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Direct measurement of soil chemical properties on-the-go using ion-selective electrodes

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Abstract

One of the main objectives of precision agriculture is site-specific management of agricultural inputs to increase profitability of crop production, improve product quality, and protect the environment. Information about the variability of different soil attributes within a field is essential to the decision-making process. Various soil sensors have been developed to map physical and chemical soil properties on-the-go. A method of direct soil measurement (DSM) using ion-selective electrodes (ISEs) has been applied in a commercial implement for on-the-go mapping of soil pH. This study describes a quantitative analysis of the potential for using a similar measurement procedure to simultaneously map soil pH, available potassium, nitrate-nitrogen and sodium contents. Response, calibration, precision and accuracy of the DSM were analyzed based on the results of a laboratory test. Precision of eight tested electrodes was assessed through the root mean squared error (RMSE) and ranged from 0.11 to 0.26 pX (negative base 10 logarithm of specified ion activity). The accuracy of electrodes was assessed while comparing test results against reference measurements conducted in commercial soil laboratories (RMSE ranged from 0.18 to 0.37 pX). The coefficients of determination (R^2) of regressions between average DSMs and corresponding reference measurements were equal to 0.93–0.96 (soil pH), 0.61–0.62 (potassium), 0.41–0.51 (nitrate-nitrogen), and 0.11 (sodium). Although DSM of pH represents a promising method for precision agriculture, the potential applicability of other ion-

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selective electrodes based on the results obtained declined in the order: potassium > nitrate > sodium. The primary reason for this decline was the difference in the level of variability of these soil properties in the set of soil samples used in this experiment rather than electrode errors. Performance of sodium electrodes remains questionable due the fact that only one probe was selected. Further research on integrated on-the-go mapping of soil chemical attributes using ion-selective electrodes is needed to investigate suitable application approaches.

Keywords: Precision agriculture; Soil sensor; Ion-selective electrode; pH; Potassium; Nitrate-nitrogen; Sodium

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1. Introduction

The main objectives of precision agriculture are to increase the profitability of crop production and to reduce potentially negative environmental impacts by adjusting application rates of agricultural inputs according to local needs (Pierce and Nowak, 1999). Variable rate management of soil pH and macronutrients is one of the most promising strategies involving precision agriculture technology. Commonly, different layers of spatial field data are integrated in order to develop application algorithms, known as prescription maps. Systematic soil sampling followed by laboratory analysis usually serves as the best estimate of soil nutrients and pH distribution throughout the field. However, variable rate application of fertilizers and lime frequently does not result in a positive economic impact (Dobermann et al., 2004). The two main limitations of the current methods are: (a) inadequate recommendation algorithms which have been developed for macro-scale agricultural practices, and (b) the high cost of soil sampling and analysis resulting in maps with inadequate spatial resolution (Dobermann et al., 2004).

As one alternative, high-density soil data layers (bare soil aerial photography, electrical conductivity maps, digital elevation models, etc.) have been utilized to modify soil sampling patterns and to develop management zones requiring similar soil treatments. In addition, a methodology for reliably obtaining higher density direct measurements of soil properties could provide the capabilities for resolving both limitations of variable rate technology. An on-the-go system for mapping soil pH and macronutrient levels has the potential for providing additional data layers for prescribing variable rate application maps, or could serve as a research tool for studying the local yield response to certain soil treatments (Adamchuk et al., 2004a). Although no successful techniques to rapidly measure soil phosphorous content have been developed at this time, on-the-go measurements of soil pH, available potassium, residual nitrate-nitrogen, and sodium content have been attempted.

Adsett et al. (1999) developed a soil sampler with a nitrate monitoring system that utilized a conveying unit to deliver soil to an extraction unit where the measurement took place. They indicated that 95% accuracy could be obtained within 6 s. Birrell and Hummel (2001) indicated that ion-selective field effect transistor (ISFET) sensors in combination with flow injection analysis represent an alternative for measuring nitrate ion concentrations in manually extracted solutions ($R^2 > 0.9$). Price et al. (2003) described their attempt to develop a nitrate extraction system that used ISFET technology to map soil nitrate on-the-go. Although no field testing results have been reported yet, some evidence of relatively low