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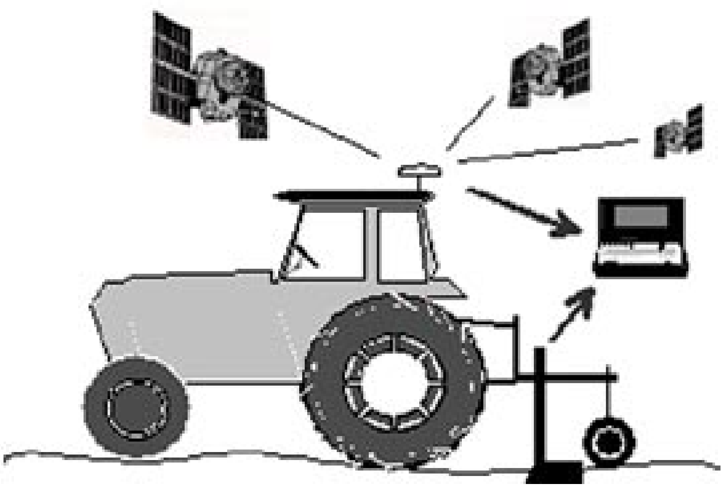
FROM THE GROUND UP
Agronomy News

Sensors



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Sensors in Agriculture

A primer on sensors currently being used or developed in Agriculture.

Today we are living in the "information age". Use of important pieces of information to make better decision is crucial for success of any enterprise. Agricultural enterprises are no different. However, what makes things challenging in agriculture is the process of gathering information to make a better decision. A sensor, i.e. equipment to sense information remotely or in contact of an object, helps in this regard. Sensors have been used in agriculture for ages, for example, sensing soil moisture content, soil pH, compaction, greenness of a leaf, etc. However, what is different in today's age and technology is sensing soil and crop properties in real-time, and making crop management decisions in real-time as a continuous process during various operations in a field. Such sensors are commonly called as "on-the-go" sensors.

There are a number of "on-the-go" sensors that are commercially available, and others that are under development or in the test phase. The most popular sensor being used today in agriculture

Sensors in Agriculture (continued)

is the “crop yield sensor”. Yield sensors have revolutionized the farmers’ perspective about the inherent variability that exists on their fields. They are fast becoming standard piece of equipment on grain combines. Like wise, sensors to quantify the differences in soil properties across a field using soil electrical conductivity meters are rapidly gaining popularity among farmers. Sensors to remotely assess the health of the crop throughout the growing season, are also available, and are being developed further for real-time applications.

This issue of our Extension Newsletter will give you a primer on various sensors that are commercially available and are currently being used in different parts of the country. Articles presented in this newsletter are from Colorado, Nebraska, Kansas, and Oklahoma, and therefore should give you a perspective on the use of sensors in agriculture in this region. Specific questions concerning site-specific farming, managing field variability, applicability of a particular sensor for your farming or consulting enterprise should be directed to Dr. Raj Khosla, Precision Agriculture Specialist, Colorado State University.

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Assistant Professor
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Extension Specialist
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GPS equipped hand-held chlorophyll sensor to monitor in season nitrogen stress in corn.

FROM THE GROUND UP

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Web Site: http://www.colostate.edu/Depts/SoilCrop/extension/Newsletters/news.html

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Soil Electrical Conductivity Mapping of Agricultural Fields

Soil electrical conductivity can help you identify productivity differences in your farm field.

Among the many advanced sensors recently introduced in agriculture, bulk soil electrical conductivity (or simply soil EC) measuring devices provide the simplest and least expensive map of soil differences across the field. Soil EC measures the amount of salt (like sodium and calcium) in the soil as well as other soil properties. Soil EC has been traditionally used in agricultural fields to survey the presence of salts that are harmful to growth of most crops. In fields with low amounts of salt, maps showing the changes in soil EC relate to soil properties such as the amount of sand, clay, and organic matter. These soil properties could have a major impact on crop yield.

Historically, farmers tend to apply the agricultural inputs (seeds, irrigation, fertilizers, and pesticides) uniformly (or the same amount) on the entire field, but the crop yield at the end of the growing season often varies across the field. Although there are many reasons why crop yield may change across the field, changes in soil properties could be a major factor. The ability of soil to hold and distribute water, fertilizers, and pesticides near the roots of a crop changes as soil properties change. It is therefore logical to apply different amounts of agricultural inputs to areas of a field that has different soil properties. Applying the right amount of agricultural inputs at the right time and at the right place in the field is what many refer to as "precision agriculture." To practice precision agriculture, the farmer must first have good field maps showing how much and where to apply the inputs across the field. A soil EC map does not identify how much change in inputs is needed across the field, but helps to quickly view the entire field's soil differences and identify where soils change across the field.

One of the simplest devices to measure soil EC in the field is a unit designed by Veris Technologies in Kansas. The Veris unit (shown in Figure 1) is pulled behind a pickup truck and takes soil EC readings every second. A Global Positioning System (GPS) mounted on the Veris unit links to satellites and tells the Veris computer exactly where each soil EC measurement point is in the given field. Data can be input into a computer program and a color map of field's soil EC is generated showing different colors representing differences in soil properties within the field. A soil EC map is shown in Figure 2 for an irrigated field near Wiggins, Colorado.

Using the soil EC map as a guide, farmers need to collect a few soil samples from each specific soil EC area to determine the soil properties for that area and decide whether or not to modify their management for different areas of the field. In the field shown in Figure 2, soil samples were collected and laboratory analyses

Figure 1. Veris 3100 soil EC Mapping System.

Soil Electrical Conductivity Mapping of Agricultural Fields (continued)

were performed to determine their properties. It was found that the light color areas in the soil EC map shown in Figure 2 are very high in sand and low in clay. The darker color areas in the soil EC map had more clay and organic matter. Without a soil EC map, many more soil samples from the field would be needed to map soil properties across the field with a significant cost increase. The example illustrates a common use of a soil EC map; as a guide for where to sample soil, locate on-farm tests plots, and select areas in the field for variable rate application of inputs.

How is soil EC measured?

Soil electrical conductivity can be measured by transmitting a low electrical current through the soil and measuring the ease (or drop in voltage) at which electrons travel through the soil. Soil can conduct electrons. Soil is made up of solid, liquid, and gases. Soil gases are insulators and do not conduct electricity. Soil solids (like clay particles) and liquid (like soil water solution) play a major role in the movement of electrons. Soil water solution usually has many different dissolved chemicals such as ions of calcium, sodium and magnesium. The ions in the solution are called electrolytes and also conduct electrical current. The electrons move through different pathways in the soil and ride along surfaces of particles that are in contact with each other. Since the pathways in the soil are related to soil texture (for instance the amount of sand and clay), soil EC is found to relate to soil texture. Soils high in clay have much more particle-to-particle contacts and thus higher soil EC. Sandy soils have low number of particle contacts and are poor conductors (or lower soil EC). Soil water has a strong effect on the values of soil EC, but research shows that even though values of soil EC may change as soil water changes, the patterns of a soil EC map stay unchanged. Thus, a single soil EC map for a field is probably sufficient for many years to characterize the soil variability patterns.

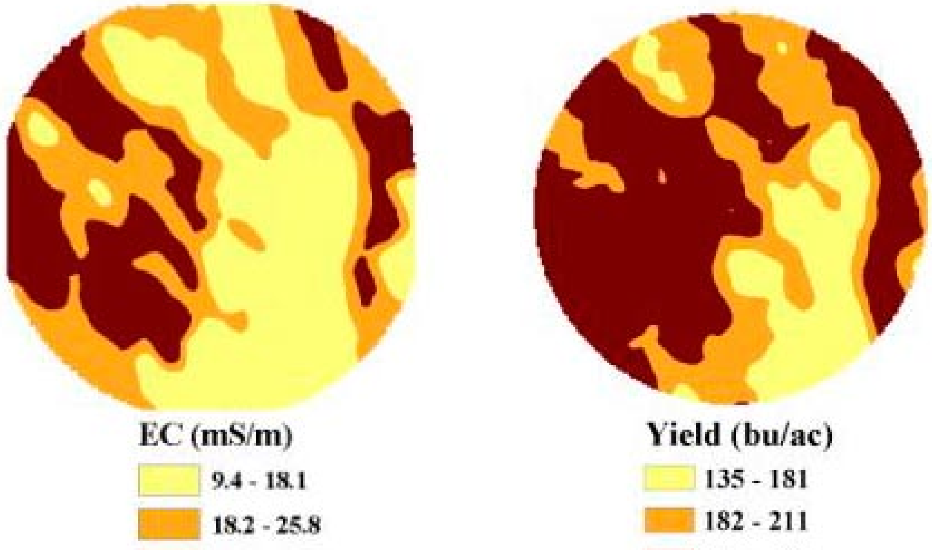

Figure 2. Electrical conductivity (left) and crop yield (right) maps from a field in Wiggins, Colorado.

