PRACTICAL UTILITY OF BULK SOIL ELECTRICAL CONDUCTIVITY MAPPING

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Abstract

Bulk soil electrical conductivity (EC) measurements are easy and relatively inexpensive to take. A few researchers have investigated the relationship between EC, soil properties, and yield. Even though research results demonstrate a correlation of EC with yield, EC is not a factor that can be managed directly to improve yield. The elusive link necessary to make EC data much more useful to producers, is how to correctly interpret and quantify the various factors affecting EC. A better understanding of the spatial and temporal variability of EC and the relative influence of various soil properties on EC are needed to enhance its utility in site-specific management. Our objective is to summarize the usefulness of EC mapping with examples from our precision agriculture project. We collected EC data from three center-pivot irrigated fields in northeastern Colorado for 1998 to 2002 that were analyzed to identify EC patterns. In these non-saline fields, the patterns in EC maps are highly stable over time and soil EC correlates strongly with texture (clay content), organic matter, and soil water. These findings strengthen the idea of using EC maps to evaluate the potential of EC-based zones for varying agricultural inputs.

Introduction

In-situ bulk soil electrical conductivity (EC) measuring devices provide by far the simplest and least expensive soil variability measurement. Electrical conductivity is a measure of the bulk soil ability to carry electric current, which is mostly dictated by the chemistry of and amount of soil water. Researchers in the field of soil salinity have capitalized on the relationship between EC and soil ionic concentration to infer salinity levels of soils from measurements of EC (Rhoades and Ingvalson, 1971). In non-saline soils, a significant interest is also emerging in using EC to quantify soil spatial variability and develop prescription maps for varying agricultural inputs. The practical utility of EC, however, remains elusive because of the complexity of the interactions between EC and soil physical and chemical properties. For that reason, the ultimate goal of inferring maps of production important soil attributes solely from EC maps may not be fully achieved in the foreseeable future. In spite of that, research has already demonstrated significant utility in using EC to aid producers and consultants evaluate the potential of site-specific management based on the degree of spatial variability reflected in their EC maps. Examples of the most immediate uses of field-scale EC are to: 1) quickly characterize field variability, 2) guide smart (or direct) soil sampling as opposed to grid sampling, and 3) develop potential management zones for variable rate seeding and chemical application.

With the advances in and availability of EC mapping devices, many attempts have been made to infer the relationship of EC and soil attributes. Although results are site-specific and empirical in nature, interesting findings are emerging. Research shows that in the absence of salinity, bulk soil electrical conductivity responds well to soil texture and particularly clay content (Williams and Hoey, 1987; Buchleiter, 2000; Johnson et al., 2001), water content (Sheets and Hendrickx, 1995; Kachanoski el al., 1988), soil organic carbon (Jaynes et al., 1994), and cation exchange capacity (McBride et al., 1990). Since these parameters equally influence field productivity, EC has been found to relate to yield (Sudduth et al., 1995; Lund et al., 1999; Johnson, et al., 2001; Heermann et al., 2002). The fact that EC synthesizes the presence of many soil attributes in a single number that is related to field productivity has prompted some people to delineate EC classes for purposes of management or productivity zone development. In the absence of other complimentary soil information, EC-based management zones prompt the immediate, but mostly unanswered question of "what to manage?" That question is not easily answered and requires careful analysis of the causes of observed variations in EC and yield between delineated zones. Our objective is to summarize some usefulness of EC mapping with examples from our precision agriculture project. For the benefit of the reader, cautionary notes are given regarding the difficulties encountered in classification and interpolation of spatial point data.

