

## Canadian Agri-Science Cluster for Horticulture 3



### Update to Industry

2018-2019

<b>Activity title:</b> Enhancement of Canadian Potato Industry through Smart Agriculture
<b>Name of Lead Researcher:</b> Dr. Athyna Cambouris (AAFC)
<b>Names of Collaborators and Institutions:</b> Drs Farooque (PEI University), Zaman (Dalhousie University), Schumann (Florida University), Esau (Dalhousie University), Al-Mughrabi (NBDAAF), Comeau (AAFC), Zebarth (AAFC), Longchamps (AAFC), Ziadi (AAFC), Chokmani (INRS-ETE), Adamchuk (McGill), Biswas (Guelph) and Marc Duchemin (AAFC).
<b>Activity Objectives (as per approved work plan):</b> <p>The overall objective is to develop and evaluate smart farming (precision agriculture: PA) practices suitable for application in several major potato production areas of Canada. Specifically, this project will 1) characterize soil spatial variability and evaluate methods for mapping this variability; and 2) develop and evaluate precision agriculture strategies most relevant to each production region.</p> <p>The main objective for the province of QC is to assess the benefits of a precision N management approach based on management zones in terms of yield and N-use efficiency as compared to uniform N management. The precision N management approach proposed will be based on soil management zones and in-season N status.</p> <p>In Prince Edward Island, the main objective is to assess the benefits of precision agriculture approach based on soil management zones and variable application rate (VRA) of fertilizer, pesticides, irrigation, plant density as compared to uniform rate application on the basis of tuber yield and quality, nutrient leaching and economic benefits. The VRA implementation will be based on spatio-temporal soil and crop property maps.</p>
<b>Research Progress to Date: Precision Agriculture in QC</b> <p>In agreement with the work plan, two main activities were pursued during the years 2018-2019. Firstly, in spring 2018, one 10-ha field under commercial potato production was characterized to determine altitude and apparent soil electrical conductivity (soil ECa) using a VERIS. Those measurements were utilized to delineate management zones (MZs). Then four N strip treatments with four repetitions were implanted in the field. The first two N banded application of N were uniform in the entire field (at planting and 30 days after planting (DAP)) to receive approximately half of the total amount of N rate applied by the producer. At 40 DAP, strip treatments consisted in varying the third N application (0, 33, 66 and 100% of the N rate) applied just before hilling. Strip treatments (six rows X length of the field) were distributed in a RCBD with four replicates and went through all the MZs.</p> <p>Many plant parameters [i.e., vegetation indices, petiole nitrate concentration (PNIT), leaf chlorophyll index (LCI)] were measured just before and 10-15 days after the third N application. The soil surface nitrate concentration was also measured at the same time at 72 georeferenced sampling points. On the same sampling point, total and marketable yield as well as residual soil nitrate were measured. All soil and plant sample laboratory analyses were just completed. Statistical analysis will be completed during the 2019-2020.</p>

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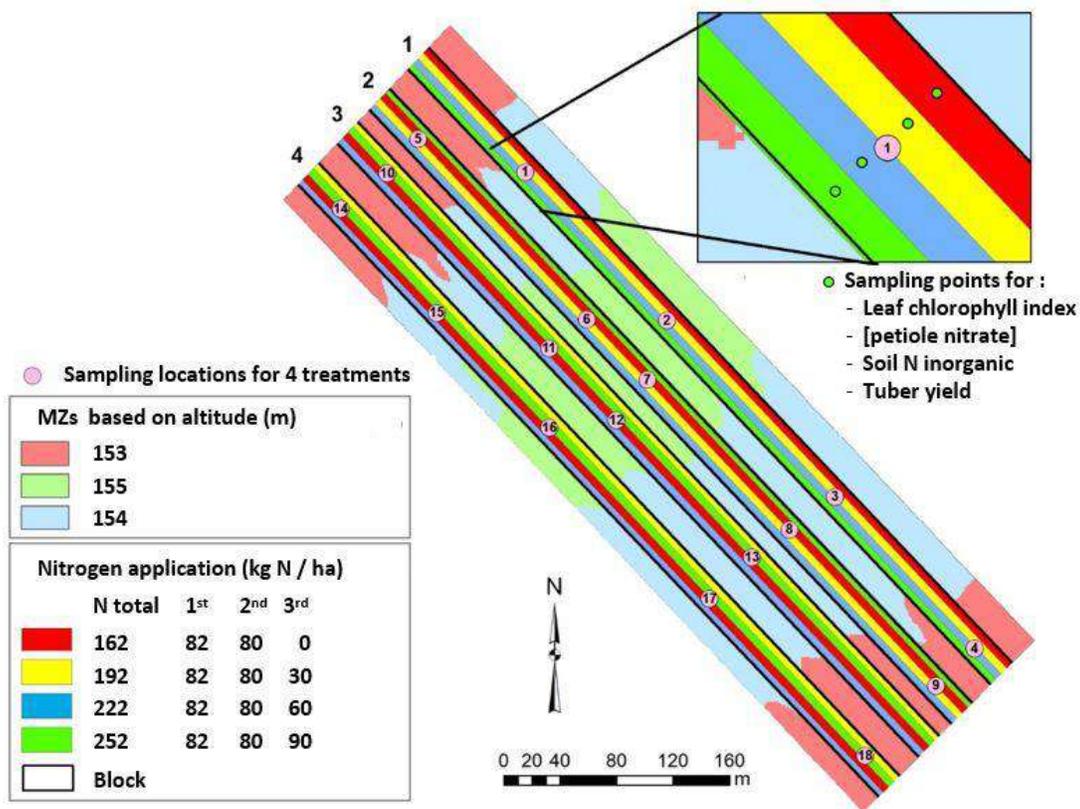


Figure 1. Management zones and the N strip treatments implemented in spring 2018.

