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MAPPING SOIL MOISTURE CONTENT VARIABILITY USING ELECTROMAGNETIC INDUCTION METHOD

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ABSTRACT In agricultural fields, large spatial variations in soil water content are associated with soil heterogeneities, topography, land cover, evapotranspiration, and precipitation. Detailed georeferenced maps would be useful to manage soil moisture according to soil variability to assess drainage and sub-irrigation requirements within wild blueberry fields. Two fields were selected in central Nova Scotia and a grid pattern of sampling points was established at each experimental site based on the geostatistical analysis of the ground conductivity survey data. The volumetric moisture content was determined for each grid point (n=86 for field 1 and n=56 for field 2) from both fields using TDR. The ground conductivity was measured and recorded with Dual EM at same selected grid points. Two comprehensive surveys were conducted in those fields to measure ground conductivity for moisture estimation in real-time using DualEM and a differential global positioning system. Linear regression analysis showed that ground conductivity was significantly correlated with the measured moisture content (R² ranged from 0.85 to 0.90) in both fields. The accuracy of the estimated values from the DualEM data was calculated as root mean square error (RMSE: 2.66 and 3.63 for F1 and F2, respectively). The estimated soil moisture maps showed substantial variation in selected fields. The slope of both fields was also mapped using automated slope mapping system. The moisture and slope maps were overlaid representing high moisture content in low lying areas and steep slope areas having less moisture content. This information could be used to assess drainage requirements as well as to schedule site-specific sub-irrigation within fields.

Keywords: Soil moisture, variability, EMI, irrigation, TDR, DGPS, GIS

INTRODUCTION One of the major deficiencies in many precision agriculture (PA) implementations is the lack of inexpensive, detailed, up-to-date, and pertinent georeferenced soil data. In wild blueberries detailed spatial water-related soil information is important to ensure the optimum long-term management (irrigation, drainage, fertility) and sustainability of fields.

Measurement of water-related soil properties, including soil moisture content, water holding capacity, infiltration rate, texture, organic matter, water table depth, and the

presence of restrictive soil layers is expensive and time consuming using soil sampling methods. As these techniques generally measure water related properties at a particular point, it is costly and time consuming to monitor large areas using them. The estimation of soil variability through the use of electromagnetic induction (EMI) can be performed quickly and inexpensively. Soil apparent electrical conductivity (ECa) is a measurement that is affected primarily by a combination of soil water content, dissolved salt content, clay content, mineralogy and soil temperature (McNeill, 1980).

Several researchers have investigated the relationship between soil water content and ECa. Soil ECa measured by EMI has been correlated with clay content (Williams and Hoey, 1987; Doolittle et al., 1994), soil water content (Kachanoski et al., 1988), sand deposition and total soluble salts (Williams and Hoey, 1987), yield (Jaynes et al., 1995), and soil available N (Eigenberg et al., 2002). Kachanoski et al. (1988) found significant correlation ($r^2 = 0.88$ to 0.94) among variation of soil water content, soil solution electrical conductivity, and ECa measured with electromagnetic induction methods (Geonics Inc., Mississauga, Canada). Morgan et al. (2000) also studied the soil water content and its relationship to ECa spatially. Brevik et al. (2006) correlated the volumetric water content with EMI values and found a significant correlation ($R^2 = 0.70$ or higher for four fields) for grasses temporally. Brevik and Fenton (2002) found that soil water content was the single most important of the four commonly cited factors influencing ECa (soluble salts, clay content and mineralogy, soil water content, and soil temperature) in determining ECa in central Iowa.

Crop growth and productivity are highly variable due to the spatial heterogeneity of soil properties (Zaman, 2002). Classical statistics are not appropriate to provide the spatial variability on a data set such as location of the high or low values, the trend or degree of continuity. Hence geostatistical analysis becomes the most useful approach to study spatial dependence of various soils and landscape attributes (Vieira et al., 1981). The semivariogram is a central tool of geostatistics and can quantify the spatial variability of soil properties as well as optimization of sampling intensity (Zaman, 2002). Geographical Information Systems (GIS) are also powerful management tools which support several interpolation and mapping techniques for evaluation and presentation of spatial variation (Miller and Whitney, 1999).