Methods of measuring soil EC.

The most common method of measuring soil EC is called the four-electrode configuration, originally suggested by a scientist named Wenner in 1915. The Veris unit uses the same method to measure soil EC. As shown in Figure 3, the Veris unit has six flat disks that act like electrodes. As the Veris unit is pulled through the field, one pair of disk-electrodes (number 2 and 5 in Figure 3) injects electrical current into the soil, while the change in voltage is measured across the other disk-electrodes. Knowing the amount of current, the change in voltage and the distances between the disks, a computer program in Veris then calculates soil EC. While the Veris disk-electrodes only penetrate the soil a few inches during measurement, the electrical network shown in Figure 3 travels much deeper in the soil. Disks 3 and 5 are closer to each other and measure soil EC for the top foot of soil. Disks 1 and 6 are farther apart and measure soil EC for the top three feet of soil. A field is usually mapped by driving back and forth through the field on parallel paths 50 feet apart. With speeds up to 15 mph, the Veris records between 50 and 100 soil EC readings per acre. The soil EC and GPS data are recorded on the Veris datalogger that can be downloaded onto a diskette.

Soil Electrical Conductivity Mapping of Agricultural Fields (continued)

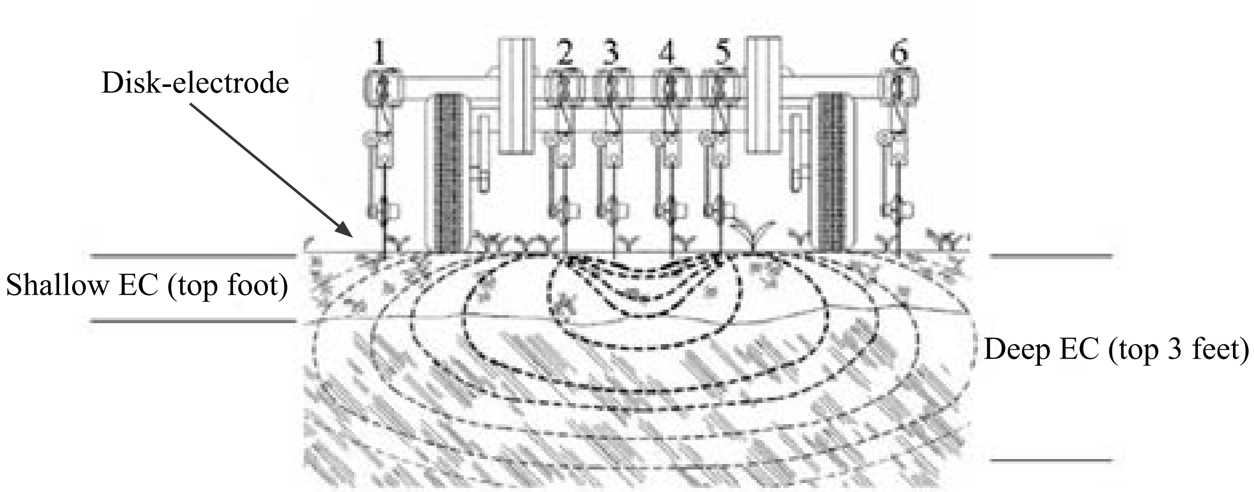

Figure 3. A diagram of the Veris soil EC Unit showing the disk-electrodes and electrical network.

Soil EC in Precision Agriculture

Soil is the primary medium for crop development and thus an accurate map of soil differences across the field is helpful in explaining the differences in crop yield. A soil EC map can help farmers evaluate soil differences across their fields. The soil properties that vary on a soil EC map, such as soil texture and the amount of salts have a direct impact on crop yield. Soil texture relates to factors that have a major impact on crop yield, such as water holding capacity of soil (or the amount of water that the soil can hold). Therefore, soil EC maps often relate well with (or look similar to) crop yield maps. This is illustrated in Figure 2 showing both soil EC and crop yield maps from an irrigated field at Wiggins, Colorado. Figure 2 shows that most of the high crop yield areas correspond to areas with higher soil EC values and the low crop yield areas correspond to areas with lower soil EC values.

It is important to note that crop yields are not always higher in high soil EC areas. In some fields, crop yields could be lower in high soil EC areas. That is because of the different factors that cause the crop yield and soil EC to vary in those areas. For example, in some fields, higher soil EC values may indicate higher clay and organic matter contents and thus a more productive soil. It may be more economical to increase agricultural inputs on those areas to improve crop yield. In other fields, the higher soil EC values may indicate too much clay and/or salt and thus a less productive soil with a limited crop yield. Reducing the amount of agricultural inputs on areas of the field where the soil is poor quality and cannot effectively store water and nutrients may be more economical. In both cases, a soil EC map of the field identifies those areas that may require a change in agricultural inputs. Although the relationship between soil EC and the amount of agricultural inputs to apply is not a simple calculation, the economic value in using a soil EC map in combination with other information about the field such as historical crop yield, soil data, and field topography (changes in elevation and slope). A soil EC map is an important piece of information in precision agriculture that can be used to guide soil sampling, conduct crop yield map analysis, and help to decide whether or not to vary the amounts of agricultural inputs (like seeds and fertilizers) across the field.

The following references were consulted in compiling this report:

Veris Technologies
(www.veristech.com)

Pioneer Hi-Bred International, Inc.
(www.pioneer.com)

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Sensible Soil Sensors Are Welcome

Mapping soil properties using soil electrical conductivity sensor.

Not too long ago I was out on the plains near Sterling and Stratton, Colorado, soil sampling each 10 x 50 ft plot of my research project, trying to assess levels of soil N. As a graduate student at Colorado State University, my first impression of soil sampling was rather easy, even fun. Of course, I have to admit I had done little soil sampling prior to my graduate work. Dad didn't use soil sampling on the small farm that I grew up on. Between barnyard manure and liberal use of fertilizer, I'm quite sure nutrient levels on our soils would have been classed as "very high." As a graduate student, it only took a couple of months for my impressions about soil sampling to change. Once I started examining the lab results, I realized how difficult it was to obtain a "representative" sample. The challenge is "the sampling." Ten composited sub-samples taken to a 6 inch depth from a one-acre area is only sampling about 1 millionth of the soil! And how often can we financially afford to even take one sample for every acre?

In spite of the difficulties of getting "representative" soil samples, soil sampling is still an extremely valuable tool for assessing the general levels of nutrients in fields. Further, taking multiple soil samples within fields (along with GPS location information) has been very successful for mapping trends in nutrient variation within fields. However, as we look to the future, our ability to measure and map nutrient variability is limited if we only have soil sampling. That is why so many have turned to testing in-field "sensors".