In preparation for the next four years of the project, nine commercial fields located in the northwest area of Quebec City were investigated in the fall 2018 to determine their spatial variability in order to evaluate their potential for the nitrogen fertilization experiment (Fig. 2). Following discussions with potato growers and agronomists involved in this project, four commercial fields had been selected based on tuber yield data (referred as Doris Beaumont, Le 15, Vézina, Yvon Beaumont Haut). Those four fields were selected because they had shown yield variability based on the knowledge of the grower and the yield data monitoring. Statistics and geostatistical analyses were performed to analyze the tuber yield spatial variability using the data from the yield monitor. The aim was to identify areas with homogeneous characteristics (management zones, MZ), to minimize intra-zone variability and maximize inter-zone variability. Delineation of MZ was performed on each field using a non-supervised classification algorithm of ArcGIS software.

The potato yield, harvested in 2017, had CVs within the range of 10.2% to 18.7% (Table 1). The greatest variability (18.7% and 15.4%) was obtained for Doris Beaumont and Vézina fields, respectively. The Le 15 and Yvon Beaumont Haut fields showed CVs of 13.9% and 10.2%, respectively. Variogram analysis indicated that exponential model was the best fit for describing the spatial structure of the potato yields (Table 3). The tuber yield nugget ration values indicated moderate spatial dependence and the ranges varied between 33 m and 88 m. Cross validation of the fields studied showed RMSE  $\leq 10\%$ . Kriging interpolation was performed to develop yield maps (Fig. 4). The yield maps were used to determine the MZs on the four fields studied. Unsupervised classification was performed to delineate each field into two and three MZs (example at Fig. 4). In spring 2019, at all four fields, the soil ECa using the VERIS will be measured as well as altitude and used to delineate MZs to determine the best combination of properties to delineate the MZs. One of these fields will be used to implement specific N fertilization experiments during the growing season 2019.



Figure 2. Geographical location of the nine studied fields.

Table 1. Descriptive statistics of potato yield dataset from yield monitor.

Fields	Area (ha)	n	Potato yield (t ha <sup>-1</sup> )				CV <sup>x</sup> (%)
			Min	Max	Moy	SD <sup>z</sup>	
Doris Beaumont	13.9	18143	19.3	70.7	46.5	8.7	18.7
Le 15	41.6	53892	23.0	80.5	53.0	7.4	13.9
Vézina	14.0	20668	33.4	94.2	64.3	9.9	15.4
Yvon Beaumont Haut	8.0	10945	37.6	78.9	58.1	5.9	10.2

<sup>z</sup>SD : standard deviation; <sup>x</sup>CV : coefficient of variation.

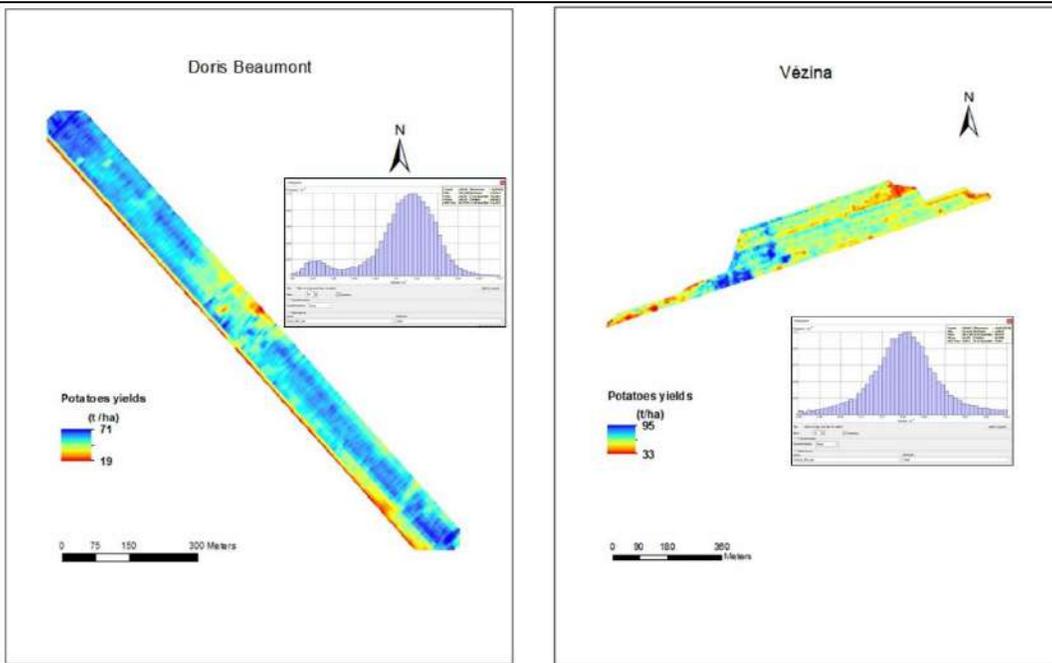


Figure 3. Examples of kriging maps of the tuber yield of selected potato fields.

