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Apparent electrical conductivity response to spatially variable vertisol properties

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A B S T R A C T

Though much has been done to understand proximally-sensed bulk apparent electrical conductivity (EC_a) in agricultural soils, many of the soil properties identified to be mappable using these techniques, such as salinity and clay content, are not expected to drive EC_a response in a non-saline Vertisol. In Vertisols, agrillipedoturbation creates meter-scale variability in soil moisture and chemical properties associated with gilgai features, and if developed from calcareous parent material, can exhibit meter and landscape scale variability in inorganic C content. The ability to map inorganic C may be especially useful in a Vertisol due to its strong correlation with shrink-swell potential. The overall goal of this project was to investigate the potential for mapping inorganic C using EC_a surveys in a calcareous Vertisol, with the future goal of mapping shrink-swell potential on these landscapes. On a 40- by 50-m field with intact circular gilgai, EC_a was mapped under both moist and dry soil conditions. Soil samples were taken for water content, clay content, inorganic C content, salinity, and depth to parent material. Under moist soil conditions, the strongest correlation to EC_a was inorganic C content ($r = -0.63$), followed by water content ($r = 0.49$); however, under dry conditions, only inorganic C content was significant ($r = -0.60$). In addition, EC_a surveys and inorganic C samples were taken for two larger watersheds of 10 and 14 ha. Again, inorganic C content was significantly and reliably correlated to EC_a for both fields, and the resulting regression slopes and intercepts were not significantly different between watersheds, though the surveys were conducted at different times. Results suggest that EC_a can be used to map inorganic C content in Vertisols weathered from calcareous parent materials, allowing for spatial inference of shrink-swell potential which may be useful in distributed hydrology modeling.

1. Introduction

Bulk apparent electrical conductivity of the soil (EC_a), as measured by electromagnetic induction, is a useful measurement that is commonly used to map the spatial variability of soil salinity, water content, and clay content, especially as they relate to agriculture and land management (Rhoades et al., 1976; McBride et al., 1990; Corwin and Lesch, 2005; Brevik et al., 2006). In moderately-fine to coarse-textured agricultural soils, the EM38 (Geonics Limited, Mississauga, Ontario, Canada), a popular electromagnetic induction instrument, has been used to map zones of soil variability for precision agriculture (Lund et al., 1999; Johnson et al., 2001; Corwin and Lesch, 2005), predict clay content (Carroll and Oliver, 2005; Weller et al., 2007; Harvey and Morgan, 2009) and soil depth (Doolittle et al., 1994; Akbar et al., 2004; Serrano et al., 2010), as well as map soil water content (Kachanoski et al., 1990; Zhu et al., 2010a; Zhu et al., 2010b). However, variability of EC_a has been observed in non-saline Vertisol landscapes when none of these properties vary under saturated soil moisture conditions (Rivera, 2011). In the calcareous Vertisols of the Texas Blackland Prairie, response of EC_a might be driven by changes in inorganic C content, as was observed in a calcareous sand (Kuhn et al., 2009). Knowledge of the soil properties that influence electromagnetic induction response on Vertisol landscapes would help assess the usability of these proximal sensors in otherwise relatively uniform, high-clay soils.

Soil properties can have a direct or indirect influence on the conductivity of the soil. Direct influence requires a soil property to alter the conductivity of either the liquid or solid phase of the soil (Rhoades et al., 1976). Soil properties such as salinity and clay content directly influence the EC_a due to increasing the conductivity of the liquid and solid phase respectively. An example of indirect influence would be soil organic matter, because while it influences the water holding capacity and the number of cations in soil solution, EC_a does not respond directly to changes in organic matter content but rather the changes in the solid and liquid phase conductivity altered by the organic matter. We propose inorganic C will have a direct influence on EC_a because increasing the amount of inorganic C will decrease the overall solid phase conductivity through a decrease in specific surface area (Holford and Mattingly, 1975) and displacing charged clay particles (Rhoades et al., 1976).

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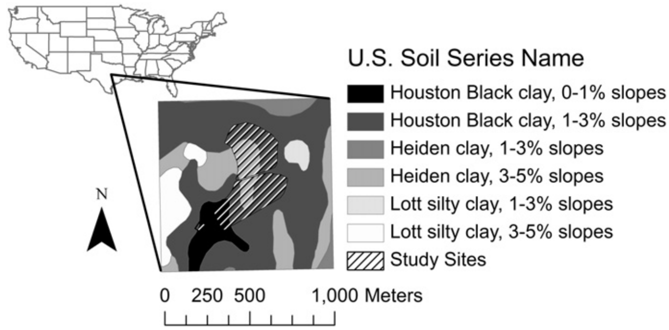

Fig. 1. Study site located near Riesel, Texas, on the USDA-ARS Grassland, Soil and Water Research Laboratory.

In Vertisols formed from calcareous parent materials, inorganic C concentrations are largely driven by the extent of weathering of the parent material and translocation of inorganic C. Variability in weathering, and therefore inorganic C content, is influenced by landscape position and can occur at the 10-m scale. In addition, Wilding et al. (1989) observed variability in inorganic C on the meter-scale due to surface microtopography features called gilgai. Gilgai are surface features consisting of small depressions (microlows) separated by ridges (microhighs), and often coincide with surface topography. Within these features, increased clay content and organic C content is found in the bowls/microlows and increased inorganic C content in the chimneys/microhighs, relative to the opposite position. Inorganic C also has a strong relationship with the shrink-swell potential of the soil (Dinka et al., 2013), making it a potentially useful soil property for mapping shrink-swell potential.

