AIP-P342: Securing Export Markets for Potato Processors by Mitigating Limitations to On-Farm Yield
Project update, March 2018

The following is a brief update of the project activities during the 2017 growing season, the final year under this AIP project.

Overall outcome: To develop innovative approaches to identify zones within potato fields with yield limitations and to overcome these limitations through mitigation practices.

Please note that numbering of figures and tables restarts within each subsection.

Specific objectives and subactivities include:

1.1 Development of innovative approaches, including the use of remote sensing data, to identify zones within potato fields in which yield is limited.

1.1a: Mapping within-field variation using high resolution imagery (NB).

Drone imagery

Imagery was acquired by Resson Aerospace over 20 fields using a fixed wing unmanned aerial vehicle (i.e. drone). On each of five dates throughout the growing season, two sets of imagery were collected, one captured with a digital camera (red-green-blue) and one captured with the multispectral Sequoia camera equipped with an incident light sensor. For the latter, light was collected in four bands (green, red, red-edge and near-infrared). The incident light sensor was used to correct for variable light conditions (e.g., clouds) but assessment of the image quality resulted in some images being discarded. The drone analysis focused on four fields for which ground data (plant biomass, petiole nitrate, and yield) were collected. The weighted green difference vegetation index (WDVI_Green) and canopy cover were derived from the multispectral and red-green-blue, respectively, and relationships with in-season biophysical properties and yield determined. A good relationship was observed between above-ground biomass and the WVDI_Green (R^2=0.65 to 0.75 depending on the sampling date and field). Combining the data from the four fields revealed a reasonably good relationship between WVDI_Green and total yield at all sampling dates except around 70 days. Based on the results of the relationships, the potential exists to derive quantitative biophysical information for the remaining 16 fields.

The potential to use drone derived WDVI_Green images to delineate zones of differential production is also being assessed. Delineation of zones at the site used for mapping soil spatial variability in NB (1.1b ii) are being identified based on WDVI_Green, canopy cover, and Brightness Index (assessed from bare soil imagery). These zone are being compared with management zones identified from mapping soil variability using proximal soil sensors.

Satellite imagery

In 2016, Planet Labs launched a further suite of small satellites that provide the potential to image every part of the Earth on a daily basis. Currently, Planet Labs operates 128 satellites that provide a potential opportunity to collect remote sensing imagery in four spectral bands (blue, green, red and NIR) at a spatial resolution of 3-4 m at unprecedented temporal resolution. For the four priority fields, Planet Lab imagery was acquired over the growing season. For each field, at least 10 images were acquired and the data pre-processed to at-surface-reflectance to enable comparisons across dates and fields. Initial assessment of the imagery suggests that the Planet Lab data may offer a feasible option for acquiring imagery throughout the season. Quantitative relationships of the satellite imagery with the in-field biophysical data are being investigated along with zoning of the fields into differential zones of production.

1.1b: Mapping within-field yield variation using yield monitor:

i) Field scale evaluation (PEI)

Two field sites were selected in the summer of 2017 for more detailed sampling. Yield maps were obtained at harvest by yield monitor, and sampling locations were selected based on the yield maps. Sampling was performed at 29 locations in one field site and at 20 locations at the second field site. Sampling locations were chosen to capture a range in crop yield as indicated by the yield monitor data. Samples were collected in the fall of 2017. Samples were used to determine soil properties and soil test values (PEI soil text lab), root lesion nematodes and *Verticillium* propagules (Potato Quality Institute lab). Sample analyses are on-going. This was a continuation of work done in previous years.

Overall, yield monitor maps identified significant within-field variation in potato tuber yield. This provides an opportunity for improved potato management with precision agriculture approaches. Mapping of soil variability using soil electrical conductivity (e.g., by Veris or Duelem), and comparison of the maps of soil variability with tuber yield, are currently on-going in other projects. However in this study, the ability to link the spatial variation measured tuber yield to variation in soil properties, indices of soil health, or pathogen levels has been limited.

ii) Field scale evaluation (NB)

Potato yield monitor data was successfully collected on a large number of commercial potato fields in 2015 and 2016 in New Brunswick. The potato yield monitor data were processed, filtered, analyzed, interpreted and geospatially mapped (with Ag Leader SMS and ArcGIS software). Yield monitor data was also collected in 2017, in a similar manner to 2015 and 2016, but for a much more limited number of fields.

Overall, the yield maps obtained through yield monitors indicated that there can be substantial within-field variation in tuber yield. It was also observed that the spatial variation in yield is consistent across years (Figure 1). This suggests that the spatial variation in yield is strongly influenced by inherent soil properties. This finding indicates that it should be feasible to identify zones within field which differ in crop yield, and that these zones have the potential to be used as the basis for site-specific within-field management. The potential to map a commercial potato field based on soil variability (section 1.1c i) or based on drone imagery (section 1.1a) will be assessed in a scientific manuscript to be initiated in 2018.

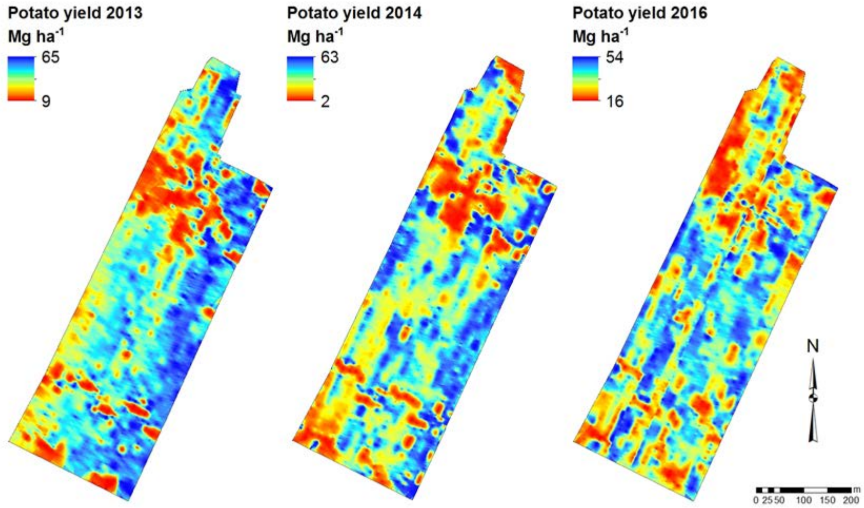

Figure 1. Relatively consistent spatial patterns of potato tuber yield were obtained by yield monitor across three growing seasons for this commercial field in New Brunswick.

1.1c: Mapping within-field variation using soil-based approaches:

i) Field scale evaluation (NB)

Two study sites (SVP and SVS) were established in commercial fields in the fall of 2015 in St-André and Centreville, New Brunswick. SVP is about 21 ha in size while SVS is 17 ha. In 2015, soil sampling was conducted in both fields using a triangular grid design with a sampling interval of 33 m on 12 ha of the field and additional soil samples (19 samples for SVP and 14 samples for SVS) were taken the same way but with a sampling interval of 71 m to complete the soil sampling of the entire fields. At each soil sampling point, a composite of five soil samples were collected by auger in a radius of 1.5 m around the georeferenced points. All sampling points (154 samples for SVP and 141 samples for SVS) were sampled for the soil surface (0-15 cm). For both sites, some sampling points (41 samples for SVP and 37 samples for SVS) were sampled at three depths of 0-15, 15-30 and 30-60 cm. The proximal sensor measurements were collected in fall 2015 including Veris-MSP3, Veris-P4000, and two Dualem instruments (model 1S and 21S) surveys on the entire field. Raw ECa measurements from Dualem model 1S (from Trimble Soil Information System) were not available. Consequently, the statistical analysis could not have been completed. The ground penetrating radar (GPR; model SIR 3000 GSS) measurements were collected in February 2016. Potato yield data was acquired with potato yield monitor in 2013, 2014 and 2016 for SVP15 and in 2014 and 2016 for SVS. Moreover in 2016, tubers were hand harvested on two 3-m length of row at 50 sampling locations in each field on 12 and 13 September 2016 for SVP15 and SVS15, respectively, to determine the total and marketable yield (MY).

