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Implementing Site-Specific Management: Map- Versus Sensor-Based Variable Rate Application

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PURDUE EXTENSION

Two Approaches to Site-Specific Farming

There are a number of questions that must be answered before establishing a site-specific, or precision, management program for crop production. Many of those questions are economic, some are agronomic, and others are technology-related. One important technology-related question is: "What methods of variable-rate application of fertilizer, crop chemicals, and seed are available?" This publication is intended to answer that question while providing a comparison of those methods.

There are two basic methods of implementing site-specific management (SSM) for the variable-rate application (VRA) of crop production inputs: **map-based** and **sensor-based**. While each method has unique benefits and limitations, some SSM systems have been developed to take advantage of the benefits of both methods.

The first site-specific management method is based on the use of maps to represent crop yields, soil properties, pest infestations, and variable-rate application plans. The ***map-based method*** can be implemented using a number of different strategies. Crop producers and consultants have crafted strategies for varying inputs based on: soil type, color and texture, topography (high ground, low ground), crop yield, field scouting data, remotely sensed images, and a host of other sources. Some strategies are based on a single information source while others involve a combination of sources. Regardless of the actual strategy, the user is in control of the development process.

To develop a plan for variable-rate fertilizer application in a particular field, the map-based method could include the following steps:

- perform systematic soil sampling (and lab analysis) for the field;
- generate site-specific maps of the soil nutrient properties of interest;
- use some algorithm to develop a site-specific fertilizer application map; and
- use the application map to control a variable-rate fertilizer applicator.

A positioning system is used during the sampling and application steps to continuously know or record vehicle location in the field. Differentially-corrected Global Positioning System (DGPS) receivers are the most commonly used positioning devices. The process of map-based, variable-rate application is illustrated in Figure 1.

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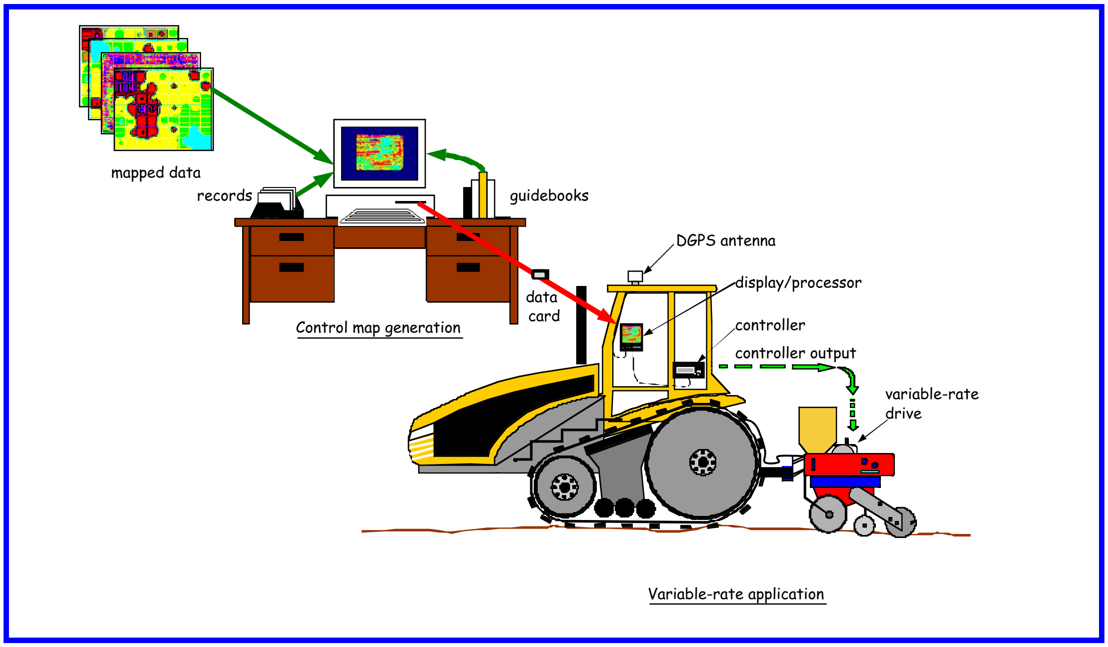


Figure 1. An illustration of a map-based system for varying crop input application rates.