The overall objective of this project was to investigate the potential for mapping inorganic C using EC_a surveys in a calcareous Vertisol, with the future goal of increased accuracy in mapping shrink-swell potential on these landscapes. In addition, it is useful to link EC_a with soil properties using correlations and empirical models, as in McBratney et al. (2005). The specific objectives of this study were to 1) describe the response of EC_a to measured soil properties on calcareous Vertisols through a small-scale, detailed study, 2) investigate the response of the EM38 to inorganic C at the field scale under two land-uses, and 3) build an empirical model to predict inorganic C content across non-saline Vertic landscapes using proximally-sensed EC_a.

2. Materials and methods

This study was conducted in the Blackland Prairie of Texas, U.S.A., an ecoregion of around 50,000 km^2 that includes the large population center of Dallas (Griffith et al., 2007). A detailed, small-field study and a large field study were conducted to evaluate the response of the EM38 to soil properties. The detailed field study measured multiple soil properties to determine the effect of soil moisture, clay content, salinity, depth of the soil to the parent material, and inorganic C content on proximally sensed EC_a across a 0.2-ha area with circular gilgai. The large field study was conducted in two, adjacent watersheds of 10 and 14 ha each. One field was cropped annually and the other was under improved pasture conditions. The large field study was only sampled for inorganic C. All study sites were located on the USDA-ARS Grassland, Soil and Water Research Laboratory watershed network near Riesel, TX (Fig. 1).

2.1. Detailed field study

A 40- by 50-m area of Houston Black clay (fine, smectitic, thermic Udic Haplusterts) was investigated for the detailed study. The study site had not been plowed for over 30 years and contained circular gilgai microtopography. One electromagnetic induction survey and soil sampling was conducted on 11 March 2011, when the field was close to field capacity, and an additional survey was conducted on 11 September 2011, under dry soil conditions. An EM38 sensor in the vertical dipole mode only was used to measure EC_a in combination with an AgGPS for geo-referencing (Trimble Navigation Limited, Sunnyvale, CA). In the vertical dipole mode, the EM38 senses from 1.5 to 2 m deep, with a sampling area of approximately 1 m^2 (McNeil, 1980). Both surveys were walked (1.1 m s^{-1}) on 1-m, parallel transects while logging EC_a measurements and GPS location automatically every second. Instrument drift was assessed using one location marked for measurements before and after surveys, and soil temperature was recorded 5 cm below the soil surface before and after surveys. All EC_a measurements were standardized to 25 °C using the Sheets and Hendrickx (1995) correction,

$$EC_{25} = EC_T * \left(0.4470 + 1.4034e^{-T/26.815}\right), \quad (1)$$

where EC_T is the EC_a data collected, and T is the measured soil temperature (°C). For simplicity, temperature corrected EC_a (EC_{25}) will still be referred to as EC_a.

Geo-referenced soil samples were collected for soil water content at the time of each survey, plus soil properties including clay content, soil depth, inorganic C content, and electrical conductivity of the soil solution were measured in the laboratory. Sampling locations across the field were stratified based on EC_a and landscape position to capture the range of measured EC_a measurements. A total of 16 sampling sites were selected for the March survey. At each sampling location, two 5-cm diameter cores were taken within 0.5 m distance. One core was taken for volumetric water content and cut into 10-cm sections, and the other was cut into 20-cm sections and air-dried at 60 °C for analysis of soil properties. During the September survey, 8 of the 16 original sampling locations were selected and soil cores for soil water content only were collected. Soil cores were taken to a depth of 2 m or to the weathered marl parent material.

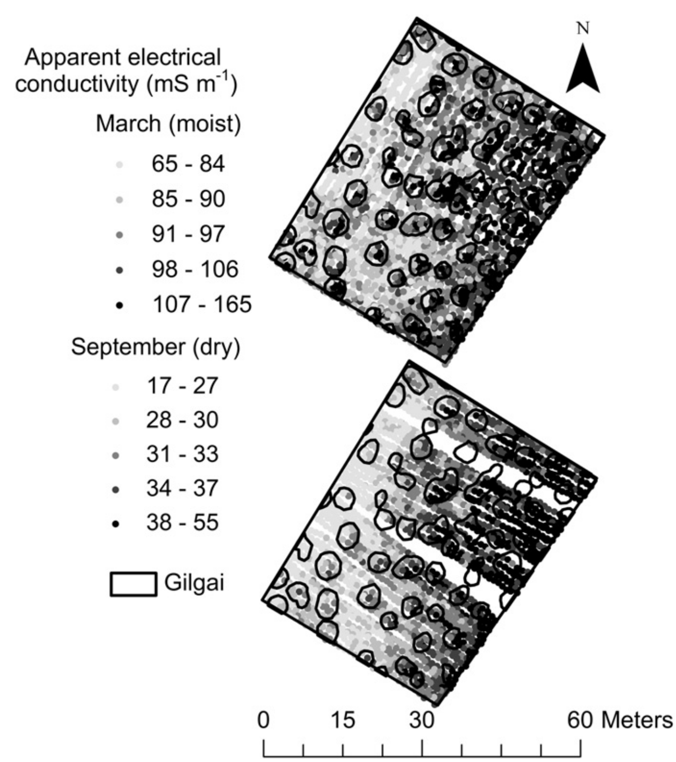

Fig. 2. Apparent electrical conductivity for the detailed field study. Apparent electrical conductivity is from moist (March) and dry (September) surveys.