FITTING SOIL ELECTRICAL CONDUCTIVITY MEASUREMENTS INTO THE PRECISION FARMING TOOLBOX[1]

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SUMMARY

- Soil electrical conductivity (EC) mapping is a simple, inexpensive tool precision farmers can use to quickly and accurately characterize soil differences within farm fields.
- Soil EC is a measurement that correlates to soil properties affecting crop productivity, including soil texture, cation exchange capacity, drainage conditions, organic matter level, salinity and subsoil characteristics.
- With field verification, soil EC can be related to specific soil properties that affect crop yield, such as topsoil depth, pH, salt concentrations and water-holding capacity.
- Soil EC maps often visually correspond to patterns on yield maps and can help explain yield variation. The EC data can also be correlated with yield, elevation, plant population, surface hydrology or remotely sensed data with a suitable Geographical Information System (GIS).
- Uses of soil EC maps include guiding directed soil sampling, assigning variable rates of crop inputs, fine-tuning NRCS soil maps, improving the placement and interpretation of on-farm tests, salinity diagnosis and planning drainage remediation.

INTRODUCTION

Precision farmers can now collect more detailed information about the spatial characteristics of their farming operation than ever before. In addition to yield, boundary and field attribute maps, a wide array of new electronic, mechanical and chemical sensors are being developed to measure and map many soil and plant properties. Soil electrical conductivity (EC) is one of the simplest, least expensive soil measurements available to precision farmers today.

Soil EC is a measurement that integrates many soil properties affecting crop productivity. These include water content, soil texture, soil organic matter, depth to claypans, cation exchange capacity, salinity and exchangeable Ca and Mg.

Soil EC measurements can add value to the farming operation if they help interpret yield variation. That increased understanding must then lead to improved management opportunities that either boost yields, reduce input costs, or accurately predict the benefits that may be obtained from tiling, liming, irrigation, windbreaks, or other types of field improvements.

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This article will examine soil EC mapping as a practical tool to characterize soil differences in farm fields. EC mapping can also improve the management of variable-rate inputs as well as strengthen a grower's decision-making ability for many other agronomic practices.

HISTORY AND USES OF EC MAPPING

Geophysical surveys which measure EC have been used since early in the 20th century to map geological features. Practical applications include determination of bedrock type and depth, location of aggregate and clay deposits, measurement of groundwater extent and salinity, detection of pollution plumes in groundwater, location of geothermal areas and characterization of archeological sites. More recently, EC mapping has been useful in locating saline seeps in the northern Great Plains (Halvorson and Rhoades, 1974) and for diagnosing salinity related problems in the irrigated Southwest (Rhoades and Corwin, 1981). Researchers have also used soil EC to measure or estimate many other chemical and physical properties of non-saline soils, including water content (Kachanoski, 1988), clay content (Williams and Hoey, 1987), cation exchange capacity and exchangeable Ca and Mg (McBride et al., 1990), depth to claypans (Doolittle et al., 1994), soil organic carbon (Jaynes et al., 1996) and herbicide behavior in soil (Jaynes et al. 1994). With the advent of the Global Positioning System (GPS), practitioners can now place EC measuring devices on GPS-equipped field vehicles and create EC maps at various scales in land use situations ranging from forests to crop and range land.

EC MEASUREMENTS IN SOIL

Electrical conductivity is the ability of a material to transmit (conduct) an electrical current and is expressed in the units milliSiemens per meter (mS/m). Soil EC measurements may also be reported in units of dS/m which is equal to the reading in mS/m divided by 100.

There are two techniques used to measure soil EC in the field; electromagnetic induction (EM) and contact electrode. EM surveys are conducted by introducing electromagnetic energy into geological materials using a current source that passes over the earth's surface but which does not make physical contact. A sensor in the device measures the resulting electromagnetic field that this current induces. The contact electrode method involves devices that direct electrical current into the soil through insulated metal electrodes that penetrate the soil surface. These devices directly measure the voltage drop between a source and a sensor electrode. The measurement of soil EC by both contact and EM methods has given comparable results (Sudduth et al., 1998).

The depth to which EC measurements penetrate the soil depends on the spacing width of coulter-mounted electrodes for contact methods and on the orientation (vertical vs. horizontal) and height and spacing of the source electrical coils for the non-contact methods. While geological testing can be done to a depth of several hundred meters, most soil EC devices (as pictured above) only "look" at the surface 3 to 5 feet. The ability to evaluate surface and subsoil layers via EC mapping can be very useful if the characteristics of these soil layers are closely related to patterns in crop yield variation. For example, the ability to estimate topsoil depth with EC mapping could be very useful in predicting crop yield potentials and therefore be a realistic guide for assigning variable crop input rates.

