Delineation of Soil Management Zones: Comparison of Three Proximal Soil Sensor Systems under Commercial Potato Field in Eastern Canada.

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Abstract. *Precision agriculture (PA) involves optimization of seeding, fertilizer application, irrigation, and pesticide use to optimize crop production for the purpose of increasing grower revenue and protecting the environment. Potato crops (Solanum tuberosum L.) are recognized as good candidates for the adoption of PA because of the high cost of inputs. In addition, the sensitivity of potato yield and quality to crop management and environmental conditions makes precision management economically important. Subdividing agricultural fields into soil management zones (MZs) with relatively homogeneous soil properties and yield potential can be used as the basis of site-specific nutrient management. It offers an effective alternative to uniform rate applications. This study evaluated the applicability of three proximal soil sensor systems to delineate MZs in a 21-ha commercial potato field located in St. André (NB). Both Veris and Dualem instruments were utilized for the mapping of apparent soil electrical conductivity (ECa) in fall of 2015. Ground penetrating radar (GPR) was utilized for mapping soil dielectric constant in February 2016. Data from the three sensor systems were used to stratify the fields into MZs using an unsupervised fuzzy k-means clustering algorithm. Soil samples (0-15 cm) collected from 154 georeferenced sampling points were analyzed for key physical and chemical properties (soil organic carbon, pH, and Mehlich-3 extractable elements). The soil particle size analysis was completed only on 41 soil samples. Potato tuber yields were measured using a yield monitor in 2013, 2014, and 2016. Both sets of ECa maps were found effective in delineating MZs whereas the GPR data failed to assist in delineating MZs with relatively consistent soil attributes. The two MZs delineated with GPR did not show significant differences in potato yields. Based on the Veris and Dualem, two MZs were found to be optimal to subdivide the potato field to implement site-specific management. The MZs showed* *significant differences in soil water regime (soil moisture: 23.4% vs 28.5%) and in soil texture (e.g., clay: 141 g kg^{-1} vs 189 g kg^{-1}). Significant differences in potato yields (e.g., 4.8, 7.6 and 10.1 Mg ha^{-1} for 2013, 2014 and 2016, respectively) between the two MZs were attributed to differing water supply associated with differing soil texture and soil drainage characteristics.*

Keywords. *Veris, Dualem, ground penetrating radar, decrease of the within-zone variance*

Introduction

Precision agriculture (PA) involves optimization of seeding, fertilizer application, irrigation, and pesticide use to account for spatially variable crop requirements. Potato (*Solanum tuberosum* L.) crops are recognized as good candidates for the adoption of PA because of the high cost of inputs, the high variability of both soil and crops, and also because the high-value of the potato crop is based on both yield and tuber quality. In addition, the sensitivity of potato yield and quality to crop management and environmental conditions makes precision management economically important. Subdividing agricultural fields into soil management zones (MZ) with relatively homogeneous soil properties and yield potential can be used as the basis of site-specific nutrient management, and offers an effective alternative to uniform rate applications (Zebarth et al. 2012). Partitioning production fields into relatively homogeneous zones can be used to optimize management of soil fertility and water availability (Mulla 1989).

Different spatial data layers, such as very detailed soil maps (Robert 1989), intensive grid soil sampling (Wollenhaupt and Wolkowski 1994), multi-year yield maps, drone and satellite images (Brisco et al. 1998) and proximal soil sensors (Adamchuk et al. 2004), can be used to delineate MZs. The proximal soil sensors (PSS) rely on electrical, electromagnetic, radiometric, optical, mechanical, acoustic, pneumatic and electrochemical measurements. Apparent soil electrical conductivity (EC_a) measured by electromagnetic induction is temporally stable and strongly related to inherent soil properties (Cambouris et al. 2006). The ground penetrating radar (GPR) is a proximal sensor that can be used to map soil attributes of importance for agriculture and natural resource management (Adamchuk et al. 2015). This study evaluated the efficiency of three proximal soil sensors (galvanic contact resistivity and electromagnetic induction instruments used to map ECa and GPR to map dielectric soil characteristics stratified with depth) to delineate MZs which are related to tuber yield, soil fertility and soil physicochemical properties.