The second SSM method provides the capability to vary the application rate of crop production inputs with no mapping involved. The ***sensor-based method*** utilizes sensors to measure the desired properties, usually soil properties or crop characteristics, on the go. Measurements made by such a system are then processed and used immediately to control a variable-rate applicator (Figure 2). This second method doesn't necessarily require the use of a DGPS system. Nor does it require extensive data analysis prior to making variable-rate applications.

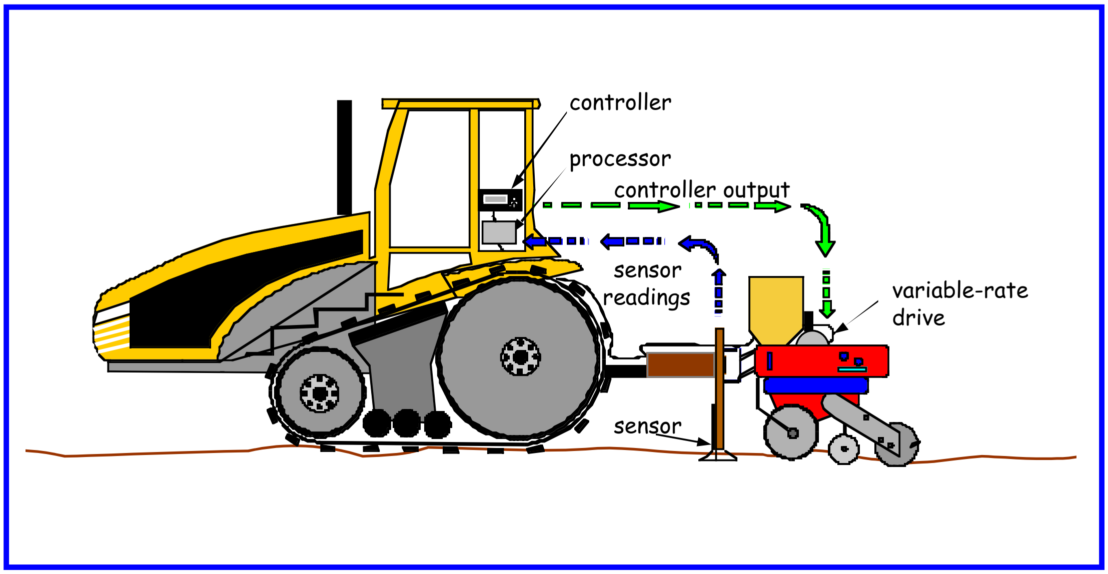
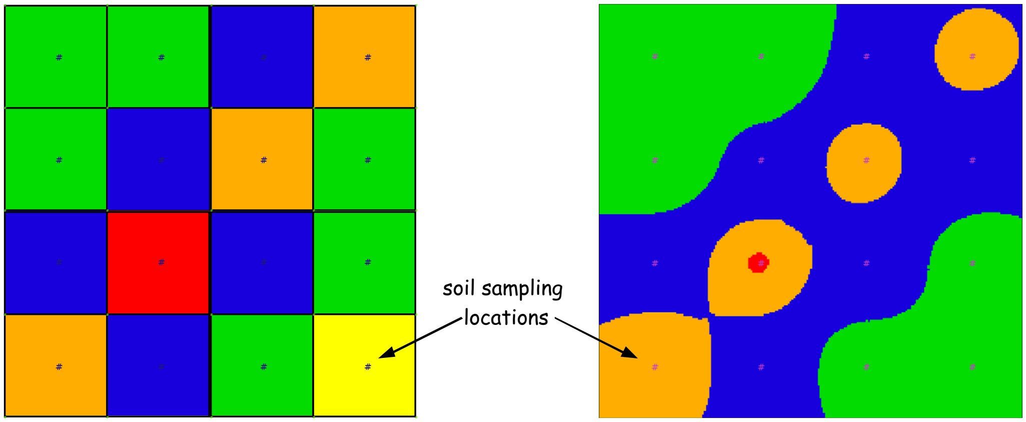


