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Relating apparent electrical conductivity to soil properties across the north-central USA

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Abstract

Apparent electrical conductivity (EC_a) of the soil profile can be used as an indirect indicator of a number of soil physical and chemical properties. Commercially available EC_a sensors can efficiently and inexpensively develop the spatially dense datasets desirable for describing within-field spatial soil variability in precision agriculture. The objective of this research was to relate EC_a data to measured soil properties across a wide range of soil types, management practices, and climatic conditions. Data were collected with a non-contact, electromagnetic induction-based EC_a sensor (Geonics EM38) and a coulter-based sensor (Veris 3100) on 12 fields in 6 states of the north-central United States. At 12–20 sampling sites in each field, 120-cm deep soil cores were obtained and used for soil property determination. Within individual fields, EM38 data collected in the vertical dipole orientation (0–150 cm

Abbreviations: CEC, cation exchange capacity; DGPS, differential global positioning system; EC, electrical conductivity; EC_a, apparent soil electrical conductivity; $EC_{a\text{-sh}}$, shallow (0–30 cm) EC_a measured by Veris 3100; $EC_{a\text{-dp}}$, deep (0–100 cm) EC_a measured by Veris 3100; $EC_{a\text{-em}}$, vertical mode (0–150 cm) EC_a measured by Geonics EM38; EM, electromagnetic induction; GPS, global positioning system; MLRA, major land resource area; PSD, profile standard deviation

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depth) and Veris 3100 deep (0–100 cm depth) data were most highly correlated. Differences between EC_a sensors were more pronounced on more layered soils, such as the claypan soils of the Missouri fields, due to differences in depth-weighted sensor response curves. Correlations of EC_a with clay content and cation exchange capacity (CEC) were generally highest and most persistent across all fields and EC_a data types. Other soil properties (soil moisture, silt, sand, organic C, and paste EC) were strongly related to EC_a in some study fields but not in others. Regressions estimating clay and CEC as a function of EC_a across all study fields were reasonably accurate ($r^2 \geq 0.55$). Thus, it may be feasible to develop relationships between EC_a and clay and CEC that are applicable across a wide range of soil and climatic conditions.

Keywords: Soil electrical conductivity; Precision agriculture; Sensors; EM38; Veris 3100

1. Introduction

Efficient and accurate methods of measuring within-field variations in soil properties are important for precision agriculture. Sensors that can collect dense datasets while traversing a field provide several advantages over traditional measurement methods that involve soil sample collection and analysis. These advantages may include lower cost, increased efficiency, and more timely results. In addition, the ability to obtain data at many more points with a sensor, as compared to sampling methods, means that overall spatial estimation accuracy can increase even if the accuracy of individual measurements is lower (Sudduth et al., 1997).

Apparent electrical conductivity (EC_a) of the soil profile is a sensor-based measurement that can provide an indirect indicator of important soil physical and chemical properties. Soil salinity, clay content, cation exchange capacity (CEC), clay mineralogy, soil pore size and distribution, and soil moisture content are some of the factors that affect EC_a (McNeill, 1992; Rhoades et al., 1999). Most of the variation in EC_a can be related to salt concentration for saline soils (Williams and Baker, 1982). In non-saline soils, conductivity variations are primarily a function of soil texture, moisture content, and CEC (Rhoades et al., 1976). A theoretical basis for the relationship between EC_a and soil properties was developed by Rhoades et al. (1989). In this model, EC_a was a function of soil water content, the electrical conductivity of the soil water, soil bulk density, and the electrical conductivity of the soil particles. Recently, techniques have been developed to use this model for predicting the expected correlation structure between EC_a data and multiple soil properties of interest (Lesch and Corwin, 2003).

Two types of portable, within-field EC_a sensors are commercially available for agriculture, an electrode-based sensor requiring soil contact and a non-contact electromagnetic induction (EM) sensor. In an early report of the electrode-based approach, Halvorson and Rhoades (1976) measured EC_a with a four-electrode sensor and used these measurements to create maps of soil salinity variations in a field. Later, a version of the electrode-based sensor was tractor-mounted for mobile, georeferenced measurements of EC_a (Rhoades, 1993). A commercial device implementing the electrode-based approach is the Veris 3100[1] (Veris

[1] Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture or its cooperators.