On-the-go soil sensors – are we there yet?

V. Adamchuk*
McGill University, Ste-Anne-de-Bellevue, QC, Canada
viacheslav.adamchuk@mcgill.ca

Abstract

Since 1996, more than a dozen on-the-go soil sensing platforms have been under development at Purdue University, the University of Nebraska-Lincoln and now McGill University. The sensing systems developed were based on 1) electrical and electromagnetic, 2) optical, 3) mechanical, and 4) electrochemical measurement methods integrated with centimeter-level positioning devices. These systems were evaluated while addressing spatial variability in soil texture profiles, compaction, organic matter and water content, as well as soil pH and some macronutrients. While individual relationships between sensor measurements and agronomic properties could be strong, the current challenge lies in defining the most appropriate combination of these sensor platforms to resolve specific challenges associated with the optimization of agricultural inputs, land reclamation and other spatially differentiated treatments. The next steps toward the development and adoption of on-the-go soil sensing technologies are discusses in this publication.

Keywords: on-the-go soil sensing, proximal sensors, system development

Introduction

Spatial variability in soils has been of interest when attempting to optimize crop production systems, or during other types of landscape management. Thus, one of the most discussed strategies of information-based management of crop production, precision agriculture, earlier termed farming by soil (Robert, 1993). The initial factors influencing variability in soils relate to the five soil-forming aspects: parent material, climate, topography, organisms (including vegetation) and time (Jenny, 1941). Remote sensing of crop vegetation, bare soil imagery field topography and yield maps have been excellent high-density data sources to assess changes in growing environments from location to location. However, as vegetation performance reveals the overall effect of a number of factors such as nutrient and water availability during the growing season, maps of agronomic soil attributes are key components in decision-making practice. It is important to know the physical, chemical and even biological properties of soil in a given location to make a management decision that would maximize use efficiency of agricultural inputs and minimize relevant risks.

The traditional method of soil assessment is through soil sampling (extracting a fixed amount of soil from a predefined depth) for off-site laboratory evaluation. The relatively high costs of soil sampling and laboratory analysis suggest a need for on-the-go soil sensors that could detect critical soil properties in every field location while moving these sensors across the field. As a result, many sensor systems capable of making soil measurements on the go have been developed (Adamchuk et al., 2004a; Viscarra Rossel et al, 2011). This paper provides several examples of prototype soil sensing systems and discusses the main challenges for sensor deployment in a production setting and also for future developments.

Materials and methods

Since 1996, a number of soil sensing systems have been developed and tested. They can be grouped according to measurement principles: 1) electrical and electromagnetic, 2) optical and radiometric, 3) mechanical, acoustic and pneumatic, and 4) electrochemical. Figures 1 and 2 illustrate eight example systems worked on at Purdue University (West Lafayette, IN, USA), the University of Nebraska-Lincoln (Lincoln, NE, USA), and McGill University (Ste-Anne-de-Bellevue, QC, Canada).