Figure 2. An illustration of a sensor-based system for varying crop input application rates.

Map-based Technologies

Currently, the majority of available technologies and applications in site-specific farming utilize the map-based method of sampling, map generation, and variable-rate application. This method is more popular due to the scarcity of sensors for rapidly monitoring soil and crop conditions. Also, laboratory analysis is still the most trusted and reliable method for determining most soil and plant properties.

Once field data have been collected and assigned position coordinates (e.g. latitude and longitude), mapping is easily performed using a computer program (usually a geographic information system (GIS) program). Such programs can use mathematical techniques for "smoothing" or interpolating the data between sampling points. However, some site-specific practitioners choose to use a constant value for the measured property over each sampling area or grid cell (Figure 3). As illustrated in Figure 3, the level indicated by each grid cell is determined by analyzing samples collected from the center of each cell. This represents the common practice of using software to divide a field into a set of imaginary, equal-sized rectangles or grid cells, identifying the center of each cell, and directing that samples be collected from the vicinity of each grid cell center.



Grid Map of Soil Sampling Data

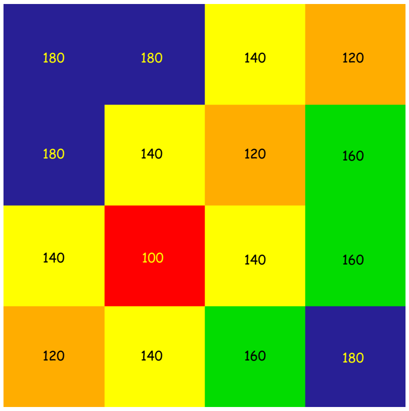
Contour Map of the Same Data

Figure 3. Two alternatives for representing systematic soil sampling data – the grid map and the contour map.

Regardless of how data are represented, the mapping facilitates long-term planning and analysis. It provides an opportunity to make decisions regarding the selection and purchase of crop production inputs well in advance of their use.

Maps are especially good for collecting and interpreting data for soil properties that do not fluctuate greatly from year to year. Properties such as organic matter content and soil texture tend to change quite slowly, if at all. Soil fertility, on the other hand, may change more quickly. Particular nutrients such as phosphorous and potassium may change from year to year, but one can probably obtain benefits from sampling only every two to three years. Levels of other nutrients may vary considerably even during a single season. For instance, the forms and concentrations of nitrogen in the soil are greatly affected by temperature and moisture conditions and can fluctuate rapidly. Nitrogen is an example of an important soil fertility factor that doesn't lend itself to a typical site-specific management program based on soil sampling data due to delays between sampling and fertilizer application. Nitrogen management approaches that rely on other, more stable information such as crop yield potential have been developed.

In order to use computer-generated maps, they must be converted to a form that can be used by a variable-rate applicator. The conversion process is performed using specialized software that applies user-selected algorithms (mathematical recipes). Algorithms are usually based on standard fertilizer recommendation formulas. The application map contains application rate information for all locations within a field. A rate map such as the one illustrated in Figure 4 is typically generated by software running on a desktop computer. The application map is then transferred to a data card that is read by a drive in the in-cab application system processor, then used by application software acting through a controller onboard an applicator to deliver the proper rate at each location in the field. Again, a DGPS system must be used to continuously correlate the vehicle's location in the field with a coordinate on the map and the desired application rate for that coordinate.



