Canadian Agri-Science Cluster for Horticulture 3

Update to Industry

Final Report – 2018 – 2023

Activity title: Enhancement of Canadian Potato Industry through Smart Agriculture

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Activity Objectives (as per approved workplan):
The overall objective is to develop and evaluate smart farming and precision agriculture (PA) practices suitable for applications in potato production areas of Canada including delineation of management zones (MZs) and variable rate application (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 in the provinces of Québec and Prince-Edward Island (PEI). Specifically, this project characterizes soil spatial variability and evaluates methods for mapping this variability, as it develops and evaluates precision agriculture strategies most relevant to each production region.

Research Progress & Results:
Activity 14A: During the 5-year project (2018-2023), two commercial fields located at Sainte-Catherine-de-la-Jacques-Cartier were utilized. The 1st field (named **Field 1**), a 10.3-ha field, selected in 2018, was also utilized in 2020 and 2022 and the 2nd field (named **Field 2**), a 14-ha field, was utilized in 2019 and 2021. Both fields were utilized to evaluate the potential of a MZ delineation approach based on soil properties to improve the nitrogen (N) management under potato production. In each field, three areas with spatial homogeneous characteristics (MZs) were delineated based on topography in the **Field 1** and on soil apparent electrical conductivity (CEa) and soil pH measurement in **Field 2** to minimize intra-zone variability and to maximize inter-zone variability. For 2018 to 2021 growing seasons, the cultivar Russet Burbank was used for potato production, while in 2022, the cultivar Mountain Gem was used.

Each year, a similar experimental design was implemented in the fields and consisted in four nitrogen (N) strip treatments varying from 150 to 270 kg N/ha and 162 to 270 kg N/ha per year in **Field 1** and **Field 2**, respectively. The first N dose was applied at planting, the second around 30 days after planting (DAP) and the last one around 40 DAP. Two times per growing season, soil samples (soil nitrate and ammonium concentrations) and plant parameters (vegetation indices via drone images, petiole nitrate concentration) were measured for every treatments. At fall, total yield (TY) and marketable yield (MY) as well as residual soil nitrate were measured for every treatments. Also, at each field, a dynamic penetrologger (Eijkelkamp) was used to measure soil penetration resistance over a depth of 80 cm and ground penetrating radar (GPR) surveys were done to detect compacted layer and to evaluate if the compacted layer depth could be induced from actual CEa maps and eventually take into account in the MZ delineation approach.

Year had a strong effect on TY and MY at Field 1, with average TY and MY significantly different for each year (Table 1). This reflects the specific climatic conditions of each growing season and a confounding effect of the cultivars Russet

Burbank and Mountain Gem in Field 1. The MZ also had a significant effect on TY and MY at both fields. In average MZ1 and MZ2 showed 10% and 20% more TY and MY that the MZ3 in **Field 1** and **Field 2**, respectively (Table 2).
In **Field 1**, this result reflects the effect of topography on water-holding capacity. The MZ1 and MZ2 of **Field 1** had a higher water holding capacity than MZ3. In **Field 2**, we have reasons to believe that the higher yield in MZ1 and MZ2 was not related to soil properties such as CEa or nitrate concentrations, but should be related to physical properties such as bulk density or penetration resistance. This will need to be dug deeper in the next year.

Table 1: ANOVA p-value for total yield (TY), marketable yield (MY), total culls (TC) and specific gravity (SG) in **Field 1** and **Field 2**. (p-value < 0.1 was considered significant and showed in bold in the table).

	Field 1 (2018-2020-2022)				**Field 2 (2019-2021)**			
Effect	TY	MY	TC	SG	TY	MY	TC	SG
Year	**0.0001**	**<.0001**	**0.0010**	**0.0069**	**0.0456**	0.4882	**0.0141**	**0.0490**
MZ	**0.0007**	**0.0003**	**0.0641**	0.1202	**0.0276**	**0.0372**	0.7918	0.2218
Year*MZ	**0.0692**	0.1527	**0.0519**	0.3447	**<.0001**	**<.0001**	0.8432	0.0947
N_rate(Year)	0.1169	0.1072	0.6054	**0.0418**	0.2008	0.4810	0.3251	0.1447
MZ*N_rate(Year)	0.8398	0.8679	0.2149	0.6259	0.7078	0.7920	0.5008	0.1006

Table 2: Average of total yield (TY) and marketable yield (MY) in **Field 1** and **Field 2**.

