Precision Agriculture: Does It Make Sense?

By Viacheslav I. Adamchuk

In everyday language, the word "sense" normally refers to the five human senses, while "making sense" describes our efforts to interpret information that may seem confusing or conflicting. In precision agriculture, both meanings are important. While new equipment and software have been developed to practically implement site-specific crop management strategies, the question of which decision support mechanism to use remains. Thus, when viewing yield maps and/or aerial imagery, it is relatively easy to identify a problematic area within a given agricultural field, but it is not always obvious what should or, at least, could be done about the problem. This article discusses the different soil and crop sensing technologies that have been developed around the world to address this particular issue.

The concept of precision agriculture emerged from the belief that the variability of plant-growing conditions is one of the major contributors to field-scale differences in yield, and the idea that it could be beneficial to vary agricultural inputs according to local changes in soil properties (Robert, 1993).

To make precision agriculture work, a producer must be able to obtain high quality information about the spatial variability of different soil attributes that may limit yield in specific field areas. The inability to generate such information rapidly and at an acceptable cost using soil sampling and laboratory analysis remains one of the biggest obstacles to the adoption of precision agriculture. Both proximal and remote sensing technologies have been implemented to provide high-density data layers that reveal soil attributes. Remote sensing involves the deployment of sensor systems using aerial platforms or spacecraft. Proximal sensing requires placement of the sensor at a close range or even in contact with the soil being measured. This allows *in situ* determination of soil characteristics at or below the soil surface at specific locations (McBratney et al., 2005). Similarly, crop sensing at the level of the canopy or individual leaves provides data regarding the performance of individual plants, which can frequently be related to local growing environments.

Some proximal sensor systems can be operated in a stationary field position and can be used to: 1) make a single site measurement; 2) produce a set of measurements related to different depths at a given site; or 3) monitor changes in soil properties when installed at a site for a period of time. For example, **Figure 1a** illustrates a manual probe developed for on-the-spot measurement of soil pH or soluble ion activity (e.g., NO_3 or K) at a preset depth. **Figure 1b** shows a node location for the wireless monitoring of soil matric potential and temperature at four depths with a 15 minute time interval. Although single site measurements can be beneficial for a variety of applications, high-resolution thematic soil maps are typically created from measurements obtained while sensor systems are moved across landscapes. These on-the-go proximal soil sensing technologies have become an interdisciplinary field of research and development that seeks to provide essential tools for precision agriculture and other areas of natural resources management (Hummel et al., 1996; Sudduth et al., 1997; Adamchuk et al., 2004; Shibusawa, 2006). Proximal crop sensors have been used to determine physiological parameters (e.g., biomass, chlorophyll content, height, etc.) that indicate the spatially inconsistent status of agricultural crops, such as N deficiency or water stress (Solari et al., 2008; Samborski et al., 2009).