Methods and Materials

The study reported herein is part of a larger multi-disciplinary precision farming research study, established in 1997 among a group of USDA-ARS Water Management Research (Fort Collins) and Colorado State University (Fort Collins) scientists on farmer-owned and operated production fields in eastern Colorado. The overall objective of the broader study is to evaluate the technical and economic feasibility of precision farming, by analyzing data from two center pivot irrigated fields near the town of Wiggins, Colorado (called Wiggins1 and Wiggins2) and one near Yuma, Colorado (called Yuma). Fields Wiggins1 and Wiggins2 are 71 and 52 ha and are a few miles apart, with soils including Bijou and Truckton loamy sand and Valentine sand. The Yuma field includes soils Haxtun loamy sand, Albinas loam and Ascalon fine sandy loam. Measurements of bulk soil electrical conductivity were all taken between 1998 and 2002 using the Veris 3100 Soil Mapping System (Veris Technologies, Salina, Kansas). The Veris unit has a total of six coulter electrodes mounted on an implement that is pulled by a pickup truck. It provides simultaneous readings of EC for shallow (0-0.3 m) and deep (0-0.9 m) soil layers. For simplicity, we will use the terms "Shallow" and "Deep" to refer to these readings. A parallel swather (Trimble, Sunnyvale, CA) mounted inside the truck guided parallel passes through the field at 12 to 18 m swath widths with a Trimble GPS unit providing spatial coordinates for each EC measurement.

Results and Discussions

Use of EC to Characterize Field Variability

The quickest representation of the degree of soil variability across a field is given by EC measurements. To create continuous surfaces (i.e., maps) from the EC point data, various geostatistical software and methods are available. Because of the high density of the EC data points per unit area (a few hundred points per hectare), simple interpolation techniques such as Inverse-Distance-Weighting (IDW) have resulted in maps similar to the more elaborate methods of kriging. Figure 1 presents plots of raw EC data and the interpolated surface (using IDW) for Wiggin2. The most obvious observation from these maps is the level of variability in the field as highlighted by different shades for EC ranges. Such maps provide an excellent starting point for producers interested in site-specific management.

For the period 1998 to present, a summary of pre-planting and/or post-harvest EC measurements resulted in mean Shallow EC values of 14.3, 19.0 and 27.5 mS/m (milli Siemen per meter) and Deep EC values of 22.9, 22.7 and 33.3 mS/m for Wiggins1, Wiggins2, and Yuma, respectively. The EC data in these irrigated fields ranged from 5 to 79 mS/m. EC readings of a few hundred mS/m or greater would be required to indicate salinity, a condition not encountered in these fields. The magnitude of the yearly mean EC values were only slightly different even though soil water and temperature, at the least, were most likely different at each measurement day.