Soil physical properties (soil particle size and moisture) showed higher coefficient of variation (CV; Table 1) in SVP than SVS. This reflects the higher pedodiversity in SVP than SVS which have been reported in two pedological studies conducted by AAFC in 1980 (SVP, 1:50 000) and 2001 (1:10 000). The chemical soil properties reveal similar CV behaviour in the two fields except for potassium. Potato yield measured by yield monitor showed CV that varied from 21 to 32% (Table 2). The CV of the proximal soil sensor varied from 14 to 75% and the highest were obtained with the Dualem-21S (Table 2).

The semivariogram results of the soil properties indicated stronger spatial structure for SVP than SVS, particularly for the soil particle size (Table 3). The cross-validation coefficient (R^2_{cv}; Tables 3 and 4) of determination, that shows how well we can predict soil measure values at unmeasured locations, were generally higher for SVP than SVS, once again particularly for the soil particle size. Correlation analysis, analysis to delineate homogeneous management zone using the proximal sensor dataset and zone validation are currently under analysis and scientific manuscripts will be completed in the near future..

The management zone (MZ) delineated using the Veris ($EC_{0\text{-}0.3m}$ and $EC_{0\text{-}1m}$), Dualem ($PRP_{p0\text{-}0.4m}$, $PRP_{p0\text{-}0.9m}$, $HCP_{v0\text{-}1.4m}$ and $HCP_{v0\text{-}3.1m}$) and GPR ($SLT_{surface}$, $SLT_{subsurface}$ and depth to bedrock) kriged data matrix with the fuzzy k-means analysis with no spatial constraint of proximity at the SVP and the SVS fields are presented at the Figures 1 and 2. The decrease of the total within-zone variance of most significant soil properties (Figs. 3 and 4) into management zone (MZ) based on the MZ delineated with the Veris, the Dualem and the GPR at the SVP and SVS fields, respectively, revealed that both fields could be delineated within two MZ for both fields. Although, the ANOVA (Table 5) confirmed that the two MZ for the SVP field had significantly different soil properties when delineating with the soil EC proximal sensors, whereas for the SVS field the soil properties were not all significantly different and no consistency exist within the soil EC proximal sensors.

The results of the present study showed that the SVP field presented highest pedodiversity attributable to higher variability of soil texture and soil moisture. In this study, soil EC obtained with the Veris and the Dualem was effective in delineating field differences in soil physicochemical properties for both fields. Consequently, at these sites, soil EC was efficient to subdivide the fields into two significant homogeneous MZ based on soil physicochemical characteristics and behaviour and tuber yield productivity. For the SVP field the differences were particularly related to soil texture and moisture. These soil properties influenced soil water availability, and consequently potato yield. In the SVS field, the Veris and the Dualem behaviour were not the same and significant differences for tuber yield and soil physicochemical properties were different if soil EC was measured from one instrument or the other. These results could be attributable to lower spatial variability of the data acquired with the proximal soil sensors. This lower spatial variability was also revealed by the intensive soil sampling for the intrinsic properties, especially soil texture. In the SVS field, the Dualem performed better in than the Veris in delineating efficient MZ. For both fields, the GPR results were not significantly different, likely due to the fact that this instrument recorded short range spatial variability. The soil EC proximal sensors (i.e., Dualem and Veris) could be used to delineate MZ and the performance of the proposed method is promising in potato production in New Brunswick especially when the field shows high pedodiversity.

A MSc student, Felipe Vargas, has done his initial deposit of his master and everything should be completed by the end of April. The aim of his studies is to compare soil proximal sensors to characterize and map soil spatial variability and therefore to delineate soil MZ of the intensive potato production of the current project. A paper will be published following his results.

Table 1. Descriptive statistics for soil physico-chemical properties for SVP and SVS fields.

		SVP						SVS					
	Unit	n	Min	Max	Mean	STD	CV %	n	Min	Max	Mean	STD	CV %
Soil Particle size													
Clay	g kg^{-1}	41	119	210	151	24.5	16	37	138	182	161	11.0	7
Silt	g kg^{-1}	41	382	609	508	52.0	10	37	443	557	485	22.7	5
Sand	g kg^{-1}	41	190	483	341	72.8	22	37	267	409	354	28.3	8
Gravel	g kg^{-1}	154	73	411	237	66.5	28	141	146	358	251	41.8	17
Indurated layer$_D$	m	41	0.3	1.0	0.7	0.3	36	37	0.3	1.0	0.9	0.2	19
Soil moisture	%	154	14.0	36.5	24.4	4.0	16	141	13.1	33.2	24.0	2.5	11
S.O.M.	%	154	1.7	4.3	3.2	0.4	11	141	2.6	6.3	3.5	0.5	14
Total N	%	152	0.1	0.3	0.2	0.0	9	141	0.2	0.4	0.2	0.0	11
Soil pH$_{water}$		154	5.2	7.1	5.8	0.4	7	141	5.1	6.7	5.8	0.3	6
Extracted by Mehlich-III solution													
P	mg kg^{-1}	154	68	358	238	57	24	141	88	347	213	51	24
K	mg kg^{-1}	154	105	336	183	43	24	141	87	439	191	69	36
Ca	mg kg^{-1}	154	351	1693	809	259	32	141	565	2458	1107	298	27
Mg	mg kg^{-1}	154	50	285	116	44	38	141	75	349	167	64	38
Al	mg kg^{-1}	154	1439	1999	1814	111	6	141	1172	1768	1582	128	8
Fe	mg kg^{-1}	154	176	479	316	51	16	141	223	557	322	54	17
Cu	mg kg^{-1}	154	1.6	7.0	3.9	1.3	33	141	1.6	6.8	3.7	1.2	33
Zn	mg kg^{-1}	154	1.6	4.2	2.9	0.6	20	141	2.5	7.0	3.7	0.7	20
Mn	mg kg^{-1}	154	19.6	143.6	39.2	14.2	37	141	31.1	163.0	69.4	28.1	41

Indurated layer$_D$ = depth to indurated layer by P4000-VERIS TECH , S.O.M. = Soil Organic matter

Table 2. Descriptive statistics for yield monitor data and soil proximal sensor measurements for SVP and SVS fields.

