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EC02-178 Precision Agriculture: On-the-Go Vehicle-Based Soil Sensors

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Precision AGRICULTURE

On-the-Go Vehicle-Based Soil Sensors

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For more information about precision agriculture research, education and demonstration programs at the University of Nebraska, visit the Web site at http://precisionagriculture.unl.edu/

Imagine that you are entering an unknown field and would like to estimate the productivity of the unfamiliar soil. You may pick up a handful of soil to evaluate its color and texture. You also can feel how difficult it is to break a clod apart, roll it into a ball or press out a ribbon. After repeating this procedure at different field locations, soil depths and times, you get a feeling of both spatial and temporal soil variability. Some of this variability can explain the non-uniformity of crop yield. If you collect soil samples and send them to a soil-testing laboratory, you can get a standardized measure of soil nutrient levels and other characteristics. The greater the sampling density, the more likely you are to obtain a good representation of the variability of soil properties across the field. This process, however, takes time and money, both when sampling and in the lab, and limits the number of soil samples which can be justified economically.

Sensors that measure a variety of essential soil properties on the go are being developed. These sensors can be used either to control variable rate application equipment in real-time (*Figure 1,* left) or in conjunction with a Global Positioning System (GPS) to generate field maps of particular soil properties (*Figure 1,* right). Depending on the spacing between passes, travel speed, and sampling and/or measurement frequency, the number of measurement points per acre varies; however, in most cases, it is much greater than the density of manual grid sampling. The cost of mapping usually is reduced as well. The purpose of this publication is to review the most promising soil sensor approaches and to present an overview of some that are commercially available.

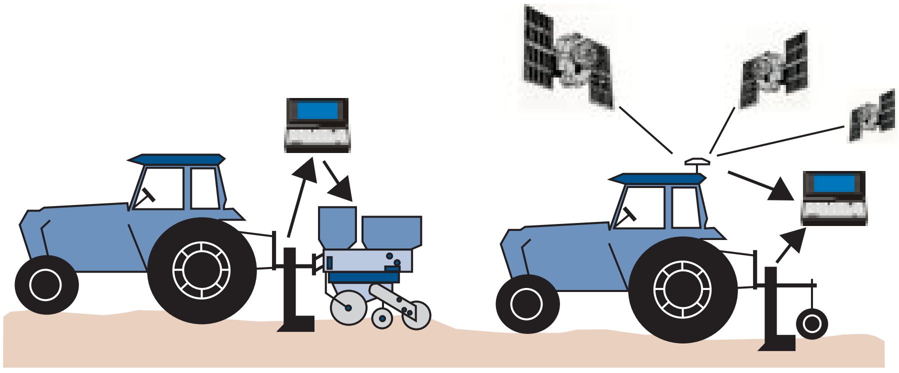

Figure 1. Real-time (left) and map-based (right) approaches to using vehicle-based on-the-go soil sensors.

Measuring Soil Properties

After creating a set of yield maps and conducting a preliminary evaluation of the results, it is necessary to identify the manageable causes of crop performance variability. Differences in soil properties are some of the most obvious reasons for yield variability. Soil pH, nutrient availability, organic matter, texture, compaction, and perhaps other soil properties may all affect crop yield. Soil maps representing various properties are commonly obtained through recommended soil sampling and analysis procedures (see "Soil Sampling for Precision Agriculture," EC 00-154). These maps are used to aid the site-specific crop management decision-making process.

Geo-referenced soil sampling, laboratory analysis, and mapping are available through several commercial vendors. The resulting interpolated soil maps become key information layers in prescribing variable rate application of fertilizers, lime and herbicides. Conventional soil sampling and analysis have shown mixed economical returns due to the high

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costs associated with labor-intensive sampling and analysis procedures and map uncertainties. In many cases, when the sampling density was not great enough, the limited number of soil samples did not produce an accurate representation of soil properties (especially for nutrient levels).

When thinking about an ideal precision agriculture system, producers visualize a sensor located in direct contact with, or close to, the ground and connected to a "black box" which analyzes sensor response, processes the data, and changes the application rate instantaneously. They also hope that the real-time information detected by the sensor and used to prescribe the application rate would optimize the overall economic or agronomic effect of the production input. This approach, however, does not take into account several difficulties met in the "real world":

1. Most sensors and applicator controllers need a certain time for measurement, integration, and/or adjustment, which decreases the allowable operation speed or measurement density.
2. Variable rate fertilizer and pesticide applicators may need additional information (like yield potential) to develop prescription algorithms (sets of equations).
3. Currently, there is no site-specific management prescription algorithm proven to be the most favorable for all variables involved in crop production.

