Site-Specific Management Guidelines

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SSMG-30

Soil Electrical Conductivity Mapping

Summary

- Soil electrical conductivity (EC) mapping is a simple, inexpensive tool that precision farmers can use to quickly and accurately characterize soil differences within crop production fields.
- Soil EC is a measurement that correlates to soil properties affecting crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, organic matter (O.M.) 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 geographic information system (GIS).
- Other uses of soil EC maps include guiding directed soil sampling, assigning variable rates of crop inputs, fine-tuning Natural Resources Conservation Service (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 operations than ever before. In addition to yield, boundary and field attribute maps, a wide array of new electronic, mechanical and chemical sensors is being developed to measure and map many soil and plant properties. Soil EC (sometimes referred to as EC_a) 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 O.M., depth to claypans, CEC, salinity, and exchangeable calcium (Ca) and magnesium (Mg).

Soil EC measurements can add value to the farming operation if they can be used to help explain 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.

This *Site-Specific Management Guideline* will examine the potential of field level mapping of soil EC values as a practical tool to characterize soil differences. Mapping soil EC values can also improve variable-rate input management as well as strengthen a grower's decision-making ability for other agronomic practices.

History and Uses of EC Mapping

Geophysical survey methods that measure differences in EC values have been used since the early 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 and for diagnosing salinity related problems in the irrigated southwest U.S.

Researchers have also used soil EC to measure or estimate many other chemical and physical properties of non-saline soils, including water content, clay content, CEC, exchangeable Ca and Mg, depth to claypans, soil O.M. and herbicide behavior in soil. 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.

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EC Measurement in Soil

Electrical conductivity is the ability of a material to transmit (conduct) an electrical current and is commonly expressed in units of millisiemens per meter (mS/m). Soil EC measurements may also be reported in units of decisiemens per meter (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 soil surface but does not make physical contact. A sensor in the device measures the resulting electromagnetic field that this current induces. The strength of this secondary electromagnetic field is directly proportional to the EC of the soil. 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 contact and EM methods has given comparable results.

Non-contact sensor using EM to measure soil EC (USDA-ARS Photo Gallery, Columbia, MO).

Coulter-mounted electrodes need soil contact to measure EC (USDA-ARS Water Management Unit, Ft. Collins, CO).

The depth to which EC will effectively measure soil properties 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 EM methods. Geological testing can be done to a depth of several hundred meters, while most soil EC devices (as pictured above) are designed to be effective for depths of 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 useful in predicting crop yield potentials and therefore be a realistic guide for assigning variable crop input rates.

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 interactions among the following soil properties:

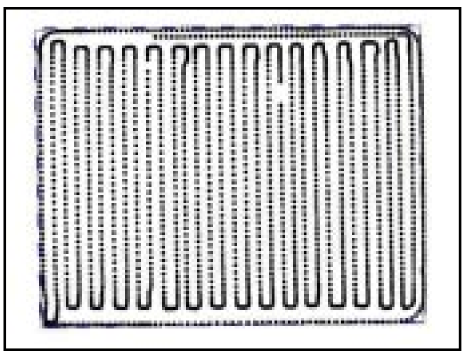
- **Pore continuity** – Soils with water-filled pore spaces that are connected directly with neighboring soil pores tend to conduct electricity more readily. Soils with high clay content have numerous, small water-filled pores that are quite continuous and usually conduct electricity better than sandier soils. Curiously, compaction will normally increase soil EC.
- **Water content** – Dry soils are much lower in conductivity than moist soils.
- **Salinity level –** Increasing concentration of electrolytes (salts) in soil water will dramatically increase soil EC. The salinity level in the soils of most humid regions such as the Corn Belt is normally very low. However there are areas that are effected by Ca, Mg, chloride (Cl), sulfate (SO_4), or other salts that will have elevated EC levels.
- **Cation exchange capacity –** Mineral soils containing high levels of O.M. (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, potassium (K), sodium (Na), ammonium (NH_4), or hydrogen (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 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 they are 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 set up 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 result in about 50 EC readings 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 density will identify soil inclusions that are 0.25 acre in size or larger.

GPS-equipped vehicle performing EC mapping passes (Veris Technologies, Salina, KS).



Typical pattern of vehicle passes used to measure soil EC within a farm field.

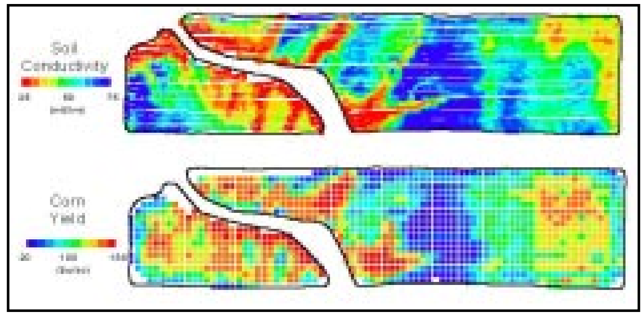
Interpreting Soil EC Maps

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 highly related to crop productivity. These include such properties as water holding capacity, topsoil depth, CEC, soil drainage, O.M. level, soil nutrient levels, salinity, and subsoil characteristics.

With adequate field checking or field calibration, soil EC can be used as a 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. 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. Seasonal variations in EC values can occur due to phenomena such as changes in temperature, soil water content, or vertical movement of salts in the soil profile. Most of these changes are temporary, however, although long term changes in EC values may occur if salts are added to the profile via irrigation water or an increase in size of saline seep discharge areas.

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, O.M. 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, as illustrated above. A more rigorous analysis involves "rasterization" of EC data and yield monitor data into square grid cells that are consistent with each other. Then, average EC values from grid cells can be compared to the yield values from the corresponding cells using linear regression and other statistical techniques. Statistical methods such as these can help to determine the level of correlation between EC values and other parameters such as yield or a soil property.

The EC results can also be correlated to other quantitative site properties that have been measured and mapped using a similar sized grid system. These site properties include elevation, plant population, surface curvature, or remotely sensed soil and crop canopy images. Comparing two spatial data layers that were measured at a 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. Finally, more sophisticated statistical methods are available to evaluate the spatial and mathematical similarities between different layers, including multivariate clustering and multifractal and autoregressive state-space analysis. 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 EC 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. ■

Table 1. Uses of EC maps.

Uses of EC Maps	Soil Properties Estimated
Delineation of management zones	Soil texture, O.M., CEC, drainage conditions. Soil factors that most influence yield, particularly plant-available water content
Directed soil sampling within more accurate soil boundaries	Soil texture, O.M., 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, O.M. 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 (see figure p. 3)	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 and placement of iron (Fe)-tolerant varieties	Water holding capacity, sub-soil properties, water content, salinity

Additional References on Soil EC Applications:

- http://www.pioneer.com/usa/technology/soil_conductivity_mapping_99.htm
- Geonics Limited at: http://www.geonics.com/
- Veris Technologies at: http://www.veristech.com/

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 mapping conditions** are found following harvest in un-tilled fields or prior to planting in prepared fields. In a corn-soybean rotation, conditions following soybean harvest may be most favorable. 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 not frozen** for both the contact and the EM methods.

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

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