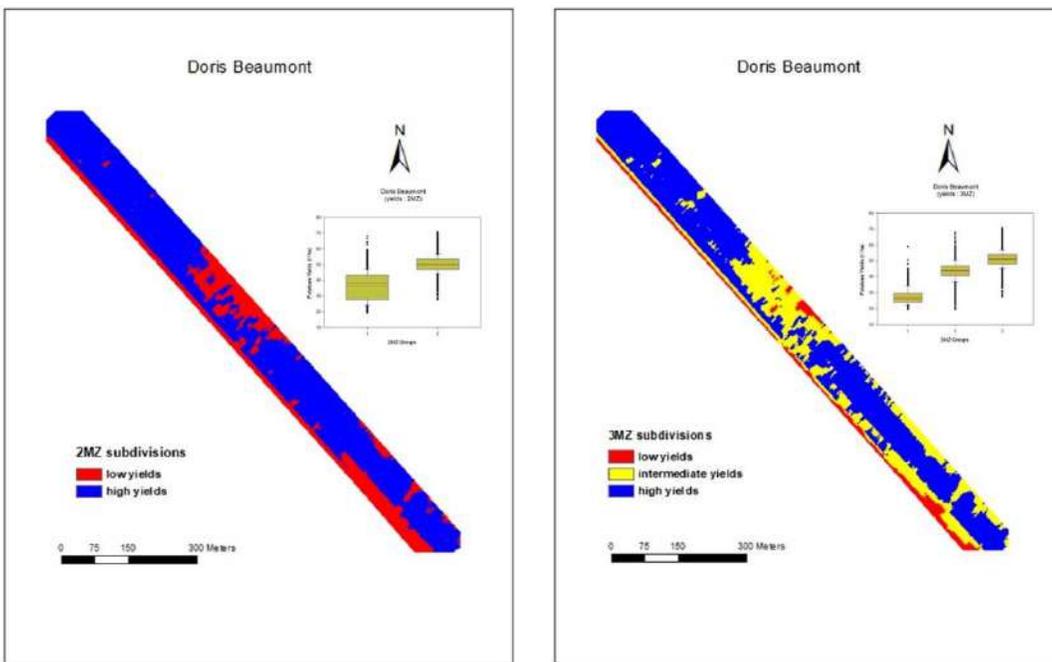


Figure 4. Examples of field delineation in two and three MZs at Doris Beaumont Field.

## Activity 14B Precision Agriculture in PEI

### Research Progress to Date:

We have completed the first year of this project. This phase of the project focused on the characterization and quantification of soil, crop and yield variability using traditional sampling and sensors. Potato fields were selected in Prince Edward Island, Canada to assess the spatial variability in soil properties, crop characteristics, field conditions, and crop yield to develop MZs for site-specific nutrient management. The field boundaries were mapped with a real-time kinematics global positioning system. The selected fields were under commercial management over the past decade and received traditional management practices (conventional fertilization, weed and disease control). The data on previous management practices were collected to strengthen the scope of this project. Four samplings to collect soil, sensors, and yield data were performed throughout the growing season (Fig. 5). A grid/zone pattern of sampling points was established at each experimental field to collect soil, crop and crop yield samples. The grid sampling based on the range of variability from DualEM-II instrument reduced the labor and cost of analyzing these samples. Soil samples were analyzed for physical and chemical properties in a commercial lab.

