APPARENT ELECTRICAL CONDUCTIVITY AS A TOOL FOR DELINEATING SPATIAL PATTERNS IN INHERENT SOIL PROPERTIES

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ABSTRACT

Soil properties affecting crop yield exhibit spatial variability. Apparent electrical conductivity (ECa) can be economically measured and is well correlated with many soil properties. Methods for processing ECa survey data and determining the relationship between ECa and soil properties are needed. An ECa survey was conducted on two fields and processed using the ESAP computer program. Soil samples to calibrate and validate the program were collected. An initial assessment resulted in a successful calibration for soil water content, bulk density, total dissolved solids, pH, Bray available P, soil organic matter, and clay content. Validation was significant for only total dissolved solids, organic matter, and clay content. Validation of additional soil properties may result with more thorough analysis of the data or an increase in the number of soil samples. Based on this initial assessment we conclude that the ESAP program has potential for processing ECa survey data, determining soil sampling designs, and relating measured soil properties to ECa.

INTRODUCTION

Soils exhibit spatial variation in soil properties. This variation complicates management and effects crop yield. Uniform management of spatially variable fields results in inefficient use of inputs and potential for environmental contamination. Variable management requires that we map the variation present in a field and understand how that variation effects crop production and crop utilization of management inputs. Mapping variation in soil properties requires some level of soil sampling and laboratory analysis. Methods such as grid sampling are labor intensive and expensive. Apparent electrical conductivity (ECa) is a measure that is affected by a number of soil properties and has potential for economically mapping spatial variability within a field (Johnson et al., 2001).

Conducting ECa surveys is relatively easy with several instruments commercially available. Methods for processing and interpreting ECa data are needed. In addition, methods for correlating ECa measurements to soil properties are needed. The ESAP computer program uses regression and spatial statistics to process ECa data, determine soil sampling designs, and estimate relationships between measured soil properties and ECa (Corwin and Lesch, 2003). The ESAP program was developed for monitoring salinity in saline soils and has not been extensively assessed in non-saline soils. The objective of this study was to evaluate the potential for using the ESAP program to process ECa data collected from non-saline soils and relate ECa data to measured soil properties.

MATERIALS AND METHODS

This study was conducted near Carleton, NE. Two fields, one cropped to soybean (*Glycine max* (L.) Merr.) and one cropped to corn (*Zea mays* L.), were selected for sampling. An ECa survey was conducted using two EM-38 electromagnetic induction sensors (Geonics Limited, Mississauga, ON, Canada) coupled together so that both vertical and horizontal readings could be recorded. This instrument was installed on a non-metalic sled pulled behind an all terrain vehicle. A global positioning system (GPS) was used to georeference ECa values as the survey was conducted. The ECa data was processed using the ESAP software package (Lesch et al., 2000). This program uses spatial statistics to select sampling locations that reflect the observed spatial variability in ECa (Corwin and Lesch, 2003). Two soil sampling designs, one to calibrate ESAP and one to validate ESAP, were generated for each field. Each sampling design consisted of 12 sampling locations. At each sampling location a soil core was collected from the 0- to 90-cm depth and depth of topsoil was determined. Samples were sectioned into 0- to 15-cm, 15- to 30-cm, 30- to 60-cm, and 60- to 90-cm increments, air-dried, and sieved. Soil water content, bulk density, pH, electrical conductivity (EC), SOM content, Bray-available P, and clay content were determined. Laboratory EC values were converted to total dissolved solids using the conversion provided by Smith and Doran, (1996). Measured soil property values for each increment were summed across the 0- to 90-cm depth.

Soil properties measured in samples collected using the first design were used to calibrate ESAP for prediction of spatial patterns in those properties. Soil properties measured in samples collected using the second design were compared to the predicted spatial patterns in those properties using the coefficient of determination (r^2) as a goodness of fit measure. Correlation analysis will be used to determine the association among ECa and soil properties.

RESULTS AND DISCUSSION

Vertical ECa readings ranged from 3 to 78 dS m^{-1} in the soybean field. Observed vertical ECa values were highest in the east and west edges of the field with lower readings in the center (Fig. 1). The center of this field was fairly level and large areas with similar ECa in that part of the field lead us to conclude that there is also little variation in other soil properties in that part of the field.

