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Precision Farming Tools:
Soil Electrical Conductivity

Robert "Bobby" Grisso, Professor and Extension Engineer, Virginia Tech
Mark Alley, W.G. Wysor Professor of Agriculture and Soil Fertility Specialist, Virginia Tech
David Holshouser, Associate Professor and Extension Soybean Specialist, Virginia Tech
Wade Thomason, Assistant Professor and Extension Grain Crops Specialist, Virginia Tech

Soil electrical conductivity (EC) is a measurement that correlates with soil properties that affect crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, organic matter level, salinity, and subsoil characteristics. This publication discusses: 1) How, with field verification, soil EC can be related to specific soil properties that affect crop yield, such as topsoil depth, pH, salt concentrations, and available water-holding capacity; 2) Soil EC maps often visually correspond to patterns on yield maps and can help explain yield variation; and 3) Other uses of soil EC maps (Table 1), including developing management zones, 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

Farmers practicing precision agriculture 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, new electronic, mechanical, and chemical sensors are being developed to measure and map many soil and plant properties. Soil EC is one of the simplest, least expensive soil measurements available to precision farmers today. Soil EC measurement can provide more measurements in a shorter amount of time than traditional grid soil sampling.

Usefulness of Soil Conductivity

The electrical conductivity of soils varies depending on the amount of moisture held by soil particles. Sands have a low conductivity, silts have a medium conductivity, and clays have a high conductivity. Consequently, EC correlates strongly to soil particle size and texture.

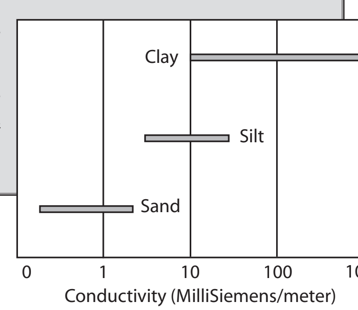
EC Measurement in Soil

Electrical conductivity (EC) 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.

What are milliSiemens per meter (mS/M)?

These are the standard units of measure of bulk soil conductivity. A Siemen is a measurement of a material's conductance.

The advantage of a standard unit of measure is that it makes the data quantitative. Visual identification of soils can often determine color differences, but cannot attribute quantitative values to those colors. Soil EC maps showing values of "X" mS/meter enables you to identify and similarly manage other areas of the field with the same values.



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In addition to EC values separating variations in soil texture, EC has been shown to relate closely to other soil properties used to determine a field's productivity.

Water-holding capacity/drainage: Droughty areas typically have distinct textural differences from those with excess water; these can be identified using EC. Soils in the middle range of conductivity, which are both medium-textured and have medium water-holding capacity, may be the most productive. Since water holding capacity typically has the single greatest effect on crop yield, this is likely the most valuable use of EC measurements for Virginia.

Cation exchange capacity (CEC): CEC is related to percent of clay and organic matter (O.M.). As the percent of clay and organic matter increase, the CEC also increases. Research bears out the correlation between conductivity and CEC through its relationship to clay.

Depth to claypan or rock outcropping: The response of conductivity to the presence of clay has been used to accurately predict the depth of topsoil over a clay layer or rock outcropping.

Porosity: The greater the total soil porosity, the more easily it conducts electricity. Soil with a high clay content has more total pore space than sandier soils when other soil parameters remain constant.

Salinity: An excess of dissolved salts in the soil is readily detected by electrical conductivity.

Temperature: As temperature decreases to 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.

Two Sensor Types Can Measure Soil EC

There are two types of sensors commercially available to measure soil EC in the field. Sensor types are contact or non-contact. Measurements by both sensor types have given comparable results.

1. Contact Sensor Measurements

This type of sensor uses coulters as electrodes to make contact with the soil and to measure the electrical conductivity. In this approach, two to three pairs of coulters are mounted on a toolbar; one pair provides electrical current into the soil (transmitting electrodes) while the other coulters (receiving electrodes) measure the voltage drop between them (Figure 1). Soil EC information is recorded in a data logger along with location information. A global positioning system (GPS) provides the location information to the data logger. The contact sensor is most popular for precision farming applications because large areas can be mapped quickly and it is least susceptible to outside electrical interference. The disadvantage of this system is that it is bulkier than non-contact sensors, and cannot be used in small experimental plots and some small fields.