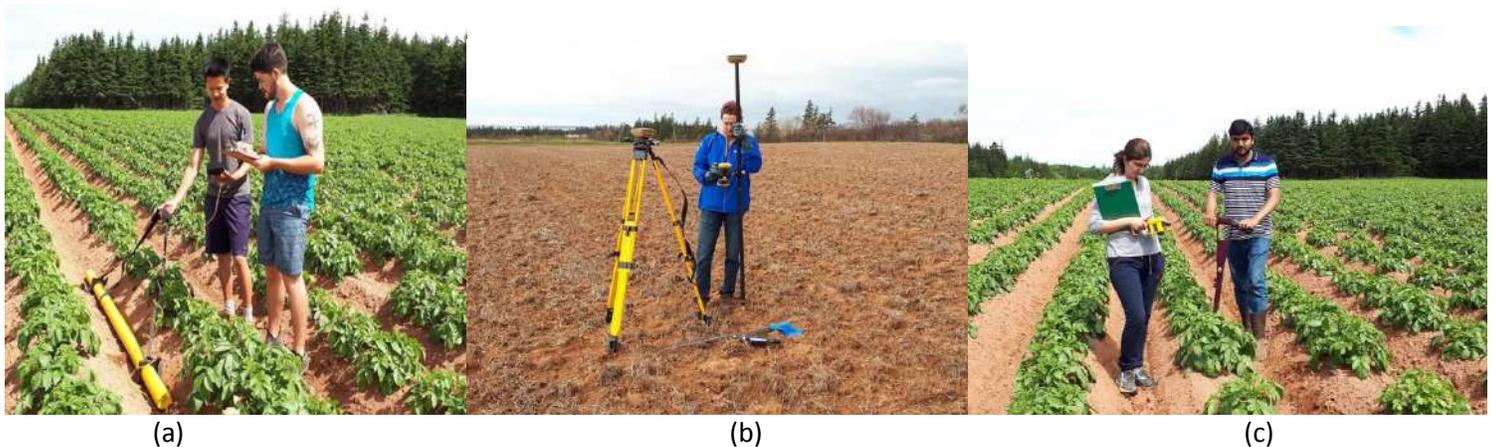


Figure 5: Measurement of a) ground conductivity using DualEM-II instrument; b) GPS mapping, NDVI and soil moisture estimation.

Sensor data were recorded from the selected sampling locations within fields to calibrate sensors, and to assess their potential in estimating/sensing soil and crop attributes non-destructively. The HCP and PRP readings were recorded using the DualEM-II instrument at each sampling location (Fig. 5b). Soil volumetric moisture content ( $\theta_v$ ) was recorded by inserting TDR-300 (Time domain reflectometry) probes (Spectrum Technologies, Inc, Plainfield, Ill.) 15 cm below the soil surface (Fig. 5c). All these sensors were calibrated and validated with actual attributes prior to sense/estimate the attribute of interest. Regression analysis was performed to identify the prediction accuracy ( $R^2$ ) of these sensors. The root mean square error (RMSE) was calculated using actual and predicted values to assess the accuracy of the sensors. Slope was also recorded for each of the sampling points.

### Yield Monitoring

The geo-referenced crop yield samples were collected from each sampling location within selected fields. The yield monitoring systems currently in use by potato industry was tested to examine its accuracy in estimating potato crop yield. The monitoring data from a selected yield monitor were collected and compared with the actual yield data to develop calibrations and validations in selected potato fields (Fig. 6). These calibrations and validations will suggest the accuracy of the yield monitoring in sensing potato crop yield.

The collected actual yield values were correlated with the soil, crop and slope values to identify the factors responsible for fluctuations in potato crop productivity within selected fields. Significant factors affecting variability in crop yield with an estimation/prediction potential via sensors were recommended to use for the delineation of MZs for site-specific fertilization within potato fields. Geo-referenced yield monitoring data was overlaid on the developed soil and crop maps in GIS to visualize the impact of soil and crop characteristics on crop yield. Accuracy of the yield monitoring system in conjunction

with its relationships with soil and crop attributes will suggest its suitability in developing MZs for potato cropping system.

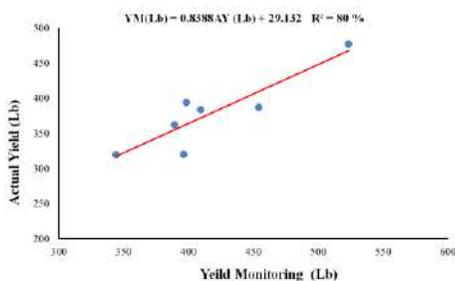


Figure 6. Collection of data for yield monitoring of potatoes.

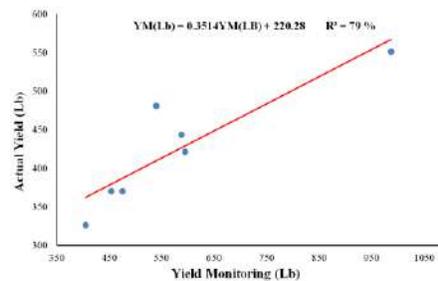
## Results and Discussion

### Calibration of Yield Monitoring System and Mapping in GIS

Results of regression analysis suggested that the accuracy was about 80% for selected yield monitors (Fig. 7a and b). The intensive yield monitor data was retrieved and plotted in GIS to examine the accuracy of the yield monitor visually. Results showed over 20% error in actual and predicted yield (Fig. 7). Results emphasize the need to conduct detailed study on yield monitors to improve the accuracy of the yield monitoring systems. Yield monitoring is one of the key variables, if predicted accurately, can be used to develop MZs for site-specific nutrient management to improve soil health and productivity. Yield monitoring data for one of the fields is presented in Fig. 7c.



(a)



(b)



(c)

Figure 7. Calibration equations for c and b) two monitoring fields and yield monitor data for selected field indicating substantial variability.

