IS IT USFUL TO MEASURE SOIL ELECTRICAL CONDUCTIVITY?

Cristine L. S. Morgan, Richard P. Wolkowski, and John M. Norman [1/]

Introduction

The success of precision agriculture depends on the economic and time feasibility of its implementation. Currently, GIS systems have capacity to analyze large amounts of spatial grid data; however, collecting, analyzing, and interpreting soil data can be expensive, time consuming, and labor intensive. One way to decrease costs associated with acquiring soil data is to develop techniques for rapidly and non-invasively measuring soil properties across a field. One soil property that can be rapidly measured in-situ by using electromagnetic induction is bulk electrical conductivity (EC). Previous EC research has shown correlations with soil water storage (Kachanoski *et al*., 1990; Kachanoski *et al*., 1988), soil organic matter (Jaynes *et al*., 1995); (Banton *et al*., 1997), salinity (Williams and Hoey, 1987), and soil texture (Williams and Hoey, 1987); (Banton *et al*., 1997).

Available water content is calculated by subtracting water in the soil at wilting point from water in the soil at field capacity. Soil water content at wilting point is a property of soil texture which is usually consistent throughout a soil series. Field capacity is the content of water remaining in a soil 2 to 3 days after having been wetted thoroughly. Field capacity in a field varies according to the sequence of soil layers and the layers' bulk density and organic matter. Both of these variables can vary considerably across a small 5 acre field. As available water is depleted, crop transpiration reduces also. Because transpiration is linearly related to crop production, water shortage results in a yield reduction.

The purpose of this paper is to determine the relationship between EC and soil volumetric water content, and use this relationship to map field capacity over a field. In addition we explore the relationship between EC and pH, CEC, and other soil test parameters. If the spatial patterns of these properties can be predicted throughout the field, at equal or higher resolutions than traditional grid sampling schemes, considerable time and dollar savings may be possible.

Materials and methods

Bulk soil EC measurements were made on an agricultural field using a Geonics Limited EM38 terrain meter (Geonics Limited, Mississuaga, Ontario, Canada). The EM38 measures soil EC using two coils, a transmitter coil and receiver coil distanced one meter from each other. The transmitter coil sends an alternating current, or primary signal, into the soil which is sensed by the receiver coil. As the primary signal moves through the soil it induces a magnetic field, or secondary

---

[1/] Graduate Research Assistant, Associate Scientist, and Professor, Department of Soil Science, University of Wisconsin-Madison.

signal, which is also detected by the receiver coil (McNeill, 1980). The ratio of these two signals allows the EC of the soil to be quantified. A second study evaluated a Veris System (Veris Technologies, Salina, KS) on a private farm field near Prairie du Sac, WI. The Veris system measures EC more directly. It uses a set of coulter electrodes that send out an electrical signal through the soil. The signal is received by a second set of electrodes that measure the voltage drop due to the resistivity of the soil.

Two studies were conducted to evaluate the relationships between EC measurements and soil properties. The first experiment was conducted at the University of Wisconsin-Arlington Agricultural Research Station, (ARS) located in Columbia County, WI. The selected field measures 479 x 413 ft. (146 x 126 m), or 4.4 acres (1.8 ha). The field landscape includes a closed depression with less than 1 percent slope. The soil series is a Plano silt loam (Typic Argiudoll). The parent material consists of eolian loess over glacial till or outwash. A layer of silty, glacial-lakebed-sediment deposits separates the loess and till layers in the closed depression of the field, creating a fragipan. The field has been cropped in corn (*Zea mays* L.) since 1997, using conventional practices.

The second field was located on a private farm in Columbia County east of the village of Prairie du Sac, WI. This field had been in CRP for the previous 10 years and had therefore not received commercial fertilizer or lime in that time. The dominant vegetation was brome grass. The USDA-NRCS Soil-Survey Map for the 30-acre field identifies Lapeer fine sandy loam as the dominant series with St. Charles silt loam dissecting it from southeast to northwest. Both soils are classified as Typic Hapludalfs.

