SPATIAL PREDICTION OF CROP PRODUCTIVITY USING ELECTROMAGNETIC INDUCTION

N.R. Kitchen, K.A. Sudduth, S.T. Drummond, and S.J. Birrell[1]

ABSTRACT

An inexpensive and accurate method for measuring water-related, within-field soil productivity variation would greatly enhance site-specific crop management strategies. This paper reports on investigations to use an electromagnetic induction (EM) sensor to map claypan (Udollic Ochraqualfs) and alluvial (Typic and Aquic Udipsamments, and Aeric Fluvaquents) soil conductivity variations and to evaluate the relationship of EM measurements to grain crop production. Grain yield measurement was obtained by yield monitoring. While yield by EM model r^2 values were fairly low, EM sensing helped explain some crop productivity variability for most crop years on both soil types. A theoretical relationship between EM and production was proposed. With several crop-years of data, the theoretical relationship was supported. This tool for measuring field variability of soils will be most useful for predicting productivity variability where the range in EM variability is large (> 30 mS/m).

INTRODUCTION

Formation of soil over landscapes along with management-induced soil changes (e.g. accelerated erosion with tillage, lime and fertilizer amendments, etc.) results in soil variation within cropped fields that impacts productivity. The soil quality that is often the most significant cause of variations in non-irrigated crop production is the soil's ability to store and provide water for plant growth. This is a quality that is a composite of many measurable influences such as soil water infiltration, soil water adsorption and desorption, soil depth, landscape position, restrictive soil layers, soil organic matter, surface residue, etc. Direct measurement of spatial productivity by yield monitoring and mapping is one way to determine this variability. However, this requires many years for various climatic conditions to be represented. Further, there are many other soil and landscape factors that also impact variability. Yield monitoring and mapping can tell the "effect" but do not tell the "cause" in this "cause and effect" investigation.

Inexpensive and accurate methods for measuring within-field soil productivity variation, particularly as it relates to the soil's ability to store and provide water for plant growth, would greatly enhance information needed to improve site-specific crop management strategies. This paper is a report on investigations to use an electromagnetic induction (EM) sensor to map claypan (Udollic Ochraqualfs) and alluvial (Typic and Aquic Udipsamments, and Aeric Fluvaquents) soil conductivity variations and to evaluate the relationship of EM measurements to grain crop production.

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Past work has shown that EM sensing for ground conductivity measurement is affected by a number of different factors including clay content, soil water content, salinity, organic compounds, and metals (Geonics Bibliography, 1992). Of these, only the first three are of significance in most agricultural soils. For well-weathered soils, salinity will be low and have little impact on EM readings. Thus the two primary factors affecting EM readings in many agricultural soils are clay and soil water content--certainly factors that are not independent of each other. Our interest was to determine if EM readings could effectively measure the relative suitability of a soil to store water for grain crop production. The ability of a soil to store water for crops entails both the water recharge rate (i.e. soil hydraulic characteristics) and the capacity for water storage (i.e. soil water holding capacity). We have hypothesized a theoretical relationship between productivity and EM as shown in Fig. 1. When EM readings are low, the soil is sandier and has high hydraulic conductivity but low water holding capacity. When EM readings are high, the soil has greater clay content and has lower hydraulic conductivity but high water holding capacity. Somewhere in the middle both hydraulic conductivity and water holding capacity are such that total soil water available is optimized and crop production is greatest. With both EM extremes, total water for plant growth is less and results in a relative decrease in crop productivity.

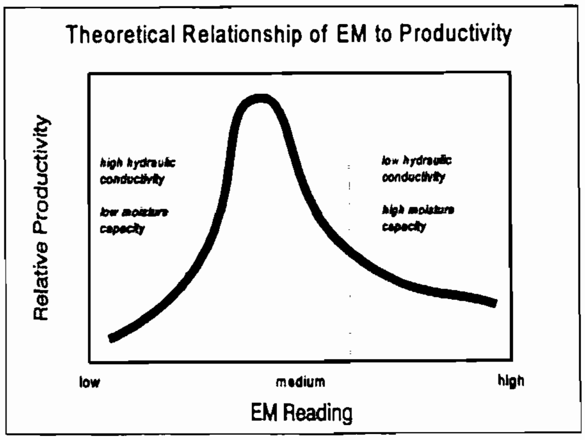

Figure 1. Relationship of EM to productivity.