### Descriptive Statistics of Soil Properties and Potato Yield

The coefficient of variation (CV) is a first approximation of field heterogeneity, soil properties are least variable if the CV < 15%, moderate if CV is between 15% and 35%, and most variable if CV > 35%. Summary statistics of soil properties for Field 1 showed that most of soil properties had moderate to high variability except for pH, SOM, CEC, sodium and aluminum (Table 2) which was less than 15%. Due to space constraints, the results of other fields are not presented. The lowest variation in pH might be due to the logarithmic scale of pH measurement. Soil properties for second and fourth sampling dates also exhibited moderate to high variation. The potato yield was moderately variable with the CVs of 21.19 (Table 2). The variation in potato yield and soil properties may be due to several factors including natural variations in soil, and crop management practices. In addition, the effect of temporal dynamics due to sampling at various times during the study should not be ignored.

Table 2. Descriptive statistics for selected soil properties at Field 1.

Variable	Mean	SD	CV	Minimum	Maximum	Skewness
Yield (cwt/ac)	373.5	79.2	21.19	207.03	494.4	-0.74
HCP (mS/m)	4.983	1.316	26.42	2.320	7.100	-0.38
PRP (mS/m)	3.625	1.209	33.36	1.660	6.000	0.28
Moisture Content (%)	6.984	2.078	29.76	3.900	11.100	0.40
Slope (%)	1.0622	0.5866	55.22	0.2400	3.0000	1.38
NDVI	0.12650	0.02379	18.80	0.07667	0.16667	-0.09
SOM (%)	3.5725	0.4182	11.71	2.7000	4.6000	0.22
pH	6.0525	0.3336	5.51	5.5000	7.3000	1.46
Phosphate (ppm)	675.4	165.3	24.47	321.0	992.0	-0.20
Potash (ppm)	140.93	32.04	22.73	92.00	267.00	1.50
Calcium (ppm)	1096.6	231.9	21.15	538.0	1595.0	-0.20
Magnesium (ppm)	97.50	21.03	21.57	56.00	145.00	0.09

Note: HCP, horizontal co-planer geometry; PRP, Perpendicular co-planer geometry.

#### Spatial Variation of Soil Properties and Potato Yield

Semivariogram analysis for potato yield showed strong spatial dependency, indicating that yield is controlled by soil properties. The spatial dependency of some of the soil properties varied between sampling dates (temporal changes) in each site. The majority of the variables showed strong spatial dependency with ratio <25% except moisture content, copper, SOM, manganese, CEC and total base saturation (Table 3). In general, most of the soil properties exhibited moderate to high spatial dependency during sampling periods of 2018 for the sites selected. Intrinsic soil characteristics such as texture, mineralogy, and microorganisms can control high spatial dependency. The range of spatial correlation changed between 22 and 50 m between three sites. The range for most of the soil properties was <60 m (Table 3) except Mg, Mn, CEC and total base saturation. Literature suggests that variability is non-random at distances shorter than 20 to 50 m. Similar results were observed for other samplings and fields.

#### Relationship among the Soil Properties and Potato Yield

The impact of soil variability on yield can also be described by the regression analysis. Figure 8 shows significant relationship between potato yield and selected soil properties. In sampling 2 and 4 the relationships were significant and similar for selected parameters. The relationships were non-significant for some of the micronutrients. There were non-significant correlations between yield and pH, copper, iron, sodium, and lime index. Overall, there were significant and positive correlations between potato yield and most of the soil properties including moisture content, organic matter, and macronutrients indicating that these parameters are among major factors affecting the potato yield.

There were significant positive correlations between HCP and PRP with moisture content and tuber yield within selected fields (Fig. 8). Significant relation of DualEM-II data with tuber yield suggested its potential to be used as a tool for delineating MZs within potato fields. These findings can be used in development of management zones based on the variation of affecting parameters and yield to increase farm profitability and reducing environmental factors.

Table 3. Geo-statistical analysis of the selected collected data to quantify spatial variability.

Parameters	Nugget	Sill	Range (m)	Nugget Ratio (%)	R <sup>2</sup>	Model
HCP (mS m <sup>-1</sup> )	0.20	3.895	27.8	5.14	0.60	Spherical
PRP (mS m <sup>-1</sup> )	0.336	2.985	36.6	11.26	0.38	Exponential
Moisture Content (%)	8.86	26.17	6.23	33.86	0.00	Gaussian
Slope	0.001	1.959	45.21	0.05	0.78	Gaussian
Organic Matter (%)	0.28	0.70	6.24	40.00	0.00	Gaussian
pH	0.0001	0.0453	48.84	0.22	0.65	Gaussian
Yield (cwt/acre)	1290	11540	22.30	11.18	0.90	Spherical
Phosphate (ppm)	10	23160	49.19	0.04	0.68	Gaussian
Potash (ppm)	1	1681	43.13	0.06	0.74	Gaussian
Calcium (ppm)	3400	46250	33.6	7.35	0.20	Spherical
Magnesium (ppm)	0.1	207	207	0.05	0.58	Gaussian

Note: HCP, horizontal co-planer geometry; PRP, Perpendicular co-planer geometry.

