Development of a Manual Soil Sensing System for Measuring Multiple Chemical Soil Properties in the Field

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Abstract. Variable Rate Fertilizer Application (VRA) requires the input of soil chemical data. One of the preferred methods for analyzing soil chemical properties in the field is by using Ion Selective Electrodes (ISEs). To accommodate portability in soil measurements, a manual soil sampling system was developed. Nitrate, Phosphate and pH ISEs were integrated to provide a general outlook on the condition of essential soil nutrients. These ISEs were placed on a modified hand-held soil sampler equipped with a variable depth adjustment, water reservoir, hand pump and spray nozzles for rinsing the ISEs. An Arduino shield from Whitebox Labs' Tentacle (Meister Whiteboxes GmbH, Basel, Switzerland) with four Atlas Scientific ORP (oxidation-reduction potential) circuit (Atlas Scientific LLC, Brooklyn, New York, USA) were used as the data acquisition (DAQ) system. Furthermore, a Global Positioning System (GPS) data logger and a temperature sensor were added to provide more input for the VRA development. This multiple ISEs manual soil sensing system is easy to operate in the field. The ISEs and DAQ system were tested for response time, sensitivity, noise and cross talk and they provided reasonable results. Overall, this system has potential to give simultaneous measurements of nitrate, phosphate and pH with good accuracy and across a range of soil types.

Keywords. direct soil measurement, ion-selective-electrode, nitrate, phosphate, pH.

Introduction

One of the key components for a successful variable rate application Fertilizer (VRA) of agricultural inputs is representative soil sampling and corresponding chemical analysis (Clay et al., 2017). Ion Selective Electrodes (ISEs) have been broadly used for analyzing soil pH and Nitrate either in the laboratory (Mulvaney, 1996; Thomas, 1996) or directly in the field (Adamchuk et al., 1999; Adsett et al., 1999). Additionally, Cobalt rods were found to be sensitive to Phosphate solution (Kim et al., 2007) which offers the possibility of direct soil measurement in the field. Various mobile platforms have been developed to analyze soil chemical properties (Adamchuk et al., 2004). However, there is less information on the portable manual soil sampler and analyzer for soil chemical properties. Therefore, the objective of this research was to further develop a manual soil sensing system for measuring multiple soil chemical properties in the field using ISEs.

Materials and Methods

SolidWorks (Dassault Systemes S.A., Waltham, Massachusetts, USA) was used to create the conceptual design of the manual soil sensing system. A conventional 90-cm long soil sampler (JMC, Clements Associates Inc., Newton, Indiana, USA) was used as a base for the soil sensing platform. The ISE clamp was designed to hold four ISE bodies (assuming 12-mm diameter of each probe) for multiple soil chemical measurements. Four Teejet XR11002VK nozzles (TeeJet Technologies, Glendale Heights, Illinois, USA) and manual piston hand pump were used to clean the ISEs. A four channel BNC circuit Arduino shield from Whitebox Labs' Tentacle (Meister Whiteboxes GmbH, Basel, Switzerland) was used as a base for the Data Acquisition System (DAQ). The DAQ was designed to have instrument nulling, soil temperature sensor, GPS, data logger and Bluetooth connectivity. To measure multiple soil chemical properties (i.e., soil Nitrate, Phosphate and pH) using ISEs, four Atlas Scientific ORP (oxidation-reduction potential) circuits (Atlas Scientific LLC, Brooklyn, New York, USA) were installed. Two models of ORP circuits were tested: customized 100-ms and standard 1000-ms sampling rate (further called the first and second Tentacle, respectively). For the first Tentacle, 100 ms was initially thought to be the optimal in terms of modeling time response. For the second Tentacle, a query time of 1000 ms for each circuit proved to be sufficient to provide a stable data stream. Each Tentacle was tested for noise and cross talk errors.

Results and DIscussions

The final design of the apparatus is shown in Fig. 1. The first Tentacle could not smooth electrical noise as well as the second Tentacle. Further examination revealed that the first Tentacle circuit reading fluctuated with operator movement and it was not suitable for ISEs with shared references. Fig. 2 shows that the first Tentacle did not have any cross-talk errors from the adjacent channels. In this test, each or combinations of different pH and Nitrate ISE were alternately dipped into its calibration solution for 90 s. The phenomenon observed in channel 2 at 700 ms was suspected because of the shared reference between the half and full cell Nitrate ISE. The reading instability was caused by multiple references when the ISEs were in their calibration solution which created a ground loop noise (Sethuramasamyraja et al., 2008; Monk and Scherz, 2016). On the contrary, there was no ground loop in the second Tentacle, which suggested that the second Tentacle was well protected.