In concept, the idea of having automated in-field sensors for helping assess soil nutrients is appealing. Many more measurements could be taken that is feasible with field soil sampling and lab analysis, thus allowing for better maps of nutrient availability. Farmers would win because of time savings

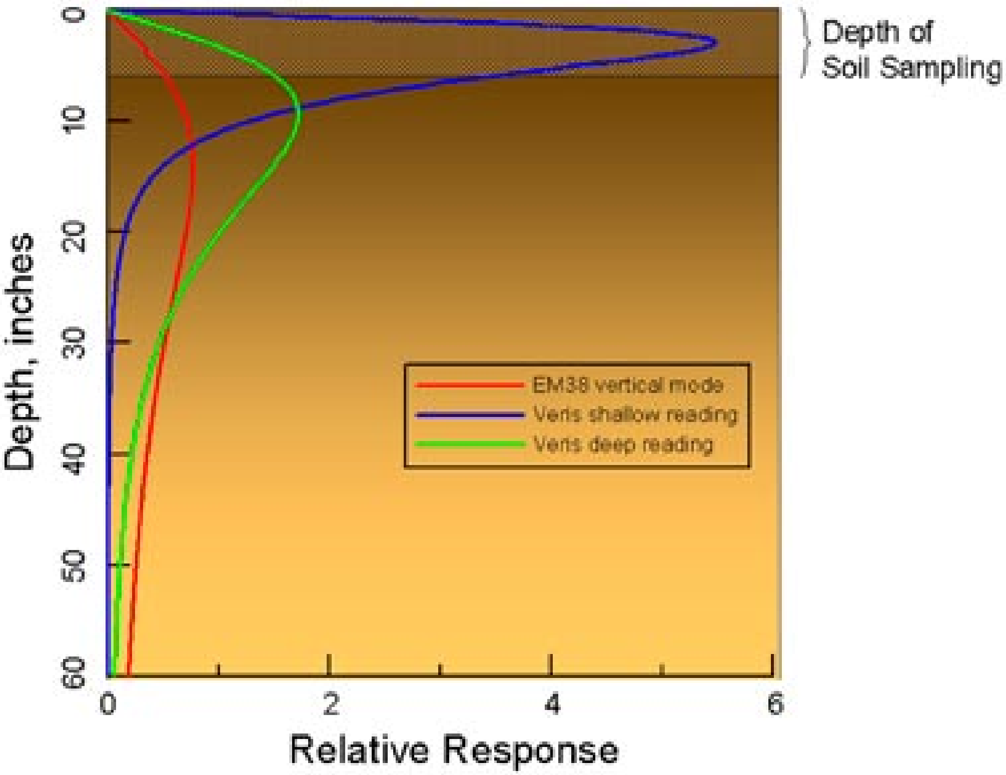

Figure 1. Soil EC sensors vary in their depth of sensing. The lines represent the relative response with depth for two soil EC sensors, the Geonics EM38 and the Veris 3100.

Sensible Soil Sensors Are Welcome (continued)

and improvements in managing within-field variability. So is there hope with this idea of using sensors to measure and manage in-field nutrients?

There has been some progress. For example, the use of either ground-based or air borne images for measurement of crop canopy reflectance has made great progress in recent years. The nitrogen supplying nature of the soil can in some cases be evaluated this way. Another sensor that has been given a lot of attention in recent years for helping assess soil nutrients is soil electrical conductivity, or soil EC. Soil EC is a measure of the soil's ability to transmit or conduct electrical current. There are two techniques primarily used to measure soil-profile soil EC in the field. They are (i) electromagnetic induction (EM) and (ii) contact electrode. Soil EC by EM is measured by introducing a magnetic field into the soil and sensing the reflected energy, without any physical contact. The contact electrode method involves devices that direct electrical current into the soil through insulated metal electrodes. These devices measure the voltage drop between a source and a sensor electrode. While measurements of the two types of soil EC sensors are comparable, differences are expected since the "depth of sensing" is unique to each sensor (See Figure 1 for comparison of two different EC sensors). For additional details on soil EC, see the guide sheet called *Soil Electrical Conductivity Mapping* # SSMG-30 at http://www.ppi-far.org/ssmg.

Soil EC is a measurement that has been found to be correlated to a number of properties affecting soil water, such as texture, drainage conditions, salinity, and subsoil characteristics. This soil EC/soil water connection is why patterns in a yield map are often visually similar

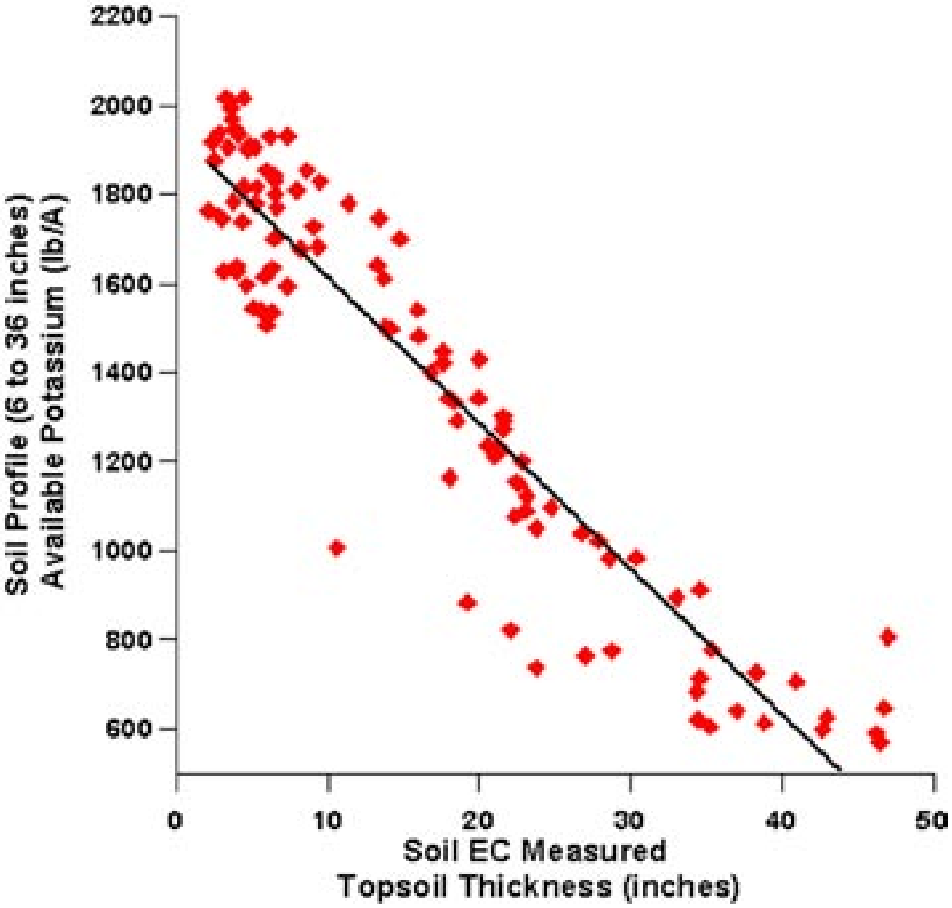

Figure 2. Soil-test potassium in the sub-soil is strongly related to topsoil thickness in a Missouri claypan soil field.

Sensible Soil Sensors Are Welcome (continued)

to patterns seen in a soil EC map. But what about soil nutrients? Can soil EC be used instead of soil sampling to estimate soil nutrients? Soil EC has been found to be affected by properties of the soil that help characterize soil nutrients, such as cation exchange capacity (CEC) and soil organic matter. In some situations soil EC has also been found to vary with differing levels of soil pH, soil nitrates, and other soil nutrients associated with repeated manure applications. When soil nutrient availability follows soil texture variation, then soil EC is likely to be helpful. In this case, many farmers have used soil EC to determine zones for soil sampling. This is called "targeted soil sampling" (for examples, see the guide sheet called *Developing Management Zones to Target Nitrogen Applications* # SSMG-5 at http://www.ppi-far.org/ssmg). Even with these examples, there has not been a "universal" relationship found relating soil EC and any specific nutrient, and I doubt there ever will be. That's because there is much more than soil nutrients affecting soil EC. It is also important to note that the depth of sensing for soil EC can be much greater than the traditional depth for which soil nutrients are assessed. Figure 1 shows the relative signal strength of two soil EC sensors as a cross section of a soil profile. Soil sampling for immobile nutrients is typically 6 to 8 inches. Even the shallow reading with the Veris sensor is about twice the soil sampling depth. Thus it is difficult to relate surface soil fertility with soil EC that encompasses much more soil volume.

The value of soil EC is in itself site-specific and can only be determined for a location with soil sampling to "calibrate" what is causing soil EC to vary within the field. Here's an example. In Missouri we have found that soil EC can be used to estimate the topsoil thickness for claypan soils (Missouri claypans can have from 50 to 65% clay). In one claypan soil field we found that soil-test potassium in the subsoil (6 to 26 inches) was very strongly related to topsoil thickness as estimated using soil EC (Figure 2). A similar relationship was found with soil-test phosphorous. Therefore for these soils, soil EC has the potential of estimating subsoil nutrients and identifying areas where crop response to fertilizer nutrients may be greater.