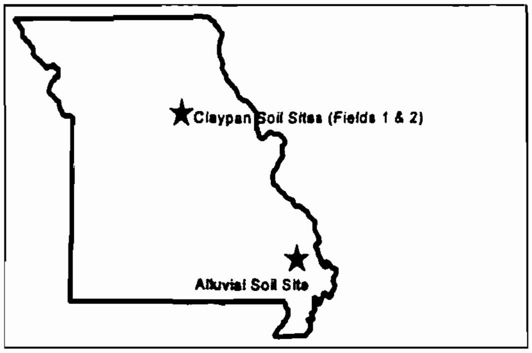

Figure 2. Research sites.

The objective of this study was to evaluate EM measurements of soil conductivity as a soil productivity indicator for Missouri claypan and alluvial soil fields.

PROCEDURES

Sites Description

Research sites included two claypan soil fields located in north-central Missouri, near Centralia, and one alluvial soil field located near Oran in southeast Missouri. The claypan soil Field 1 was cropped in a corn-soybean rotation with reduced tillage. The claypan soil Field 2 was cropped in a corn-soybean-wheat rotation with reduced tillage through 1993 and no-tillage since. The alluvial soil field was cropped in a corn-wheat-soybean rotation (wheat and soybean double-cropped), with conventional tillage.

EM Sensing

The EM instrument used in this study was the EM38[2] manufactured by Geonics Limited, Mississauga, Ontario, Canada. The EM38 is a lightweight bar approximately 3 ft in length and includes calibration controls and a digital readout of apparent conductivity in milliSiemens per meter (mS/m). An analog output port is provided to allow data to be recorded on a data logger or computer. The instrument was operated in the vertical dipole mode, providing an effective measurement depth of approximately 5 ft (McNeil, 1992) which is well suited for focusing on most annual grain crops. The instrument response to soil conductivity varies as a nonlinear function of depth. The apparent conductivity measured by the instrument is determined by the soil conductivity with depth, as weighted by the instrument response function.

For mapping of crop production fields, a mobile EM measurement system was developed. The EM38 was mounted on a 10 ft long cart consisting of a wooden beam supported at the rear by two spoke-wheeled pneumatic tires. Use of the wooden beam was necessary because the EM38 will respond strongly in the presence of metallic objects within approximately 3 ft. The tongue of this cart was attached to the rear of a second, similar cart, which was in turn attached to the rear hitch of a four-wheel, all-terrain vehicle (ATV). The second cart was necessary to increase the distance between the EM38 and the ATV, for eliminating the effects of ATV engine noise on the EM readings. With this configuration, the EM38 was suspended 8 inches above the ground surface during data collection.

EM conductivity data were read through an IOtech Daqbook data acquisition interface into an IBM laptop computer mounted in front of the ATV operator. Data obtained from an Ashtech M-XII GPS receiver were integrated with the EM data to provide the coordinates of each measurement point. The GPS data were differentially corrected by post-processing to obtain absolute position accuracies of 10 ft or better. EM and GPS data were collected on transects approximately 66 ft apart over the study areas. Data were recorded on a 1 s interval corresponding to a measurement every 6 to 12 ft along the measurement transects, giving approximately 60 to 80 EM readings/acre.

Grain Yield Sensing

Two different grain flow sensors were used to measure yield variations. A Gleaner R62 combine with the AgLeader Yield Monitor 2000 yield sensing system was used to obtain data for yield maps on the claypan soil fields. This sensor measured the force of the grain impacting against a plate situated at the top of the clean grain elevator. The force and other parameters such as elevator speed, grain moisture and ground speed were then used to determine grain flow rate. The output from the AgLeader was logged through an RS-232 serial port into a portable computer along with GPS position and GPS time at one second intervals.

For wheat yield in 1994 on the alluvial soil field, yield data were collected with a Claydon Yieldometer installed on a Claas Commandor 116 CS combine. This yield sensor measured the

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[2] Mention of trade names or specific products is made only to provide information to the reader and does not constitute an endorsement by the University of Missouri or the USDA Agricultural Research Service.

volume flow of grain from the clean grain elevator. A capacitive grain level sensor controlled the rotation of a six-flight paddle wheel to maintain the level of grain above the paddle within certain thresholds. An angular position encoder was connected to the shaft of the paddle wheel and counted revolutions with distance. For corn yield in 1995, an AgLeader Yield Monitor 2000 yield sensor as described above was used on the Claas Commandor 116 CS combine.

The raw yield and distance counts were smoothed and then were used to calculate instantaneous yield after the application of appropriate time shifts to account for combine dynamics. Data were input to a geostatistical analysis package for the interpolation of unknown data and the creation of yield maps.

Combined Spatial Data

The yield and EM data used for interpretive analyses were obtained by interpolating the mapped data to common 33 ft grid cells.