	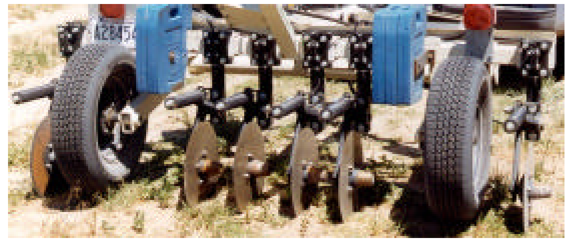
Non-contact EC sensor using electromagnetic induction (USDA-ARS Photo Gallery, Columbia, MO)	Coulter-mounted electrodes need soil contact (USDA-ARS Water Management Unit, Ft. Collins, CO)

Figure 1. Non-contact and contact sensors used to measure soil electrical conductivity.

FACTORS AFFECTING SOIL EC

The conduction of electricity in soils takes place through the moisture-filled pores that occur between individual soil particles. Therefore, the EC of soil is influenced by the interactions between the following soil properties (Geonics Limited, 1980):

- **Pore Continuity** – Soils with water-filled pore spaces that are connected directly with neighboring soil pores tend to conduct electricity more readily. Soils with high clay content have numerous, small water-filled pores that are quite continuous and usually conduct electricity better than sandier soils. Curiously, compaction normally increases soil EC.
- **Water content -** Dry soils are much lower in conductivity than moist soils.
- **Salinity level** – An increasing concentration of electrolytes (salts) in soil water will dramatically increase soil EC. The salinity level in most humid regions such as the Corn Belt is normally very low. However there are areas that are affected by Ca, Mg or other salts that will have elevated EC levels.
- **Cation exchange capacity (CEC)** – Mineral soils containing high levels of organic matter (humus) and/or 2:1 clay minerals such as montmorillonite, illite or vermiculite have a much higher ability to retain positively charged ions (such as Ca, Mg, K, Na, NH_4, or H) than soils lacking these constituents. The presence of these ions in the moisture-filled soil pores will enhance soil EC in the same way that salinity does.
- **Depth** – The signal strength of EC measurements decreases with soil depth. Therefore, subsurface features will not be expressed as intensely by EC mapping as the same feature if it were located nearer to the soil surface.
- **Temperature** – As temperature decreases toward the freezing point of water, soil EC decreases slightly. Below freezing, soil pores become increasingly insulated from each other and overall soil EC declines rapidly.

MAPPING SOIL EC IN AGRICULTURAL FIELDS

Mapping of soil EC requires a field vehicle that is equipped with both a differentially-corrected GPS receiver and an EC measuring device. Ideally, the vehicle should be equipped with a differentially corrected GPS receiver. However it is possible to correct the GPS data after it is collected by means of post processing but location accuracy is compromised. The vehicle traverses the field in a series of closely-spaced passes, collecting input from both devices. It is recommended to setup the GPS receiver to collect data at one-second intervals.

A ground speed of 10 mph, a logging interval of one second and a pass spacing of 60 feet results in a sampling density of about 50 per acre. This results in a much denser data set than is feasible with grid soil sampling (usually one per 2.5 acres) producing a type of soil map with much greater resolution than is possible with a typical nutrient soil test map. Mapping at this sampling density will identify soil inclusions that are at least 0.25 acres in size.

	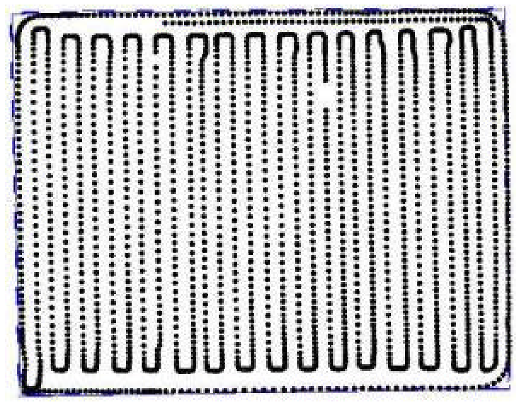
GPS-equipped vehicle performing EC mapping passes (Veris Technologies, Salina, KS)	Typical pattern of vehicle passes used to measure soil electrical conductivity within a farm field

Figure 2. Collecting georeferenced soil EC data.

INTERPRETING SOIL EC MAPS

Soil EC has no direct effect on crop growth or yield. The utility of EC mapping comes from the relationships that frequently exist between EC and a variety of other soil properties that are highly related to crop productivity. These include such properties as water holding capacity, topsoil depth, cation exchange capacity, soil drainage, organic matter level, soil nutrient levels, salinity and subsoil characteristics.