180	180	140	120
180	140	120	160
140	100	140	160
120	140	160	180

Figure 4. Example of an application rate map with rates indicated for each grid cell.

Most variable-rate controllers are designed to synchronize the application rate with the position in the field by "looking ahead" on the map for the next change in rate. This takes into account the ground speed of the vehicle and the time required to change the rate of product coming out of the applicator. A fertilizer spreader truck may operate at field speeds exceeding 15 miles per hour. Without the "look ahead" feature, if the applicator took only one second to respond to a rate change command from the controller, an area at least 22 feet long and as wide as the spread pattern would be treated at the wrong rate. With the "look ahead" feature available in map-based application systems, it is not necessary to reduce travel speeds to accomplish accurate variable-rate applications.

One commercially-available system that utilizes pre-sampling and map-controlled application is called Soilection™ (Ag-Chem Equipment Co., Inc., Minnetonka, MN). The system utilizes an integrated set of hardware and software components from one source to manage a wide variety of crop production inputs including fertilizers and crop chemicals. Variable rates of up to 10 different products can be applied by this system in a single pass based on a set of maps. The Soilection™ system is also capable of generating a record of actual application rates to produce "as-applied" maps.

While the Soilection™ system utilizes a set of hardware and software products (including the applicator, controller package) and software, supplied by one company, a number of other map-based, variable-rate applicators rely on components from different sources. With such systems, the user must select compatible components to ensure proper function.

One benefit of the map-based method is the knowledge of the needed amounts of chemicals, or inputs, for the operations prior to entering a field. This knowledge can aid in managing field operations. The multiple sources of data that are necessary to facilitate map-based applications can also be used in other decision-making processes for a farming operation. A farm manager using GIS software can examine all yield, soil property, pest, and as-applied data.

With typical map-based variable-rate application systems, the high cost of the soil analysis limits the number of samples that a farmer can afford to test. There is currently much discussion on the optimum number of acres represented by each sample and the location of those samples. The usual practice is to sample a field based on a 2.5-acre grid pattern. Research in the eastern Cornbelt is showing that 2.5-acre grid data on soil properties is not always representative of actual field conditions. This is one limitation of map-based soil fertility data that is collected using traditional, manual methods. In the next section, we will discuss how sensors can be used either to help generate application maps or to eliminate the necessity of such maps altogether.

Sensor-Based Technologies

While knowing how much product will be needed is a benefit of map-based systems, sensor-based systems hold a significant advantage in sampling density. A typical map-based application program is based on a single sample or small set of samples from 2.5-acre areas within a field. A sensor-based system can collect dozens of “samples” from each acre. This increase in sampling density should produce a more accurate depiction of within-field variability.

At this point, the major challenge is to develop sensors that will work accurately in field conditions at realistic working speeds. Sensor-based application systems must be capable of accomplishing the sensing, data processing, and application rate adjustment steps in one machine pass. Speed, both in regard to sensing and processing, is a major requirement of true sensor-based systems. There is lag time between sensing a soil or crop property and converting the sensor signal to information that can be used by the system to change the rate of application. Developers of sensor-based systems must synchronize the sensor measurement site with the desired application rate for that same site. In some instances, the sensor may have to be mounted on the front of the tractor, or applicator truck, to give the variable-rate controller enough time to adjust the rate accordingly before it passes the sensed location. In order to effectively accomplish this on-the-go control, the sensors must respond almost instantaneously to changes in the soil or crop characteristics.

One component of an on-the-go control system that has been developed at Purdue University is a soil organic matter sensor (Figure 5). This sensor is designed to facilitate the variable-rate application of dry soil-applied herbicides and/or blended fertilizer on the go, without a map. The organic matter sensor consists of a light sensor (photodiode) surrounded by six light sources (light emitting diodes or LEDs). The light sensor measures the amount of light reflected by the soil. This reflection signal is related to the amount of organic matter in the soil. High organic matter content results in dark soil color and a reduction in light reflectance. Moisture can also affect the sensor but as long as the soil is uniformly moist, the effects are small.