Many researchers have been investigating the mapping of ECa for the appraisal of one or two specific factors contributing to soil condition and productivity (Kachanoski et al., 1988; Williams and Hoey, 1987; Brevik et al. 2006). However, there is little information in the literature regarding the use of EMI to evaluate, and mapping the spatial variation in soil moisture content for wild blueberry crop. Currently, crop management practices are implemented uniformly with inadequate attention being given to substantial variation in soil/plant characteristics, topographic features and fruit yield. These variations within wild blueberry fields emphasize the need for precise site-specific crop management. The objective of this study is to map the moisture variability using EMI and to relate the volumetric moisture content to the ground conductivity values measured by DualEM. Detailed georeferenced maps for ground conductivity, and volumetric water content would be useful to manage soil moisture according to soil variability to access drainage and sub-irrigation requirements within wild blueberry fields.

MATERIAL AND METHODS Two wild blueberry (*Vaccinium angustifolium* Ait.) fields in central Nova Scotia, Canada were selected to map the moisture variability. The Carmal site (1.2 ha; 45.44° N, 63.54° W) and the North River site (1.6 ha; 45.27° N, 63.12° W) were selected. Both fields were in their vegetative sprout year of the biennial crop production cycle in 2009, and both will be in their crop year in 2010. The fields had been under commercial management over the past decade and received biennial pruning by mowing for the past several years along with conventional fertilizer, weed and disease management practices.

A grid pattern of sampling points was established at each experimental site to record volumetric water content using time domain reflectometry (TDR). The ground conductivity meter (DualEM, Milton, Ontario, Canada) survey data was utilized to develop the soil sampling strategy for both fields. Geostatistical analysis was performed using GS+ software to produce a semivariogram. Based on the geostatistical results a sampling strategy (grid size 15 X 15 m) was developed. The volumetric moisture content was recorded using TDR at each grid point up to the depth of 0-15 cm. The sampling coordinates for grid points were recorded using a ProMark3 mobile mapper GPS (Thales Navigation, Santa Clara, Cal.).

The ground conductivity readings were also recorded from the same grid points for both fields. The ground conductivity meter ((DualEM, Milton, Ontario, Canada) consisted of a single transmitter and two receivers, simultaneously providing two different depth-weighted estimates of apparent electrical conductivity (ECa). Both the transmitters and one of the receivers have horizontal windings, forming what is termed a horizontal coplanar (HCP) geometry that generates the deeper of the two readings. The other receiver has vertical windings, forming a perpendicular (PRP) geometry that generates a shallower reading (Sudduth, 2003). The DualEM ground conductivity meter along with a Trimble Ag GPS 332 unit can be used to make non-invasive geo-referenced EMI measurements of the fields.

Slope variability was measured and mapped with an automated slope measuring system (ASMMS). It consists of a tilt sensor that determines the tilt of the vehicle in any orientation on a slope and a Trimble AgGPS-332 DGPS antenna (Trimble Navigation Limited, Sunnyvale, CA) mounted on the all terrain vehicle (ATV) to determine the location of the sampling point. The ASMMS also include a laptop computer with the software that incorporates sensor and GPS data to calculate slope in real time. The detailed procedure for measurement and mapping of slope was adopted from Zaman et al. (2008).

RESULT AND DISCUSSIONS The ground conductivity survey data for both fields was utilized to determine the range of the variability. Semivariograms were used to quantitatively assess spatial correlation in observations measured at sample locations. The semivariogram developed by using GS+ Geostatistics for the Environmental Sciences Version 7 (Gamma Design Software, LLC, Woodhams St, Plainwell, MI) software gave the spatial variability for both fields (Fig. 1). The semivariance is calculated for every possible pair of data points (Di et al., 1989). There are three components of a semivariogram: nugget, sill and range. Nugget semivariance is the variance at zero distance. Sill is the lag distance between measurements at which one value for a variable does not influence the neighboring values. The range is the distance at which the values

of one variable become spatially independent from one another. The separation distance specifies the range over which autocorrelation was calculated. The semivariogram models were fitted to the semivariance data for quantifying the spatial variation in ground conductivity values (Webster and Oliver, 2001).