Sensors haven't replaced soil sampling, yet. Sensors, like soil EC, are helping us to be smarter about where we sample. In some situations we may even be able to take fewer samples with the aid of sensors. But for the time being, keep your soil probe rust free.

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University of Missouri

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Remote Sensing in Agriculture using Radiometers

Using remote sensing to quantify and control nitrogen stress in corn.

Site specific management or precision farming has been defined as applying the right amount of agricultural input (water, nitrogen, herbicide, etc.) in the right place at the right time. Remote sensing using radiometers has potential as a data collection technique to assist management decisions for in-season water and nitrogen management.

Remote sensing is the measurement of some property of an object by a recording device that is not in physical contact with the object under study. Reflected or emitted radiation in the electromagnetic spectrum is the source of energy capable of conveying information about the object of interest. Figure 1 represents the ordered array of known electromagnetic radiation that extends from the very short wavelengths of gamma rays to the long wavelengths of radio energy. Within this continuum of energy, the human eye is only sensitive to the visible region which ranges from blue light (4 x 10^{-5} cm or 400 nm) to red light (7 x 10^{-5} cm or 700 nm). The visible, infrared (IR), and the microwave regions of the electromagnetic spectrum are of primary interest to agriculture. This article focuses on the visible and near infrared (NIR) region for detecting information within a soil/crop scene. Figure 2 shows spectral curves for bare soil and mature corn in the visible and NIR regions of the electromagnetic spectrum. The energy reflected from a bare soil surface is much different than energy reflected from a mature, healthy corn crop when very little soil can be seen through the plant canopy. Bare soil reflectance is essentially a straight line which increases as wavelength increases. A healthy, green plant strongly absorbs blue and red light due to the presence of chlorophyll in the leaves, moderately reflects green light because of its color, and strongly reflects NIR light due to scattering within the canopy. These particular properties are known as spectral characteristics. They indicate where the most information can be obtained by concentrating on these areas of the spectrum. Thus, instead of using expensive spectroradiometers which produce spectral curves as shown in Figure 2, radiometers that measure radiation in predetermined areas of the electromagnetic spectrum are used. This provides a more economical approach to data collection.

Radiometers are nonimaging instruments in the sense that they do not produce a picture. These instruments integrate over the area within their field-of-view to produce a single number that characterizes the electromagnetic energy emitted or reflected by the object. A radiometer typically has three major components; these are (1) the optical system which consists of lenses and filters, (2) the detector which provides an electrical signal proportional to radiant energy impinging on its active surface, and (3) the signal processor which performs specified functions on the electrical signal to provide the desired output data. The four channel radiometer shown in Figure 3 has filters that only allow blue light (450-520 nm), green light (520-600 nm), red light (630-690 nm), and NIR light (760-900 nm) to strike the detector in each respective channel. These wavebands are similar to the four spectral bands used in the ThematicMapper onboard the Landsat series of satellites, the Ikonos satellite operated by SpaceImaging, and the QuickBird satellite operated by DigitalGlobe.

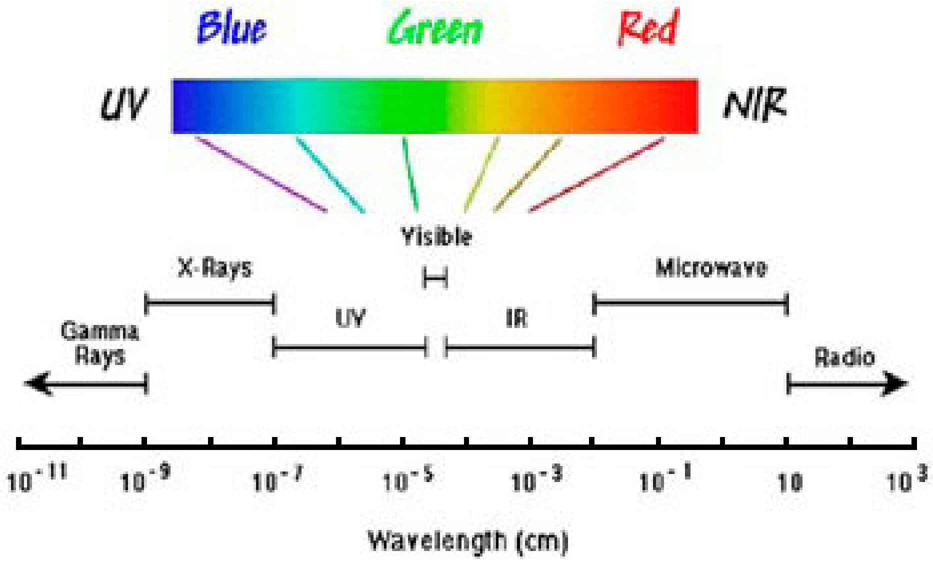

Figure 1. The electromagnetic spectrum.

Remote Sensing in Agriculture using Radiometers (continued)

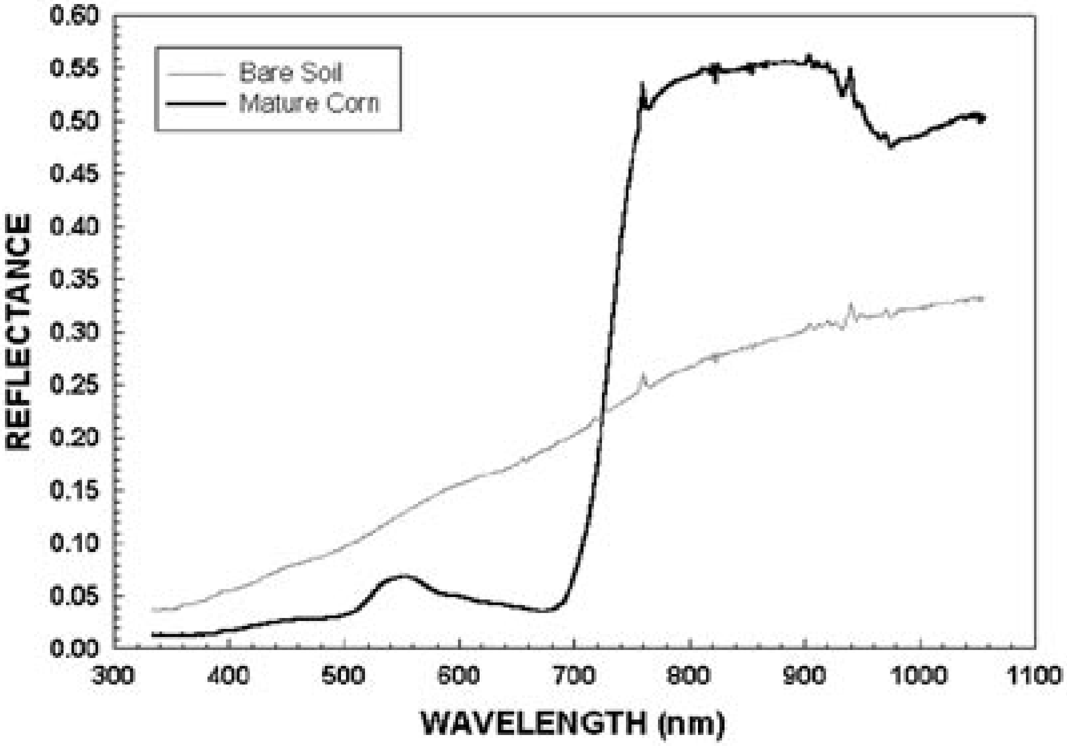

Figure 2. Spectral reflectance of bare soil and a mature corn canopy.

Radiometers have been manufactured with as few as two broad band channels and as many as 16 narrow band channels. Virtually any spectral band in the 400 to 1100 nm range with a bandwidth of 10 nm or more can be used in these instruments. However, narrow bandwidth filters decrease the amount of light that strikes the detector which means that additional electronics must be incorporated into the instrument to obtain useful output signals.

Radiometers can be used in various ways from handheld operation for detailed studies on individual plant leaves to mounting in aircraft to obtain spectral data representative of large areas. Figure 4 shows radiometers attached to an extendable boom which is mounted on a high-clearance tractor for field access. The downward looking radiometer on the end of the boom measures energy reflected from the crop while the upward looking radiometer on the tractor's roll over protection system simultaneously measures incoming radiation. A circular area 2.5 m in diameter is viewed by the down-looking radiometer from a height of 10 m; approximately 30 corn plants are contained within this area. Data from the radiometers are recorded every two seconds as the tractor moves through the field. GPS coordinates are also taken with each data point to determine location of the sensor in the field. Data transects through the field are taken at 24-row intervals. Crop reflectance in each of the four spectral wavebands is calculated as a ratio of the energy measured from the crop divided by the incoming energy.