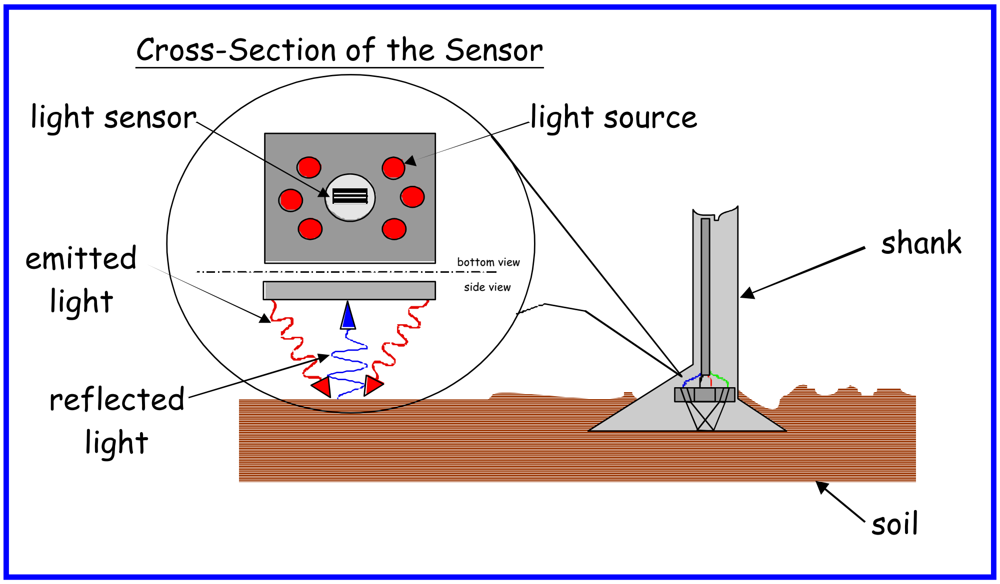


Figure 5. Soil organic matter sensor.

Some technologies for on-the-go sensing and variable-rate control are already on the market. One such system is the Soil Doctor® (Crop Technology, Inc., Houston, TX). The system uses pairs of ground-engaging rolling electrodes to examine soil type, organic matter, cation exchange capacity, soil moisture, and nitrate nitrogen levels in the soil volume between electrode pairs. By sensing these properties on the go, the need for a positioning system is eliminated and the data processing is greatly reduced because no maps are required. And, if the operator desires to record the sensor outputs and use this information for other operations, the system is capable of interfacing with a GPS receiver and generating site-specific maps.

Another commercially-available sensor-based applicator is the WeedSeeker® selective spray system (Patchen, Inc., Ukiah, CA). The WeedSeeker® system is built around sensors that measure light reflectance to distinguish between green weeds and bare soil. Each sensor unit consists of a light source and an optical sensor (Figure 6). The sensors are mounted on a bar and aimed at the ground. When a chlorophyll (green) reflectance signal exceeds a threshold set during calibration by an operator, a signal is sent from a controller to a solenoid-operated valve to release herbicide. The system is designed to turn on slightly before a weed is reached and stay on until slightly after a weed is passed. It can operate at travel speeds between three and ten miles per hour. In areas where weed infestation levels are variable, the unit can significantly reduce chemical application amounts (compared to uniform, continuous applications). Since the WeedSeeker® is not designed to distinguish between plant types (desirable crops vs. unwanted weeds), its agricultural use is focused on between-the-row applications in standing crop or on spot treatment of fallow ground.

