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Characterization of Claypan Soils in Southeastern Kansas

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Abstract

Soil erosion reduces topsoil depth. In areas with a claypan, removal of productive topsoil reduces crop yield where the claypan layer is near the surface. The topsoil and claypan layer each have unique characteristics that impact crop production and within-field variability. To better understand these differences, the soil from an area of low crop yield and high crop yield were collected and laboratory tests were performed to determine the soil classification and undrained shear strength. Understanding the soil properties and the interaction between the topsoil and claypan layers may aid in understanding the process by which topsoil is being eroded.

Keywords

claypan soils, agriculture, soil classification, soil physical properties, undrained shear strength

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Cover Page Footnote

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Characterization of Claypan Soils in Southeastern Kansas

M.A. Mathis II, S.E. Tucker-Kulesza, and G.F. Sassenrath

Summary

Soil erosion reduces topsoil depth. In areas with a claypan, removal of productive topsoil reduces crop yield where the claypan layer is near the surface. The topsoil and claypan layer each have unique characteristics that impact crop production and within-field variability. To better understand these differences, the soils from an area of low crop yield and high crop yield were collected and laboratory tests were performed to determine the soil classification and undrained shear strength. Understanding the soil properties and the interaction between the topsoil and claypan layers may aid in understanding the process by which topsoil is being eroded.

Introduction

Claypan soils are characterized by a highly impermeable clay layer within the soil profile that may act as a barrier to infiltrating water and root growth. Claypan soils are usually resistant to erosion and as a result the soil overlying the claypan layer may erode more easily. To better understand the difference in soil properties between the claypan layer and the topsoil, we closely examined different soil layers in two crop production fields in southeast Kansas.

Scientists and engineers classify soil differently. Scientists rely on soil particle size, while engineers rely on both particle size and behavior of the soil. Soil particle size generally indicates the type of soil (i.e., sand, silt, or clay). Sand particles range from 0.4 to 16 gnat's eye in size, while silt particles range from 0.016 to 0.4 gnat's eye in size and clay particles are less than 0.016 gnat's eye in size (Coduto et al., 2011). The "behavior" that engineers use also indicates the range of water content over which soil is moldable (i.e., plastic). There are different soil classification systems. Agronomists commonly use the United States Department of Agriculture soil texture classification, which is based only on particle size (NRCS, 2019), while engineers use the Unified Soil Classification System (USCS; ASTM, 2017b).

Engineers classify soils using the USCS, which relies on both particle size distribution and the Atterberg limits test, which measures the plasticity behavior of the soil. Particle size distribution is used to characterize the soil based upon the range of soil particle sizes in a soil sample. In this research, the soil samples are classified as either lean clay or fat clay according to the USCS. Lean clay has a particle size less than 0.016 gnat's eye and a low plasticity. Fat clay has a particle size less than 0.016 gnat's eye and a high plasticity.

The particle size distribution is based on a wet and dry sieve test of the soil to determine the distribution (in percent) of soil particle sizes. First, a wet sieve test is conducted to determine the percentage of silt and clay-sized particles. The wet sieve has a mesh of 200 openings per square inch (i.e., P_{200}). Soil particles larger than this sieve size are retained on the sieve and are dry sieved separately. Next, a dry sieve test is conducted to determine the distribution of soil particles larger than the 200-openings per square-inch sieve. Conversely, silt and clay-sized particles are finer than a 200-openings per square-inch sieve and pass through the sieve. Finally, a hydrometer test is conducted to determine the distribution of silt and clay-sized particles. A final particle size gradation curve can then be generated from the wet sieve test, dry sieve test, and hydrometer test to establish the soil particle distribution within the sample. Classification of fine-grained soils (i.e., silt and clay-sized particles) is not based solely on size gradation. The Atterberg limits test is used to fully classify the soil according to the USCS. Specifically, the Atterberg limits test is used to distinguish between clay and silt soils, and low or high plasticity.