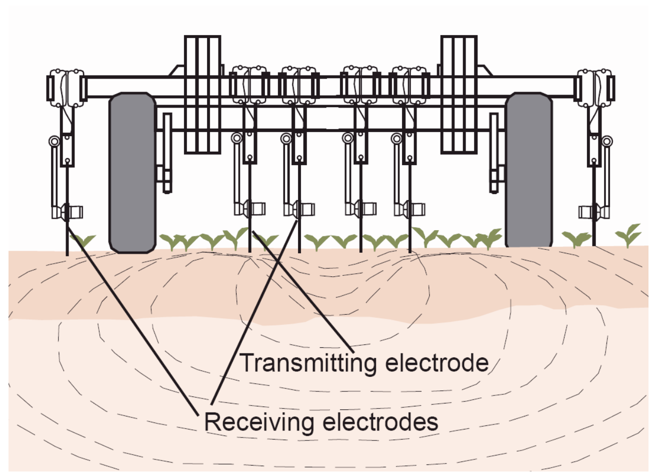

Figure 1. Principle of operation for the contact type EC sensor. Selected coulters act as transmitting electrodes and others as receiving electrodes. (Veris Technologies, Salina, Kansas)

Currently, Veris Technology manufactures a contact type of EC measuring device. Several models of Veris units are available commercially. For example, one model provides EC readings from two different depths (1 foot and 3 feet). A smaller model can be pulled by a small ATV, but it only provides EC measurements at a single depth. Both models can be pulled behind a truck (Figure 2) at field speeds up to 10 mph. The distance between measurement passes ranges from 20 to 60 feet, depending on the desired sampling density or the amount of soil variability within the field.

Figure 2. Truck pulling a contact type EC measurement cart in field. Note the DGPS system mounted on the cab to determine the location for the soil EC measurement. (Veris Technologies, Salina, Kansas)

2. Non-contact Sensor Measurements

Non-contact EC sensors work on the principle of electromagnetic induction (EMI). EMI does not contact the soil surface directly. The instrument is composed of a transmitter and a receiver coil (Figure 3), usually installed at opposite ends of the unit. A sensor in the device measures the resulting electromagnetic field that the current induces. The strength of this secondary electromagnetic field is proportional to the soil EC. These devices, which directly measure the voltage drop between a source and a sensor electrode, must be mounted on a non-metallic cart to prevent interference (Figure 4). These sensors are lightweight and can be handled easily by a single individual, thus making them useful for small areas.

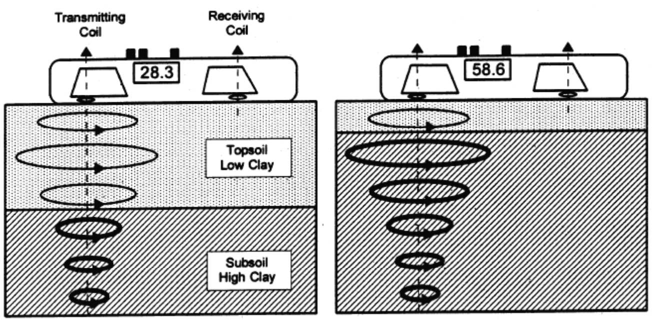

Figure 3. Principle of operation for the non-contact type EC sensor. The transmitting coil sends an electrical field into the soil and the ability to carry the electrical field is related to the soil properties. With unit on the left, the less conductive sandy surface soil reduces the field strength as compared to the unit on the right with more clay in the soil profile.

Figure 4. The EM device mounted on a custom-made cart constructed of nonmetallic materials.

EM38 (Geonics Limited) and GEM-2 (Geophex) are two popular models of non-contact sensors. GEM-2 is a digital, multi-frequency sensor that is capable of measuring EC at different depths. EM-38 works only with a fixed frequency and has an effective measurement depth of 5 feet in horizontal mode or 2.5 feet in vertical mode.

Correlation of Soil EC and Crop Yield

After precision farmers create yield maps and conduct a preliminary evaluation of the yield response, they will identify the manageable causes of crop yield response (see *Interpreting Yield Maps – "I gotta yield map – now what?",* Virginia Cooperative Extension publication 442-509). Differences in soil properties are some of the most obvious reasons for yield variability. Soil EC has the potential to estimate variations in some soil physical properties in a field.

Yield maps are frequently correlated to soil EC, as shown in Figure 5. In many situations, these similarities are explained through differences in soil. The water-holding capacity of the soil is a major factor affecting yield, and the yield map will likely show a strong correlation to the soil EC. In general, soil EC maps may indicate areas where further exploration is needed. Most likely, soil EC maps give valuable information about soil differences and similarities, which makes it possible to divide the field into smaller management zones. Zones that have consistent EC readings are areas that have similar soil properties and can be grouped together for soil sampling and management.