The operation of the apparatus in the field was started by turning on the DAQ. Then, the DAQ performed a system check for one minute. Initializing procedures can be started by placing a BNC cover on each ORP channel and followed by holding the "start" button for 5 s. The DAQ will enter instrument nulling mode. The DAQ will make an average of 15 sets of ISEs measurement from each channel. The resulting "tare" value will be used to subtract the ISEs measurement when sampling. Soil sampling was done by pressing the soil sampler into the soil at the pre-set depth (Fig. 3a). Then, the hand pump handle was operated so that the ISEs would have firm contact with the soil sample (Fig. 3b). The soil measurement began by pressing the "start" button. Then, the DAQ will collect the GPS data for 5 s and four ISEs measurements for 90 s. After each measurement, the ISEs were cleaned using a manual pump-sprayer (Fig. 3c). The sampled soil will get removed automatically as the next sample enters the soil sampler.

Conclusion

The soil sensing platform was convenient to use, offered good ISE contact with the soil and effectively cleaned the ISEs. The 1000-ms sampling rate Tentacle was chosen as the DAQ platform because it provided better noise and ground loop protection. Overall, the new soil sensing system would improve the VRA by providing replication and an overview of the target soil chemical properties range.

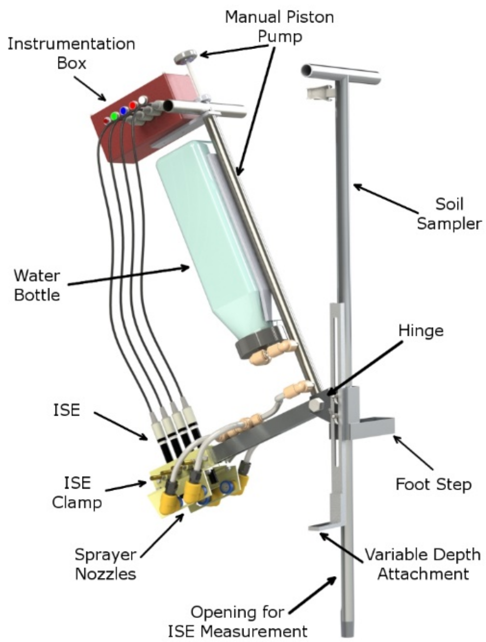

Fig. 1 Conceptual Design of the Multiple ISEs Manual Probe

(a) **(b)**

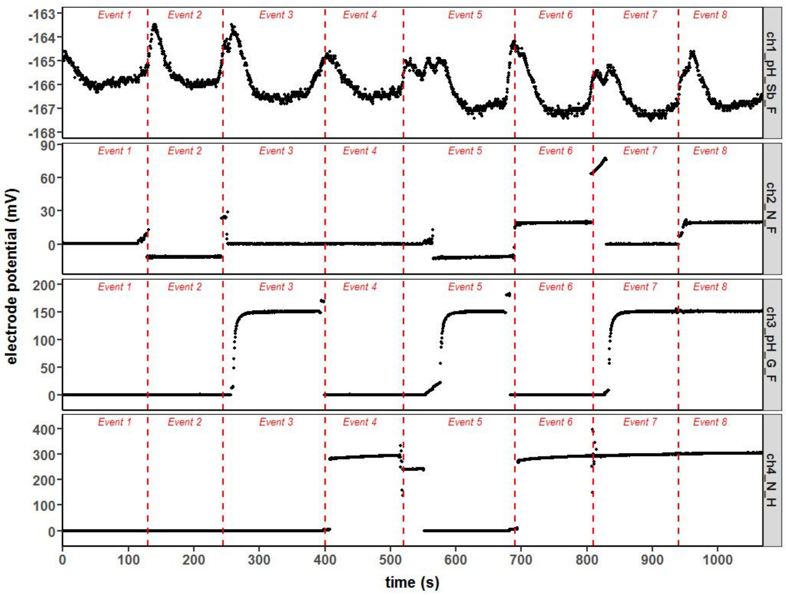

Fig. 2 The First Tentacle channel 1 Cross Talk Test

(c)

Fig. 3 Multiple ISEs Manual Probe Operation: (a) Soil Sampling, (b) Soil Measurement, (c) ISE cleaning

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