The liquid limit (LL) and plastic limit (PL) are determined by the Atterberg limits test. The LL is the water content at which the lower limit of viscosity occurs. The PL is the water content at which the soil deforms permanently and cracks. The plasticity index (PI) is a measure of the range of water contents between the LL and PL. The soil will form without cracking at water contents within the PI. In general, the higher the PI, the greater the amount of clay present and the more plastic the soil.

The undrained shear strength (S_u) indicates the soil strength and has been correlated with the resistance of the soil to erosion. There are three failure mechanisms of material: compression, tension, and shear. Because soil is inherently in compression in the subsurface, this is not a failure mechanism; rather soil typically fails in shear. Soil has very little tensile strength, and there are limited applications where soil could fail in tension. The undrained shear strength can be determined by the unconsolidated undrained triaxial test. The shear strength is a soil's ability to resist forces that cause the structure of the soil to fail. Soil strength may aid in determining how susceptible soil layers are to erosion between two distinct soil layers.

The hydraulic conductivity (k) test indicates the rate of fluid flow through a soil. The larger the k the more permeable the soil, and the smaller the k the more impermeable the soil. Typical k values for a lean clay and a fat clay are 3.34E-06 ft/s and 4.21E-06 ft/s, respectively. The rate at which water flows through the soil may aid in understanding the interaction of water flow between two distinct soil layers.

The soil properties between an area of low crop yield and high crop yield were determined to understand how the soil properties of these two areas differ. Disturbed and undisturbed soil samples were collected based on the measured electrical resistivity tomography (ERT) surveys performed in two crop production fields (Mathis et al., 2018). Disturbed samples are samples that do not keep in situ properties of the soil (i.e., structure, density, or the stress conditions) and are not considered representative of underground soils in the collection process. Undisturbed samples are samples that keep their structural integrity of the in situ soil. Soil classification tests, hydraulic conductivity, and undrained shear strength tests were performed to fully measure the soil properties between high-yielding and low-yielding soils. Understanding the soil properties between the low- and high-yielding subsoil compositions will help determine if the underlying claypan layer is contributing to the undermining of the overlying topsoil (Mathis et al., 2019). Measuring soil properties is important to engineers for designing infrastructure against foundation cracking or failure of bridge supports. Understanding soil properties can assist agronomists to better understand how management practices, such as tillage, impact the loss of soil from a field through erosion.

Experimental Procedures

Soil sample locations were determined from the ERT surveys performed in two crop production fields in a low- and high-yield area (Mathis et al., 2018). A total of four samples were collected from each site: two disturbed samples (i.e., one low yield area and one high yield area) and two undisturbed samples (i.e., one low yield area, one high yield area). The undisturbed samples were taken within close proximity of the disturbed samples (i.e., within 10 ft). The disturbed and undisturbed samples were collected via a direct push method using a tractor-mounted Giddings soil sampler (Giddings Machine Company, Windsor, CO). The disturbed samples were collected from the field in 2.5-ft long × 0.24-ft diameter plastic tubes. The undisturbed samples were collected from the field in 1.0-ft long × 0.24-ft diameter thin-walled Shelby tubes. The water content of each sample was determined according to the standard protocol ASTM D2216-10 (ASTM, 2010) before being sealed at both ends and stored in a moisture room until performing soil classification and strength tests in the laboratory. The water content for each sample was determined to record in situ moisture conditions.

The disturbed soil samples were used to classify the samples collected in the low and high yielding areas from both fields. Most of the samples contained two layers with distinctly different soil characteristics; therefore, the soil properties were recorded for each layer (i.e., Top (T) of sample and Bottom (B) of sample). These samples were classified according to the USCS (ASTM, 2017b). The USCS classifies soils according to particle size via a wet sieve analysis, ASTM C117-17 (ASTM, 2017a), a dry sieve analysis, ASTM C136/C136M (ASTM, 2015a), and LL, PL, and PI, ASTM 4318-17e1 (ASTM, 2017c). The hydrometer test was also performed on each sample according to ASTM D7928-17 (ASTM, 2017d). A final size gradation curve was generated combining the particle size distribution data from the wet sieve analysis, dry sieve analysis, and hydrometer analysis. The P_{200} sieve analysis was determined from the data collected after performing the wet sieve test and indicates the percent fines (i.e., silt and clay-sized particles) passing a 200-openings per square-inch sieve.