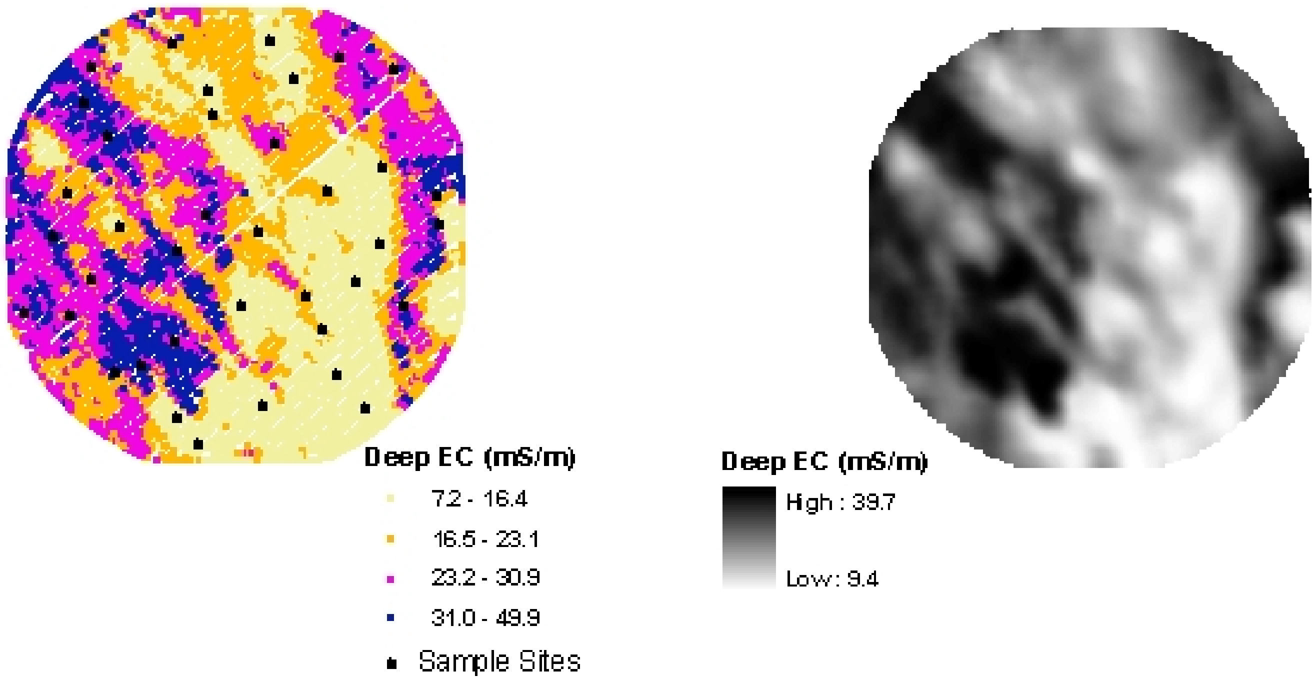

Fig. 1. The 1999 EC measurements (left) and interpolated surface (right) for field Wiggins2.

In regard to the relative behavior of location-specific Shallow versus Deep EC readings, we found a positive correlation between the two with calculated ratios of Shallow to Deep readings mostly below unity. In uniform profiles, higher Deep readings are generally expected to prevail because of mostly higher water content in the soil sub-layer than the top surface layer. In practice and upon repeated mapping, field areas with any observed reversal in the ratio of Shallow to Deep readings or significant changes in EC may warrant closer examination for possible undesirable planting environments and/or unusual accumulation or leaching of chemicals.

In an effort to compare the magnitude of EC data between two seasonal measurements, we placed a 15m by 15m grid surface over the field map and obtained mean EC values for each grid, thus effectively smoothing the data and its directional bias. Figure 2 presents a comparison of the Shallow and Deep readings between 1998 and 2002 measurements in Wiggins1. It is obvious that variability and temporal change are more pronounced in the Shallow (Fig. 2 left) than Deep readings (Fig. 2 right). This is explained by the fact that the surface soil layer is subjected to a more dynamic environment and disturbing agricultural implements than the subsurface soil. The implications are that for purposes of zone development, the Deep EC readings seem to be more stable over time than Shallow readings. For processes that relate to near surface soil properties, such as pesticide binding and bioactivities, delineating zones based on the Shallow readings may be more appropriate while yield and water holding capacity for example may best more appropriately explained by whole profile characteristics or the Deep EC readings.

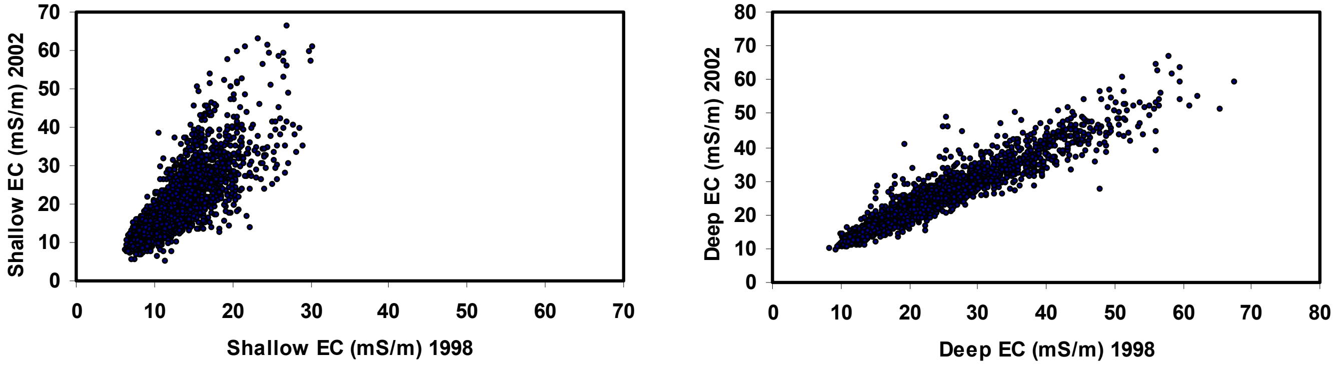

Fig.2. Comparison of Shallow and Deep EC (mean of 15m grid) between 1998 and 2002 readings at Wiggins1.