		SVP						SVS					
	Unit	**n**	**Min**	**Max**	**Mean**	**STD**	**CV %**	**n**	**Min**	**Max**	**Mean**	**STD**	**CV %**
Potato yield measured by yield monitor													
Yield$_{2013}$	Mg ha^{-1}	16482	6.5	70.0	40.5	10.4	26	-	-	-	-	-	-
Yield$_{2014}$	Mg ha^{-1}	16586	3.0	62.5	36.9	10.3	28	31722	0.1	81.4	39.0	11.9	32
Yield$_{2016}$	Mg ha^{-1}	14602	15.7	55.9	34.2	7.3	21	27787	6.3	77.5	41.9	9.6	23
Soil apparent electrical conductivity measured by the VERIS													
ECa$_{0-0.3m}$	mS m^{-1}	9502	0.3	8.2	1.7	1.1	63	7291	1.1	7.5	2.9	0.8	29
ECa$_{0-1m}$	mS m^{-1}	8704	0.4	18.1	2.5	1.7	68	7094	1.5	8.5	4.0	1.1	27
Soil electromagnetic conductivity measured by the Dualem-21S													
HCP$_{V\ 0-1.4m}$	mS m^{-1}	7888	3.7	11.0	5.5	1.3	24	4667	2.7	7.6	5.4	0.8	14
HCP$_{V\ 0-3.1m}$	mS m^{-1}	7890	2.8	9.8	4.7	1.3	27	4697	3.1	10.8	6.6	1.0	16
PRP$_{P0-0.4m}$	mS m^{-1}	7857	0.1	5.6	1.3	1.0	75	4671	0.4	4.9	2.4	0.6	25
PRP$_{P0-0.9m}$	mS m^{-1}	7871	0.1	7.6	1.9	1.3	71	4688	0.1	6.4	3.3	0.8	24
Horizon properties calculated from the GPR measurements													
SLT$_{Surface}$	m	228907	0.1	0.3	0.1	0.0	25	244507	0.1	0.3	0.2	0.0	19
SLT$_{Substratum}$	m	207257	0.2	1.2	0.7	0.1	19	222289	0.2	1.2	0.7	0.1	20
Depth to Bedrock	m	225545	0.5	1.3	0.9	0.1	15	245256	0.5	1.4	0.9	0.1	15
Altitude (DGSP)													
Altitude	m	207257	228.9	245.7	239.3	3.0	1	238278	137.9	158.5	147.9	4.0	3

ECa$_{0-0.3m}$: Soil apparent electrical conductivity shallow by VERIS.
ECa$_{0-1.m}$: Soil apparent electrical conductivity depth by VERIS.
ECa$_{0-0.5m}$: Soil apparent electrical electromagnetic 0.5 m by DUALEM 1S.
ECa$_{0-1.5m}$: Soil apparent electrical electromagnetic 1.5 m by DUALEM 1S.
HCP$_{V\ 0-1.4m}$: Soil apparent electrical electromagnetic vertical dipole mode 0-1.4 m by DUALEM model 21S.
HCP$_{V\ 0-3.1m}$: Soil apparent electrical electromagnetic vertical dipole mode 0-3.1 m by DUALEM model 21S.
PRP$_{P0-0.4m}$: Soil apparent electrical electromagnetic perpendicular dipole mode 0-0.4 m by DUALEM model 21S.
PRP$_{P0-0.9m}$: Soil apparent electrical electromagnetic perpendicular dipole mode 0-0.9 m by DUALEM model 21S.
SLT$_{surface}$: soil layer thickness surface by GPR.
SLT$_{substratum}$: soil layer thickness subsurface by GPR.

Table 3. Geostatistical parameters of soil physico-chemical properties for SVP and SVS fields.

	---------------------SVP----------------------------					---------------------SVS----------------------------				
	Model[z]	**Nugget ratio**[y]**,%**	**Spatial class**[x]	**Range**[w]	**R^2_{cv}**	**Model**	**Nugget ratio,%**	**Spatial class**	**Range**	**R^2_{cv}**
Particle size										
Clay	Gauss	0.2	S	261	0.83	P.N.	100	R	n.a.	n.a.
Silt	Sph	20.6	S	176	0.58	Gauss	14.0	S	159	0.10
Sand	Gauss	15.7	S	175	0.74	Exp	99.7	W	152	0.09
Gravel	Sph	33.8	M	175	0.49	Exp	44.9	M	232	0.21
Indurated layer$_D$	P.N.	100.0	R	n.a.	n.a.	Exp	44.4	M	150	0.03
Soil moisture	Gauss	46.4	M	260	0.54	Exp	10.7	S	45	0.18
O.M.	Sph	54.1	M	157	0.32	Exp	33.1	M	237	0.41
Total N	Exp	49.9	M	447	0.29	Exp	37.0	M	242	0.38
Soil pH$_{water}$	Sph	6.2	S	201	0.61	Exp	41.1	M	219	0.27
Extracted by Mehlich-III solution										
P	Gauss	29.2	M	294	0.61	Gauss	22.1	S	284	0.62
K	P.N.	100.0	R	n.a.	n.a.	Exp	47.4	M	432	0.26
Ca	Gauss	25.2	M	150	0.58	Gauss	15.3	S	265	0.57
Mg	Exp	8.4	S	332	0.61	Exp	13.8	S	216	0.53
Al	Exp	33.8	M	228	0.27	Exp	25.5	M	241	0.53
Fe	Exp	51.1	M	246	0.31	P.N.	100	R	n.a.	n.a.
Cu	Gauss	8.3	S	245	0.79	Gauss	17.0	S	225	0.74
Zn	Gauss	40.1	M	180	0.48	Exp	50.6	M	83	0.21
Mn	Gauss	39.2	M	75	0.39	Exp	38.5	M	131	0.37

[z]**:** Semivariogram model : Gauss: Gaussian, Sph: spherical, Exp: exponential; P.N. : pure nugget

[y]: Nugget ratio = (nugget semivariance/total semivariance) × 100.

[x]: Spatial class: S = strong spatial dependence (<25%); M = moderate spatial dependence (25–75%); W = weak spatial dependence (>75%); and R = random spatial dependence (100%) (Cambardella et al., 1994).

[w]: Range: the distance at which a semivariance becomes constant.

Table 4. Geostatistical parameters of yield monitor data and soil proximal sensor measurements for SVP and SVS fields.

	----------------------SVP----------------------------					----------------------SVS----------------------------				
	Model[z]	Nugget ratio[y],%	Spatial class[x]	Range[w]	R^2_{CV}	Model	Nugget ratio,%	Spatial class	Range	R^2_{CV}
Potato yield measured by yield monitor										
Yield$_{2013}$	Exp	19.2	S	39	0.82	-	-	-	-	-
Yield$_{2014}$	Exp	1.2	S	39	0.92	Exp	27.8	M	29	0.65
Yield$_{2016}$	Exp	11.4	S	29	0.82	Sph	10.2	S	13	0.84
Soil electrical conductivity measured by the VERIS										
Eca$_{0\text{-}0.3m}$	Exp	3.0	S	57	0.96	Exp	5.0	S	45	0.81
ECa$_{0\text{-}1m}$	Exp	8.3	S	59	0.94	Exp	16.7	S	58	0.83
Soil electrical conductivity measured by the Dualem-21S										
HCP1	Sph	5.8	S	154	0.96	Exp	5.0	S	199	0.95
HCP2	Sph	0.7	S	154	0.98	Sph	1.3	S	130	0.98
PRP1	Sph	20.8	S	48	0.93	Sph	33.0	M	70	0.77
PRP2	Sph	19.8	S	50	0.94	Exp	22.0	S	150	0.77
Horizon properties calculated from the GPR measurement										
SLT$_{Surf}$	Exp	3.1	S	10	0.95	Exp	26.2	M	6	0.72
SLT$_{Sub}$	Exp	22.2	S	10	0.51	Exp	18.9	S	10	0.74
Bedrock$_D$	Exp	69.2	M	30	0.37	Exp	16.2	S	10	0.75
Altitude (DGSP)										
Altitude	Gauss	22.5	S	50	0.99	Gauss	1.6	S	240	0.99

[z]**:** Semivariogram model : Gauss: Gaussian, Sph: spherical, Exp: exponential; P.N. : pure nugget
[y]: Nugget ratio = (nugget semivariance/total semivariance) × 100.
[x]: Spatial class: S = strong spatial dependence (<25%); M = moderate spatial dependence (25–75%); W = weak spatial dependence (>75%); and R = random spatial dependence (100%) (Cambardella et al., 1994).
[w]: Range: the distance at which a semivariance becomes constant.