Undisturbed samples collected in a low- and high-yielding area were used for the unconsolidated-undrained (UU) triaxial compression test ASTM D2850-15 (ASTM, 2015b). Similar to the disturbed samples, the T and B of the undisturbed sample were tested per sample to determine S_u between a low- and high-yield area (e.g., one sample will have a S_u for the T of the sample and a S_u for the B of the sample).

Ongoing research will include performing hydraulic conductivity tests according to ASTM D5084-16a (ASTM, 2016). The hydraulic conductivity (k) indicates the rate of a fluid flow through a soil.

Results and Discussion

Table 1 summarizes the soil parameters and classification of the samples collected from site 1. Two distinct soil layers were present in sample 1 and sample 2. The two distinct soil layers in both samples were characterized according to the USCS as a lean clay overlying a fat clay and had nearly the same initial water content (ω). Both samples contained more than 85% of silt and clay-sized particles passing a 200-openings per square-inch sieve (i.e., P_{200}). Figure 1A shows the hydrometer test, which was used to determine the particle size distribution of fine-grained (i.e., silt- and clay-sized particles) soil. Figure 1B shows a final particle size gradation curve generated from the wet sieve test, dry sieve test, and hydrometer test. The particle size gradation curves allow for the determination of coarse-grained and fine-grained soil particles. The PI determined for the T and B of sample 1 were relatively low, with the B portion of the sample having a relatively higher PI than the T portion of the sample. Sample 1 was collected from the low-yielding area. Interestingly, the B portion of sample 2 had a PI that was about six times greater than the T portion of the sample. Sample 2 was collected from the high-yielding area. This indicates the fat clay soil in the B portion of sample 2 has a significantly higher plasticity than the T portion.

The two undisturbed samples collected in thin-walled Shelby tubes were collected within close proximity of the disturbed samples in the low- and high-yielding area at site 1. The T and B of these samples were tested in an unconsolidated undrained triaxial test. Figure 2A shows the plotted compressive strength versus axial strain collected during the unconsolidated undrained triaxial test on sample 2-T and sample 2-B. The S_u of the sample was determined from the unconsolidated undrained triaxial test by taking the maximum force loaded on the cylindrical sample over the testing period and dividing by two. Axial strain is the measure of the change of height of the sample relative to the initial height of the sample. Figure 2B shows sample 2-B after performing the unconsolidated undrained triaxial test. The initial parameters of sample 2-B had a height of 5.58 in., a diameter of 2.83 in., and a volume of 35.0 in.^{3}. The S_u value was about two times higher in the B portion than the T portion of the sample 1. The underlying fat clay layer had an S_u of 14.9 psi and the overlying lean clay layer had an S_u of 6.82 psi. The underlying fat clay layer is likely more resistant to erosion than the overlying lean clay layer because of its higher S_u. This supports our hypothesis that the underlying soil (i.e., fat clay) may be enhancing the erosion of the overlying topsoil layer (i.e., lean clay) by the process of undermining at site 1. Interestingly, the T and B of sample 2, collected in the high-yielding area, shared similar S_u results as sample 1 in that the underlying soil layer (i.e., fat clay) had a higher S_u relative to that measured in the topsoil layer (i.e., lean clay). The T and B of sample 2 yielded S_u of 4.76 and 9.30 psi, respectively. The S_u for the T and B portions of sample 2 should be similar in the high-yielding area because no underlying claypan layer was present, although two distinct soil layers were observed from the disturbed sample. The difference between T and B S_u values may be attributed to the presence of a higher strength soil where sample 2 was collected.