The EC of the ARS field was measured twice in the spring of 1999 after snow melt. The first set of measurements was made 24 hours after a 1 inch rain event, and the second set was 48 hours after a 0.9 inch rain event. The second set of fits the description of in-situ field capacity more accurately (Soil Sci. Soc. Am., 1997). The EM38 unit and differential GPS were mounted onto a handmade wooden sled allowing both instruments to record simultaneously. The sled was pulled across the field making continuous measurement in transects 16.6 feet (5 meters) apart. A third set of readings was collected in the fall prior to corn harvest, while the soil was at its driest. These readings were taken by hand and not continuously. Soil samples were also taken at selected georeferenced locations at one foot depth increments to a total depth of 3 feet. Each sample was analyzed for water content, particle size distribution, and solution electrical conductivity (EC_S) evaluation in the lab. The EC_S was determined by measuring the electrical conductivity of a extract of the soil solution diluted 5 times with water deionized by reverse osmosis (EC<=.01 dS/m), (Page, 1982). To quantify the particle size distribution, sand was captured on a No. 270 sieve and weighed. The hydrometer method was used to determine percent silt and clay fraction. The water content was measured gravimetrically then converted to a volumetric basis using bulk density samples previously taken throughout the field.

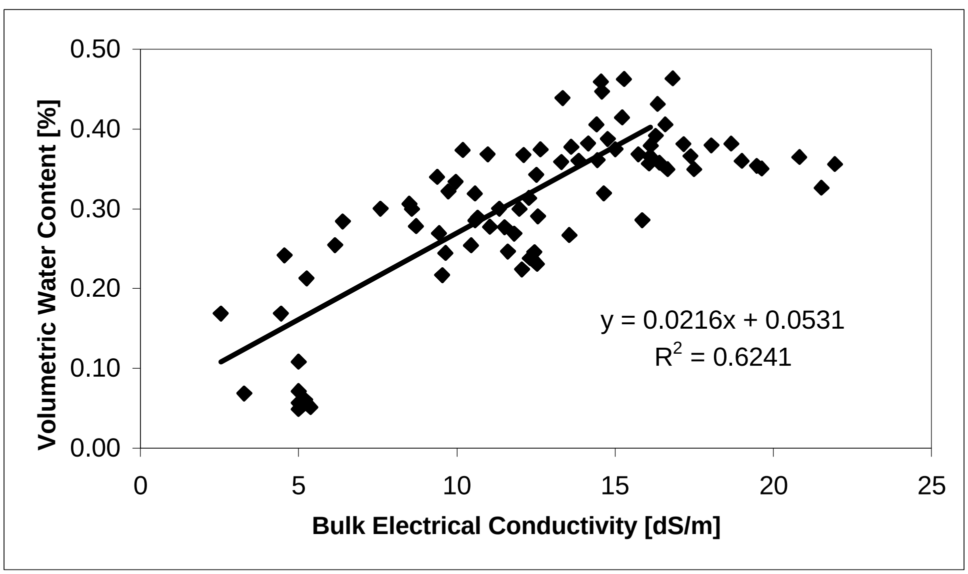
Veris measurements were made on in the Prairie du Sac field by a representative of the manufacturer on 14 August 1997. Rainfall amounts of 0.56 and 0.53 in. were recorded at Prairie du Sac on 12 and 13 August 1997, respectively. Transects, 60 ft. apart, were made east to west across the long dimension of the field. The field was subsequently soil sampled on a one acre grid. Elevation readings from the GPS unit, and Munsell soil colors and hand texture were recorded in one foot increments for the top three feet of soil.

Spatial data were interpolated using routines in Surfer (Golden Software, Golden, CO) for the ARS field and Arcview (ESRI) fro the Prairie du Sac field. Correlation and regression analysis between EC measurements and soil parameters were conducted with standard statistical procedures.

Results and Discussion

The field-measured volumetric water content at field capacity averaged 38 % and ranged from 33 to 44 %. A linear relationship existed between the volumetric water content, averaged to a depth of 3 feet, and EC (Figure 1). This linear relationship becomes skewed as water contents exceed 40%. This shows the instrument's inaccuracy in predicting water contents above 40%. No significant correlation was found between field measurements of EC with the EM38 and EC_S, or texture.

Figure 1. Linear response of the EM38 to volumetric water content.



The EC readings also show spatial trends that were not quantified in this experiment (Figure 2). The highest EC readings appear along the steepest slope in the field (NE corner) and at a more gradual slope as the landscape rises from the basin in the SW corner. Other visual observations depict EC responding to an identified fragipan located 70-100 cm below the surface (Figure 2 "star"). The EC response does not show the full extent of the fragipan in the field, but the EC response was greatest were the fragipan is at its shallowest and has its highest bulk density.

