Kansas Agricultural Experiment Station Research Reports

Volume 4
Issue 3 *Southeast Agricultural Research Center Reports*

Article 13

2018

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Recommended Citation

Mathis, M. A. II; Tucker-Kulesza, S. E.; and Sassenrath, G. F. (2018) "Electrical Resistivity Tomography of Claypan Soils in Southeastern Kansas," *Kansas Agricultural Experiment Station Research Reports*: Vol. 4: Iss. 3. https://doi.org/10.4148/2378-5977.7574

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Electrical Resistivity Tomography of Claypan Soils in Southeastern Kansas

Abstract
Claypan soils cover approximately 10 million acres across several states in the central United States. The soils are characterized by a highly impermeable clay layer within the profile that impedes water flow and root growth. While some claypan soils can be productive, they must be carefully managed to avoid reductions to crop productivity due to root restrictions, water, and nutrient limitations. Clay soils are usually resistant to erosion but may exacerbate erosion of the silt-loam topsoil.

Soil production potential is the capacity of soil to produce at a given level (yield per acre). The productive capacity is tied to soil characteristics, which can be highly variable within a field. In this project, we have used imagery analysis to study the aerial images and terrain of fields during different productive times of the year to identify where soil samples should be collected for more discrete analysis. Soil samples provide valuable information; however, the amount of data obtained from a relatively small area within a field does not provide sufficient information to delineate the subsurface characteristics. To address the limitations of sampling, we have also employed the use of yield maps collected from commercial yield monitors on production-scale combines and surface electrical conductivity measurements (Sassenrath and Kulesza, 2017).

Soil conductivity is a measurement of how well a representative volume of soil conducts electricity. Soil conductivity is a function of the soil clay content, moisture content, and other measurable soil properties (Kitchen et al., 2003); as such, it has become a valuable tool for mapping in-field variability. The main advantage of a soil conductivity measurement is that the entire surface of a field can be imaged. The disadvantage of a soil conductivity measurement is that data are only collected near the surface (10 – 30 inches) and the measurements are relative measurements. This means that the conductivity mappers can identify changes in soil properties, but they cannot directly tell researchers what caused these changes.

Electrical resistivity tomography (ERT) is a popular near-surface geophysical measurement for geophysical and engineering applications. The term "near-surface" generally means down to around 30 feet in the subsurface. Electrical resistivity is the reciprocal measurement of electrical conductivity; therefore, both systems measure differences in the same soil properties. ERT measurements are different than surface electrical conductivity measurements because ERT collects a "slice" of data into the subsurface, as opposed to only changes at the surface area. Relative measurements, similar to those collected in an electrical conductivity survey, are collected; however, in ERT studies the data are mathematically inverted to yield the true electrical resistivity of the soil with depth. This allows an interpretation of the changing soil properties with depth to reduce the required amount of sampling. A disadvantage of an ERT survey is that the data acquisition is stationary so mapping an entire field is not feasible. We have used a coupled process of imagery and terrain analysis, yield maps, and electrical conductivity measurements to guide the locations of ERT surveys in this project (Tucker-Kulesza et al. 2017).

Keywords
Soil health, tillage, cover crops

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Cover Page Footnote
This work is supported by the U.S. Department of Agriculture National Institute of Food and Agriculture, Hatch project 1003478, and partial funding through a grant from the National Science Foundation, Environmental Sustainability (CBET #1705823). The authors gratefully acknowledge the support of the Kansas State University Women in Engineering Program. The authors thank Lonnie Mengarelli, Garth Blackburn, and Adam Harris for their contribution to the field measurements. We gratefully acknowledge the cooperation of the participating farmer in providing us access to his land. The findings in this report are those of the authors and may not reflect the views of the USDA or the National Science Foundation.

This Cropping Systems Research article is available in Kansas Agricultural Experiment Station Research Reports: http://newprairiepress.org/kaesrr/vol4/iss3/13

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Summary

Crop production and yield in southeast Kansas are highly variable. This may be attributed to many factors, including the variability of soil properties within a field. The relationship between soil and crop yield can be determined by studying bulk properties at the surface such as soil conductivity, crop production maps, and terrain; however, this does not give a complete picture of the underlying causes. Electrical resistivity tomography (ERT) measures changes in soil properties with depth, creating an image of the soil subsurface. Previous researchers believed that the claypan structure in southeastern Kansas was fairly consistently present across fields. The ERT analysis conducted in this study showed that the depth to claypan and the structure of the claypan is actually highly variable. Understanding the subsurface stratigraphy may help to improve crop production and yield by highlighting the ongoing subsurface processes.