With adequate field checking or field calibration, soil EC can be used as a “surrogate” (substitute) way to measure soil properties that affect crop yield. In general, the correlation between soil EC and yield will be the greatest when yields are primarily influenced by the soil’s available water holding capacity.

The patterns of soil EC within a field do not tend to change significantly over time (Lund et al., 1999). Generally, once an EC map has been made, it will remain relatively accurate unless significant soil movement occurs such as with land leveling, terrace construction, or some type of natural occurrence.

There are many ways to visually present soil EC data in map form. One convenient way is to divide or classify the data into five ranges that contain about the same number of points in each range (equal count). This will effectively differentiate between soils with distinctly different textural, organic matter and drainage properties.

The simplest way to interpret a soil EC map is to visually compare it to yield or soil survey maps from the same field. A more rigorous analysis would involve "rasterization" of the EC data and yield monitor data into square grid cells that are consistent with each other. The average EC values from grid cells can be compared to the yield values from the corresponding cells using linear regression and other statistical techniques.

The EC results can also be correlated to other quantitative site properties that have been measured and mapped using a similar sized grid system. Comparing two spatial data layers that were measured at much different resolution from each other can lead to erroneous correlations. For example, correlations of soil EC values mapped at a 10m resolution to remotely sensed greenness data mapped at 30m resolution may be suspect, and correlations to soil test values mapped at 100m resolution will almost certainly be of little value. These site properties include elevation, plant population, surface curvature or remotely sensed soil and crop canopy images. Finally, more sophisticated statistical methods are available to evaluate the spatial and mathematical similarities between different layers including multivariate clustering (Lark et al., 1997), multifractal and autoregressive state-space analysis (Wendroth et al., 1999). These techniques are currently research tools that may be included in future generations of precision farming software and crop simulation models.

USES OF SOIL EC MAPS

There are numerous possible uses of electrical conductivity maps (see Table 1). These applications will vary from grower to grower and region to region due to differences in soil characteristics, grower needs and interest, and user expertise in utilizing spatial data. For some uses, the grower or data analyst will need access to a moderately powerful GIS rather than just simple yield mapping software. Private consultants and mapping centers are now available to assist with EC mapping and analysis.

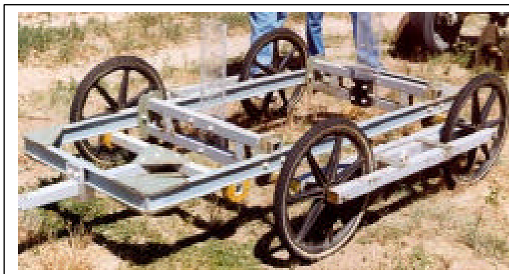

Figure 3. Non-metallic cart used for transporting Non-contact EM sensor (USDA-ARS Water Management Unit, Ft. Collins, CO)

Tips for Collecting Good Data

- **Good soil-coulter contact** is required for soil-penetrating sensors. Take EC measurements when the soil is neither excessively moist nor very dry.
- **Best soil conditions** are found following soybean harvest and before planting for fields in a corn-soybean rotation. Otherwise, firm but non-compacted soil and a smooth field surface are preferred for accurate EC measurement.
- **Avoid metal interferences with EM (non-contact) sensors** by keeping a distance of about 4 to 5 feet between the sensor and any metal object. This can be accomplished with careful placement of the sensor beneath a high-clearance vehicle or on a custom-made cart constructed of non-metallic materials (photo below).
- **Conduct EC mapping when soils are <u>not frozen</u>** for both the contact and the EM methods.

Table 1. Potential uses of EC maps.

Application of EC Mapping	**Soil Properties Estimated**
Delineation of Management Zones	Soil texture, organic matter, CEC, drainage conditions. Soil factors that most influence yield, particularly plant-available water content
Directed soil sampling within more accurate soil boundaries	Soil texture, organic matter, CEC, drainage conditions
Variable rate seeding	Topsoil depth, CEC
Variable rate nutrient application based on soil productivity	Depth to claypan subsoil or parent material, soil texture
Variable rate herbicide application	Soil texture and organic matter and CEC
Interpretation of yield maps	Soil factors that most influence yield, particularly plant-available water content
Fine-tuning of NRCS soil maps by refining soil type boundaries and identifying unmapped inclusions	All soil factors
Guidance for placement and interpretation of on-farm tests	All soil factors
Soil salinity diagnosis	Electrolytes in soil solution
Drainage remediation planning	Water holding capacity, sub-soil properties, water content

For Additional Information on Soil EC Applications:

- Geonics Limited at: http://www.geonics.com/
- Veris Technologies at: http://www.veristech.com/

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