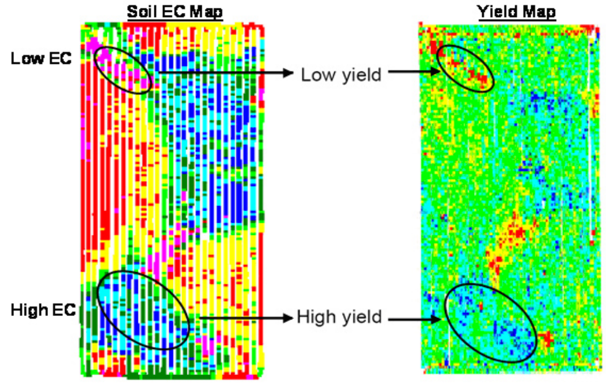

Figure 5. Comparison between the yield map (right) and soil EC map (left). The areas of low soil EC (pink) relate to low yield (reds) as well as a high soil EC (blue) relates to high yield (blue).

Impact of soil water

The question regarding soil water that seems central to evaluating the usefulness of EC mapping in precision agriculture is: Does a field mapped under different soil water conditions show new zones that change based on different field moisture conditions? For soil EC maps to have value, the patterns and areas identified must be consistent and repeatable. In fields with different cropping histories or for soil EC readings taken on the same field at different times, EC readings may need to be normalized (standardized). For example, consider a field in Virginia where the field was planted half to corn and harvested several weeks before the soybean crop on the adjacent half of the field. These fields had different electrical conductivity measurements, but these differences were due to soil water content and not soil properties. The corn side of the field had plenty of soil moisture from post-harvest rains, but the soybeans depleted much of the soil water during this time period. This left the field with a large variation in soil moisture between the side with no growing crop (corn harvested) and soybeans that were still growing and using water. Mapping both sides of the field immediately after soybean harvest produced a map with three distinct zones within the field. But the zone differences are primarily from the differences in soil moisture content associated with the different crops. Standardizing the soil EC across the two halves of the field effectively removed the soil moisture influence. After standardizing the soil EC measurements, the soil EC values along the field boundaries of the two halves of the field matched very closely, and there were only two distinct zones within the field.

It has been demonstrated that fields mapped several times during the year with varying moisture contents had soil EC value changes but the zone delineation did not. With the exception of almost pure sand, the soil EC varies by only 5 percent to 10 percent. As a result, variations in soil type can be detected no matter what the moisture condition of the field. On the other hand, this also means that conductivity is not the tool of choice for determining the moisture content of soils, but rather its relative moisture holding capacities.

Do soil EC maps correlate with NRCS soil Maps?

In virtually every field where the soil EC and NRCS maps have been compared (Figure 6), there is a definite correlation between the two maps. This is to be expected since soil texture is a key influence behind both. There are some important differences that generally occur:

1. The soil EC map identifies inclusions not found on the NRCS maps. Order 2 soil surveys allow for 2.5-acre inclusions – smaller areas of differing soil characteristics were thought to be too small to identify when the NRCS maps were created.

2. Because the original NRCS maps were not geo-referenced with GPS technology, the exact location of the soil unit line is frequently 50 to 200 feet from where the soil EC map places the change.

3. Because soil changes throughout a field are a continuum, not a set of lines or polygons, the data point per second approach of a soil EC map identifies these changes as transition zones – not lines.

4. The soil EC map identifies areas of contrasting conductivity/texture. Using it in conjunction with a good NRCS map provides the ability to benchmark the EC data against other soil types with similar conductivity values.

5. NRCS maps identify other field characteristics such as slope and crop suitability, which, layered with a soil EC map, results in a more accurate management tool than either map individually.