Introduction

Claypan soils cover approximately 10 million acres across several states in the central United States. The soils are characterized by a highly impermeable clay layer within the profile that impedes water flow and root growth. While some claypan soils can be productive, they must be carefully managed to avoid reductions to crop productivity due to root restrictions, water, and nutrient limitations. Clay soils are usually resistant to erosion but may exacerbate erosion of the silt-loam topsoil.

Soil production potential is the capacity of soil to produce at a given level (yield per acre). The productive capacity is tied to soil characteristics, which can be highly variable within a field. In this project, we have used imagery analysis to study the aerial images and terrain of fields during different productive times of the year to identify where soil samples should be collected for more discrete analysis. Soil samples provide valuable information; however, the amount of data obtained from a relatively small area within a field does not provide sufficient information to delineate the subsurface characteristics. To address the limitations of sampling, we have also employed the use of yield maps collected from commercial yield monitors on production-scale combines and surface electrical conductivity measurements (Sassenrath and Kulesza, 2017).

Soil conductivity is a measurement of how well a representative volume of soil conducts electricity. Soil conductivity is a function of the soil clay content, moisture content, and other measurable soil properties (Kitchen et al., 2003); as such, it has become a valuable tool for mapping in-field variability. The main advantage of a soil conductivity measurement is that the entire surface of a field can be imaged. The disadvantage of a soil conductivity measurement is that data are only collected near the surface (10 – 30 inches) and the measurements are relative measurements. This means that the conductivity mappers can identify changes in soil properties, but they cannot directly tell researchers what caused these changes.

Electrical resistivity tomography (ERT) is a popular near-surface geophysical measurement for geophysical and engineering applications. The term "near-surface" generally means down to around 30 feet in the subsurface. Electrical resistivity is the reciprocal measurement of electrical conductivity; therefore, both systems measure differences in the same soil properties. ERT measurements are different than surface electrical conductivity measurements because ERT collects a "slice" of data into the subsurface, as opposed to only changes at the surface area. Relative measurements, similar to those collected in an electrical conductivity survey, are collected; however, in ERT studies the data are mathematically inverted to yield the true electrical resistivity of the soil with depth. This allows an interpretation of the changing soil properties with depth to reduce the required amount of sampling. A disadvantage of an ERT survey is that the data acquisition is stationary so mapping an entire field is not feasible. We have used a coupled process of imagery and terrain analysis, yield maps, and electrical conductivity measurements to guide the locations of ERT surveys in this project (Tucker-Kulesza et al. 2017).

Experimental Procedures

Crop production fields were selected in collaboration with farmer co-operators. Yield information was collected at harvest. Yields were recorded with commercial yield monitors on production-scale combines. A Veris 3100 system was used to measure soil electrical conductivity for the entire field. The Veris system measures apparent electrical conductivity (EC_a) through the field using two arrays of electrodes on coulters. The arrays measure EC_a at two depths in the field: 0-10 inches and 0-30 inches. The minimum depth, 0-10 inches, was used because this is the depth of interest for this study. The boundary condition for a designated "low yield" area and "high yield" area was determined using the electrical conductivity data and the crop yield data for the field.

ERT surveys were used to measure the apparent resistivity of the underlying soil profile. These surveys began in a low crop yield area and ended in a high crop yield area to show the change in soil subsurface material. Setup for an ERT survey included attaching 56 stainless steel electrodes to 56 stainless steel stakes and driving the stakes into the ground so that the electrodes sit just above the surface (Figure 2). The spacing between each electrode determined the survey depth, therefore, 0.5 feet spacing was used to provide detailed information on the upper soil layers (less than 5 feet). The sequence of measurements, or array type, in an ERT survey affects the resolution of the results and the data collection time. A strong gradient was selected as it collects high resolution data near the surface in approximately one hour. A terrain analysis was conducted to measure the elevation at each electrode. ERT data were mathematically inverted to determine the electrical resistivity of the subsurface using geophysical mathematical procedures. Soil samples were collected in discrete locations throughout the field and will be tested to determine soil type and soil erosion properties in the next phase of this research.

Results and Discussion

Figure 1A shows the EC_a across the field. High EC_a measurements are indicative of soils with high clay content. The high EC_a measurements directly correlated to areas of low crop yield in the field as shown in Figure 1B. The black line in Figure 1B shows where the ERT surveys were conducted. Three surveys were collected starting in the middle of the low crop yield area and working north to the high yield area in Figure 1B. The surveys shown in Figure 3 overlap with each other such that the middle of Figure 1A is the starting point of Figure 1B and the middle of Figure 1B is the starting point of Figure 1C.