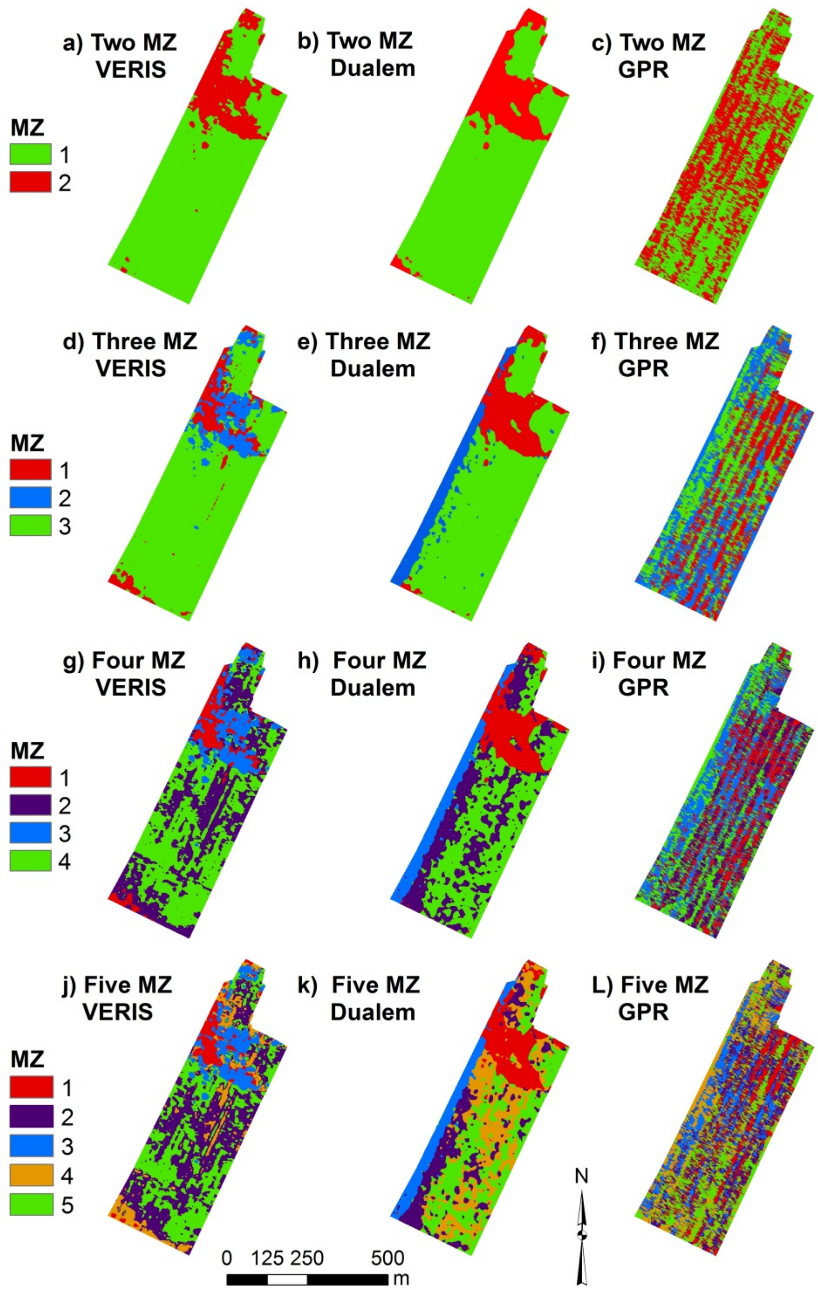

Figure 1. Management zone (MZ) delineated using the Veris ($EC_{0-0.3m}$ and EC_{0-1m}), Dualem ($PRP_{p0-0.4m}$, $PRP_{p0-0.9m}$, $HCP_{v0-1.4m}$ and $HCP_{v0-3.1m}$) and GPR ($SLT_{surface}$, $SLT_{subsurface}$ and depth to bedrock) kriged data matrix with the fuzzy k-means analysis with no spatial constraint of proximity at the SVP field.

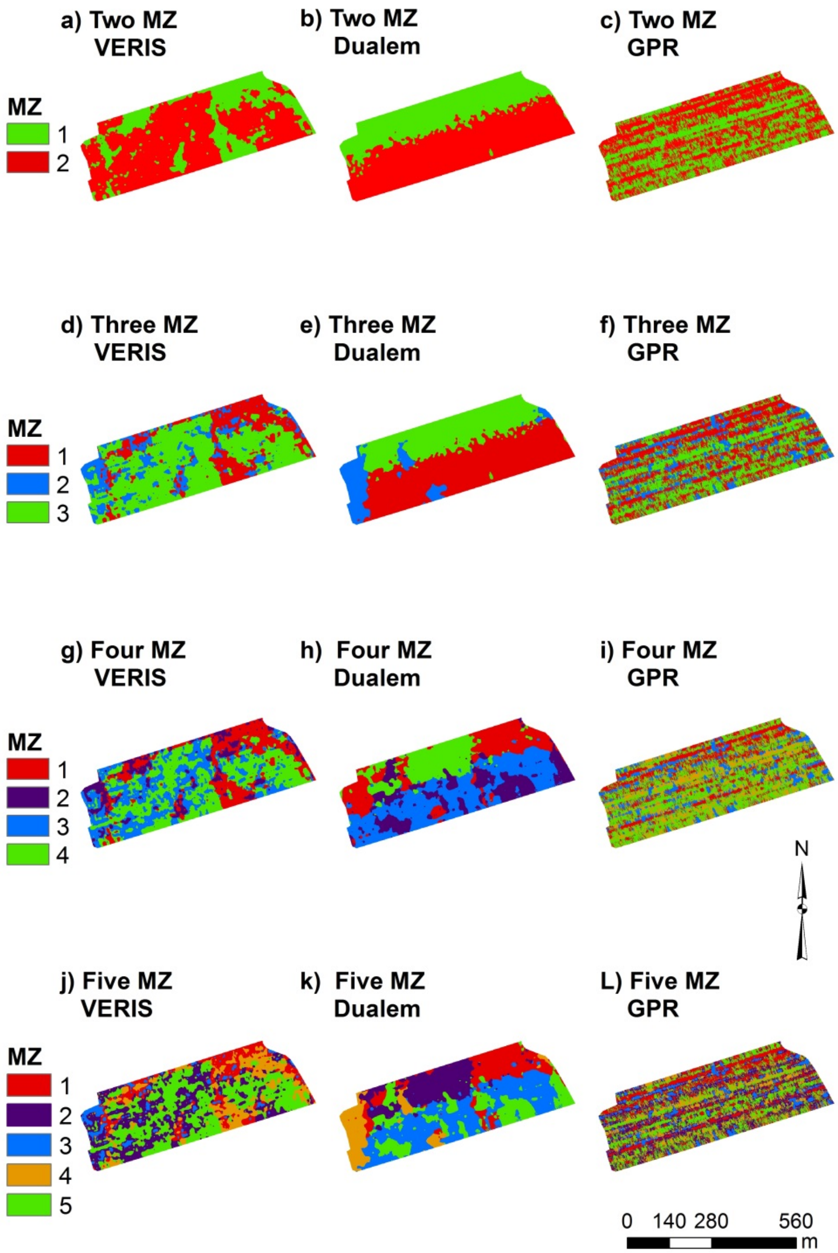

Figure 2. Management zone (MZ) delineated using the Veris (EC0-0.3m and EC0-1m), Dualem (PRPp0-0.4m, PRPp0-0.9m, HCPv0-1.4m and HCPv0-3.1m) and GPR (SLTsurface, SLTsubsurface and depth to bedrock) kriged data matrix with the fuzzy k-means analysis with no spatial constraint of proximity at the SVS field.