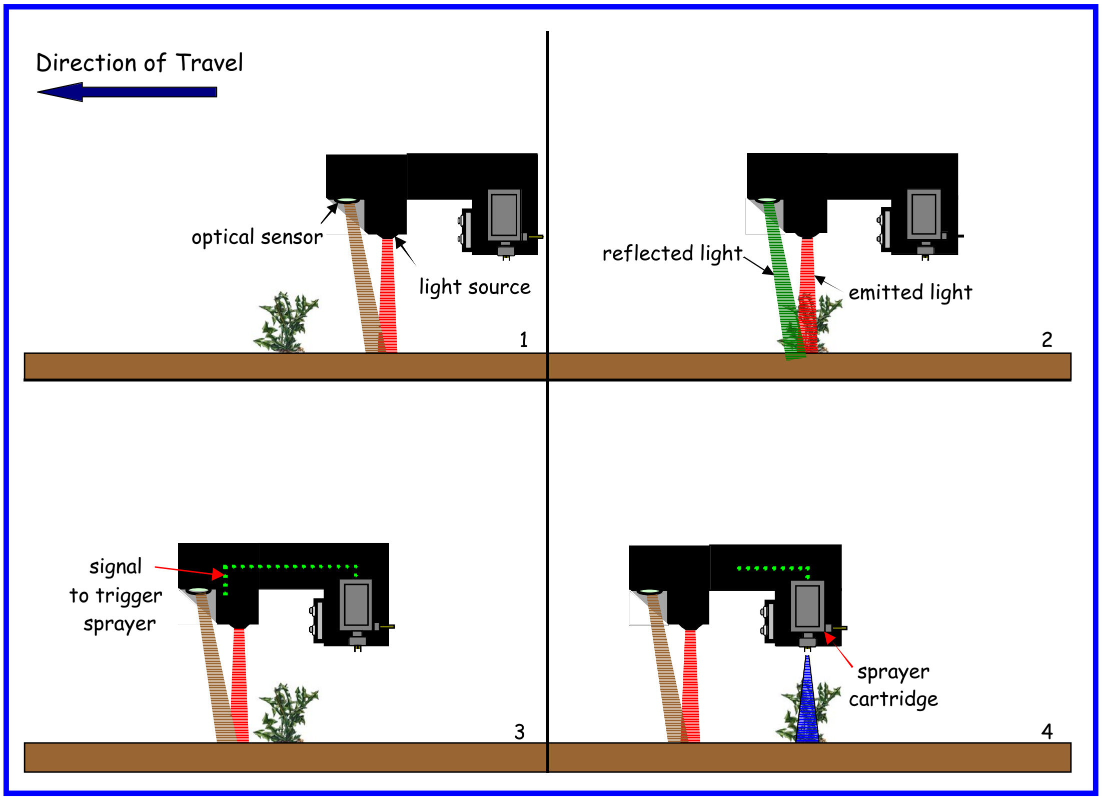


Figure 6. Illustration of the Patchen WeedSeeker® during the selective spraying process.

Researchers around the world are actively developing additional sensors for on-the-go soil property measurements including: nitrate nitrogen, pH, potassium, phosphorous, and soil texture. Application systems that use variations in plant canopy color as the basis for varying nitrogen fertilizer application rates are being developed. So are post-emergence sprayers that can distinguish between weeds and crops. When these research and development efforts succeed, site-specific farming will become more economical – possibly even automatic.

In the meantime, there are approaches available to take advantage of sensors within a more traditional map-based variable rate application program. There is at least one sensor-based tool that takes advantage of a high-rate sampling to create data-dense soil property maps. Veris® technologies (A division of Geoprobe® Systems, Salina, KS) manufactures devices that measure soil electrical conductivity (EC). The company offers vehicle-drawn units that use rolling electrodes (coulters) as sensing elements and combine EC data with GPS-supplied position data (Figure 7). Data collected by the units can be used to produce highly-detailed maps of soil electrical conductivity. EC information can then be related to soil physical characteristics such as texture and topsoil depth. This information can then be used to produce variable-rate application plans.