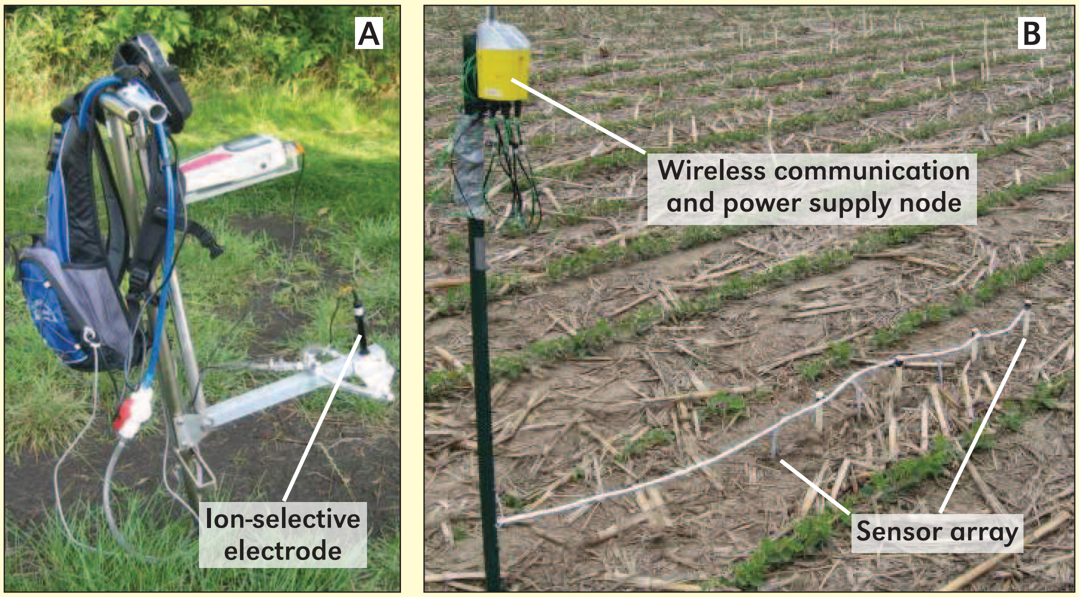

Figure 1. Instrumentation for point-based a) measurements of soil pH using a manual probe (University of Nebraska-Lincoln, Lincoln, Nebraska), and b) monitoring of soil matric potential and temperature (Crossbow Technology, Inc., San Jose, California).

The sensors have been used to supplement either predictive or reactive approaches to differentiate management practice. The reactive (real-time) method of sensor deployment involves changing the application rate in response to local conditions assessed by a sensor at the time of application. By contrast, a predictive (map-based) strategy involves the use of many soil sensors to generate soil properties maps that can be processed and interpreted off-site prior to making decisions about the optimized distribution of agricultural inputs. Unfortunately, real-time sensing is not always feasible due to the time delay

Abbreviations: N = nitrogen; NO_3 = nitrate; K = potassium.

Note: Mention of a company or product name does not imply and endorsement or recommendation by the author or by the publisher.

or is not suitable if the spatial distribution of the sensed soil properties (e.g., soil electrical conductivity) does not change during the growing season. On the other hand, more dynamic parameters (e.g. crop performance indices) need to be defined in real-time so that differentiating an agricultural input can be accomplished in time to address the cause of variable crop performance. Therefore, different research groups have focused their recent studies on the most promising integrated method.

A great variety of design concepts exists, but most on-the-go soil sensors being developed involve one of the following measurement methods: 1) electrical and electromagnetic sensors that measure electrical resistivity/conductivity or capacitance affected by the composition of the soil tested; 2) optical and radiometric sensors that use electromagnetic waves to detect the level of energy absorbed/reflected or emitted by soil particles; 3) mechanical sensors that measure forces resulting from a tool engaged with the soil; 4) acoustic sensors that quantify the sound produced by a tool interacting with the soil; 5) pneumatic sensors that assess the ability to inject air into the soil; and 6) electrochemical sensors that use ion-selective membranes producing a voltage output in response to the activity of selected ions (e.g., hydrogen, K, NO_3, etc.).