The first survey (Figure 3A), starts in the middle of a low crop yield area. A low resistivity layer, shown in purple, of approximately 10 Ohm-m was measured from the surface to approximately 0.46 ft. The electrical resistivity of clay is generally 1-20 Ohm-m (Everett 2013), indicating that this layer is likely a clayey soil. This highly impermeable clay layer is exposed at the surface. Although Figure 3A shows the soil in the lower layer had a resistivity of 20 Ohm-m, it was in fact higher, indicating a sandy soil beneath the clay layer at the surface (yellow to red zone). The upper level of 20 Ohm-m was set to improve visualization of the shallow soils of interest near the surface.

The ERT survey conducted in the transition area between the low and high crop yield area (Figure 2B) shows the impermeable clay layer thinning as the region of measurements moves towards a high crop yield area. Figure 3C was conducted in a high crop yield area. No low resistivity areas (10 Ohm-m or less) were noted in this section of the field. This is significant because it was originally thought that claypan soils were uniform throughout the region. The ERT profiles show that the claypan layer is not present in certain areas of the field. Rather than being overlain with topsoil, the clay layer is not present under the high-yielding region of the field. This is contrary to previous research that indicated a persistent clay layer, with differing depth to clay layer. Soil samples were collected from each survey shown in Figure 3. The soil classification will be performed to further explore differences in soil textural information between these different locations.

Acknowledgments

This work is supported by the U.S. Department of Agriculture National Institute of Food and Agriculture, Hatch project 1003478, and partial funding through a grant from the National Science Foundation, Environmental Sustainability (CBET #1705823). The authors gratefully acknowledge the support of the Kansas State University Women in Engineering Program. The authors thank Lonnie Mengarelli, Garth Blackburn, and Adam Harris for their contribution to the field measurements. We gratefully acknowledge the cooperation of the participating farmer in providing us access to his land. The findings in this report are those of the authors and may not reflect the views of the USDA or the National Science Foundation.

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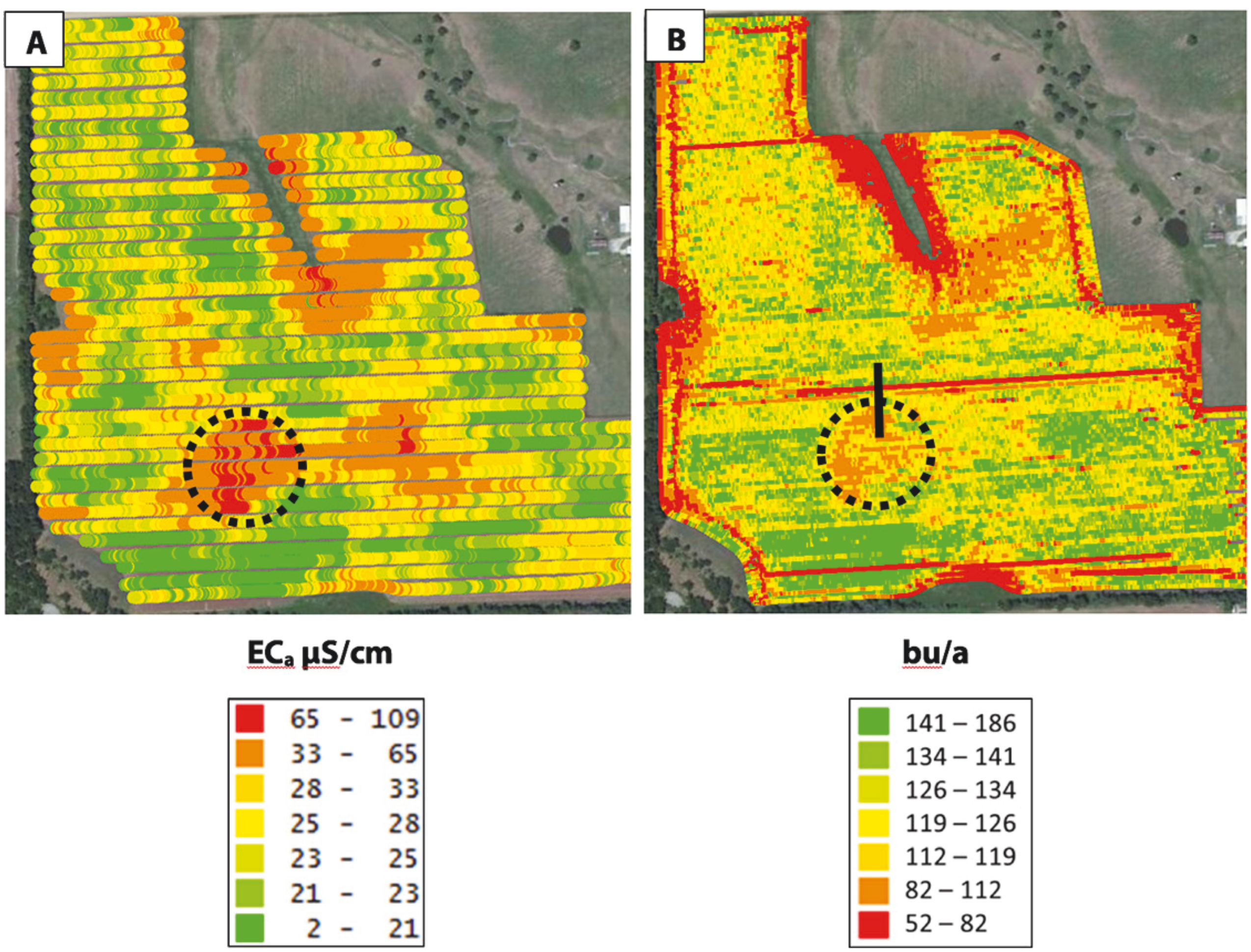