RESULTS AND DISCUSSION

From previous work, the correlation relationship between yield and any single soil measurement (e.g., P, K, Ca, Mg, pH, organic matter, CEC) was low. Yield controlling factors can be numerous and vary spatially within fields. Thus, single-factor correlation analysis and modeling applied to whole-field data will in most cases not be adequate for explaining yield variations. Data analysis by sub-field regions similar in yield-limiting factors is suggested (Drummond et al., 1995).

For claypan soil fields 1 and 2, lower EM readings were associated with deeper topsoil. For claypan soil fields, EM sensing has been shown to be strongly correlated to topsoil depth above the claypan horizon (Doolittle et al., 1994).

For the alluvial soil field, the range in EM readings was less than for claypan soil fields. Total soil clay content and variation in clay content between soil horizons are generally less in these alluvial soils than claypan soils. Lower EM readings for the alluvial soil field were associated with sandier soil areas having low clay content (< 12% clay).

Winter wheat growth is mainly during the cool and wet fall and spring seasons and thus is not typically water limited like summer grown crops. Also, irrigation decreases water limiting effects on production for summer grown crops. Thus for the Claypan Soil Field 2 in 1993 and the Alluvial Soil Fields the relationship of EM to productivity as illustrated in Fig. 1 would not be expected to be as significant.

Figures 3-8 show the relationship of grain yield and EM measurements for the three experimental fields. Each graph point represents a cell of about 1000 ft^2. As previously indicated, many factors will affect yield within fields. While the data are widely distributed for similar EM values, the clouds of data provide a shape of the relationship being investigated. Table 1 provides the field size, number of data cells, and the r^2 values for the "best-fit" line shown in each graph. The variations in point shading represent standard deviations around the "best-fit" curve.

Claypan Soil Field 1 (Fig. 3, 4)

The 1993 growing season was very wet and water deficiency was not a yield limiting factor. The lowest EM readings are associated with areas where the crop was partially drowned out, depressing yields. Water was limiting because of "excessiveness" not "deficiency" and thus the relationship between EM and productivity is different than that shown in Fig. 1 for this year.

In 1994 rainfall during the growing season was approximately 4 inches lower than the long-term average. Low soil water resulted in lower soybean grain production. The relationship between the EM reading and the grain yield for this data was the most statistically correlated (Table 1). In this year where water was limiting crop production, the EM by yield figure resembles the right half of the theoretical relationship found in Fig. 1.

Table 1.

Field	Field Size (acres)	No. Data Cells	Year	r^2
1	70	2576	1993	0.13
			1994	0.33
2	50	1997	1993	0.11
			1994	0.04
3	120	5317	1994	0.06
			1995	0.17

Claypan Soil Field 2 (Fig. 5, 6)

With both crop years, a poor relationship existed between yield and EM readings. For wheat in 1993, wet conditions resulted in unusually high occurance of plant diseases.

For corn in 1994, poor weed control over the whole field reduced crop productivity. Compared to a adjacent "weed-free" field planted on the same date, yield was reduced about 40% due to weeds. Still in some locales within the field the same relationship found in Claypan Soil Field 1 could visually be observed, with yield increasing with lower EM readings.

Alluvial Soil Field (Fig. 7, 8)

The lowest EM readings (sandy soil areas) for both crop years were associated with relatively lower grain production. These were areas of the field where the soil dries very quickly because of low soil water capacity. Higher EM readings for both crops were also generally associated with relatively lower grain production. This is explained by an observed reduced crop stand in the lower elevation drainage areas of the field (higher clay content soil areas).

Of the six EM by yield graphs, Fig. 8 most resembles the theoretical relationship proposed with Fig. 1. Almost all cells yielding above 200 bu/acre had EM measurements between 15 and 20. Below an EM of 15 (the sandier soil areas of the field), yields dropped off quickly. Above an EM of 20 there was a wide range of yield measurements from about 50 up to 200 bu/acre.

CONCLUSIONS

While yield by EM model r^2 values are fairly low, EM sensing still helped explain some crop productivity variability for most crop years on both soil types. Using this technique of EM sensing, we are able to detect some soil variability within fields with much more detail than traditional soil survey maps.

EM sensing will be most useful for predicting productivity variability for summer-grown crops that are non-irrigated. It will be most useful for predicting productivity variability where the range in EM variability within fields is extreme (> 30 mS/m). We propose that EM maps can be used to estimate soil productivity on some soil types. From such, spatial prediction of crop needs may be determined to improve variable-rate management strategies.