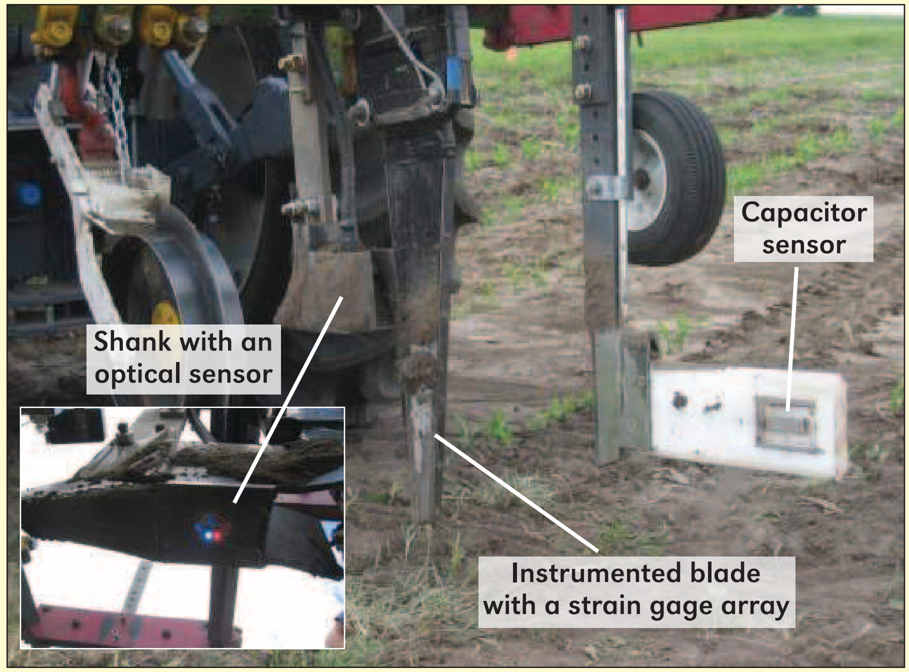

Figure 2. Prototype system comprised of mechanical, electrical and optical sensing components (University of Nebraska-Lincoln, Lincoln, Nebraska).

Ideally, a soil sensor would respond to the variability of a single soil attribute and would be highly correlated to a particular conventional analytical measurement. Unfortunately, in reality, every sensor developed responds to more than one soil property. Separating their effects is challenging; the process depends on many region-specific factors. **Table 1** provides a summary of the main types of on-the-go soil sensors with corresponding agronomic soil properties affecting the signal. In many instances, an acceptable correlation between the sensor output and a particular agronomic soil property was found for a specific soil type, or was achieved when the variation of interfering properties was negligible.

As an example, **Figure 2** shows a prototype integrated soil physical properties mapping system (ISPPMS) developed at the University of Nebraska-Lincoln. **Figure 3** shows another example, a mobile sensor platform (MSP) integrating electrical conductivity and an automated soil pH mapping unit operated with a centimeter-level global navigation satellite system (GNSS) receiver. Both systems integrate different types of sensors. ISPPMS measured dielectric soil properties using a capacitor sensor in order to better interpret the meaning of soil mechanical resistance measurements produced using the instrumented blade and optical reflectance measurements made using a set of photodiodes. From a practical viewpoint, it appears such a system could be used to address spatial variability in soil water and organic matter contents as well as compaction. For producers using the MSP, the soil pH delineates field areas with acidic soils, and electrical conductivity measurements have been used to indirectly predict the amount of lime needed to raise the soil pH to a desired level (different amounts for different soil series). Using a centimeter-level GNSS receiver allows a producer to obtain a quality map of field elevation. In non-saline conditions, combining information about landscape topography with geophysical measurements such as electrical conductivity yields useful information about spatially variable soil water-holding capacity and potential for run-offs.

Table 1. Predictability of main soil properties using different soil sensing concepts.

	Soil sensors				
Soil property	Electrical and electromagnetic	Optical and radiometric	Mechanical	Acoustic and pneumatic	Electrochemical
Soil texture (clay, silt and sand)	Good	OK		Some	
Soil organic matter or total carbon	Some	Good			
Soil water (moisture)	Good	Good			
Soil salinity (sodium)	OK				Some
Soil compaction (bulk density)			Good	Some	
Depth variability (hard pan)	Some		OK	Some	
Soil pH		Some			Good
Residual nitrate (total nitrogen)	Some	Some			OK
Other nutrients (potassium)		Some			OK
CEC (other buffer indicators)	OK	OK			

In general, proximal soil sensing data provide low-cost, high-density information on spatial variability. The resulting maps are integrated with digital field elevation maps to delineate field areas with significantly different crop production environments, as well as to prescribe locations for targeted soil sampling. Even when using proximal sensing, soil sampling