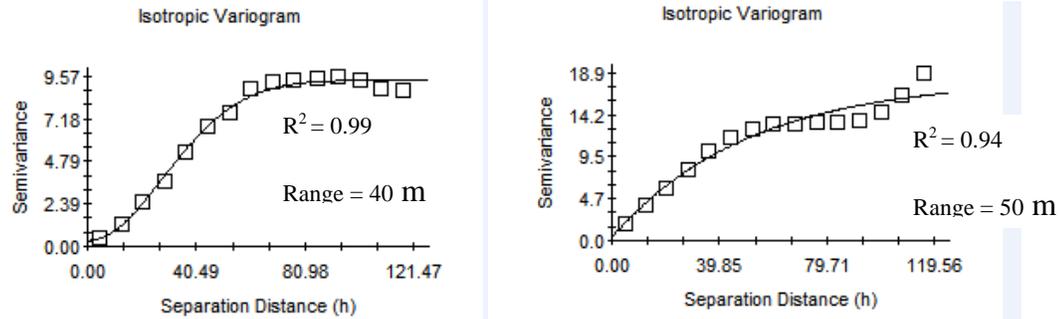


Figure 1. (a) Semivariogram Carmal field (b) Semivariogram N. River field

On the basis of the range of variability of both fields the grid size for sampling was decided as 15 x 15 m to record TDR and ground conductivity values at each grid point. Descriptive statistics was performed using Minitab 15 statistical software to calculate minimum, maximum, mean, coefficient of variation and skewness of all data sets collected from both fields (Table 1). TDR probes were calibrated with the gravimetric method for moisture determination. Twelve soil samples with known volume were collected and moisture content was determined using the oven dry method, and TDR readings were also recorded from the same sampling points. TDR readings were significantly correlated ($r^2 = 0.92$) with gravimetric moisture content.

Table 1 . Descriptive statistics for Carmal and North River fields

Carmal Site						
Variable	Minimum	Maximum	Mean	Std	CV (%)	Skewness
HCP (mSm-1)	0.30	11.20	5.35	2.78	52.12	0.10
TDR (vol. basis)	3.80	30.67	18.14	7.62	39.48	-0.02
North River Site						
Variable	Minimum	Maximum	Mean	Std	CV (%)	Skewness
HCP (mSm-1)	0.10	17.70	6.47	4.94	76.36	0.50
TDR (vol. basis)	1.50	41.60	19.32	11.21	58.04	0.26

The regression analysis was performed to find the correlation between volumetric moisture content and ground conductivity determined by ground conductivity meter. The values for ground conductivity (HCP) were significantly correlated with the volumetric water content determined by TDR for both fields (Fig 2 and 3).

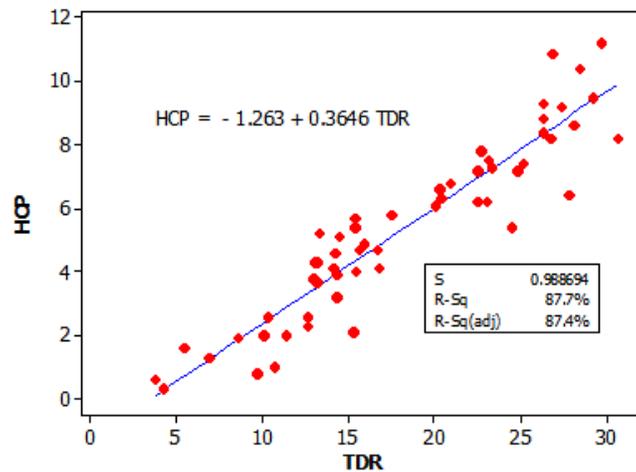


Figure 2. Regression curve between HCP and TDR for Carmal site

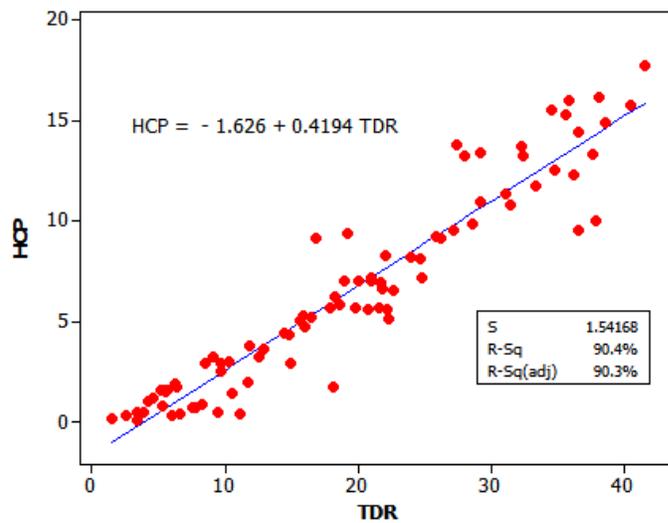


Figure 3. Regression curve between HCP and TDR for N. River site

The values for moisture content were predicted from ground conductivity data using the regression equation for both fields. The summary statistics for predicted values was calculated using Minitab 15 statistical software (Table 2). The root mean square error (RMSE) was 2.66 for Carmal Field and 3.63 for North River Field (Table 2). The maps for slope and volumetric moisture content were developed in Arc GIS 9.3. Data were interpolated using the Inverse Distance Weighted method (IDW interpolation) to find the values at unsampled points. The values for moisture content were higher in the low lying areas and lower on the steep slope areas (Fig. 4 and Table 3) for both fields. The values for moisture content (TDR) were determined with respect to slope by performing a zonal statistics function in Arc GIS 9.3. Similar pattern was observed for both fields. The pattern of the moisture content variability was also determined with respect to ground conductivity values using zonal statistics in Arc GIS 9.3 (Fig. 5).