Figure 1. Experimental site: (A) Apparent electrical conductivity (EC_a) map. High EC_a indicates high clay content. (B) Corn crop yield map. Note that low crop yield is correlated with high EC_a. The black line shows where ERT surveys were collected.

Figure 2. ERT survey experimental setup. Each stainless steel stake is 12 in. long and placed at half-foot intervals across the survey. The stainless steel electrodes are attached to the stainless steel stakes where an electrical current is transmitted through each electrode. The apparent resistivity measurements are recorded for each electrode and stored for later analysis to build the soil profile images presented in Figure 3.

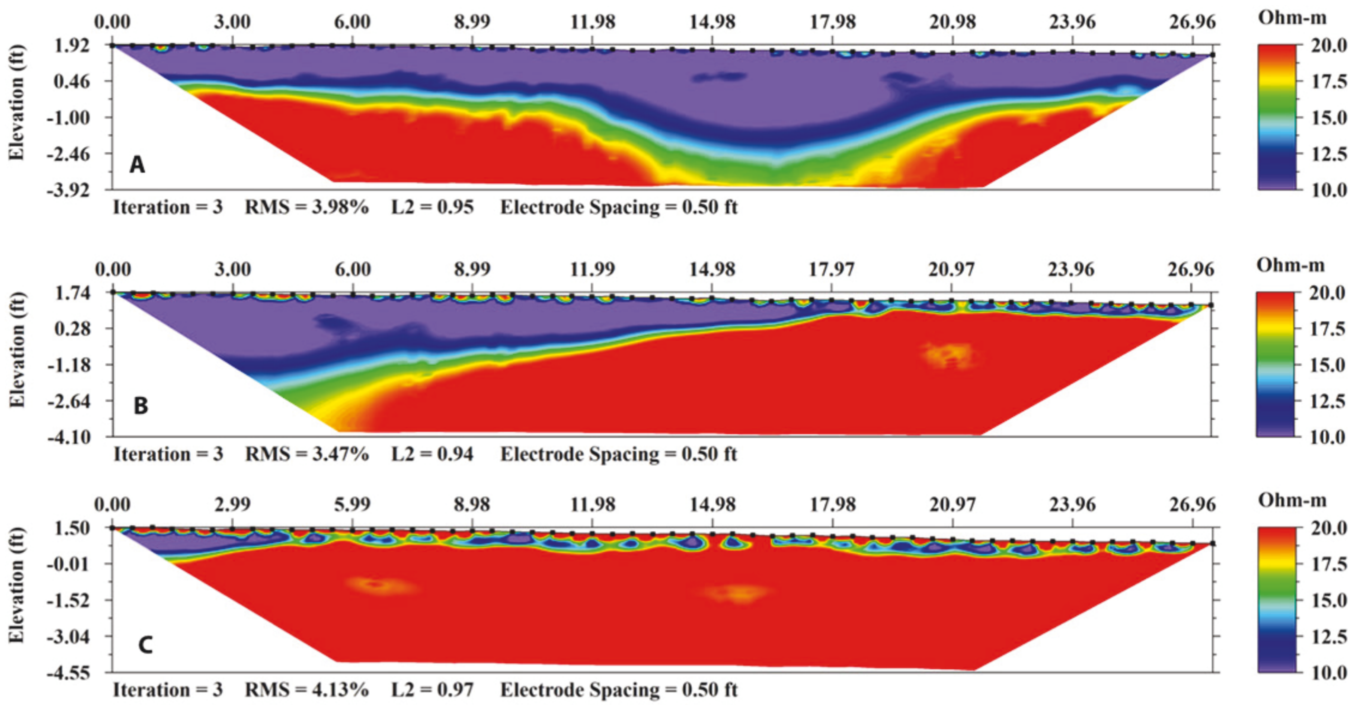

Figure 3. ERT survey results: (A) Low crop yield area; (B) transition area between a low and high crop yield; and (C) high crop yield area.