---------------------Field 1----------------------							**---------------------Field 2-----------------------**						
MZ	**Year**	**N rate kg ha^{-1}**	**TY T ha^{-1}**		**MY T ha^{-1}**		**MZ**	**Year**	**N rate kg ha^{-1}**	**TY T ha^{-1}**		**MY T ha^{-1}**	
	2018		45.4	b	42.1	b		**2019**		57.9	b	55.2	
	2020		38.9	c	37.1	c		**2021**		61.9	a	56.1	
	2022		50.1	a	48.7	a		-		-	-	-	-
MZ							**MZ**						
1			46.1	a	44.1	a	**1**			63.7	a	59.3	a
2			46.2	a	44.0	a	**2**			62.8	a	58.7	a
3			42.1	b	39.8	b	**3**			53.1	b	48.9	b
MZ	**Year**						**MZ**	**YEAR**					
1	**2018**		47.9	a	44.4		**1**	**2019**		60.8	a	58.2a	
2			44.3	ab	41.4		**2**			62.3	a	59.2a	
3			44.1	b	40.6		**3**			50.7	b	48.1b	
1	**2020**		39.8	a	38.6		**1**	**2021**		66.6	a	60.3 a	
2			42.6	a	40.4		**2**			63.3	a	58.2a	
3			34.3	b	32.2		**3**			55.7	b	49.7 b	
1	**2022**		50.6	ab	49.2		-	-	-	-	-	-	-
2			51.7	a	50.3		-	-	-	-	-	-	-
3			48.1	b	46.5		-	-	-	-	-	-	-
	Year	**N rate**						**Year**	**N rate**				
	2018	162	45.1	ab	41.8	ab		**2019**	180	57.9		55.5	
		192	43.0	b	39.8	b			210	58.3		55.8	
		222	46.0	ab	42.5	ab			240	55.8		53.0	
		252	47.5	a	44.3	a			270	59.6		56.6	
	2020	170	38.5	a	36.7	a		**2021**	162	57.4	b	51.6	b
		204	38.8	a	36.7	a			192	62.1	ab	56.6	ab
		237	38.8	a	37.3	a			222	61.9	ab	56.3	ab
		270	39.5	a	37.5	a			252	66.1	a	59.9	a
	2022	150	47.4	b	45.8	b		-	-	-	-	-	-
		180	49.4	b	48.2	ab		-	-	-	-	-	-
		210	50.7	ab	49.3	ab		-	-	-	-	-	-
		240	52.8	a	51.4	a		-	-	-	-	-	-

The significant interaction Year*MZ for TY at **Field 1** supported this result that MZ1 = MZ2 > MZ3 for TY, while not reflected in the MY. This interaction was observed due to MZ2 that showed TY similar to MZ1 or to MZ3, depending on the year. This is well known in the literature when there is three MZ, with the intermediate MZ, like MZ2, sharing behaviors and trends between MZ1 and MZ3. The significant interaction Year*MZ for TY and MY at **Field 2** indicated that MZ1 = MZ2 > MZ3 for TY and MY, with the highest yield in MZ2 for 2019 and in MZ1 for 2021.

All other variable analyses such as petiole nitrate, soil nitrogen and drone images are in process. Multivariate analyses will be performed to extract and understand combined effects on the crop N status and consequently on the tuber yield. Using the GPR surveys, a similitude analysis was performed between maps of the compacted layer depth obtained from GPR and dynamic penetrologger, and maps of CEa obtained from a VERIS. Results showed great similarity between these soil property maps and are promising for refining the MZs delineation approach.

Activity 14B:

This project strives to develop and implement the MZs to accomplish site-specific fertilization (P, K) within potato fields to improve soil health, conserve soil within agricultural fields, increase profitability for growers, and lower environmental risks. Over the course of the project years, this study characterized and quantified the spatial variability in soil properties, crop characteristics, topographic features, and yield within potato fields. Relationships among soil, crop, topography, and yield parameters were used to identify the significant factors affecting productivity, to calibrate and validate a yield monitoring system to map potato yield in real-time. The MZs were created by integrating data from various sources to create a detailed map of soil characteristics, while MZs were identified based on variations in soil, crop, and yield across the field. The results of this study provided very useful information for farmers to make data-driven decisions to optimize their crop yields, improve soil health, and increase profitability.

Variable rate (VR) potato seedings were trialed across Prince Edward Island during the project's 5th year as well, based on the management zones (MZs) developed using soil, water, and topographic features (SWAT Map) of the selected fields. Before germination, preliminary soil apparent electrical conductivity (ECa) and topography surveys were conducted to delineate fertility based MZs, (e.g., low, medium, and high). Eight locations were selected from each MZ for soil sampling (organic matter, macro- and micro-nutrients) and sensor-based data collection (soil moisture, ECa, soil temperature, and slope). In VR seeding trials, seeds were planted based on the productivity potential of the selected sites as dictated by the DualEM-II-based surveys. Plants were seeded tightly in highly productive/high-fertility areas, growers' standard practice was used in medium productivity zones, and wider spacing for the low productivity MZs. Zones sampling for soil, crop, and tuber yield data continued throughout the growing season to assess spatial variations within the developed MZs. In all trials, germination rates, crop health, soil/plant temperatures, and plant counts were monitored and assessed throughout the growing season using high-resolution drone imagery, normalized difference vegetation index (NDVI), drone thermal surveys, and artificial intelligence-based plant count models. Thermal imagery was used to measure soil radiation and map soil moisture for improved irrigation practices. RGB imagery identified vegetation and bare soil areas and mapped soil texture and topography. Multispectral imagery captured light in various wavelengths and mapped nutrient and organic matter distribution in the soil.