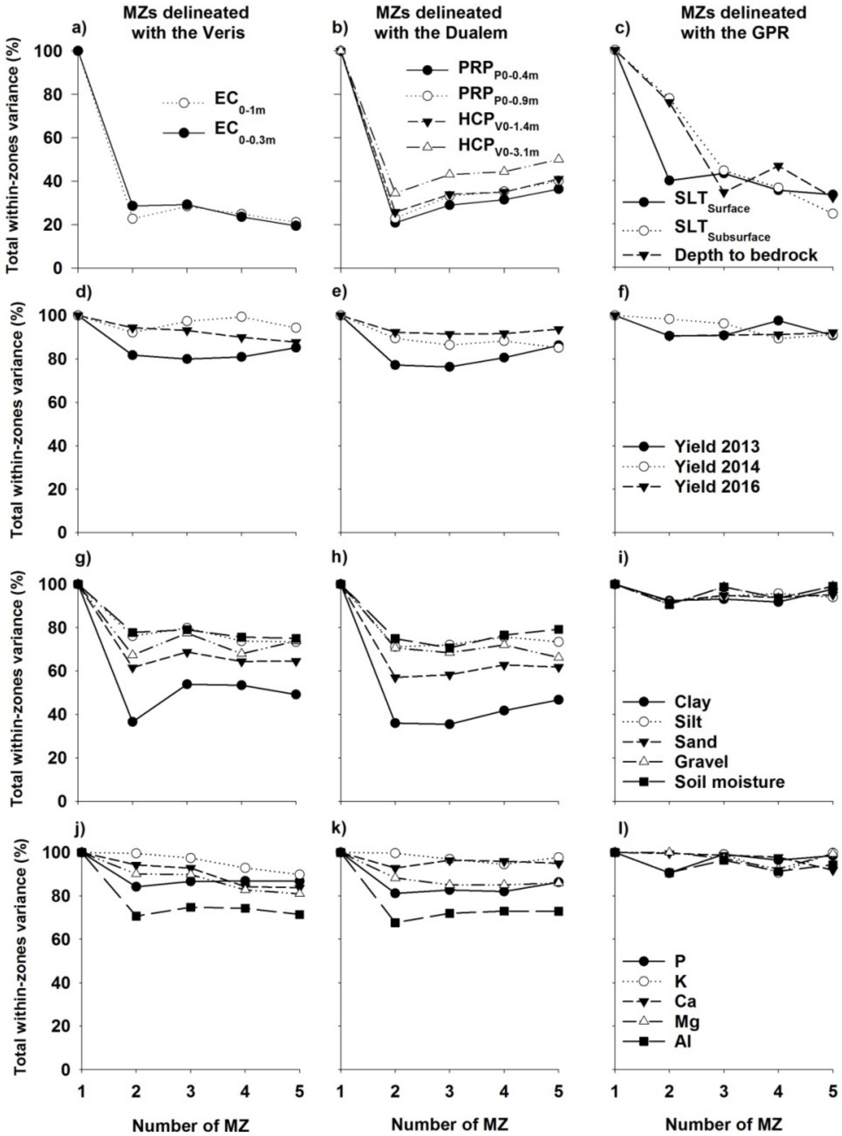

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Figure 3. Decrease of the total within-zone variance of a) soil electrical conductivity using the Veris, b) the Dualem, c) the thickness of soil layers derived with the GPR parameters, d-e-f) yield 2013, 2014 and 2016 from yield monitor, g-h-i) soil particles sizes (clay, silt, sand), gravel and soil moisture, j-k-l) Mehlich-3 extractable elements (P, K, Ca, Mg and Al) into management zone (MZ) based on the MZ delineated with the Veris, the Dualem and the GPR at the SVP field, respectively.

Table 5. Comparison of soil electrical conductivity (EC) and the soil layers thickness (SLT) into two MZ at the SVP and SVS site.

Number of MZ	Unit	PSS	SVP MZ1		SVP MZ2		SVS MZ1		SVS MZ2	
Tuber yield measured by yield monitor										
		Veris	31.9	b	41.2	a	n.a.		n.a.	
$Yield_{2013}$	$Mg\ ha^{-1}$	Dualem	31.4	b	41.5	a	n.a.		n.a.	
		GPR	39.4	a	39.9	a	n.a.		n.a.	
		Veris	30.5	b	37.4	a	37.3	a	40.0	a
$Yield_{2014}$	$Mg\ ha^{-1}$	Dualem	30.0	b	37.6	a	35.3	b	41.5	a
		GPR	37.5	a	34.8	a	40.0	a	37.5	a
		Veris	30.9	b	35.0	a	40.8	a	42.4	a
$Yield_{2016}$	$Mg\ ha^{-1}$	Dualem	30.5	b	35.1	a	40.2	b	42.9	a
		GPR	34.3	a	34.2	a	41.5	a	42.2	a
Altitude (DGPS)										
		Veris	215.5	b	216.5	a	124.7	b	127.2	a
Altitude	m	Dualem	215.4	b	216.6	a	124.3	b	127.6	a
		GPR	216.1	a	216.6	a	126.7	a	125.5	b
Soil particle size										
		Veris	191	a	142	b	159	a	162	a
Clay	$g\ kg^{-1}$	Dualem	189	a	141	b	161	a	161	a
		GPR	151	a	152	a	165	a	157	b
		Veris	248	b	363	a	353	a	355	a
Sand	$g\ kg^{-1}$	Dualem	250	b	366	a	349	a	357	a
		GPR	345	a	334	b	350	a	358	a
		Veris	158	b	254	a	253	a	249	a
Gravel	$g\ kg^{-1}$	Dualem	171	b	253	a	267	a	239	b
		GPR	239	a	236	a	246	a	257	a
		Veris	28.5	a	23.5	b	23.8	a	24.0	a
Soil moisture	%	Dualem	28.5	a	23.4	b	24.3	a	23.7	a
		GPR	24.3	a	24.4	a	24.2	a	23.6	a
		Veris	3.3	a	3.1	a	3.6	a	3.5	a
S.O.M.	%	Dualem	3.4	a	3.1	b	3.7	a	3.4	b
		GPR	3.2	a	3.1	a	3.6	a	3.5	a
		Veris	0.2	a	0.1	a	0.23	a	0.22	b
Total N	%	Dualem	0.2	a	0.1	b	0.23	a	0.22	b
		GPR	0.1	a	0.2	a	0.23	a	0.22	a
		Veris	5.9	a	5.8	a	5.8	a	5.7	b
pH_{water}		Dualem	5.9	a	5.8	b	5.8	a	5.8	a
		GPR	5.7	a	5.8	a	5.7	a	5.8	a
Mehlich-3 extractable elements										
		Veris	188	b	249	a	193	b	226	a
P	$mg\ kg^{-1}$	Dualem	186	b	250	a	198	b	224	a
		GPR	239	a	237	a	218	a	207	a
		Veris	195	a	181	a	176	b	201	a
K	$mg\ kg^{-1}$	Dualem	194	a	181	a	194	a	190	a
		GPR	181	a	185	a	188	a	197	a
		Veris	956	a	778	b	1311	a	981	a
Ca	$mg\ kg^{-1}$	Dualem	964	a	773	b	1193	a	1047	b
		GPR	782	a	837	a	1074	a	1153	a
		Veris	148	a	109	b	166	a	168	a
Mg	$mg\ kg^{-1}$	Dualem	149	a	108	b	165	a	169	a
		GPR	112	a	120	a	166	a	170	a
		Veris	1681	b	1842	a	1497	b	1636	a
Al	$mg\ kg^{-1}$	Dualem	1681	b	1845	a	1529	b	1619	a
		GPR	1812	a	1816	a	1608	a	1546	b