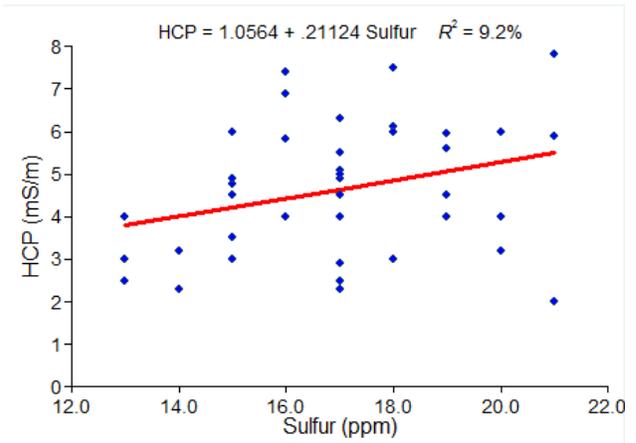
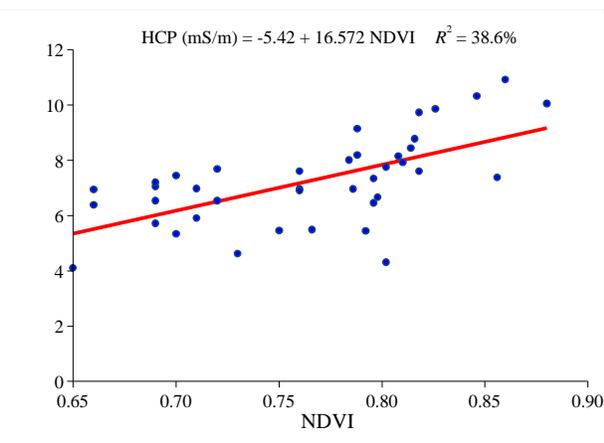
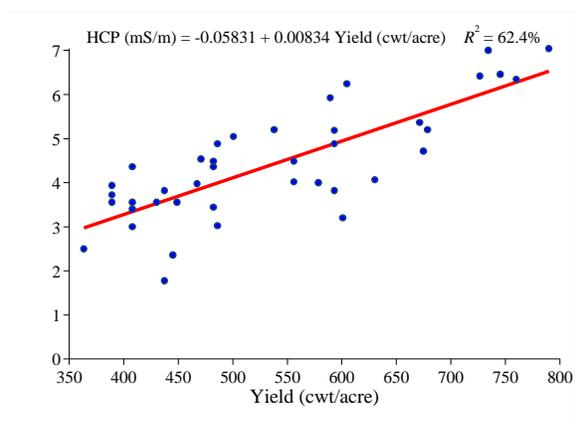
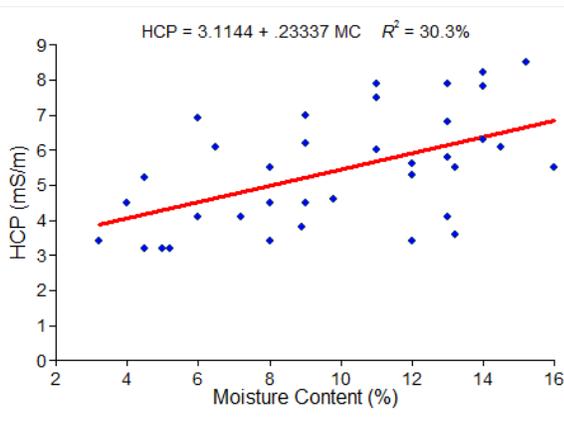


Figure 8. Regression analysis for selected parameters within selected fields.

### Mapping of Soil Properties and Potato Yield

The maps of soil properties and potato yield were created using inverse distance weighted (IDW) interpolation to show the spatial variation of values across the field. The interpolated maps showed substantial variability within selected fields (Fig. 9), which agreed with the finding of summary statistics and geo-statistical analysis. The variability within fields was random and spatially different suggesting its management using innovative tools for site-nutrient management to ensure uniform productivity across the fields. Sample variability maps for one field are presented in Fig. 9. Due to space constraints, the other maps are not presented here.

