HUMAN-POWERED PROXIMAL SOIL SENSING FOR SMALL FARMS

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ABSTRACT

Over the past 25 years several on-the-go proximal soil sensors have been developed, commercialized, and adopted by crop consultants, retailers, and growers for mapping large fields and farms. These technologies are used to map soil texture--which impacts water and nutrient holding capacity, organic matter--a measure of soil health and productivity, and pH—which directly affects nutrient availability. Typically, these sensors are deployed with tractors or other off-road vehicles, used in fields larger than 20 ha, and have a retail price well above US$25,000. If these sensing technologies are to be cost-effective and useful in most African fields, they must replicate the proven sensing accuracy of the larger, more expensive units. They will need to be human powered, provide detailed soil mapping in 1 ha fields, and have an affordable cost—including many locally manufacturable components. Handheld versions of Veris Technologies' soil electrical conductivity, Vis-NIR optical, and pH sensors have been developed and used in a multi-field project in Kenya. These sensors mapped soil texture, soil organic matter, and soil pH, respectively. Currently a second generation of these sensors is being developed in collaboration with Kansas State University. Objectives of the Kenya study and the ongoing handheld sensor development are to provide rapid, accurate, and affordable soil mapping for small fields.

INTRODUCTION

A significant obstacle facing smallholder farmers' efforts to improve crop yields is their farm's soil health, including low organic matter levels, inadequate soil nutrients, and soil acidity (Vanlauwe et al., 2023). These challenges are exacerbated by the spatial heterogeneity of smallholder fields. Soil variations within fields can be significant and have both pedogenic and anthropogenic causes (Tittonell et al., 2005). Although studies have found significant yield and profit increases with modest increases in crop nutrition, adoption has been slowed by inadequate financial resources (Hijbeek et al., 2021; Owino, 2015). If the spatial heterogeneity is properly mapped and amendments placed site-specifically, the reduced initial costs and improved economic returns will encourage adoption of these practices (Snapp, 2022).

The use of proximal, on-the-go soil sensors to map farm fields began to be adopted in the late 1990's on larger scale, mechanized farms in developed countries. The first commercialized proximal sensors measured apparent soil electrical conductivity (ECa), which in non-saline soils correlates with soil texture (Lund et al., 1998). This innovation was followed in the early 2000's with on-the-go pH sensing using ruggedized ion-selective electrodes (Adamchuk et al., 2005), and organic matter mapping using Vis-NIR spectroscopy (Kweon et al., 2013). Today, these technologies are being used in more than 60 countries. Hand-held, human-powered prototype versions of the ECa, Vis-NIR, and pH sensors were deployed on a five-field project in Embu County, Kenya. The average size of the project fields was less than 1 ha. The sensors were able to be inserted into the soil in diverse field conditions and collect satisfactory measurements. The maps provided valuable information, revealing pH variability in each field that would significantly reduce liming costs. The in-field heterogeneity was clearly evident, and at a variety of spatial scales, generating insights for in-field mapping protocols.

This paper provides a description of the sensing technology and its capabilities, key results from the Embu study, and a discussion of utilizing proximal sensing in African smallholder fields.

MATERIALS AND METHODS

Sensing technology

Soil ECa is measured by the direct soil contact method which uses at least four electrodes in physical soil contact to inject a current with one electrode pair and the second pair measures the voltage that results. The usefulness of soil conductivity stems from the fact that sands have a low conductivity, silts medium, and clays have high conductivity (Williams and Hoey, 1987). Coupled with GPS, each sensor reading is georeferenced. When points are closely spaced, interpolated soil ECa maps are generated that show detailed soil texture variations. On large commercial Veris systems the electrodes are rolling electrodes which permits mapping in crop residue (Figure 1). For the human powered version, a set of fixed tines are attached to a probe handle (Figure 2).

Figure 1. Veris ECa system with rolling electrodes. Figure 2. Human-powered ECa device.

Veris deployed the first on-the-go Vis-NIR spectrophotometer in 2002 and commercialized a hydraulically-powered Vis-NIR spectrophotometer probe in 2008 (Christy, 2008). Currently, the commercial versions of Veris on-the-go U3 and CoreScan hydraulic probes use a dual wavelength Vis-NIR system (Figure 3). The same wavelengths are used in the human-inserted probe (Figure 4). Veris commercial equipment and its hand-held version both measure pH directly on moist soil using a ruggedized ion-selective electrode (Figure 5). The results of this rapid method have been shown to correlate well with lab measured pH (Schirrmann et al., 2011).

Figure 3. CoreScan probe.

Figure 4. Handheld Vis-NIR probe.

Figure 5. pH probe.