Table 2. Summary statistics of predicted values for Carmal and North River fields

Carmal Site						
Variable	Minimum	Maximum	Mean	Std	Skewness	RMSE
TDR (vol. basis)	4.29	34.18	18.14	7.65	0.10	2.66
North River Site						
Variable	Minimum	Maximum	Mean	Std	Skewness	RMSE
TDR (vol. basis)	4.12	46.09	19.33	11.79	0.50	3.63

Table 3. Relationship of TDR with respect to slope (Carmal site)

Slope (Degrees)	Moisture content (TDR)			
	MIN	MAX	MEAN	STD
0.0 - 5.0	4.98	29.79	20.75	3.19
5.0 - 10.0	3.81	30.66	18.70	4.34
10.0 - 15.0	4.02	29.72	15.95	5.34
15.0 - 20.0	5.26	25.80	11.00	2.77

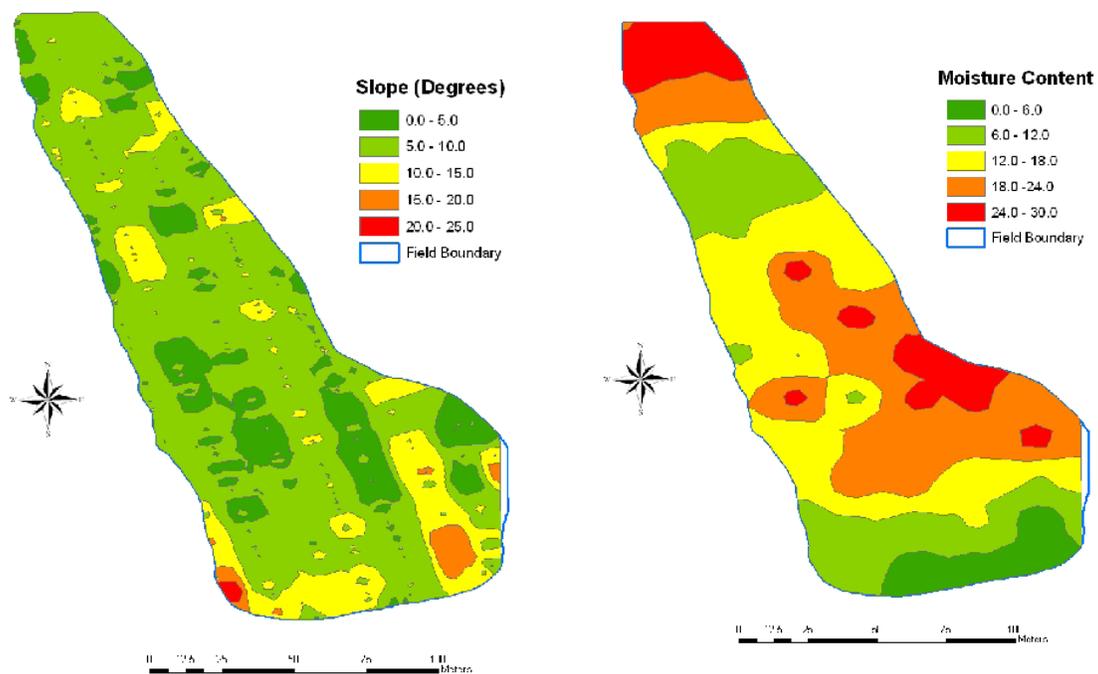


Figure 4: Slope and moisture content maps for Carmal site.