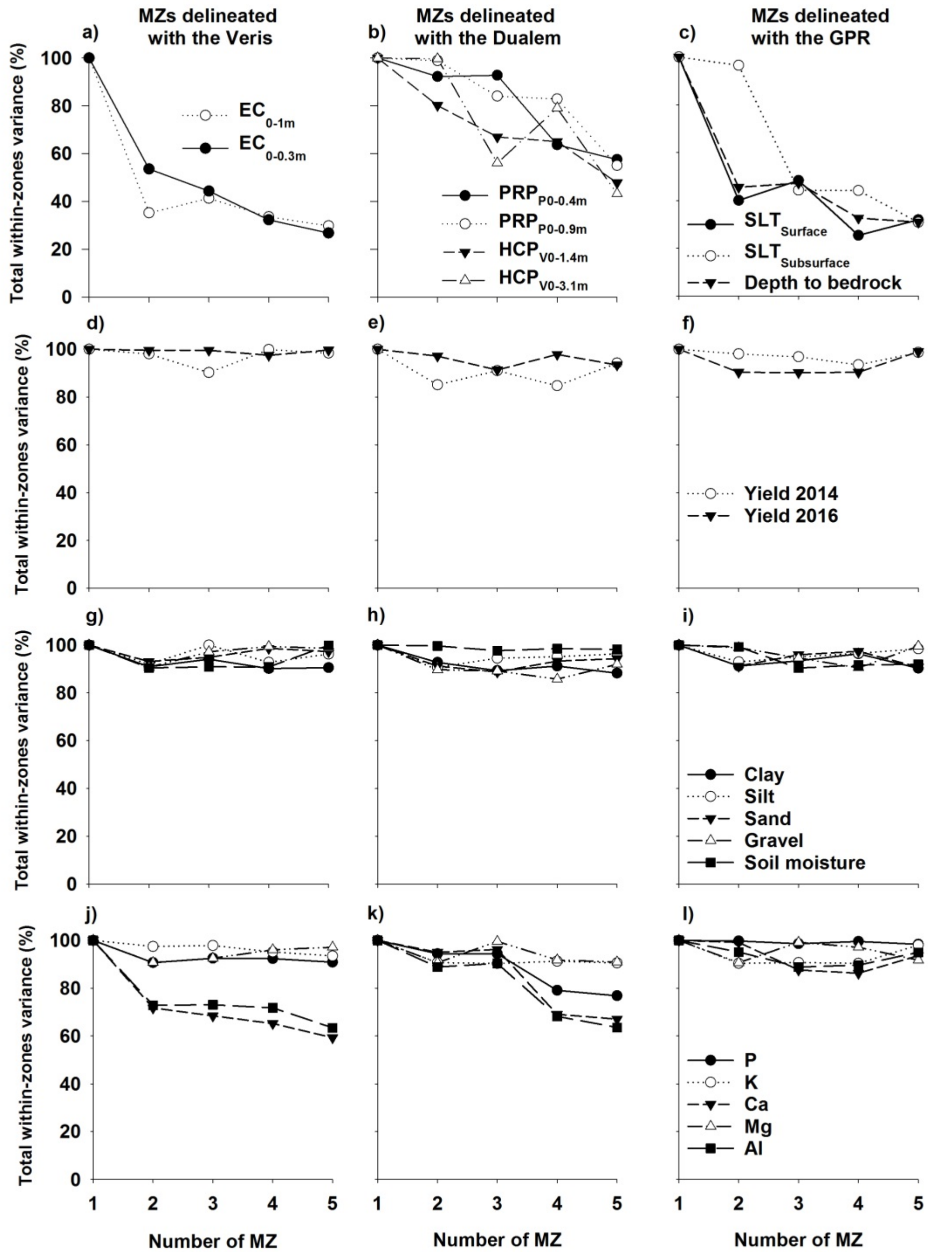

Figure 4. Decrease of the total within-zone variance of a) soil electrical conductivity using the Veris, b) the Dualem, c) the thickness of soil layers derived with the GPR parameters, d-e-f) yields 2014 and 2016 from yield monitor, g-h-i) soil particles sizes (clay, silt, sand), gravel and soil moisture, j-k-l) Mehlich-3 extractable elements (P, K, Ca, Mg and Al) into management zone (MZ) based on the MZ delineated with the Veris, the Dualem and the GPR at the SVS field, respectively.

ii) Field scale evaluation (MB)

The study site (~20 acres) within the larger field (~55 acres) was established in 2015, which was in canola production. The majority of the mapping information was collected in 2015, including a 30 m soil sampling/testing grid, a Veris survey, and a detailed soils report at the research site from an experienced soil pedologist. In 2016, an additional Veris survey was collected in the spring to capture "wet" soil conditions. The results from the survey are being processed, and will be compared to the soil test results.

The 2017 field studies were conducted to further evaluate the application of a radiometer-equipped UAV and in-situ soil moisture sensors to map changes in soil moisture levels and to use the information to assist in the development and implementation of prescription irrigation maps. Two producer fields and the CMCDC off-site location were used to collect data throughout the growing season. Field RB1 was a non-irrigated field that was seeded to wheat. Field RB2 was located to the east of RB1 and was under irrigated potato production. Four temporary soil moisture stations were installed on each field at pre-determined locations (Figure 1). Stevens hydraprobes were used to collect hourly soil moisture and temperature data at the 5, 15 and 30cm depth. A tipping bucket was installed on RB1-1 to collect precipitation amounts during the growing season. The sensors were installed on June 8 and removed on August 15 (RB1) and August 30 (RB2). The following is a summary of field data that was collected at RB1 (non-irrigated, wheat crop in 2017).

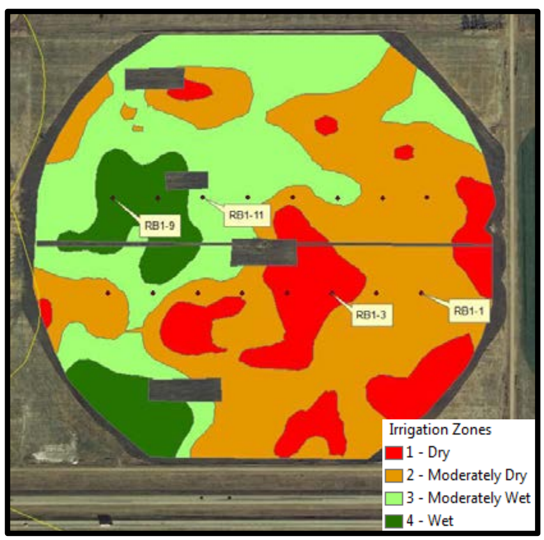

Figure 1. RB1 field located west of CMCDC, Carberry, MB

Analysis of detailed soil survey data for the area shows soils at RB1 to be a Fairlands (FND) series. These are well drained lacustrine soils with a SL-LS surface texture. Field Capacity (FC) is listed as 30% while Permanent Wilting Point (PWP) is 9%. Plant available water content (AWC) is 21%. The general target soil moisture level for irrigation is 70% of AWC. For this soil, 70% of AWC equates to 23.7% volumetric soil moisture.

Soils at this location are fairly uniform and elevation generally slopes east (high) to west (low). Using topographic and soil data, CropCare Consulting had provided a prescription irrigation map for this field. Temporary soil moisture stations were located in each of the 4 zones to monitor moisture levels during the season (see Figure 1).

Analysis of the soil moisture data revealed no significant differences in soil moisture during the growing season. Precipitation amounts that were received from June – August totalled 140mm. This was only 64% of 30 year normal (220mm) for this area (Environment & Climate Change Canada). Soil moisture content was higher in the early part of the season, near field capacity of 30%. Given the similarities in soils and plant water loss, volumetric soil moisture levels at the 15 and 30 cm depth dropped throughout the season to 10-15% at all 4 locations, staying just above PWP. Soil moisture levels at the 5 cm level dropped steadily during the growing season to levels well below PWP.