Use of EC to Guide Smart (or direct) Soil Sampling

A second important use of an EC map is to guide smart (or direct) soil sampling as opposed to grid sampling. With the current lack of knowledge of converting EC maps to soil properties maps, this step of relating the spatial variability of EC to soil properties is essential. In doing so, we used the 1999 EC data and selected a total of 20 to 40 sample sites from each field for purposes of sampling. An example of the selected sampling sites was previously given in Fig. 1 for Wiggins2 where four to six random sample sites were selected from each distinct EC class. Soil profile cores were obtained and analyzed for texture and organic matter.

Results from the soil sampling are summarized in Table 1 along with mean EC values from each field. As given, fields Wiggins1 and Wiggins2 seem to be exceptionally similar in their textural characteristics. The Yuma field is higher in clay and organic matter than the other two fields, a result reflected in its higher Shallow and Deep EC values. For each field, we found a strong correlation between EC and clay and organic matter and water contents. Figure 3 presents percent clay versus Deep EC in the top 0.9 m soil profile for the combined data from all fields, showing a strong coefficient of determination (R^2) of 0.85. That finding indicates that in these non-saline soils, EC is not only a reflection of soil texture, but also independent of field location. The correlation between EC and organic matter and water contents (data not shown) were equally strong. Identifying the characteristics of EC classes enhances the utility of EC maps and will improve understanding of location-specific relationships between EC, yield, and possibly other important properties such as water holding capacity.

Table 1. Mean EC, texture, and organic matter (OM) for two soil depths at the Wiggins and Yuma fields.

	Shallow Soil Profile (0 – 0.3 m)					Deep Soil Profile (0 – 0.9 m)				
	EC	Sand	Silt	Clay	OM	EC	Sand	Silt	Clay	OM
Site	(mS/m)		(%)			(mS/m)		(%)		
Wiggins1	14.3	87	5	7	0.9	22.9	82	8	9	0.8
Wiggins2	19.0	81	10	8	0.9	22.7	82	10	9	0.7
Yuma	27.5	57	29	14	1.6	33.3	54	30	16	1.5

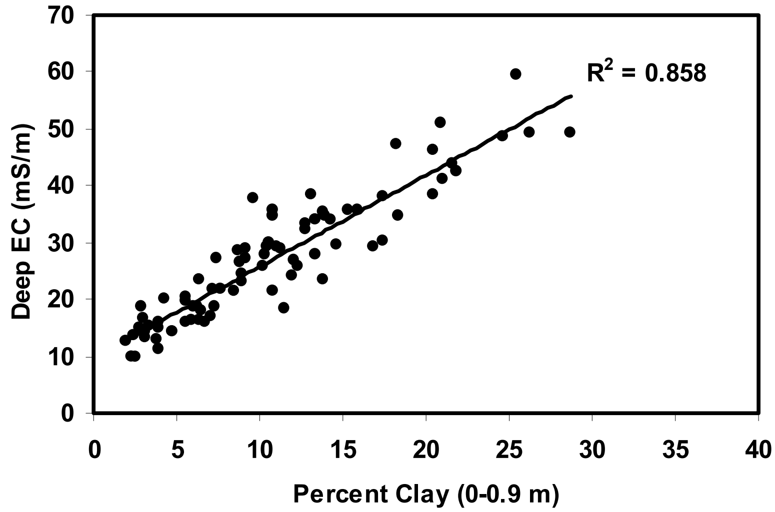

Fig. 3. Deep EC versus percent clay for the 0.9 m soil layer at the three sites in Wiggins and Yuma.