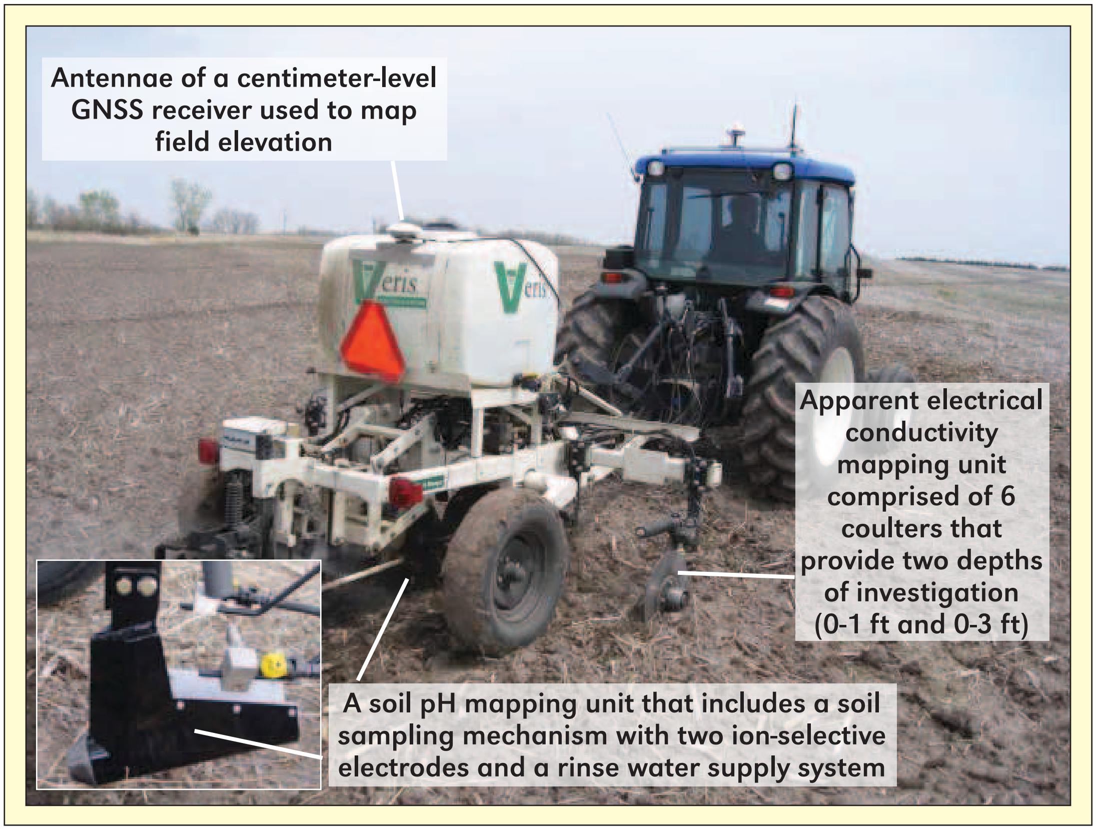

Figure 3. Veris® Mobile Sensor Platform integrating soil electrical conductivity and pH mapping units (Veris Technologies, Inc., Salina, Kansas) equipped with a Trimble AgGPS® 442 (Trimble Navigation Ltd., Sunnyvale, California) centimeter-level GNSS receiver.

and laboratory analysis remain critical components of the mapping process. However, the number of samples needed to characterize field variability can be much smaller than during systematic grid sampling as many soil properties follow spatial patterns that can be accurately delineated using on-the-go soil sensing. At this time, research is ongoing to determine which sampling strategy is the most efficient for enhancing the information value of on-the-go soil sensors (Lesch, 2005; Minasny and McBratney, 2006; de Gruijter, 2008; Adamchuk et al., 2008)

Crop sensors have been used to detect parameters related to the physical crop size using mechanical, ultrasonic, or other proximal sensing methods. Recently, optical reflectance sensors have become popular to detect the ability of the crop canopy to reflect light in visible and near-infrared parts of the electromagnetic spectrum. Physical crop size has been used to vary the use of agricultural chemicals according to the predicted demand, while crop status sensing has been used to alter the in-season supply of fertilizer and/or water to supplement local availability. However, it has been noted that variable soil conditions may require different rates of in-season fertilization to account for spatially different crop response.

Summary

Information on the variability of different soil attributes within a field is essential to the decision-making process for precision agriculture. On-the-go proximal soil sensing is the most promising strategy for obtaining much-needed high-density measurements of key soil properties. Proximal soil sensing systems are based on measurement concepts that are electrical and electromagnetic, optical and radiometric, mechanical, acoustic, pneumatic, and electrochemical. The major benefit of on-the-go sensing is its ability to quantify the heterogeneity (non-uniformity) of soil within a field and to adjust other data collection and field management strategies accordingly. The integration of different sensing systems in multisensor platforms may allow better prediction of agronomic soil attributes. Additional crop sensing options will allow producers to use these measurements to adjust in-season treatments in real-time. BC

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