Table 2 shows the soil parameters and classification of the samples collected from site 2. As with site 1, two disturbed samples were collected (i.e., one in a low-yielding area and one in a high-yielding area) and used for classifying the soil between the two areas. Unlike site 1, only one soil layer was observed from the disturbed samples collected in site 2. The samples from the low- and high-yielding area both classified as a lean clay and contained more than 85% silt and clay-sized particles passing a 200-opening per square-inch sieve (i.e., P_{200}), though the initial water content (ω) was higher in the high-yielding area. The PI was low for both samples but sample 3, which was collected in the low-yielding area, had a relatively higher PI than sample 4. This indicates that sample 3 has a higher plasticity than sample 4. The T and B of the undisturbed samples collected in the low- and high-yielding areas were tested using the unconsolidated undrained triaxial test to determine the S_u even though only one distinct layer was observed in the disturbed samples. Testing the T and B portion of the undisturbed samples would confirm the presence of one soil layer if the S_u were similar. The T and B S_u for sample 3, collected in the low-yielding area, were 4.06 psi and 8.70 psi, respectively. As with site 1, the low-yielding area at site 2 had a relatively higher S_u in the B portion than the T portion of sample 3. This indicates a relatively stronger soil in the B portion of sample 3 than the T portion even though one distinct soil layer was observed from the disturbed sample. Interestingly, the T and B portion of sample 4, which was collected in the high-yielding area, had a S_u of 6.09 psi and 6.82 psi, respectively. This confirms the presence of one distinct soil layer in the high-yielding area at site 2 because there is no underlying claypan layer present.

The S_u follows a similar trend between the T and B portion of the undisturbed samples collected in the low-yielding area between site 1 and site 2. However, the S_u for the T and B portion of sample 1 is about two times larger than the T and B portion of sample 3 between sites. The S_u for the T and B portion of sample 2 and sample 4 in the high-yielding areas doesn't seem to follow any trend between site 1 and site 2. The B portion of sample 2 had a higher S_u relative to the B portion of sample 4. Unlike sample 4 from site 2, the S_u value for the T and B portions from sample 2 at site 1 were not similar. Further investigation will include performing the unconsolidated undrained triaxial test on samples collected in the low- and high-yielding area at both sites to confirm the first set of S_u values (i.e., T and B portion of undisturbed samples) obtained from samples 1, 2, 3, and 4.

The hydraulic conductivity test will be performed on the T and B portion of undisturbed samples collected in the low- and high-yielding area at both sites to determine the flow of water between the topsoil and claypan layer. The flow of water between the layers will aid in better understanding the mechanism by which the topsoil is eroding due to an underlying claypan layer.

This research has concluded that the presence of a claypan layer (i.e., fat clay) near the surface resulted in low crop yield. The presence of topsoil (i.e., lean clay) at the surface and no underlying claypan layer resulted in higher crop yield. Erosion test results indicated that the claypan layer (i.e., fat clay) was characterized as low erodibility. Conversely, the topsoil layer (i.e., lean clay) characterized moderate erodibility (Mathis et al., 2019). Results from this study indicated the low erodibility soils had higher strength and the moderate erodibility soils had lower strength. Therefore, the presence of a high strength soil underlying a low strength soil is likely increasing the rate of erosion of the more erodible soil by undermining at the interface between the two soil types. Data from this research will aid in the improvement of soil management practices and existing erosion models at field and watershed scales.

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References

ASTM. 2010. D2216-10: Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. West Conshohochen, PA: ASTM Int.

ASTM. 2015a. C136/C136M-14: Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. West Conshohochen, PA: ASTM Int.

ASTM. 2015b. D2850-15: Standard Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils. West Conshohochen, PA: ASTM Int.

ASTM. 2016. D5084-16a: Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Material Using a Flexible Wall Permeameter. West Conshohochen, PA: ASTM Int.

ASTM. 2017a. C117-17: Standard Test Method for Materials Finer than 75-µm (No.200) Sieve in Mineral Aggregates by Washing. West Conshohochen, PA: ASTM Int.

ASTM. 2017b. D2487-17: Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). West Conshohochen, PA: ASTM Int.