An example for use of radiometer data to assist with in-season nitrogen management on irrigated corn to improve nitrogen use efficiency is presented below. Corn leaves with a nitrogen deficiency contain relatively little chlorophyll and tend to have a pale green color; thus, reflectance in the green portion of the visible spectrum increases as plant nitrogen deficiency increases. Changes in the red area of the spectrum show small increases in reflectance, but not as abrupt as the green reflectance. Corn canopy reflectance in the NIR portion of the electromagnetic spectrum tends to decrease as plant nitrogen deficiencies increase. Therefore, the green and NIR reflectance values can be used to calculate the Nitrogen Reflectance Index (NRI) to determine when and where in a field nitrogen should be applied to keep crop growth and yield at an optimum level without excess applications of nitrogen. Figure 5 is an example of a nitrogen sufficiency map for irrigated corn at its 8th leaf growth stage generated from NRI information. Light colored areas within the field had NRI values less than 0.95 which indicate early signs of nitrogen deficiency. The dark

Figure 3. Four channel radiometer manufactured by Exotech Incorporated.

Remote Sensing in Agriculture using Radiometers (continued)

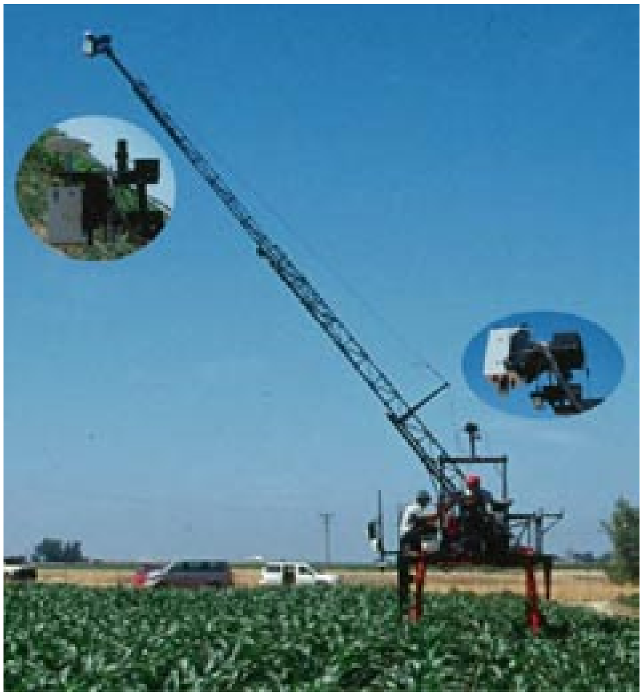

Figure 4. High-clearance tractor instrumented with various remote sensing instrumentation.

colored areas indicate that the corn is healthy and not in need of additional nitrogen at that particular time. Applying nitrogen to the light colored areas would be the recommended practice at this particular growth stage to reduce the amount of nitrogen applied to the field and reduce input costs.

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USDA-ARS Water Management Research Unit

Unit Definitions and Conversions

Feet (ft)	
Meter (m)	1 m = 3.28 ft
Centimeter (cm)	1 cm = $1x10^{-2}$ m
Nanometer (nm)	1 nm = $1x10^{-9}$ m

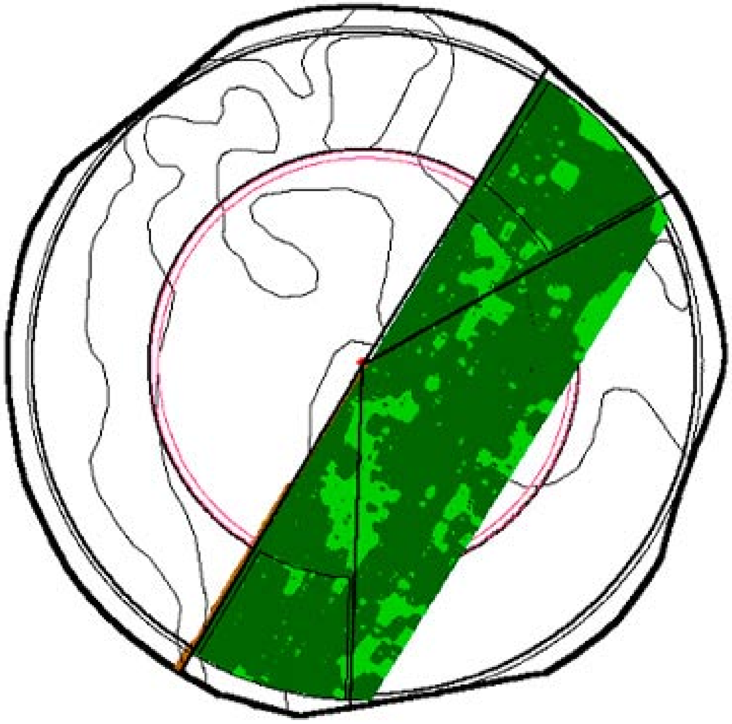


Figure 5. Nitrogen sufficiency map developed from NRI data for part of a corn field; light colored areas represent nitrogen deficient corn.

A New, Sensor-Based, Fertilizer Management Strategy

Precision ag research team at Oklahoma State University have developed sensor based, variable rate fertilizer management strategy for field crops.

Nitrogen fertilizer is one of the largest seasonal variable costs for farmers. The most common approach to determining a nitrogen (N) fertilization rate, in many regions, has been to estimate a yield goal (usually equal to or slightly greater than the 5-year average) and multiply that times an assumed N requirement for each unit (e.g., bushel) of yield expected. Available soil test-N is usually subtracted from the total requirement to arrive at a rate for the area, usually a preplant application. The attractive part of this approach was that it relied mainly on knowing the realistic yield goal for the field and it could often reliably separate field N needs in relation to productivity. While this has been a much better approach than simply guessing, it has several limitations that reduce farmer profitability and increase risk of N loss to the environment.

Traditional N application strategy:

There are four constraints with the traditional strategy of N fertilizer, and two of them have to do with what kind of a 'production' year it will be. The four constraints are:

1. Determining the potential yield for a field prior to a growing season.
2. Determining how much non-fertilizer N (soil-N) will be available for the potential yield.
3. Applying all, or most, of the seasonal nitrogen requirement in most cases, before we plant the crop.
4. Applying single rates of N for areas of the field that have different potential yields.

These "faults" of the traditional strategy are a result of assuming it will be an "average" production year and that the field is perfectly uniform. In rain-fed farming, to assume it will be an average year is to assume the weather will actually be average for the year. Everyone that has farmed for a few years knows that average weather conditions seldom occur. Likewise, when whole fields are viewed from a distance (as from an airplane at 10,000 feet), they seldom appear to be very uniform.

Temporal variability.

Results of 30 years continuous wheat research at the Oklahoma State University North Central Research Station in Lahoma, Oklahoma, show that when we fertilized for the average yield (2 lb N/bu):

- 60 % of the time we incorrectly estimated the actual yield by at least 10 %.
- Additionally, because available non-fertilizer N changes from year-to-year, 30 % of the time the average rate was the correct rate.
- 37 % of the time the average rate was short by at least 20 lb N/acre.
- 33 % of the time 20 to 80 lb excess N/acre (average = 38 lb) was applied.

Also, compared to applying all the crop needs as preplant N:

- Topdress N was about 35 % more efficient than preplant N.

Changing tradition.

To improve on the traditional approach we need a strategy, or plan, that gives us a chance to evaluate the effects of current-year weather conditions on the potential yield achievable and the amount of non-fertilizer N that was supplied by "nature" (rainfall and that mineralized from soil organic matter). This reading of "nature" needs to be done during the growing season at a point when we will still have time to add needed nitrogen. The reading is made possible by reducing, or eliminating, preplant nitrogen except for a strip (spreader width) through the field at a rate that will assure nitrogen will not be limiting. This "Nitrogen-Rich Strip" can then be read, or compared, to the condition of the rest of the field, mid-season when there is still time to topdress any needed N.