Human-powered mapping approach

Fields are traversed by walking across the field on approximately 12-15m transects and stopping every 12-15 meters to insert the probes. This method results in approximately 50 sensor points/ha (Figure 6). Using the system under development, it is anticipated that a 1 ha/hour capacity will be achievable.

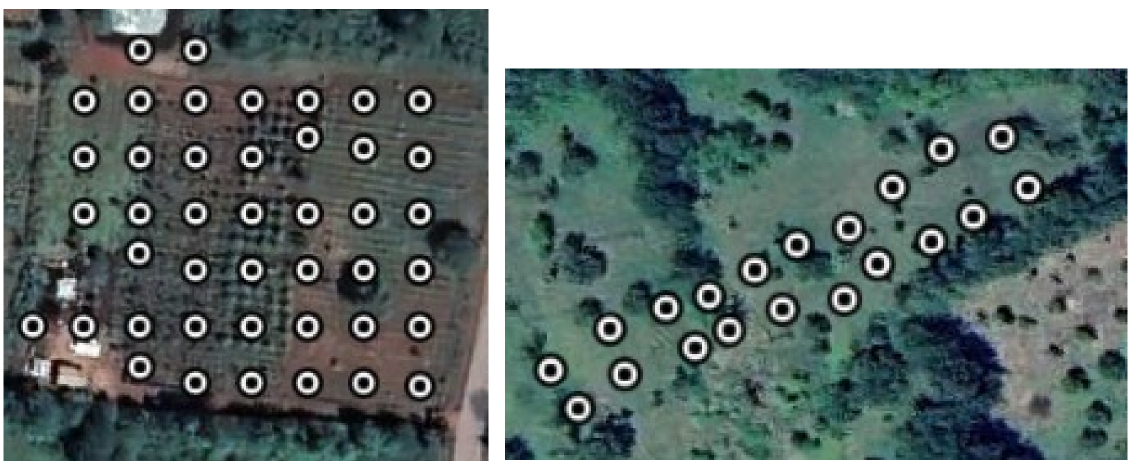

Figure 6. Two of the Embu County project fields with sensor probe locations.

RESULTS

Sensor-lab correlations

The Embu County project consisted of comparing several soil sensing technologies and sensor measurements were validated with 165 lab-analyzed soil samples. Of all sensors tested, the best single sensor results were for measuring soil organic carbon using the red wavelength of the human-powered sensor probe (Piikki et al., 2016). The unpublished pH sensor results using an early generation pH sensor were the most encouraging, with an overall correlation coefficient of .80 and negligible bias. This suggests that the handheld pH sensor data could be used directly for lime applications with no lab-analysis needed.

Mapping protocols

In addition to evaluating sensor accuracy, the Embu County project provided important insights of smallholder field variability that can help develop the rationale for optimal field mapping protocols. Soil variability is evident on smallholder fields at three scales: Macro, Meso, and Micro. Macro scale are the pedogenic-related variations in soil texture and organic matter that occur naturally. This variability is best identified by the complete coverage gained by collecting ECa and optical sensor readings every 12-15 m which generates a long-term map of basic water and nutrient holding capacity and productive potential. Meso scale are those anthropogenic soil variations that are the result of farmer action—areas of livestock feeding, burn piles, biomass or waste disposal, small gardens etc. The pH and OM in these areas can be expected to vary significantly from the general field areas. Depending on the size of these meso scale areas and objectives of the map, these can either be avoided or mapped with additional intensity. Micro scale areas are typically small and should be avoided so as to not overstate their area or importance. Examples include areas such as where a single, large tree has been burned, small manure piles, and visible anomalies that are less than 10 square meters in size.

DISCUSSION

How could soil mapping with soil sensors benefit smallholders? It appears that the most rapid and calculable return is to site-specific lime application. A script for the Embu University field would lime 25% of the field--only the area below 5.5 pH. Using lime costs of \$160/ha for a 1.5 ton/ha application (Jaleta et al., 2023), liming the most acidic 50% of each field in the Embu County study would save on average \$80/ha. The cost of collecting the sensor measurements would depend on many factors, but using a charge of \$10/ha, a crop advisor who maps 3 ha/day would generate \$30/day of gross income.

Figure 7. Only 25% of the Embu University field required lime application.

Other inputs are more difficult to value but include variable plant density based on water-holding variability, site-specific biomass additions to build up low OM zones, yield-goal fertilization based on productive potential, and soil zone-specific cultivars. If lab-analyzed soil tests are available, soil samples can be directed by the macro scale zone map.

CONCLUSION

Soil sensing has become standard practice for many growers in the developed world. The same technology in human-powered form is becoming available for smallholders. Initial testing in Kenya showed the potential for accurate, rapid, and affordable mapping.

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