EC Map Creation and Classification (or Zoning)

Generally speaking, EC classification involves more art than science. Various geostatistical packages have been used to create classified maps from a distribution of EC point data, ranging from sophisticated methods such as fuzzy clustering to simple methods such as quantiles. Regardless of the method used, the critical issue is that one must specify the number of desired classes of EC, a priori. In the case of EC data from Veris with two readings per location, the additional difficulty is "which EC layers, Shallow or Deep or a combination of both, are to be used for classification? Depending on the shape of the distribution of data, different methods of classification could yield different patterns and thus classes for the same field. An example is given in Fig. 4 for Wiggins1, in which we used the method of Equal Interval to produce three classes in Fig. 4(left) and used the method of Quantiles to produce similar number of classes in Fig. 4(right). Obviously the two patterns of classes are different. This was caused by the skewed distribution of the EC data at Wiggins1. For a normally distributed data like Yuma, similar class patterns were found regardless of the classification method. The above example cautions against blind classifications without careful examination of data distribution. EC based classes must be soil sampled to quantify the intra-heterogeneity in EC and soil properties of interest. By definition, a class or zone must exhibit the least intra-class and the most between-class heterogeneity.

Temporal Stability of EC and Yield and Their Relationship

While the spatial variability of EC and yield and their relations to soil physical and chemical properties are of significant importance in site-specific management, understanding their temporal variability is equally important. That is particularly true if spatial classes (or zones) developed based on EC, yield, and/or a combination of both are to be used to vary agricultural inputs across the field and over years. Lack of temporal stability in such maps would dictate repeated mappings. Obviously absolute magnitudes of location-specific EC measurements are to exhibit some time-of-measurement dependencies because of the varying transient properties of soil temperature, water content, and ionic concentration. The effects of the stable properties of texture and organic matter on EC maps (or patterns) are, however, expected to remain independent of time. Yield is, however, influenced by more than just soil properties and thus expected to be temporally less stable.

In an effort to determine whether the imposed cultural and cropping practices alter the temporal stability of EC patterns over years, we created maps from EC point data using IDW and employed the method of Natural Breaks (jenks) to produce 3 EC classes for each data set. Although we have conducted quantitative comparison of EC maps for 1998 to 2002 and substantiated that EC maps remain highly stable over time, we rely on a simple visual comparison (see Fig. 5 for Wiggins2) to convey that message of temporal stability. For yield, however, we classified the data into two classes of above and below mean for simplicity. The resulting yield patterns are presented in Fig. 6 for 1997 and 1998 corn harvests. Visual examination of Figs. 5 and 6 reveal that a strong stability is reflected by EC over a span of 4 years while yield patterns failed to hold from one year to the next. The year 1997 was exceptionally wet which apparently removed any effects of varying soil water on yield. Yields for 1999 to 2001 more resemble the 1998 data than the 1997, but the stability in pattern was never as strong as EC. These observations were not surprising as yield is influenced by climatic and management input practices that may not significantly influence EC.

The interesting observation from these figures is the striking similarity between EC and yield patterns in 1998. EC is found to not only reflect the more stable soil properties but also important properties affecting field productivity. While literature reported EC versus yield relationships are promising findings, such relationships are only expected when same soil variables influence both location-specific yield and EC. That condition was apparently met in 1998 but not in 1997 as yield patterns changed. For that reason, EC versus yield relations could exhibit seasonal dependencies. If the 1997 yield map were used for management zone, then those zones would have changed in 1998. This confounds any analysis about the effect of variable management on yield.