Reading nature.

Although differences in the Nitrogen-Rich Strip and the rest of the field could be "read" by any measure of crop condition (height, color, tillers, etc..), Oklahoma State University researchers have used a commercially available (NTech, Inc.), hand-held optical sensor that integrates components of crop health (biomass and functioning chlorophyll). The sensor calculates an index (normalized difference vegetative index, or NDVI) from reflected red and infrared light. Once the readings (NDVI) have been made, a response index (RI) is

A New, Sensor-Based, Fertilizer Management Strategy (continued)

Hand-held optical sensor

calculated by dividing the reading of the Nitrogen-Rich Strip by the reading representing management for the rest of the field. Using the optical sensor to read the N-Rich Strips results in an unbiased number that is not affected by who does it or when the strip is being read. The response index (RI) tells us how much of a yield response to expect from topdress nitrogen.

Field response variability.
Oklahoma State University research on 10 winter wheat fields in 2002 found RI_{NDVI} values that ranged from 1.1 to 1.6. These readings mean that we could expect to get 10% to 60% yield increase from in-season topdress N applications. This wide range of values also shows that the response to topdress nitrogen differs greatly from field to field in the same year and in some instances, in the same general location. In order to take full advantage of this new strategy/technology, every field that has a different soil, management history, or growing environment, can be expected to respond differently to the needs for N. Consequently, like soil testing, every field should have a Nitrogen-Rich Strip. With time some fields may be found to respond alike and treated the same based on reading one Nitrogen-Rich Strip.

Treating spatial variability.
Oklahoma State University researchers have found that areas as small as about 6 square feet can be different from each other and require different input of N. The "Precision Ag Team" has promoted and researched development of technology to identify and treat field areas this small. The technology is now available to sense and treat every 4 square feet at 15 mph using conventional boom applicators and solution 28 (UAN).

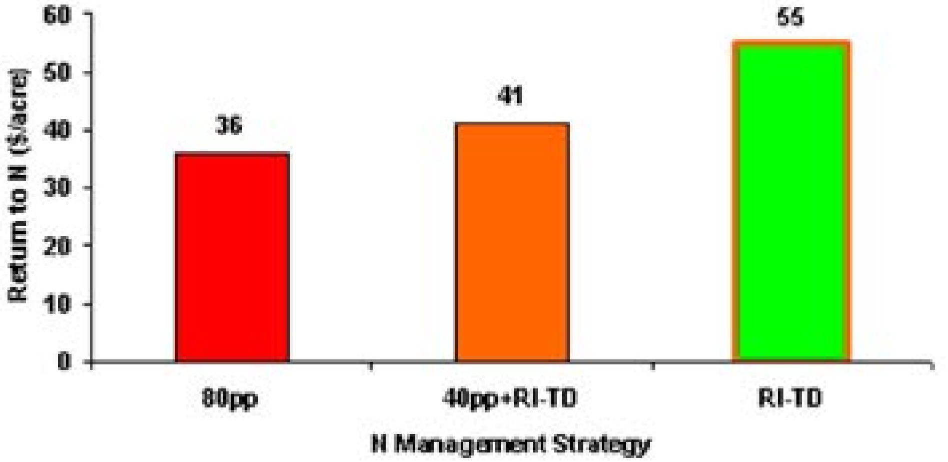
New strategy economics.
The bottom line on implementing this new strategy is increased farmer profits. Estimates using the 30-year data on continuous wheat, show that if N was applied only as a topdress at rates based on a Nitrogen-Rich Strip there would be an average increased return of about $19/acre/year, compared to 80 lb N/acre preplant for a 40 bushel yield goal.

With 40 lb N/acre as preplant and additional N topdressed based on the Nitrogen-Rich Strip, the benefit is not as good because of estimated lower efficiency of preplant N and that some years 40 lb is excessive. The question is how much fertilizer to apply each year. The answer is given from the Nitrogen-Rich Strip. Accurate reading of the Nitrogen-Rich Strip is crucial to this new strategy. This technology (hand-held sensor) will likely be available through fertilizer dealers. This and the technology for spatial treatment of every 4 square feet will be an added expense to the farmer, paid from profit.

A New, Sensor-Based, Fertilizer Management Strategy (continued)

Field experience.

Results from 10 field-scale treatments for the 2002 crop showed an advantage of 4 to 9 dollars per acre from using the N-Rich Strip and applying a "flat" rate, in a year of drought and delayed topdressing. Combined with the spatial treatment of every four square feet the average improvement compared to a "farmer practice" was consistently greater than $12/acre.



Strategies:

- **80pp** = 80 lb N applied preplant costing $0.15/lb.
- **40pp** = 40 lb N preplant costing $0.15/lb, plus topdress N at $0.25/lb based on N-Rich Strip, plus $2/acre application cost.
- **RI-TD** = All N applied topdress at $0.25/lb based on N-Rich Strip, plus $2/acre application cost

Wheat at $3/bu.

G.V. Johnson, W.R. Raun, John Solie and Marvin Stone
Professors in the Departments of Plant & Soil Sciences and Biosystems and Ag Engineering
Division of Agricultural Sciences & Natural Resources
Oklahoma State University

Results from 10 field-scale treatments for the 2002 crop showed an advantage of 4 to 9 dollars per acre from using the N-Rich Strip and applying a "flat" rate, in a year of drought and delayed topdressing. Combined with the spatial treatment of every four square feet the average improvement compared to a "farmer practice" was consistently greater than $12/acre.

On-the-Go Soil Sensors for Precision Agriculture

A summary of real-time sensors and their applications in agriculture.

When looking at a yield map, one can observe how variable is crop performance in a field. However, the yield map does not give much information about the reasons for differences in crop yield. In some cases, it is related to special management practices or past history. However, frequently we can relate low yield to crop stresses associated with non-optimal soil conditions. Soil maps help us better understand the spatial patterns in soil properties that cause yield variability. A proper decision-making process prior to variable rate application must take into account soil variability. As a result, higher profits from implementation of precision agriculture are expected while reduced waste will help in maintaining the quality of our environment.

Currently, soil maps representing various properties are commonly obtained through recommended soil sampling and analysis procedures. 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 costs associated with labor-intensive sampling and analysis procedures and map uncertainties. In many cases, when the sampling density was not large enough, the limited number of soil samples did not produce an accurate representation of soil properties (especially for nutrient levels).

Several researchers as well as commercial institutions have been investigating various measurement techniques that could be suited to automated soil mapping (similar to yield monitoring). The sensors developed could be used either to control variable rate application equipment in real-time (Figure 1 left) or in conjunction with 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 points of measurements per acre varies; but in most cases, it is much greater than the density of manual grid sampling. The cost of mapping could be 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 currently commercially available.

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 that

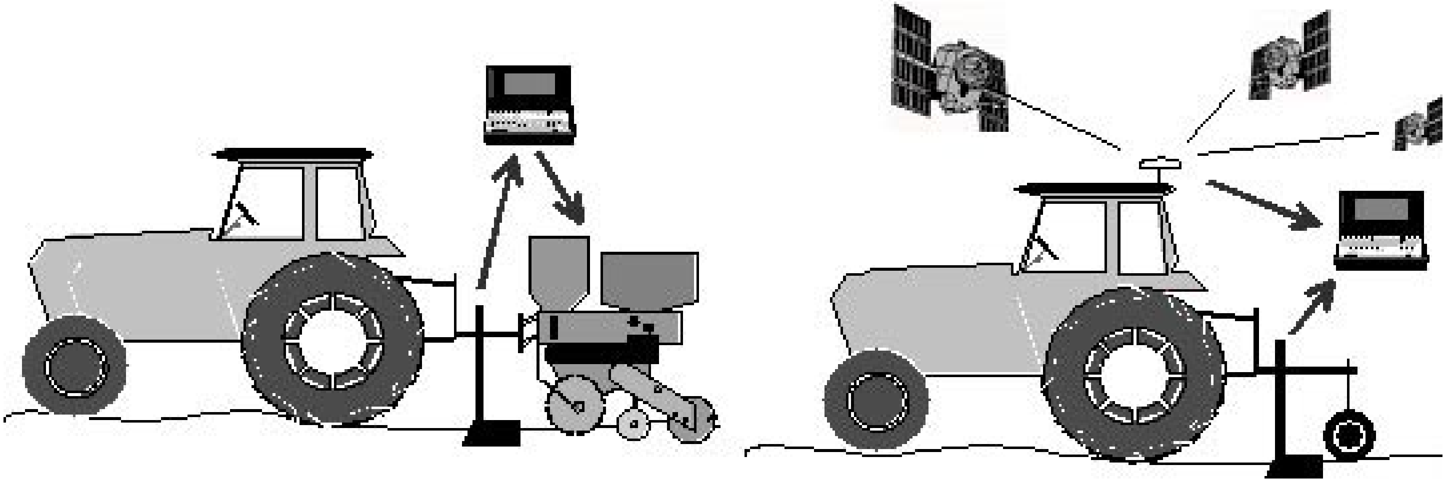


Figure 1. Real-time (left) and map-based (right) approach to use vehicle-based on-the-go soil sensors