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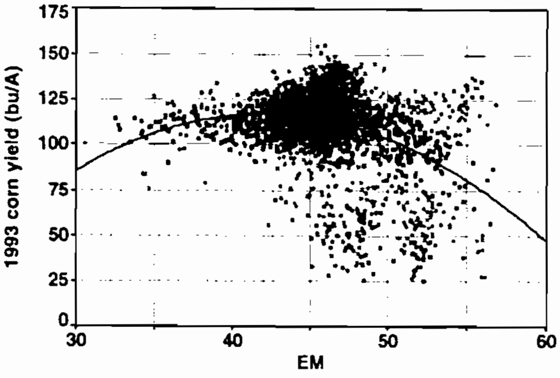

Figure 3 Claypan soil Field 1, 1993.

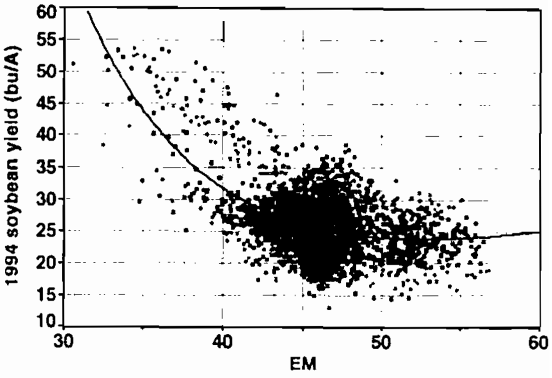

Figure 4 Claypan soil Field 1, 1994.

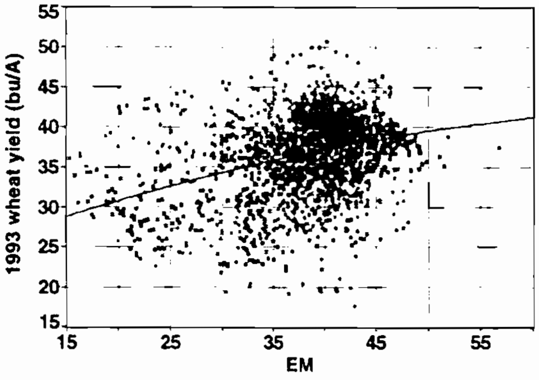

Figure 5 Claypan soil Field 2, 1993.

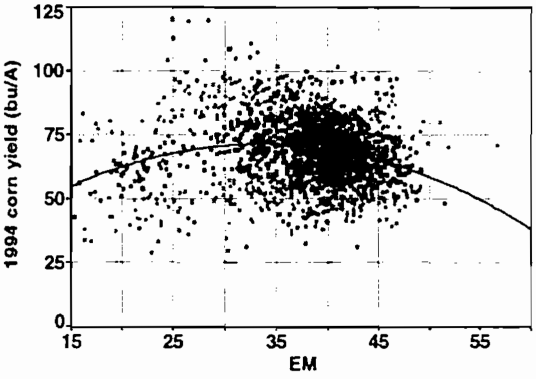

Figure 6 Claypan soil Field 2, 1994.

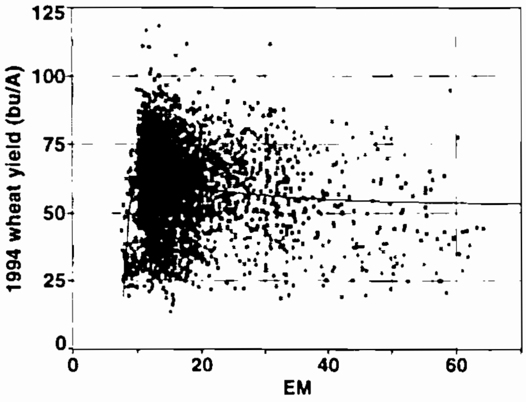

Figure 7 Alluvial soil field, 1994.

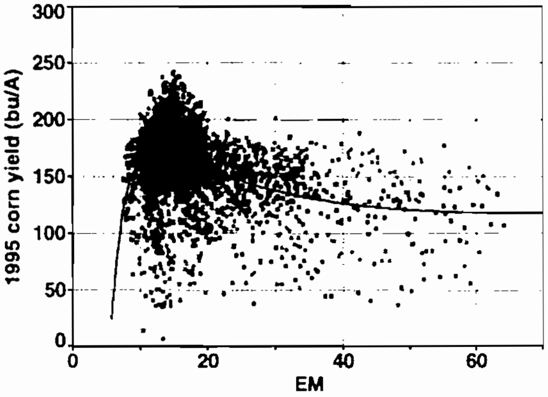

Figure 8 Alluvial soil field, 1995.

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