Rather than using real-time, on-the-go sensors with controllers, a map-based approach may be more desirable because of the ability to collect and analyze data, make the prescription, and conduct the variable rate application in two or more steps. In this case, multiple layers of information including yield maps, a digital elevation model (DEM), and various types of imagery could be pooled together using a geographic information system (GIS) software package designed to manage and process spatial data. Prescription maps can be developed using algorithms that involve several data sources as well as personal experience. Probably the most essential piece of data is a set of maps representing variation in soil characteristics that influence yield, such as:

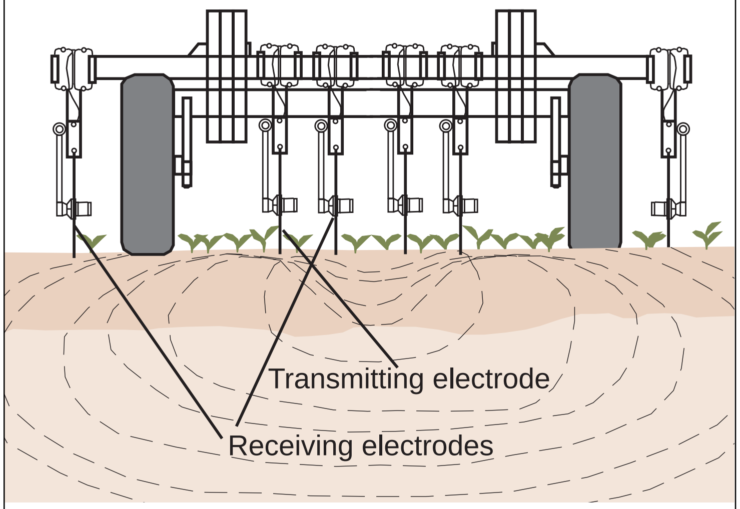

Figure 2. Veris® EC Probe electrical conductivity mapping system (figure from Veris Technologies, Salina, Kansas)

- soil pH and buffer pH,
- macronutrient level (nitrogen, phosphorus, potassium),
- soil organic matter (carbon) content,
- soil texture (clay content),
- soil moisture and temperature,
- cation exchange capacity (CEC),
- soil compaction,
- depth of any root restricting layers, and
- soil structure and bulk density.

Sensors for Automated Measurements

Scientists and equipment manufacturers are trying to modify existing laboratory methods or develop indirect measurement techniques that could allow on-the-go soil mapping. To date, only a few types of sensors have been investigated, including:

- electromagnetic,
- optical,
- mechanical,
- electrochemical,
- airflow, and
- acoustic.

Electromagnetic sensors use electric circuits to measure the capability for soil particles to conduct or accumulate electrical charge. When using these sensors, the soil becomes part of an electromagnetic circuit, and changing local conditions immediately affect the signal recorded by a data logger. Several such sensors are commercially available:

- Mapping electrical conductivity (Veris® 3100, Veris Technologies, Salina, Kansas)[1]
- Mapping transient electromagnetic response (EM-38, Geonics Limited, Mississauga, Ontario, Canada)
- Using electrical response to adjust variable rate application in real-time (Soil Doctor® System, Crop Technology, Inc., Bandera, Texas)

For example, one way to estimate soil electrical conductivity is by electromagnetic induction using a commercially available Geonics Limited EM38 meter. The transmitting coil induces a magnetic field that varies in strength with soil depth. The magnetic field strength/depth to soil relationship can be altered to measure various soil depths to a maximum of 1.5 meters. A receiving coil measures the primary and secondary "induced" currents in the soil and relates the two to soil electrical conductivity. Another commercially available instrument for mapping soil electrical conductivity, the Veris® EC Probe *(Figure 2)*, measures electrical conductivity more directly. It uses a set of coulter electrodes that send out an electrical signal through the soil. The signal is received by two sets of electrode coulters that measure voltage drop due to the resistivity of the soil, indicating electrical conductivity of two depth ranges.

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[1] Mention of brand names is for identification purposes only. No endorsement or criticism is intended for those mentioned or any equivalent products not mentioned.

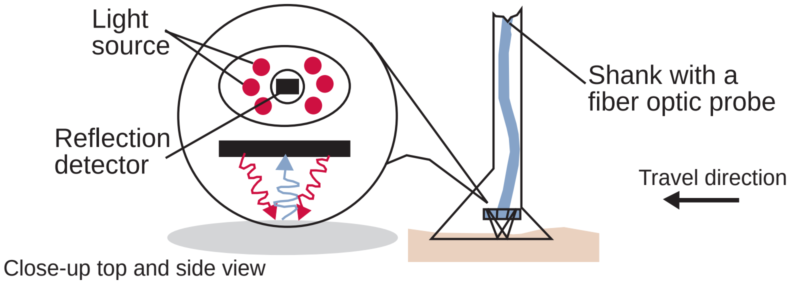

Figure 3. Schematic of a subsurface soil reflectance optical sensor.