In the soybean field, ECa correlated well with all of the measured soil properties in the calibration run (Table 1). When observed and predicted values were compared in the validation run the coefficient of determination was lower for all soil properties and correlations for water content and topsoil depth were poor. Results from this field lead us to conclude that mapping spatial variability in inherent soil properties such as bulk density, organic matter content, and clay content using ECa and ESAP directed soil sampling would be feasible. Results for pH and Bray P lead us to conclude that an ECa map could potentially be used as an application map for lime or P fertilizer.

Figure 1. Vertical Apparent Electrical Conductivity map for the soybean site near Carlton, NE.

Table 1. Correlation between observed and predicted soil properties in the 0- to 90-cm depth used in the calibration run and validation run for the soybean field near Carleton, NE

Soil Property	Calibration		Validation	
	r^2	p-value	r^2	p-value
Water Content, kg m^{-2}	0.55	0.006	0.14	0.230
Topsoil depth, cm	0.83	0.001	0.15	0.215
Bulk density, g cm^{-3}	0.98	0.001	0.55	0.006
Total dissolved solids, g m^{-2}	0.59	0.004	0.48	0.012
pH	0.72	0.001	0.28	0.079
Bray P, g m^{-2}	0.68	0.001	0.56	0.005
Soil organic matter, kg m^{-2}	0.82	0.001	0.28	0.076
Clay content, kg m^{-2}	0.73	0.001	0.37	0.035

Vertical ECa readings ranged from 20 to 113 dS m^{-1} in the corn field. Observed vertical ECa values were highest in the northwest corner of the field with small areas of lower ECa in the south and east areas of the field (Fig. 2). This field exhibited higher ECa values, a slightly larger range in ECa values, and greater spatial variability in ECa than did the soybean field.

In the corn field, ECa correlated well with all of the measured soil properties except topsoil depth in the calibration run (Table 2). When observed and predicted values were compared in the validation run the coefficient of determination was lower for all soil properties and correlations for all soil properties except clay content, soil organic matter, and total dissolved solids were poor. These results lead us to conclude that even in this more variable field, mapping spatial variability in inherent soil properties such as bulk density, organic matter content, and clay content using ECa and ESAP directed soil sampling would be feasible.

Figure 2. Vertical Apparent Electrical Conductivity map for the corn site near Carlton, NE.

Table 2. Correlation between observed and predicted soil properties in the 0- to 90-cm depth used in the calibration run and validation run for the corn field near Carleton, NE

Soil Property	Calibration		Validation	
	r^2	p-value	r^2	p-value
Water Content, kg m^{-2}	0.69	0.001	0.23	0.115
Topsoil depth, cm	0.25	0.094	0.01	0.951
Bulk density, g cm^{-3}	0.47	0.014	0.02	0.145
Total dissolved solids, g m^{-2}	0.86	0.001	0.72	0.005
pH	0.63	0.002	0.15	0.221
Bray P, g m^{-2}	0.68	0.001	0.04	0.531
Soil organic matter, kg m^{-2}	0.87	0.001	0.43	0.021
Clay content, kg m^{-2}	0.56	0.005	0.47	0.014

In both fields there was a correlation between observed and predicted values for inherent soil properties such as clay and organic matter content in both the calibration and validation runs. Others have also shown a correlation between inherent soil properties and ECa (Johnson et al., 2001). The correlation between total dissolved solids and ECa in both fields relates to the importance of soil water solutes for conductivity. In non-saline agricultural soils nitrate is often a dominant anion and ECa directed sampling may have potential for delineating variation in residual fertilizer nitrate-N. Eigenberg et al. (2002) demonstrated that ECa could be used to quantify changes in soil nitrate during the growing season.

Results in this paper are an initial attempt to use ESAP for ECa directed soil sampling to quantify the spatial variability in soil properties. This approach has potential based on the results from the soybean field. We feel that further analysis of the data (closer evaluation of sample distribution, comparison of different regression models, and assessing the appropriateness of the sample size in the sample design) will improve the results.

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