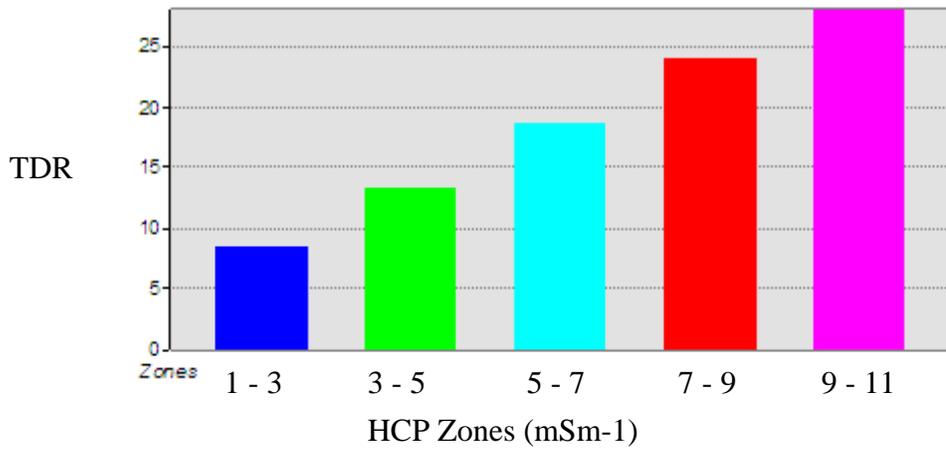


Figure 5. Relationship of moisture content (TDR) with HCP for Carmal Field

The predicted values for moisture content were plotted in Arc GIS to see the variation of the moisture for both fields (Fig. 6). The maps for predicted values showed that there was low moisture present on the steep slopes and high moisture in the low lying areas.

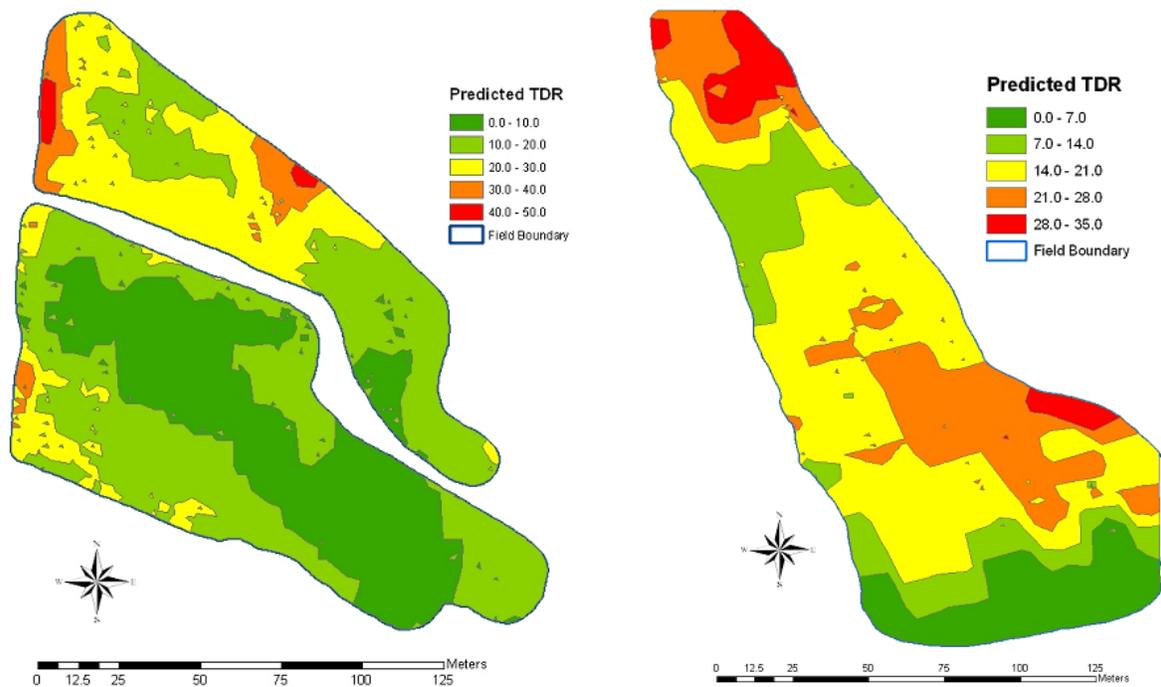


Figure 6. Predicted moisture content maps for Carmal and North River fields.

CONCLUSIONS

- There was a significant correlation between HCP and moisture content (r^2 0.85 to 0.90 for both fields)
- The correlation between predicted volumetric moisture content was also significantly correlated with the moisture content measured with TDR (r^2 0.87 and 0.92 for Carmal and N. River site respectively)
- Low moisture values were observed on the steep slope and high values for moisture in the low lying areas.

Based on the results it can be concluded that electromagnetic induction methods are suitable to map moisture content variability efficiently and reliably. This information could be used to access drainage requirements as well as to schedule site-specific sub irrigation within fields.

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