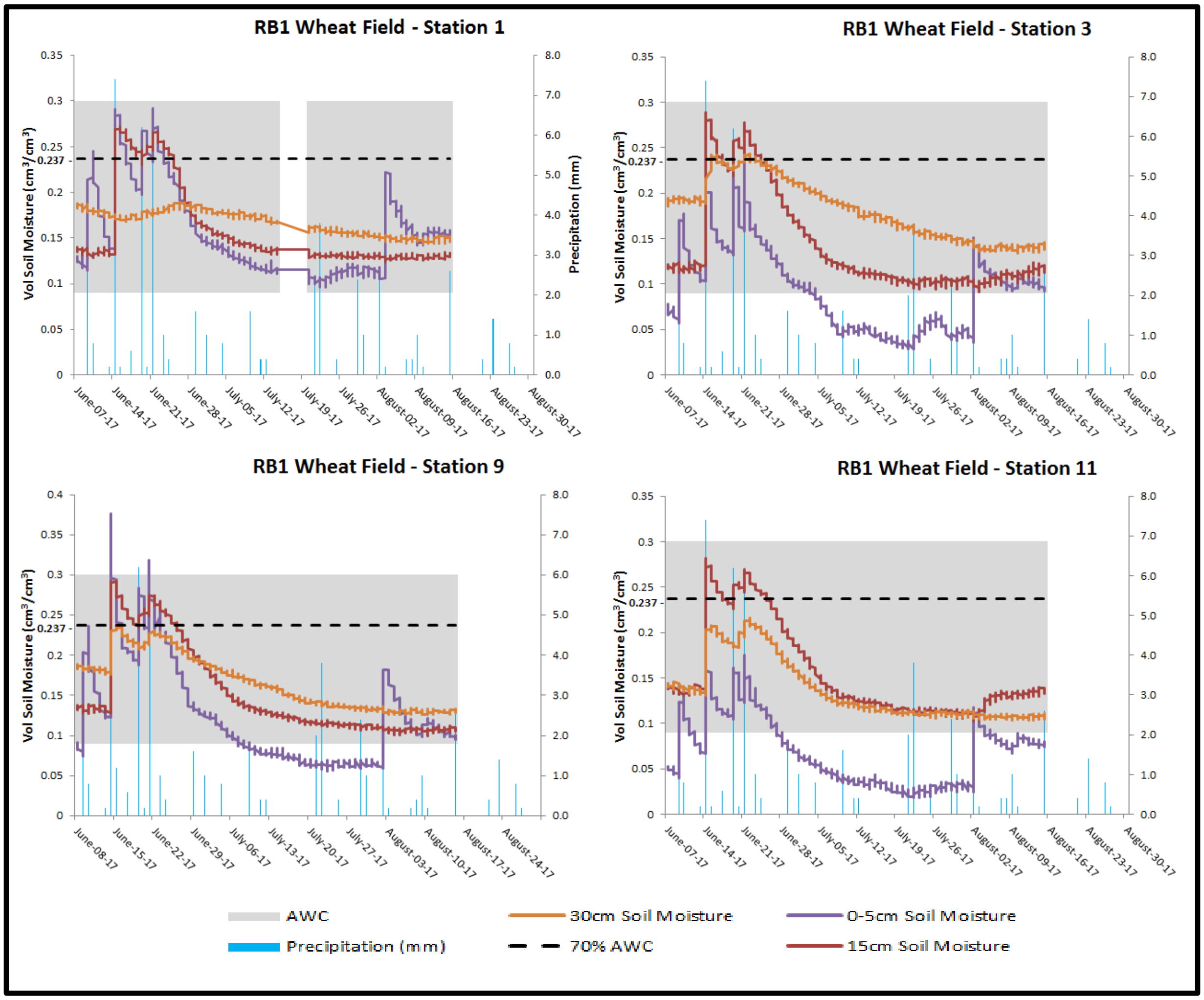

Figure 2. RB1 soil moisture and precipitation June 8-Aug 15

Skaha Remote Sensing used a UAV to collect radiometer data 2 times during the growing season; May 31, June 1, 2 and July 14, 18. The radiometer measures the level of microwave emission emitted by the soil (top 10-15 cm). Microwave emissivity is then correlated with soil moisture with dry soil having a higher emissivity than wet soils.

Imagery from June 1 (see Figure 3) shows generally dry surface soil conditions towards the eastern edge of the field (12-17 %) and slightly wetter conditions on the lower sloped areas to the west. The imagery acquisition occurred prior to the installation of the temporary stations and precipitation that followed in mid-June. This increased soil moisture content at all stations and soil moisture readings approached the upper threshold of AWC. Imagery from the second collection on July 14 shows a clear dry trend across all areas of the field. Very little rain was received in the weeks before the July acquisitions. Surface soil moisture levels were mostly below PWP of 10% across the extent of the field. This is confirmed by data from the 4 stations which also recorded surface soil moisture readings below 10% at this time.

Overall, the radiometer did a good job of capturing the surface soil moisture values at both periods of the growing season. Visual comparison of the imagery that was collected on June 1 with the prescription map confirms the trend of drier zones in the eastern part of the field and wetter zones to the west. The trend is not as pronounced when comparing the July 14 imagery when conditions are extremely dry.

The collection of UAV radiometer soil moisture maps provides a good snapshot in time of the surface soil moisture condition and can assist in the development of irrigation maps based on soil and landscape factors. Monitoring of surface and root-zone soil moisture levels during the growing season provides valuable information on soil moisture fluctuations in relationship to soil water holding capacity. Knowledge of this information is essential in development of water scheduling for producers using variable rate irrigation technologies.

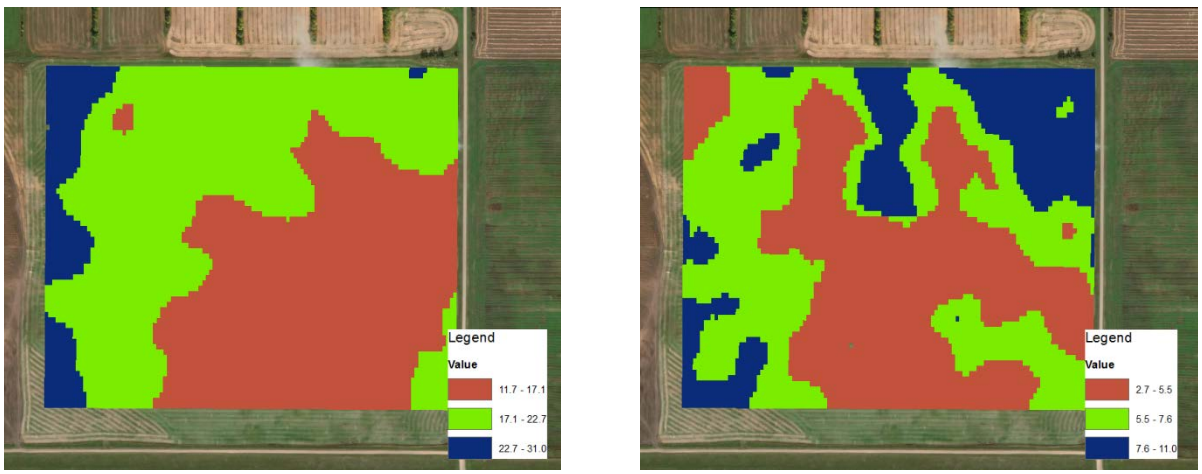

Figure 3. Radiometer surface soil moisture map at RB1, June 1/2017 (left) and July 14/2017 (right)

<u>1.2. Identify of the causes of yield limitations</u>

1.2a: Soil sampling to identify causes of yield limitations (PEI & NB)

Soil samples from field sites in NB and in PEI are being analyzed for a series of indices of soil health. Sample analyses under this activity includes measurement of soil texture, soil pH, soil organic carbon, soil total N, soil labile C as determined by soil respiration and as determined by permanganate oxidation, labile N as determined by a short term aerobic incubation, particulate organic matter carbon and nitrogen, and soil aggregate stability. We currently have all lab methods up and running.