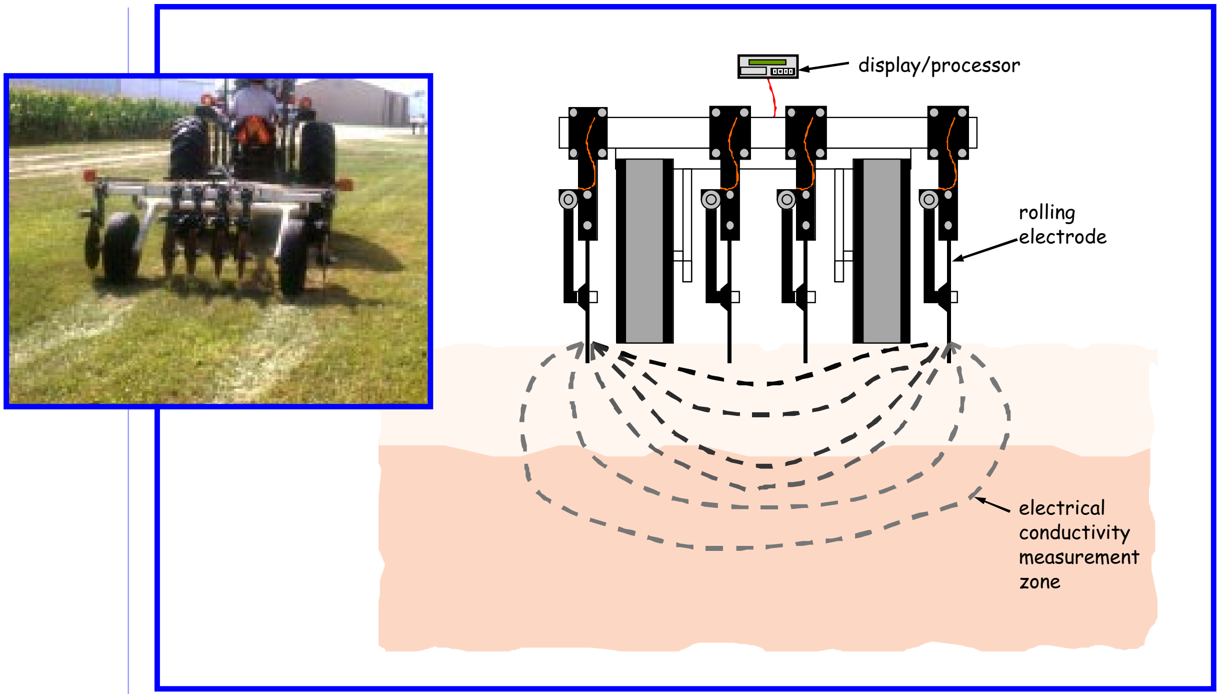


Figure 7. A Veris® soil electrical conductivity mapping system unit.

Summary

Both map- and sensor-based variable-rate application systems are available to the site-specific farmer. There are also VRA strategies that incorporate aspects of both sensing and mapping. Each variable-rate application method holds advantages and disadvantages. Strong points of each system are summarized below:

Advantages of Map-Based Variable-Rate Application

- systems are already available for most crop production inputs
- the user has a database that can be useful for a number of management-related activities
- the user can employ multiple sources of information in the process of formulating a variable-rate application plan
- the user has significant control regarding the function of such systems because of the involvement in application rate planning
- field travel speeds need not be reduced

Advantages of Sensor-Based Variable Rate Application

- pre-application data analysis time requirements can be eliminated
- sensors produce far higher data resolution than traditional sampling methods
- no time delay between measurement and application with real-time systems
- systems are self-contained

It is important to match the application system with the objectives of the overall site-specific management program in which it will be used. Producers should expect an increasing number of options for both map-based and sensor-based site-specific operations as research and development efforts continue.

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or refer to:

The Precision Farming Guide for Agriculturists, John Deere Publishing, Moline, IL. 117 p.

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