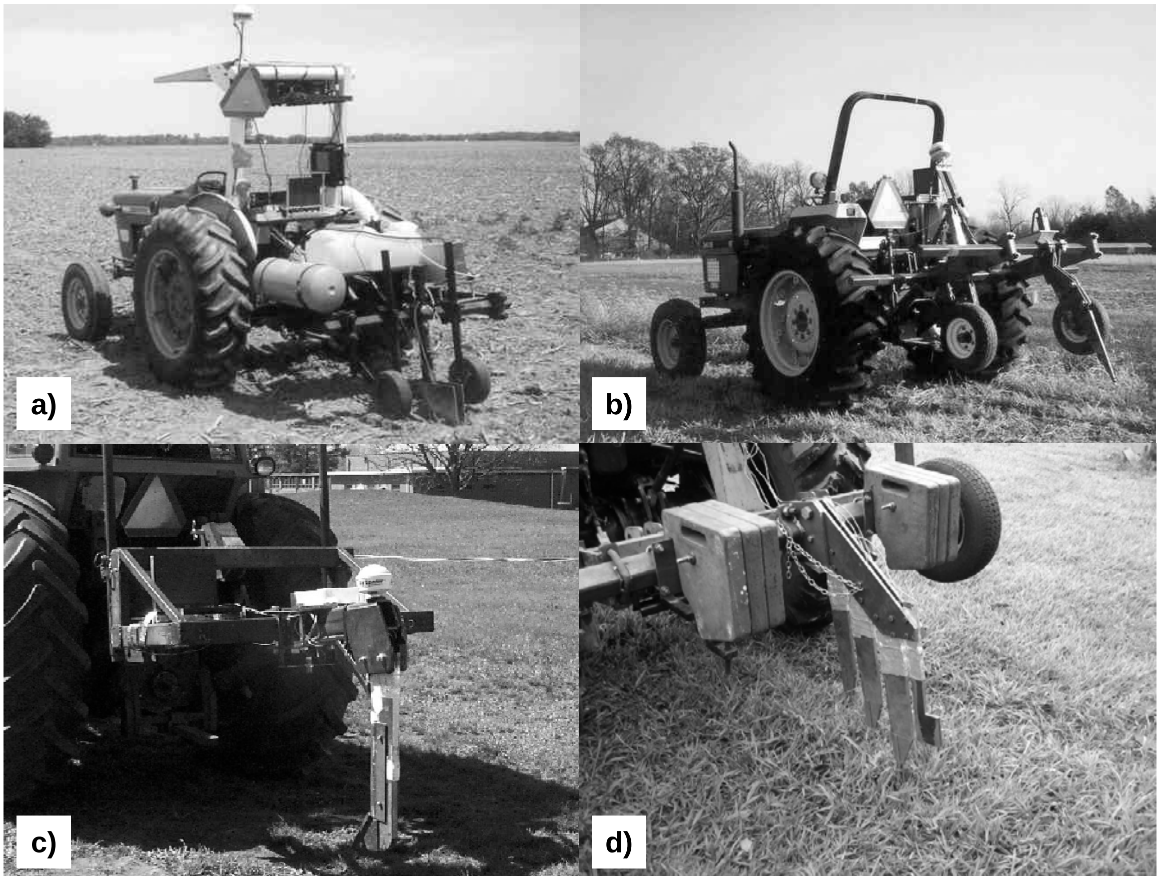

Figure 1. Examples of a) an automated soil pH mapping system (Adamchuk et al., 1999), b) an instrumented blade system (Adamchuk et al., 2001), c) an instrumented deep tillage implement (Adamchuk et al., 2004b), and d) a multiple blade system (Siefken et al., 2005).

Thus, apparent soil electrical conductivity (EC_a) sensors (Figure 2a and 2d) have been used to create maps of a soil's ability to conduct an electrical charge, which can be related to the ability of soil to accumulate water and nutrients. Such types of on-the-go soil sensors are the most popular today. Detecting the change of (EC_a) with depth has been of special interest as it relates to the depth of topsoil and different important soil processes. Alternatively, dielectric sensors (e.g., Figure 2b) have been shown to have strong relationships with soil water content.
An optical reflectance of soil (Figure 2b) has been related to soil carbon and organic matter contents, as darker soil usually means higher soil humus for the same soil series and moisture. Selecting an appropriate combination of wavelengths and soil reflectance indices has been the main challenge while trying to minimize the effect of different soil textures and water content. Hyperspectral soil reflectance has been used to predict certain chemical soil properties, which has been viewed as the major benefit of on-the-go soil sensing technology.

Figure 2. Example of a) Veris® Mobile Sensor Platform (Adamchuk et al., 2007), b) an integrated soil physical properties mapping system (Adamchuk and Christenson, 2007), c) an instrumented disc coulter (Hemmat et al., 2008), and d) a pneumatic angular scanning system (Mat Su, 2010).

Mechanical sensors (Figures 1b, 1c, 1d, 2c) have been developed to address spatial heterogeneity in soil strength that may indicate changes in bulk density. Predicting the depth profile of soil mechanical resistance to optimize tillage and compensating for the differences in soil water content have been the main challenges when developing these sensors.
Finally, electrochemical sensors (Figures 1a and 2a) have been developed to map soil pH and some macronutrients using a traditional potentiometric approach. In this case, an actual chemical analysis takes place while the system moves from one sampling location to the next. These systems do not need to stop when collecting new samples. The challenges of integrating different ion-selective sensing components and site-specific adjustment of any bias attributed to a given sensing scenario have been addressed in a number of research projects.

Discussion and Conclusions

Based on the evaluation of the on-the-go soil sensing systems mentioned above, at a lower cost than using the traditional methods, it is possible to obtain high-density soil measurements, which are produced using four main types of sensors. Unfortunately, these data may not be adequate for an appropriate decision support system as the measurements may react to a change of more than one agronomic soil property. Therefore, future research should focus on: 1) sensor fusion to bring together sensing components that may have different degrees of response to different soil phenomena, 2) localized sensor calibration methods to define relationships between sensor outputs and laboratory soil test results for specific environments, 3) data integration to employ benefits of remote sensing, proximal crop canopy sensing and yield mapping to better understand manageable soil processes, and 4) turn-key applications to make sensor technology accessible, affordable and useful for agricultural production, land remediation and other situations where soil heterogeneity is an influential factor.

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