On-the-Go Soil Sensors for Precision Agriculture (continued)

are seen in the "real world":

1. Most sensors and applicator controllers need certain measurement, integration, and/or adjustment time, 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 different 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:

- Soil pH and buffer pH
- Macronutrient level (N-P-K)
- Soil organic matter (carbon) content
- Soil texture (clay content)
- Soil moisture and temperature
- Cation exchange capacity (CEC)
- Soil compaction
- Depth of any root restricting layer
- Soil structure and bulk density

Sensors for Automated Measurements

Scientists and equipment manufacturers are trying to modify existing laboratory methods and 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
- 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 have become commercially available. For example, one way to estimate soil electrical conductivity (EC) 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 different depths of the soil to a maximum depth 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 EC, Veris® EC Probe, measures EC 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 soil EC for two different depth ranges. (See detailed article on soil electrical conductivity on page 3).

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. Several researchers have worked on the development of optical sensors to predict clay, organic matter, and moisture content. Rather than using optical reflectance, some researchers are utilizing ground-penetrating radars to investigate wave movement through the soil. Changes in wave reflections may indicate changes in soil density or restricting soil layers. (See detailed article on remote sensors on page 9.)

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. Several researchers have developed prototypes that show the feasibility

On-the-Go Soil Sensors for Precision Agriculture (continued)

of continuous mapping of soil resistance, however, none of these devices is commercially available. The draft sensors or “traction control” system on tractors use a similar technology to control the 3-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 are 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. 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 have been commercialized and widely used to date. Ideally, producers would like to operate sensors that provide direct 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 that make it possible to divide the field into smaller and relatively consistent areas referred to as management zones.

For example, such zones could be defined according to various soil types found across a field. In fact, soil EC 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 can also be easily identified on a soil EC map. Figure 2 compares a soil survey and a soil EC map for the same field showing some differences in boundaries.

Crop yield maps also frequently correlate to soil EC maps. In many instances such similarities can be explained through differences in soil. In general, the soil EC 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. These patterns can often be revealed through a soil EC map as well. 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

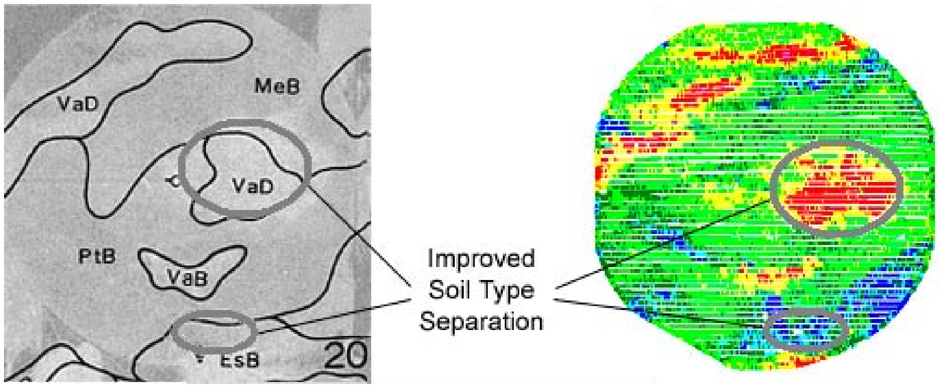


Figure 2. Soil EC map (right) compared to soil survey (left).

On-the-Go Soil Sensors for Precision Agriculture (continued)

be prescribed based on a reduced number of soil samples located within the zones on the EC 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 that could reduce the effect of soil variability within each management zone.

Summary

More accurate soil property maps are needed to succeed in implementing 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 the mapping of electromagnetic soil properties is available commercially. These maps can be used to define management zones reflecting obvious trends in soil properties. Each such zone can be sampled and treated independently. Smaller management zones will be feasible when new on-the-go soil sensors are developed and commercialized.

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*Mention of brand names is for identification purposes only. No endorsement or criticism intended for those mentioned or any other equivalent products.

Meet Mary Schutter

Mary was born in Panarama City, California, but the first few years of her life were spent playing on the beaches of Papua New Guinea while her parents were missionaries. Her family then moved to the small town of Harveyville, Kansas, the site of a family homestead, where Mary spent the rest of her childhood. She attended the same schools as did her grandfather and great uncles before graduating from Mission Valley High School in 1989. Mary received her B.S. in Biology/ Microbiology from West Chester University in Pennsylvania, her M.S. in Soil Science at the University of Delaware, and her Ph.D. in Soil Science at Oregon State University.

As a child, Mary always wanted to be a biologist. She began to focus her interests on microbiology as an undergraduate student, when she became involved in a project studying bacteria adapted to extremely salty environments. She then turned to the study of microorganisms living in soil, partly because of the diverse habitats which soils provide. Because of the complex physical and chemical nature of soil, says Mary, “soils can support the greatest diversity of bacteria compared to any other ecosystem on earth”.

After a post-doctoral position with USDA-ARS in Fresno, CA, Mary moved to CSU in August 2001. Her research interests include how soil microbial communities and their activities respond to habitat disturbances. She currently is studying the recovery rates of soil bacteria and fungi in forest soils burned by the Hayman fire. She is also investigating how long-term applications of biosolids may benefit microorganisms in rangeland soils. Mary is also excited for the opportunity to work in dryland agroecosystems, where she plans to compare the microbial ecologies of conventionally-tilled soils versus no-tillage soils.

Mary is engaged to John Stromberger, who also works at CSU. Besides planning their June wedding, she enjoys reading and hiking in her spare time. She also loves turtles, and looks forward to raising box turtles again.

Sensors In Yield Monitoring

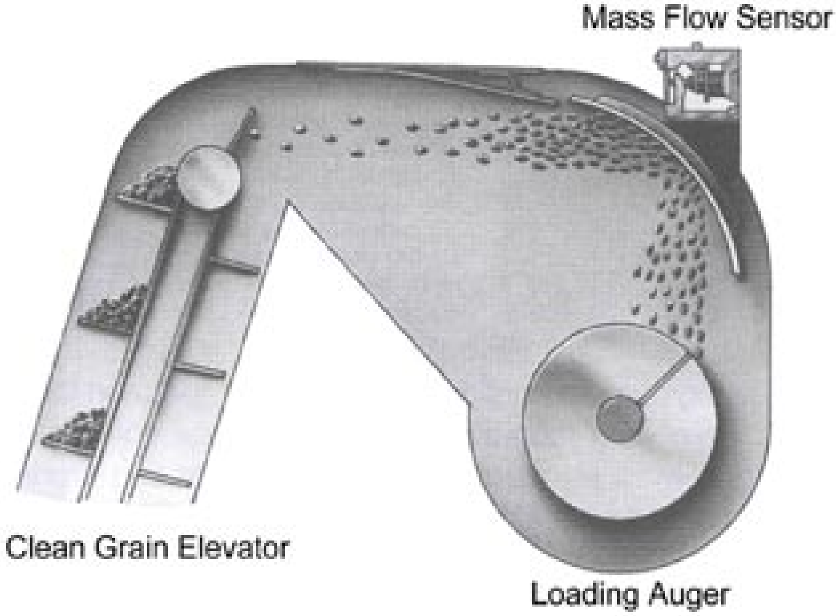
Sensors used in grain yield monitoring, their functions, and how grain yield is calculated instantaneously.