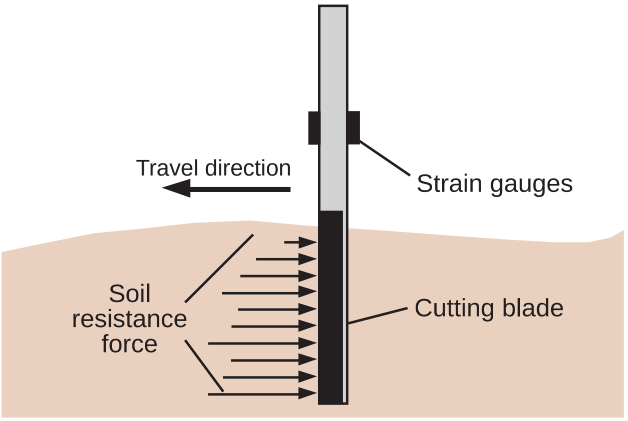

Figure 4. An example of a soil mechanical resistance measurement device.

Electromagnetic soil properties, for the most part, are influenced by soil texture, salinity, organic matter, and moisture content. In some cases, other soil properties such as residual nitrates or soil pH can be predicted using these sensors. Several approaches for applying electromagnetic sensors have been observed in recent years. A later section will discuss this in more detail.

Optical sensors use light reflectance to characterize soil. These sensors can simulate the human eye when looking at soil as well as measure near-infrared, mid-infrared, or polarized light reflectance. Vehicle-based optical sensors use the same principle technique as remote sensing. To date, various commercial vendors provide remote sensing services that allow measurement of bare soil reflectance using a satellite or airplane platform. Cost, timing, clouds, and heavy plant residue cover are major issues limiting the use of bare soil imagery from these platforms.

Close-range, subsurface, vehicle-based optical sensors *(Figure 3)* have the potential to be used on the go, in a way similar to electromagnetic sensors, and can provide more information about single data points since reflectance can be easily measured in more than one portion of the spectrum at a time. Several researchers have developed optical sensors to predict clay, organic matter, and moisture content.

Optical sensors have been developed commercially to conduct automated point-based mapping of soil reflectance at various depths (3-D Soil Property Mapping, Earth Information Technologies, Madison, Wisconsin); however, this application requires the vehicle to stop when making measurements. Rather than using optical reflectance, some researchers are using ground-penetrating radars to investigate wave movement through the soil. Changes in wave reflections may indicate changes in soil density or restricting soil layers.

Mechanical sensors can be used to estimate soil mechanical resistance (often related to compaction). These sensors use a mechanism that penetrates or cuts through the soil and records the force measured by strain gauges or load cells *(Figure 4)*. Several researchers have developed prototypes that show the feasibility of continuous mapping of soil resistance; however, none of these devices is commercially available. The draft sensors or "traction control" system on tractors uses a similar technology to control the three-point hitch on the go.

Electrochemical sensors could provide the most important type of information needed for precision agriculture — soil nutrient levels and pH. When soil samples are sent to a soil-testing laboratory, a set of standardized laboratory procedures is performed. These procedures involve sample preparation and measurement. Some measurements (especially determination of pH) are performed using an ion-selective electrode (with glass or polymer membrane or ion sensitive field effect transistor). These electrodes detect the activity of specific ions (nitrate, potassium, or hydrogen in case of pH). Several researchers are trying to adapt existing soil preparation and measurement procedures to essentially conduct a laboratory test on the go. The values obtained may not be as accurate as a laboratory test, but the high sampling density may increase the overall accuracy of the resulting soil nutrient or pH maps.

Airflow sensors were used to measure soil air permeability on the go. The pressure required to squeeze a given volume of air into the soil at fixed depth was compared to several soil properties. Experiments showed potential for distinguishing between various soil types, moisture levels, and soil structure/compaction.

Acoustic sensors have been investigated to determine soil texture by measuring the change in noise level due to the interaction of a tool with soil particles. A low signal-to-noise ratio did not allow this technology to develop.

