weight of a soil at which the soil mass ceases to be plastic and becomes brittle.

Shrinkage limit — The water content below which a reduction in moisture will not cause a decrease in the volume of the soil mass.

Shrinkage ratio — The ratio between a soils volume change and the corresponding change in water content above the shrinkage limits. It is theoretically the apparent specific gravity of the dried soil peds.

Vertical linear extensibility — COLE multiplied by the thickness of the horizon.

Volume change — The volume change, expressed as a percentage of the dry volume of the soil mass when the moisture content is reduced from the field capacity to the shrinkage limit.

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