Yield monitoring is one of the most popular precision agricultural applications among farmers across the country. Yield monitoring sensors have enabled farmers to quantify inherent variability that exists in their fields. It has given a sense of realization to farmers what factors (such as weeds, insects, pests, diseases, soil compaction, etc.) can cause significant damage to their crop. Traditionally, farmers had one average number in terms of crop yield for a field. Average crop yield masks the variability in yield that exists across a field. Although farmers know their fields well and are able to estimate the performance of crop in different parts of the field, yield monitoring have transformed those "estimates" into real, quantified crop yield values.

More and more combine manufacturers are providing their customers with combines that are equipped with Global Positioning Systems (GPS), yield monitors and mapping technology. It is fast becoming a standard part of new combines. This article provides information on various sensors and their functions in a grain yield monitoring system. Although some of the sensors may vary from one manufacturer of yield monitoring system to another, most instantaneous yield monitoring system has the following sensors: (i) Grain flow sensor; (ii) Grain moisture sensor; and (iii) Ground speed sensor.

(i) Grain Flow Sensor: There are several grain flow sensor that are commercially available. However, the most common one used for grain crops is the "Impact Plate Sensor". It is mounted at the top of the clean grain elevator i.e., in the path of the grain. The volume of the grain moving through the clean grain elevator is measured two ways: (a) by the amount of force the grain applies as it hits the impact plate, or (b) by the amount of displacement of the impact plate that occurs when grain hits the impact plate. Either way, the force on the impact plate or displacement of the impact plate is in-directly related to the amount of grain flowing through the clean grain elevator. This measurement is recorded by the computer in the combine every second along with the GPS data, which is used to prepare a yield map.

(ii) Grain Moisture Sensor: Determining moisture content of the grain is important for various reasons including, time of harvest, estimating costs associated with drying of grain, storage and handling issues to minimize losses, and the farmer's ability to make comparisons in crop performance. There are several grain moisture sensors that are commercially available. However, the most common one is based on measuring the di-electric properties of the grain. As the grain flows through the clean grain elevator, the grain moisture sensor that is located near the grain flow sensor measures the di-electric constant of the grain. Di-electric property is related to the moisture content in the grain. The higher the di-electric constant of grain, higher the moisture content.



Displacement-type grain flow sensor.

Sensors In Yield Monitoring (continued)

A capacitance-type grain moisture sensor.

(iii) Ground Speed Sensor: There are various ways by which ground speed can be measured, such as radar sensors, GPS unit readings, shaft speed sensors, etc. Speed information is needed by the computer in the combine to estimate the area harvested in certain time period. Speed is converted into distance (multiplying speed by time). Distance covered is then multiplied by the swath width of the combine header to calculate the area harvested.

The information from the grain flow sensor along with information from the speed sensor together provide instantaneous data to calculate grain yield harvested every second at a certain moisture content that is ascertained from the moisture sensor.

For example: An 8-row header at 30-inch row spacing recorded the following information for the previous second on a corn yield monitoring system.

Grain flow sensor recorded: 30 lbs of grain flow/sec

Grain moisture sensor recorded: 17.5% moisture content in grain

Speed sensor recorded: 4 miles/hour speed of combine.

Instantaneous yield for the previous second is calculated as follows.

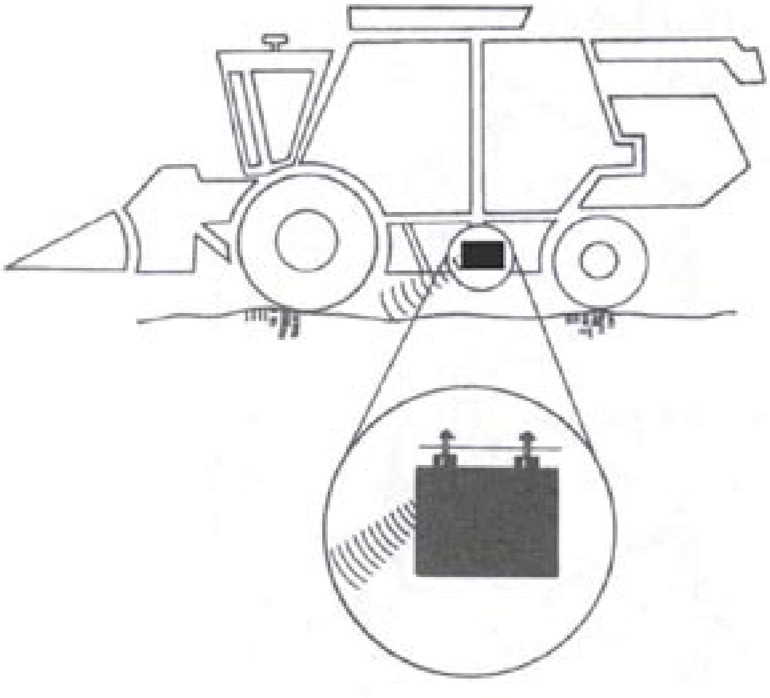
(i) Area harvested during the previous second:

8 row corn x 30 inch spacing = 240 inch or 20 ft header width.

Combine speed for the previous second was 4 miles/hour i.e.,

4 miles/hour x 5280 ft/mile x 1hr/3600 seconds = 5.9 ft/second (Speed of combine)

Area = 20 ft x 5.9 ft = 118 ft^2.



An ultrasonic ground speed sensor.

Sensors In Yield Monitoring (continued)

Therefore the area harvested by an 8-row combine moving at a speed of 4 miles/hr during the previous second was 118 ft^2.

(ii) Grain yield in bushels/acre.

The combine harvested 30lbs of grain during the previous second from an 118 ft^2 area. That translates into

30 lbs/118 ft^2 x 1 bushel/56 lbs x 43,560 ft^2/acre = 198 bushels/acre grain yield. This would be the wet grain yield at 17.5 % moisture content.

(iii) Corrected grain yield at 15.5 % moisture content:

(198 bushels – [198 x 0.175]) x 1/0.845 = 193 bushels/acre corn grain yield at 15.5 % moisture.

The computer on the combine performs the above calculations instantaneously for all the readings recorded by the yield monitoring sensors and displays the information on the "Display Console" in the combine. Farmers view the yield information every second as they drive their combine across the field.

Raj Khosla
Assistant Professor
Precision Agriculture
Extension Specialist
Colorado State University

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Watch this website:

http://lamar.colostate.edu/~rkhosla/Extension/ExtensionIndex.html

for

Precision Ag Field Days 2003

Meet Hamid J. Farahani

Hamid is an agricultural engineer with the USDA-Agricultural Research Service, Water Management Unit in Fort Collins. His main fields of interest include precision agriculture, water management, agricultural modeling, and soil variability and electrical conductivity. Hamid is a faculty affiliate at the Civil engineering department and advises and serves on graduate student committees. He is an active member of ASAE, serving as technical associate editor in soil and water division. Hamid was born in Tehran and immigrated to the US in 1978. He received his BS from Kansas State Univ., MS from Univ. of Arizona and PhD from Colorado State University, all in the traditional agricultural engineering discipline with emphasis on soil and water. He has held post-doc positions with USDA-ARS Great Plains Systems Research in Fort Collins and has worked extensively with the Department of Soil and Crop Sciences on Dryland Agroecosystem and Precision Agriculture Projects. Hamid used to have many favorite pastimes, but those all changed with the birth of his daughter (Maryam).

Web Sites

Precision Agriculture / Yield Monitoring

http://www.agleader.com (GPS receivers, yield monitors, and controllers)

http://www.omnistar.com (DGPS differential correction subscription service)

http://www.trimble.com (DGPS receivers)

http://www.precisionag.com (Precision agriculture equipment buyers guide)

http://www.starlinkdgps.com (DGPS receivers)

http://www.redhorsetech.com (Yield monitors for specialty crops)

http://www.harvestmaster.com (Field data collection tools)

http://www.deere.com/greenstar (Combine yield monitors)

E.C.

http://www.veristech.com (Soil mapping equipment based on E.C. sensors)

http://www.ppi-far.org/ppiweb/ppibase.nsf/$webindex/article=BD1CF45C852569D700636EDAC9ADC4DE
(Site specific management guidelines)

http://www.pioneer.com/usa/technology/soil_conductivity_mapping_99.htm
(Soil E.C. mapping introduction and summary)

Remote Sensing

http://www.digitalglobe.com (Satellite Imagery)

http://www.earthscan.com (Satellite Imagery)