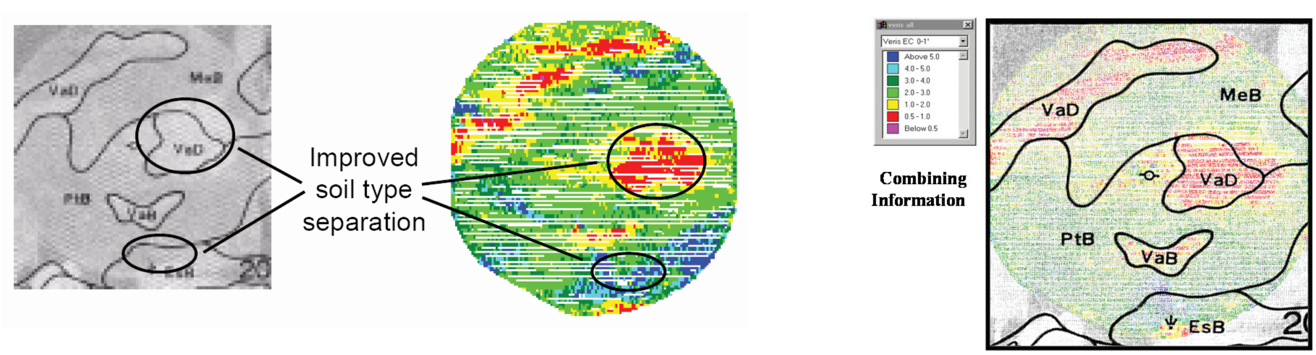

Figure 6. Soil survey (top left) compared to the soil EC map (top right). When these maps are combined, the zones can be more finely delineated.

Can the soil EC reading be used to control a planter or applicator in real time?

The relationship between conductivity and crop production inputs (seed, fertilizer, etc.) is not linear. The highest economic value is using soil EC in conjunction with other information such as: historical productivity, soil sample data, and local agronomic knowledge. For example, in some areas, higher conductivity indicates higher clay and CEC, resulting in higher yield goals and additional inputs on those sites. In other regions, the higher conductivity indicates excessive clay, which may limit production, thus reducing inputs. In both cases, a soil EC map of the field identifies those sites and allows individual recipes to be created. Possible prescriptions that can be developed from soil EC maps are:

1. Variable seeding and N rates based on site-specific yield goals based on CEC levels.
2. Variable seeding rates based on the depth of topsoil.
3. Variable soil-applied herbicide rates based on organic matter, texture, and CEC.
4. Variable lime rates based on zone sampling according to CEC levels.
5. Limit applications of gypsum to sodic areas.

Tips for collecting soil EC data

- Take EC measurements when the soil is neither excessively moist nor very dry. Good soil-coulter contact is required for direct contact sensors.
- Best mapping conditions are found following harvest in smooth, untilled fields or prior to planting in prepared fields. In a corn-soybean rotation, conditions following soybean harvest may be most favorable since the soybean residue is less. Otherwise, firm but non-compacted soil and a smooth field surface are preferred for soil 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 nonmetallic materials (Figure 4).
- Conduct soil EC mapping when soils are not frozen.
- Collect data on measurement pass spacing no greater than about 60 feet. Experience shows that 40- to 60-foot passes provides a map that adequately identifies the spatial patterns of a field. Such a pass may represent half to a full spray-boom width or a multiple of the planter or combine width, and consequently the smallest area most growers will variably manage.
- To add value to your soil EC maps, it is important that your service provider take a deep soil sample or compaction measurement at a few points in each field. Soil physical characteristics and moisture measurements will aid in interpreting what is causing soil EC variations. The sampling should be done at the same time as soil EC data are collected.

Misleading Soil EC Signals

Soil EC measurements can sometimes be unreliable. For example, measuring soil EC following application of high rates of manure or biosolids may result in a misleading map. Since the underlying soil properties may contain excessive salts from such an application, EC values obtained in this type of situation may not represent soil conductivity but rather reflect variations in manure/biosolid applications. Extremely dry soils may also lead to erroneous readings. Avoid making measurements when soils are dry to a depth of 12 to 16 inches as conductivity is significantly reduced and readings are more variable. Awareness of these situations will assure that readings produce the highest quality EC map.

Summary

More accurate soil property maps are needed to successfully implement precision farming decisions. Inadequate sampling density and the high cost of conventional soil sampling and analysis may prevent soil property segregation and classification. However, the use of soil EC measurements represents an alternative to intensive soil sampling and could both improve the resolution (increased sampling density) and reduce the cost of soil maps. Soil EC maps can be used to define management zones reflecting obvious trends in soil properties. Each zone can be sampled and treated independently.

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Table 1. Uses of EC Maps

Use	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, CEC: Soil factors that most influence yield, particularly plant-available water content
Variable rate nutrient application based on soil productivity	Depth to claypan subsoil or parent material, soil texture
Variable rate herbicide application	Soil texture, organic matter, CEC
Interpretation of yield map	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 and placement of iron (FE)-tolerant varieties	Water holding capacity, subsoil properties, water content, salinity