Spatial distribution of field capacity water content predicted by EC is shown in Figure 3. The map shows that the moisture content of this field near field capacity is not highly variable. At lower moisture conditions in the fall, the predicted spatial distribution of water content using EC measurements was similar to that of the measured water content distribution (RMS=0.04). Figure 4 is the spatial pattern of water content predicted by EC. While a map of the actual water content, using 38 measured points in the field, is shown in Figure 5.

The simple correlation coefficients relating the Veris EC measurements to soil test parameters in the 0-1 and 0-3 ft. soil zones is shown in Table 1. These data show significant correlations ($p<0.10$) between the 0-1 ft. EC and pH; soil test P, Ca, and Mg; soil organic matter; and estimated CEC. The 0-3 ft. EC did not appear to be as sensitive because only soil-test Mg, elevation, and estimated CEC were significantly related to EC.

Table 1. Simple correlation coefficients between the Veris System EC 0-1 ft. and EC 0-3 ft. plow layer soil test measurements (n=30), Prairie du Sac, WI, 1997.

Depth		pH	P	K	Ca	Mg	OM	CEC	Elevation
0-1 ft.	r	0.42	-0.30	0.09	0.46	0.45	-0.46	0.51	0.25
	Prob.	0.02*	0.10^{+}	0.64	0.01*	0.01*	0.01*	0.01**	0.18
0-3 ft.	r	0.11	-0.07	0.28	0.15	0.36	-0.26	0.32	0.60
	Prob.	0.55	0.71	0.13	0.42	0.05*	0.16	0.09^{+}	0.01**

**, *, + = Significant at the 0.001, 0.01, and 0.1 p levels respectively (rounded to two sig. digits).

Figure 6 shows the spatial relationships between the two different Veris readings and the soil organic matter and estimated CEC. Elevation contours are overlain on the 0-1 ft. EC map. Although the correlation between these two variables was not significant, some kind of relationship does appear to exist between them. The elevation contours show the field's drainage runs roughly from the southeast to the northwest, which is generally the area classified as the St. Charles soil. The visual relationships between soil organic matter and estimated CEC are not as apparent as the high correlation coefficient would suggest.

Summary

Knowing the spatial distribution of EC throughout an agriculture field has the potential to be a useful management too for obtaining detailed maps of soil properties important to plant growth. Examples include soil water content and cation exchange capacity. EC is shown to integrate soil properties throughout a significant part of the root zone. The signal can be correlated with properties, such as CEC, organic matter, pH, and volumetric water content. Knowing the spatial distribution of these properties throughout a field can provide useful information to interpret unexplained crop yield differences often found on yield maps. The soil EC may also help to identify areas of pedological change that impact crop yield. Additional work is needed to correlate EC measurements, soil factors, and crop yield to determine if EC can fit into a producer's arsenal of successful management tools.

References

Soil Science Society of America. 1997. Glossary of Soil Science Terms. Soil Sci. Soc. of Am., Madison, WI.

Banton, O., Seguin, M. K., and Cimon, M. A. 1997. Mapping field-scale physical properties of soil with electrical resistivity. Soil Sci. Soc. of Am. J. l 61:1010-1017.

Jaynes, D. B., Novak, J. M., Moorman, T. B., and Cambardella, C. A. 1995. Estimating herbicide partition coefficients from electromagnetic induction measurements. J. Environ. Qual. 24:36-41.

Kachanoski, R. G., De Jong, E., and Van-Wesenbeeck, I. J. 1990. Field scale patterns of soil water storage from non-contacting measurements of bulk electrical conductivity. Can. J. Soil Sci. 70:537-541.

Kachanoski, R. G., Gregorich, E. G., and Van-Wesenbeeck, I. J. 1988. Estimating spatial variations of soil water content using noncontacting electromagnetic inductive methods. Can. J. Soil Sci. 68:715-722.

McNeill, J. D. 1980. Electromagnetic terrain conductivity measurement at low induction numbers. Rep. No. TN6. Geonics, Ltd., Mississauga, Ontario.

Page, A. L., ed. (1982). "Methods of Soil Analysis: Chemical and Microbiological Properties," Vol. 9. Soil Sci. Soc. of Am., Madison, WI.

Williams, B. G., and Hoey, D. 1987. The use of electrical induction to detect the spatial variability of the salt and clay contents of soils. Aust. J. Soil Res. 25:21-27.