Sensor Data Usage

Although various vehicle-based soil sensors are under development, only electromagnetic sensors are commercially available and widely used. Ideally, producers would like to operate sensors that provide inputs for existing prescription algorithms. Instead, commercially available sensors provide measurements such as electrical conductivity (EC) that cannot be used directly since the absolute value depends on a number of physical and chemical soil properties such as: texture, organic matter, salinity, moisture content, etc. Alternatively, electromagnetic sensors give valuable information about soil differences and similarities, which makes it possible to divide the field into smaller and relatively consistent areas referred

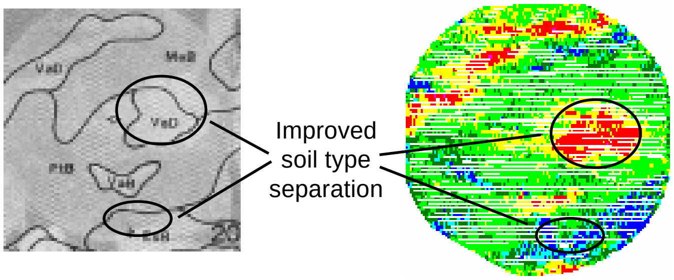

Figure 5. Soil survey (left) compared to map of soil electrical conductivity.

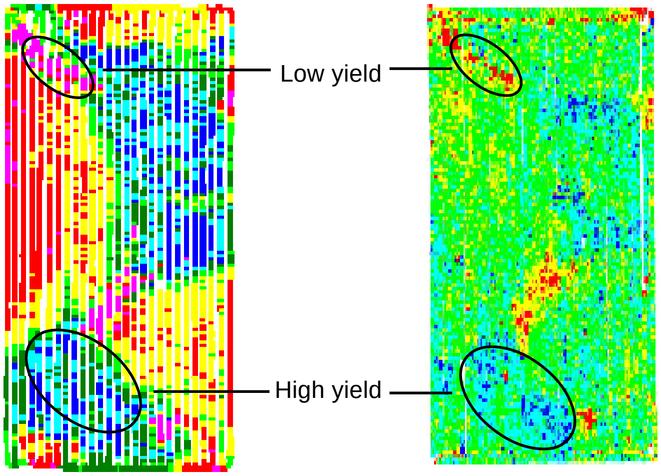

Figure 6. Comparison between yield map (right) and soil electrical conductivity map (left).

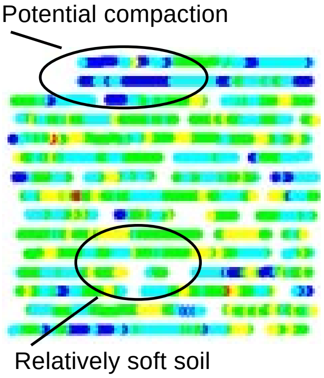

Figure 7. Mechanical resistance soil map of a no-till field reveals areas with potential compaction problems.

to as management zones.

For example, such zones could be defined according to various soil types in a field. In fact, electrical conductivity maps usually can better reveal boundaries of certain soil types than soil survey maps (used for rural property tax assessment). Different anomalies such as eroded hillsides or ponding also can be easily identified on an electrical conductivity map. *Figure 5* compares a soil survey and an electrical conductivity map for the same field showing some differences in boundaries.

Yield maps also frequently correlate to electrical conductivity maps, as shown in *Figure 6*. In many instances, such similarities can be explained through differences in soil. In general, the electrical conductivity maps may indicate areas where further exploration is needed to explain yield differences. Both yield potential and nutrient availability maps may have a similar pattern as soil texture and/or organic matter content maps. Often these patterns also can be revealed through an electrical conductivity map.

Therefore, it seems reasonable to use on-the-go mapping of electromagnetic soil properties as one layer of data to discover the heterogeneity (differences) of soil within a field (similar to using bare soil imagery). Zones with similar electrical conductivity and a relatively stable yield may receive a uniform treatment that can be prescribed based on fewer soil samples in the zones on the electrical conductivity map.

As new on-the-go soil sensors are developed, different real-time and map-based variable rate soil treatments may be economically applied to much smaller field areas, reducing the effect of soil variability within each management zone. *Figure 7*, for example, shows a map of soil mechanical resistance obtained using a prototype sensor. Variable (spot) tillage could be implemented using this map.

Summary

More accurate soil property maps are needed to successfully implement site-specific management decisions. Inadequate sampling density and the high cost of conventional soil sampling and analysis have been limiting factors. On-the-go, vehicle-based soil sensors represent an alternative that could both improve the quality and reduce the cost of soil maps. When further developed, on-the-go soil sensors may be used for either real-time or map-based control of agricultural inputs. To date, only systems that map electromagnetic soil properties are available commercially. These maps can be used to define management zones reflecting obvious trends in soil properties. Each zone can be sampled and treated independently. Smaller management zones will be feasible when new on-the-go soil sensors are developed and commercialized.

Researchers at the University of Nebraska continue work on vehicle-based soil sensors, which could be used for research and commercial applications. The sensors can improve the quality and decrease the cost of soil maps and will facilitate the decision-making process.

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