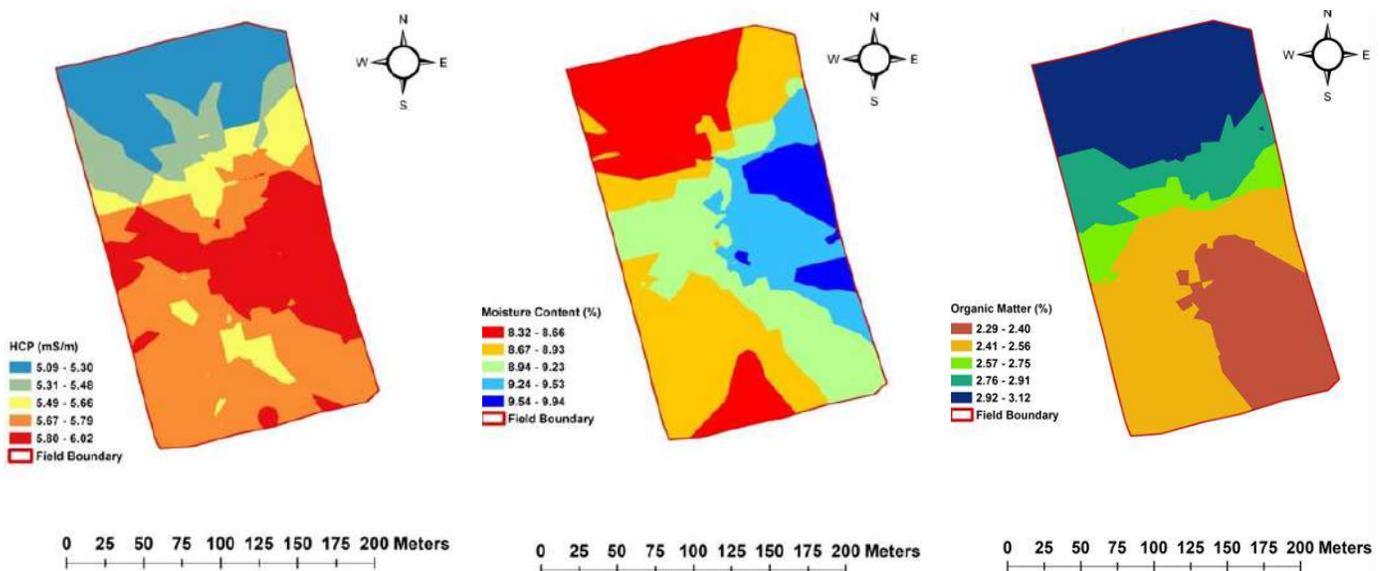


Figure 9. Examples of interpolated maps selected soil properties for one monitoring site.

### Delineation of Management Zones using Cluster Analysis

The results discussed in previous sections and spatial variability of yield and soil properties indicates the need for development of MZs for each site. The soil properties extracted from the stepwise regression equation and yield were clustered using Minitab 18 statistical software to group the potato yield and soil properties. The results of cluster analysis could differentiate the areas with different fertility status within fields.

The productivity levels to develop management zones were decided based on the potato yield, i.e. excellent, very good, good, poor and very poor. The natural grouping of soil properties and potato yield showed that most of the sampling points were in poor to good category, and around five data points were in the category of very good and excellent group (Fig. 10). Regarding the soil properties, the highest values of soil properties such as HCP, potash, and moisture content were observed in the zones with highest value of potato yield (437.88 cwt/acre), which was indicated as excellent zone. In zone very good, the mean potato yield was 392.12 cwt/acre, and HCP, potash, and moisture content were 6.5 mS/m, 290 ppm, and 8%, respectively. As the potato yield in good and poor zones decreased, the values of HCP, potash, and moisture content also decreased. As seen in Figure 10 the potato yield was around 248 cwt/acre in very poor zone, and the level of HCP, potash, and moisture content were also lower.

The results of cluster analysis suggested that the HCP in combination with potato yield can be used to develop management

zones for site-specific fertilization in potato fields. The clustered data based on their class membership was imported in ArcGIS and IDW interpolation was applied to produce detailed maps representing MZs. Figure 11 shows the MZs. The MZs

map represented various levels of productivity across the site which shows the need for a proper application of agricultural practices in each zone. The comparison of potato yield and MZ map shows that the higher potato yield was produced in the area indicated as the excellent zone and vice versa. The close resemblance in the trend of variation for HCP, tuber yield and MZs revealed that the DualEM-II sensor can be used to develop MZs in potato cropping system. Non-destructive mapping with DualEM-II sensor can help to save sample analysis cost and to manage nutrients based on soil and crop needs. These results could be used to apply proper rate of nutrients to improve farm productivity and reduce the environmental risks.

#### Conclusions

The purpose of the activity 14B was to characterize and quantify the spatial variation of soil properties and potato yield and to develop management zones. The first year and the related objectives of this study has been completed. The study achievements include potato yield monitoring accuracy of about 80% with varying standard errors. The Coefficient of Variance showed moderate to high variability in collected data. Furthermore, the semivariogram range of influence and geo-referenced mapping in GIS showed substantial spatial variability in collected data.

Regression analysis suggested that the sensor conductivity was able to explain >60% variability in tuber yield. The prediction accuracy of DualEM-II sensor was improved by adjusting the sensing depth based on the results from last studies. Furthermore, DualEM-II sensor conductivity significantly correlated with moisture content, OM, and major macro and micro nutrients. The cluster analysis was performed to group soil, crop, sensor and potato yield into five groups as very poor, poor, good, very good, and excellent and MZs were delineated using GIS applications. Means were compared using least significant difference method for delineated MZs for the influential soil and crop variables having significant impact on yield. Results showed higher yield in highly productive areas and vice versa. Results of this study suggested that the DualEM-II sensor showed significant potential to be used for the delineation of MZs. Site-specific nutrient management based on soil and crop variability can ensure farm profitability and environmental sustainability.