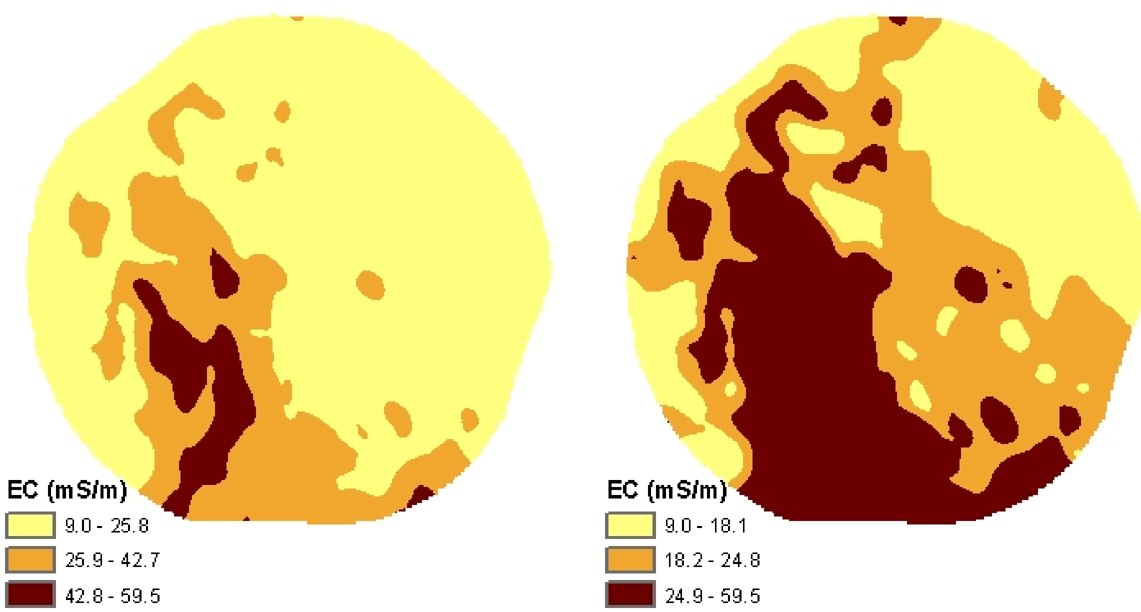

Fig. 4. Maps of EC created using the methods of Equal Intervals (left) and Quantiles (right) for Wiggins1.

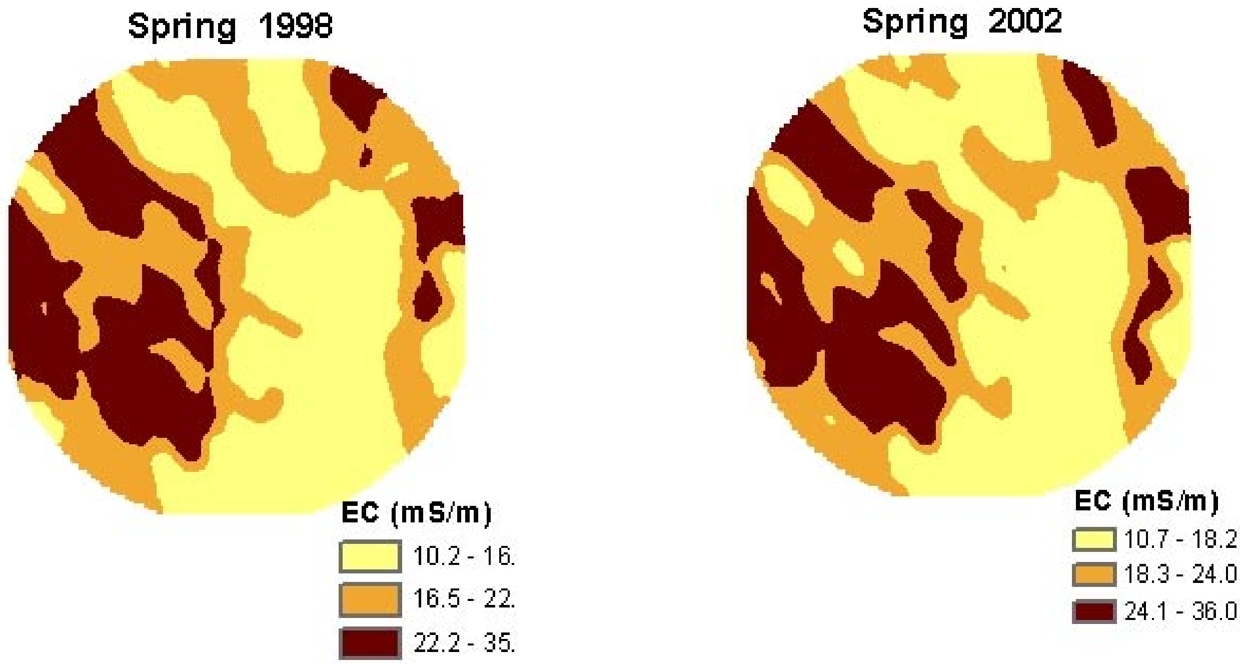

Fig. 5. Maps of EC from Wiggins2 as measured in 1998 (left) and 2002 (right).