Material and Methods

Site description

The study site was a 21-ha commercial potato field located in St. André (NB). Four soil series were identify by Langmaid et al. (1980): 1-Homesville, 2-Undine, 3- Johnville and 4- Siegas. According to Milburn et al. (1989), soil depths are shallow and varied from 0.30 to 0.65 m for all soil series.

Soil and Sampling Analyses

Soil surface samples (0-15 cm) were collected from 154 georeferenced sampling points using a triangular grid design with a sampling interval of 33 m on 12 ha, and of 71 m on the rest of the fields. The samples were analyzed for physical and chemical properties, including: soil organic carbon, pH water, and Mehlich-3 extractable elements (P, K, Ca, Mg and Al). Soil particle size analysis was completed only on 41 sampling points.

Proximal Soil Sensor Data Collection

The Veris and Dualem instruments were used for the measurement of ECa in fall of 2015. The Veris system (Veris-MSP3, Veris Technologies, Inc., Salina, KS, USA) simultaneously investigates soil at two depths, 0-0.3 m and 0-1.0 m (Kweon et al. 2012). The Dualem (Dualem-21S, Inc., Milton, ON, Canada) sensor recorded simultaneously the data from four soil layers: 0-0.5 m, 0-1.0 m, 0-1.5 m and 0-3.2 m. Ground penetrating radar (GPR), GSSI SIR-3000 model (Geophysical Survey Systems, Inc., Nashua, NH, USA) with an antenna of 400 MHz, was utilized for the measurement of the soil dielectric constant derived from radargram in February 2016. The GPR data were used to characterize the soil profile to calculate the depth to bedrock (DBR) and the soil layer thickness (SLT) of the surface ($SLT_{surface}$) and the subsurface ($SLT_{subsurface}$).

Tuber Yield Monitor

Spatial distributions of tuber yield were measured in 2013, 2014 and 2016 using a potato harvester yield monitor (RiteYield system, Greentronics, Elmira, ON, Canada).

Statistical and Geostatistical Analysis

The statistical analysis (descriptive, correlation, ANOVA) were carried out with the MATLAB® 8.3 software (Mathworks 2014). Geostatistical Analyst in ArcGIS 9.3.1 (ESRI, Redlands, CA, USA) was used to perform all the geostatistical computations and model validations. A k-means clustering with a non-spatial constraint of proximity was carried out using FuzME software (Minasny and McBratney 2002) to delineate the MZ using the proximal sensor datasets. The decrease of the within-zone variance was used to determine the optimal number of MZ.

Results

The fuzzy k-means clustering algorithm was used to split up the fields into two to five MZs. By increasing the number of zones from one to two, the total within-zone variance of the soil EC values decreased from 71% to 77% and from 65% to 79% with the Veris and the Dualem, respectively. According to the decrease of the total within zone variance, two MZ seem to be most suitable with these two PSS systems. Based on the SLT, the stratification of the field from one to three MZ decreased the total variance from 55% to 65% and three MZ seems to be most suitable. Effectively, two MZ were significantly different when using the soil EC_a proximal sensor to delineate the field. With the GPR, only $SLT_{surface}$ was considered significant at the chosen 5% level when delineating the field into two MZ.

The highest soil EC_a zone was characterized with shallowest soil depth ($SLT_{surface}$). The average difference in tuber yield acquired with the yield monitor for the three years was 6.8 Mg ha^{-1} and 7.4 Mg ha^{-1} when using the Veris or Dualem to delineate MZ, respectively. The lowest yield zone is also characterized by highest amount of clay (clay: 141 g kg^{-1} vs 189 g kg^{-1}) and soil moisture (soil moisture: 23.4% vs 28.5%) content. The MZ with the wettest soil conditions could be managed with specific drainage or improved surface water management to reduce the greatest amount of water in the soil in this area, which could increase the tuber yield potential in this zone. Under those circumstances, identifying the underlying factors responsible for the variation in crop yield, it would be possible for potatoes producers to use MZ in order to optimize their profitability (De Caires et al. 2015).

Conclusion

The Veris and Dualem were found to be effective in delineating MZ whereas the GPR was not effective. The two MZs delineated with GPR did not show significant differences in potato yields. Based on the Veris and Dualem soil EC dataset, two MZs were found to be optimal to subdivide the potato field. The MZs showed significant differences in soil water regime and in some soil physical and chemical properties. Significant differences in potato yields between the two MZs were attributed to differing water regime associated with differing soil texture and soil drainage characteristics.

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