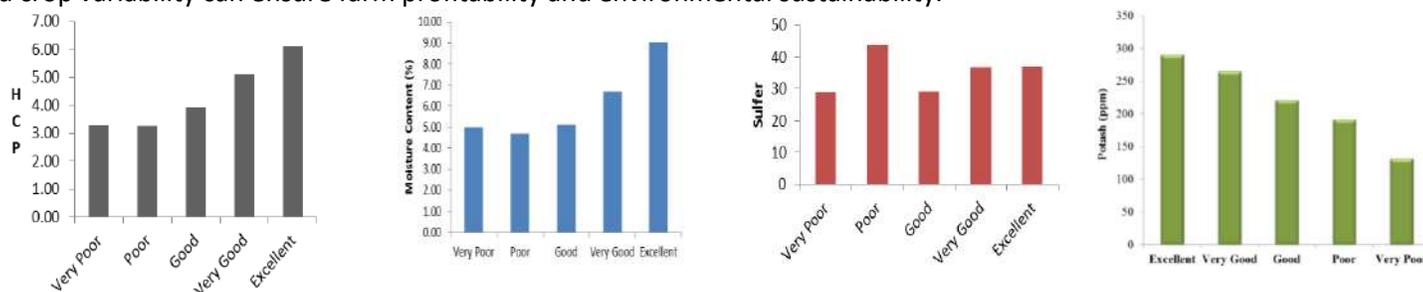
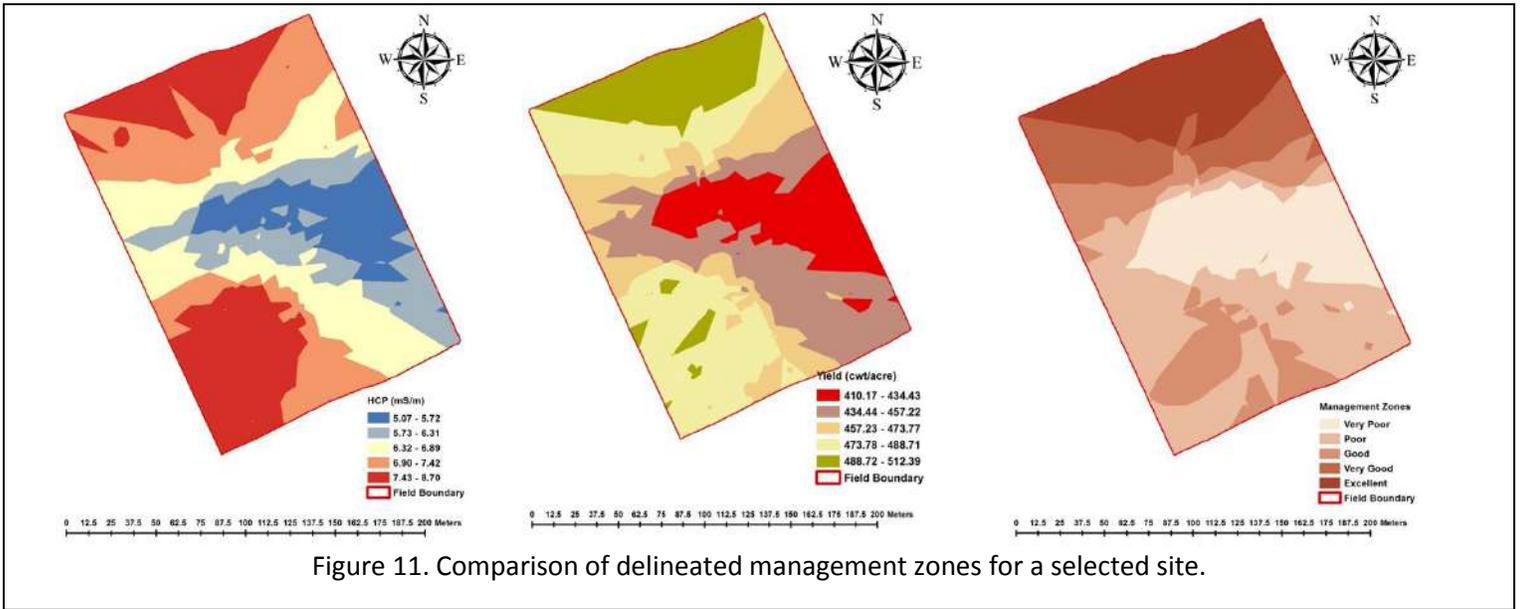


Figure 10. Variation of selected parameters in developed management zones.



**Early Outcomes (if any) or Challenges:**

Delineation of MZs using yield dataset from yield monitor reduce the spatial variability of yield data and seems to have a good potential for delineation of productivity MZs. Adding the soil ECa measurements will probably improve the delineation of the MZ for site specific application in the QC province.

DualEM-II sensor used in PEI province showed a strong potential to be used as a mapping tool to tailor the best management practices. We will be repeating the experiments this year to have a sense of stability of data over time for temporal variations (if any). Nutrient management based on soil and crop needs can ensure economic viability and environmental safety.

**Key Message(s):**

- ✚ Develop map/sensor-based precision agriculture systems for Québec and Atlantic provinces Canada's potato industry based on proper characterization and quantification of variability.
- ✚ Identify sensor-based options to perform mapping and tailor management practices to reduce labour and sample analysis cost.
- ✚ Apply nutrients based on need to evaluate the productivity benefits.
- ✚ Evaluate environmental benefits of the variable rate nutrient management.
- ✚ Develop user-friendly protocols for farmers/industry use.
- ✚ Train HQP and industry personnel in the emerging area of precision agriculture.

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