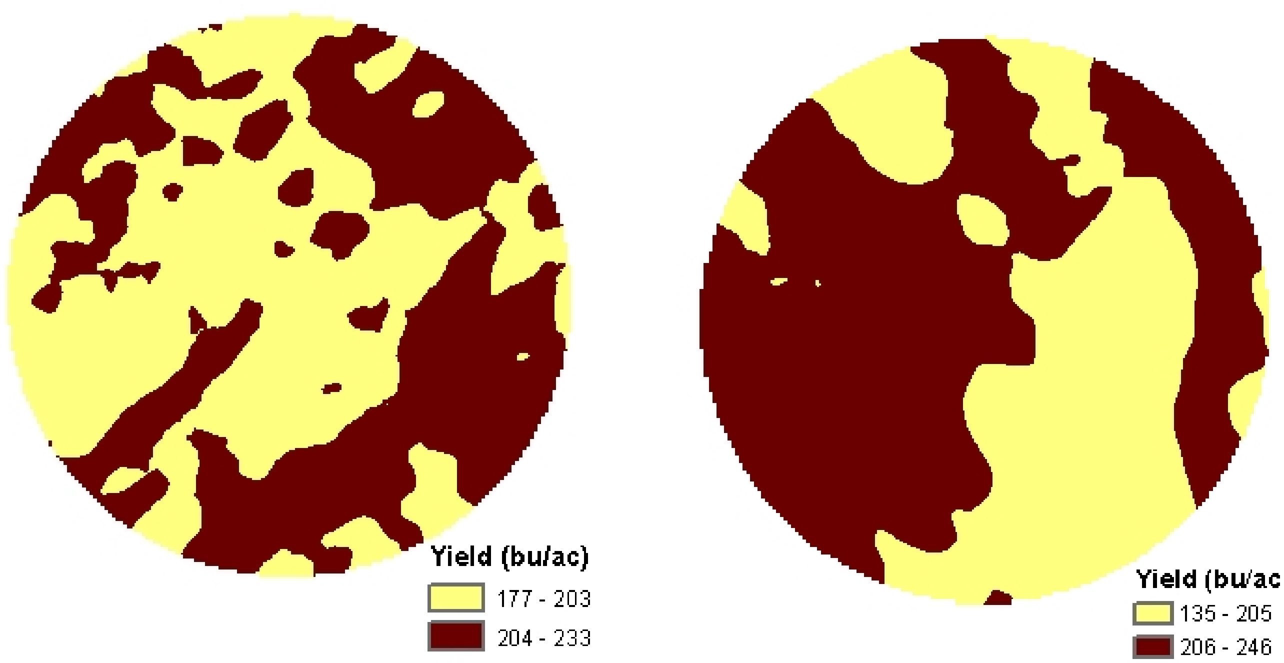

Fig. 6. Maps of yield from Wiggins2 as measured in 1997(left) and 1998 (right).

Summary and Conclusions

The advantages of EC maps over the more costly and labor intensive grid based sampling techniques will be improved significantly once EC maps can be translated to maps of soil attributes that are important in delineating zones of yield potentials, fertility, chemical leaching, and water holding capacity. Yield and EC maps were compared over several years to see if patterns were temporally stable. Results show that in non-saline soils, spatial patterns of EC are reflections of stable soil properties such as clay content and organic matter and thus any measured heterogeneity (or patterns) in EC is expected to remain stable over time. Only significant land modifications (such as leveling) could alter soil stable properties and thus EC patterns. Even though soil water and temperature will most likely differ at different measurement times, these transitory variables are only expected to affect the absolute magnitudes of EC values and not the inherent heterogeneity. Yield is influenced by more than just soil properties and thus found to be temporally less stable.

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