The summary statistics for the selected fields indicated moderate to high variability in most of the soil properties. The relationship between slope, soil moisture, and soil surface temperature, versus yield in the low, medium, and high productivity zones was significant. For instance, in the O'Leary field, the low-productivity zones had the highest slope and vice versa, This trend had a direct correlation with the soil moisture; with the low-productivity zones retaining the least moisture (13.5%), followed by the medium (16.1%) and high-productivity zones (18.4%). Moreover, the soil organic matter was consistently higher in high-fertility MZs (2.41%) compared to medium (2.31%) and low-fertility MZs (2.19%).
Plant counts models with high-resolution drone imagery was used to measure plant spacing and assess the correlation between MZ, canopy growth, and tuber size at harvest. The distance between two successive seeds is mostly determined by planter performance and speed, and less than a 5% difference in target versus actual spacing is considered good. A strong correlation existed between early-season canopy coverage and the landscape position of the field. The lower-lying areas of the field landscape had high soil moisture and higher early-season canopy coverage. Conversely, the driest part of the field had the lowest early-season canopy coverage.

Potato tuber sizes were also analyzed across SWAT MZs, wherein 280 tuber yield samples were collected over the two seasons. It was found that lower productivity zones had a higher percentage of small potatoes (14%) compared to the medium and higher productivity zones, which had significantly lower percentages of small potatoes (11%). On the other hand, out of the found 248 large-sized (>10 oz) potato samples, the higher productivity zone had its highest percentage (19%), while the intermediate and higher zones had 14% and 11.5%, respectively.

In the VR seed spacing trials, tight spacing treatment had the highest yield in terms of value per acre ($5,391 per acre), followed by growers' standard practice ($5,090 per acre), and wide spacing ($5,199 per acre). Overall, Zone 3 showed that the tight spacing treatment generally yielded the highest value per acre across all the varieties and years. In contrast, in Zone 1, wide spacing treatment generally yielded the highest value per acre. Nevertheless, in a low productive zone, wider spacing would be beneficial because it allows each plant more access to soil nutrients, water, and other resources, which can help maximize yield per plant. In contrast, in a highly productive zone, tighter spacing would be beneficial because there are ample resources available, and a higher plant density can help increase the overall yield per acre.
In conclusion, the results of VR seeding, and nutrient management trials conducted over the years using MZs, based on soil, water, and topographic features (SWAT) in potato fields, demonstrated that it is vitally important to consider spatial variations in soil properties such as slope, soil moisture, and organic matter in managing soil fertility and productivity thereof. Furthermore, the analysis of potato tuber quality parameters across the different MZs provided valuable insights into the impact of management practices on tuber size, yield, and value. These findings strongly emphasize the need to use precision agriculture practices for optimizing productivity and enhancing crop quality in potato fields.

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 (DualEM, VERIS).
- Identify sensor-based options to perform mapping and tailor management practices to reduce labor and sample analysis cost (i.e. Chrysalabs probe).
- Apply nutrients (N, P, K) based on need to evaluate the productivity benefits.
- Evaluate environmental benefits of the variable rate nutrient management (residual soil nitrate).
- Develop user-friendly protocols for farmers/industry use.
- Train HQP and industry personnel in the emerging area of precision agriculture.

Overall benefit to industry:

The project aims to develop and implement management zones (MZs) for site-specific fertilization (N, P, K) in potato fields to improve soil health, conserve soil, increase profitability, and lower environmental risks. The study involved characterizing and quantifying soil variability, developing relationships among soil, crop, topography, and yield parameters, calibrating and validating yield monitoring systems and sensors, and creating prescription maps for site-specific applications. VR potato seedings were trialed based on MZs developed using soil, water, and topographic features. The study found that topography, soil moisture, and organic matter were important factors affecting productivity. Plant counts models using drone imagery showed a correlation between early-season canopy coverage and the landscape position of the field. The VR seed spacing trials showed that tight spacing treatment generally yielded the highest value per acre across all the varieties and years, while wider spacing is beneficial in low-productivity zones. The study provides useful information for farmers to optimize crop yields, improve soil health, and increase profitability.

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