ASTM. 2017c. D4318-17e1: Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity of Soils. West Conshohochen, PA: ASTM Int.

ASTM. 2017d. D7928-17: Standard Test Method for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis. West Conshohochen, PA: ASTM Int.

Coduto, D. P., Kitch, W.A., & Yeung, M.R. 2011. Geotechnical engineering: Principles and practices. Upper Saddle River, NJ: Pearson.

Mathis II, M.A., Tran, T.V., Tucker-Kulesza, S.E., Sassenrath, G.F. 2019. Erosion mechanism of claypan soils in southeastern Kansas. Geo Congress, 2019. March 24-27, 2019. Philadelphia, PA. In press.

Mathis, M.A. II, Tucker-Kulesza, S.E., Sassenrath, G.F. 2018. Electrical Resistivity Tomography of Claypan Soils in Southeastern Kansas. Kansas Agricultural Experiment Station Research Reports: Vol. 4: Iss. 3. https://newprairiepress.org/kaesrr/vol4/iss3/13/

NRCS 2019. Soil Texture Calculator. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054167

Table 1. Soil parameters and classification of site 1

Location	Sample	ω	LL	PI	P_{200}	USCS classification	S_u
		------------------------%------------------------					psi
Low crop yield-1	1-T	27.3	30	14	89	Lean clay	T = 6.82
	1-B		53	29	85	Fat clay	B = 14.9
High crop yield-1	2-T	25.8	27	9	89	Lean clay	T = 4.76
	2-B		76	51	95	Fat clay	B = 9.30

T = top of sample; B = bottom of sample; ω = percent water content; LL = Lower Limit, %; PI = Plasticity Index, %; P_{200} = percent soil particles passing through a 200-openings per square-inch sieve; S_u = undrained shear strength, psi.

Table 2. Soil parameters and classification of site 2

Location	Sample	ω	LL	PI	P_{200}	USCS classification	S_u
		------------------------%------------------------					psi
Low crop yield-2	3	24.7	31	14	88	Lean clay	T = 4.06 B = 8.70
High crop yield-2	4	35.6	30	11	85	Lean clay	T = 6.09 B = 6.82

T = top of sample; B = bottom of sample; ω = percent water content; LL = Lower Limit, %; PI = Plasticity Index, %; P_{200} = percent soil particles passing through a 200-openings per square-inch sieve; S_u = undrained shear strength, psi.

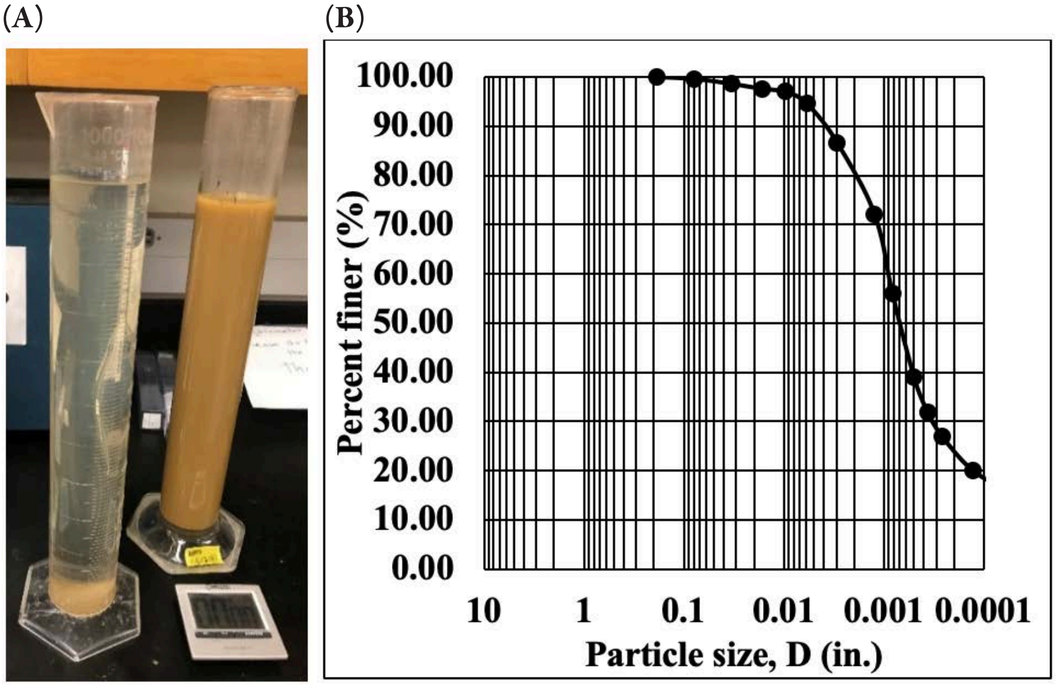

Figure 1. (A) The hydrometer test was used to determine the particle size distribution of soil particles that passed a 200-openings per square-inch sieve (i.e., P_{200}, silt and clay soil particles). The graduated cylinder in front with the clear liquid contains the water with dispersant. The cylinder in back with the cloudy liquid contains the soil sample in the water-dispersant solution used to measure soil particle size. (B) The data from the wet sieve test, dry sieve test, and hydrometer test were used to generate a particle size gradation curve. The particle size gradation curve plots the soil particle passing percentage vs. the particle size and allows for the determination of coarse-grained and fine-grained soil particles.

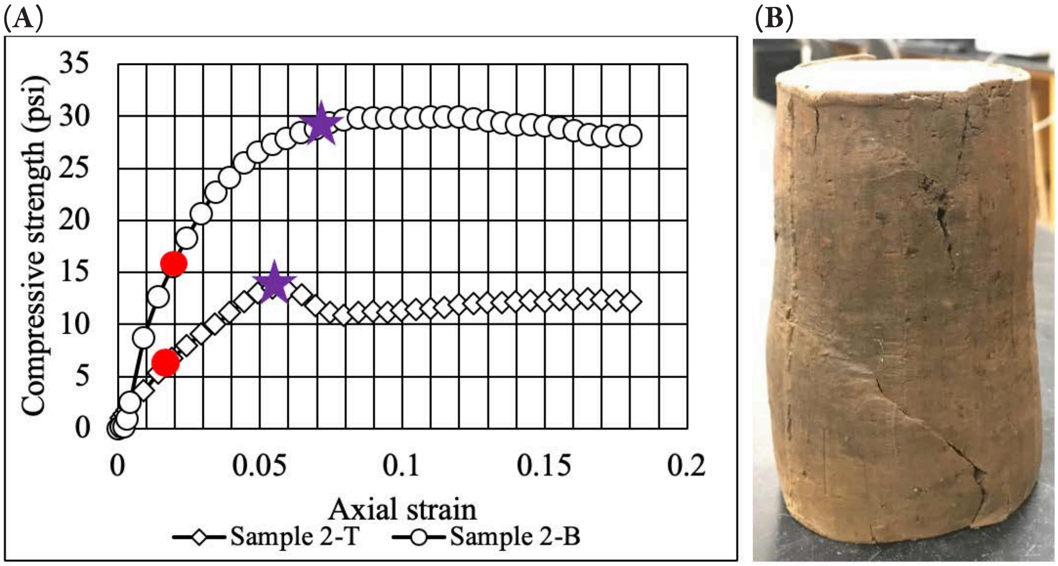

Figure 2. Unconsolidated-undrained triaxial test results. The solid red dot represents the undrained shear strength of the sample and the purple star represents the maximum axial load applied to the sample. (A) Sample 2-T (diamond-shaped points) produced an undrained shear strength (S_u) at failure equal 6.82 psi and axial strain equal to 0.017. Sample 2-B (circle-shaped points) produced an S_u at failure equal to 15.0 psi and an axial strain equal to 0.020. (B) Sample 2-B test specimen after performing the unconsolidated undrained triaxial test.