The first priority was to complete analyses of a suite of indices of soil health for samples collected from the small plot compost trials (under 1.3a ii). This was used to get all the methods working properly, and to see if single, duplicate or triplicate analyses were required to get good analytical results. These analyses are now complete, and a scientific manuscript summarizing the results has been submitted.

The second priority was to analyze a suite of indices of soil quality parameters on one spatial variability site (i.e., site SVP under 1.1c i above). These analyses have been completed, and a scientific manuscript summarizing the results is currently in preparation.

The final step will be to analyze soil samples collected from field sites in NB and PEI for a subset of these indices of soil health. In NB, soil samples were obtained from approximately 85 field sites from 2013 to 2017. Our plan is to complete the necessary soil analyses by the end of August 2018. We have arranged for Hong Gu (Dalhousie University) to assist in the analyses of this data. Our goal is see if we can identify a link between indices of soil health and potato productivity (both tuber yield as well as tuber quality parameters).

1.2b: Gene expression-based plant diagnostic tools:

i) Identification of abiotic and biotic stresses (NB)

A series of activities are underway to utilize gene-expression based markers to quantify plant stress.

N status:

Candidate N status biomarkers were identified using gene expression data from transcriptome sequencing (Galvez et al. 2016). Validation of the N status gene expression biomarker is underway using Nanostring nCounter. We have tested 63 genes using RNA samples from across seven site-years of data obtained through previous projects, including trials in NB, PEI and Manitoba. Gene expression associated with N treatment variation and N uptake were identified as candidate biomarkers for monitoring N status. Loss of tuber yield and specific gravity potential is another indicator of stress conditions requiring management. Regression analysis was done to identify foliar gene expression associated with tuber yield and specific gravity. Further analysis using supervised machine learning data mining tools is underway. Gene expression biomarkers will be utilized to enhance nutrient management decision support.

P & K status:

Transcriptome sequencing has been completed using samples from a field trial which had variation in rates of NPK fertilizer. Bioinformatics analysis on the data is completed and a manuscript is in preparation. The NPK fertilizer treatments did not result in significant yield variation in response to all treatments, however, there was significant variation in gene expression associated with yield and specific gravity potential. Gene expression analysis is underway.

Multi-stress test:

Detection of multiple yield-limiting potato stressors in a single test provides an opportunity for increased efficiency in diagnosing problems in the field. Gene expression analysis can be applied for this purpose. Potato genes responsive to varying N rates have been identified as noted above. Potato genes responsive *Verticillium* infection, *Phytophthora* infection, PVY^{O}, PVY^{NTN} and PVX infection were obtained from an analysis of the literature. Genes indicative of these stressors were included in the multi-stress test. In addition, *Verticillium dahliae* and *Phytophthora infestans* genes expressed during infection were also included. The multi-stress test will also allow detection of PVY^{O}, PVY^{NTN} and PVX virus RNA.

The multi-stress test was developed using the Nanostring nCounter SPRINT platform with the new TagPlex design. The platform allows for multiplexing of 96 samples for examination of 24 targets (Table 1). This platform allows quantification of a gene expression of up to 24 target genes for approximately 1/8 the cost of the standard nCounter platform. The multi-stress nCounter assay has been designed and will be tested and validated on leaf samples from potato. Validation samples have been collected, additional time will be required to run gene expression analysis.

A new small plot field trial was conducted in 2016 at the Fredericton Research and Development Centre. This trial examined the gene expression response to S alone or in combination with N. Treatments included with or without 30 kg S/ha and with or without 180 kg N/ha. Leaf discs were collected for gene expression analyses on three dates. This experiment was repeated in 2017.

A second new small plot field trial was also conducted in 2016. This trial compared a series of 12 commercial potato cultivars, grown with or without 100 kg N/ha, to examine differences in gene expression patterns. The cultivars grown included Bayside Red, Chieftain, Eva, Granola, Green Mountain, Kennebec, Rochedale Gold, Russet Burbank D, Shepody, Spunta, Superior and Yukon Gold. This trial was also repeated in 2017.

Table 1. nCounter CodeSet for multi-stress detection.

Gene ID	Gene name
***Solanum tuberosum* housekeeping genes** (Genbank accession #)	
X83206.1	Cox1-B
AB061263.1	EF-1-alpha
AF126551.1	cyclophilin
U60482.1	actin
***Solanum tuberosum* test genes** (iTAG IDs)	
pathogen response:	
Sotub01g043810.1.1	pathogenesis-related protein PR-1
Verticillium response:	
Sotub09g012370.1.1	Ve1
Soil N response:	
Sotub12g007850	Cytosol aminopeptidase family protein
Sotub08g027190	Cystathionine gamma-lyase
Sotub03g016050	Cysteine protease inhibitor 1
Sotub02g036900	Cystine transporter Cystinosin
Sotub02g033060	NAD-dependent epimerase/dehydratase
Sotub05g028860	Flowering locus T protein
Sotub12g012740	Chloroplast lipocalin
Sotub05g012720	Nodulin MtN21 family protein
Sotub12g031130	Poly(A) polymerase
Sotub09g024290	Sulfate adenylyltransferase
Sotub10g017020	Unknown Protein
***Verticillium dahliae* genes** (Genbank accession #)	
XM_009652930.1	SNF protein kinase
XM_009652591.1	Endo-glucanase G1
***Phythophthora infestans* genes** (Genbank accession #)	
XM_002904603.1	T30-4 Major Facilitator Superfamily (MFS) (PITG_07711)
L23939.1	Ipio
Virus genes (Genbank accession #)	
M95516.1	Potato virus X (PVX)
HM367076.1	Potato virus Y strain O isolate RB (PVYO-RB)
HQ631374.1	Potato virus Y strain NTN isolate HN1 (PVYNTN-HN1)/

ii) Identification of *Verticillium* wilt (MB);

Two Manitoba commercial fields that had fumigation strips applied in the fall of 2016 were sampled (leaf discs) for gene expression in 2017, in the potato phase of the rotation. Gene expression samples were collected at three different time points starting in early August to capture early, mid and late time periods along the disease progression of the early dying complex. Samples were collected in both the fumigated and non-fumigated strips and all samples have been shipped to the laboratory at Fredericton. In total in Manitoba, five fields over two years were sampled for gene expression-based diagnostic testing for *Verticillium* wilt.

iii) Identification of heat stress (MB);

Heat stress chambers were applied to the heat stress trial plots at multiple time points during the growing season. The chambers were installed for approximately 24 hours, removed, and leaf disc samples collected immediately after removal for gene expression analysis using transcriptome sequencing. Three sampling dates of gene expression leaf discs were collected for heat stress, and shipped to New Brunswick.

iv) Image-guided implementation of gene expression based diagnostics tools (NB).

This work was planned for 2017 using field sites established in New Brunswick. However, the tools needed for analyzing the data are still in development and are not yet ready for use. As a result, this work will not be completed and instead efforts will be focussed on completing development of the diagnostic tools.

1.2c: Characterization of soil microbial communities as a measure of soil health:

i) Effect of compost application, biofumigation and landscape position on soil microbial communities (NB)

For 2017, the data from the study about the effect of soil properties and landscape features on bacterial communities was further analyzed to evaluate the effect of different pH and soil organic carbon on the 50 more predominant bacterial species (Figure 1). The data was presented in one scientific conference and will be soon published. Data about the fungal communities in the landscape of a potato field are currently being analyzed and will be published in 2018-2019.

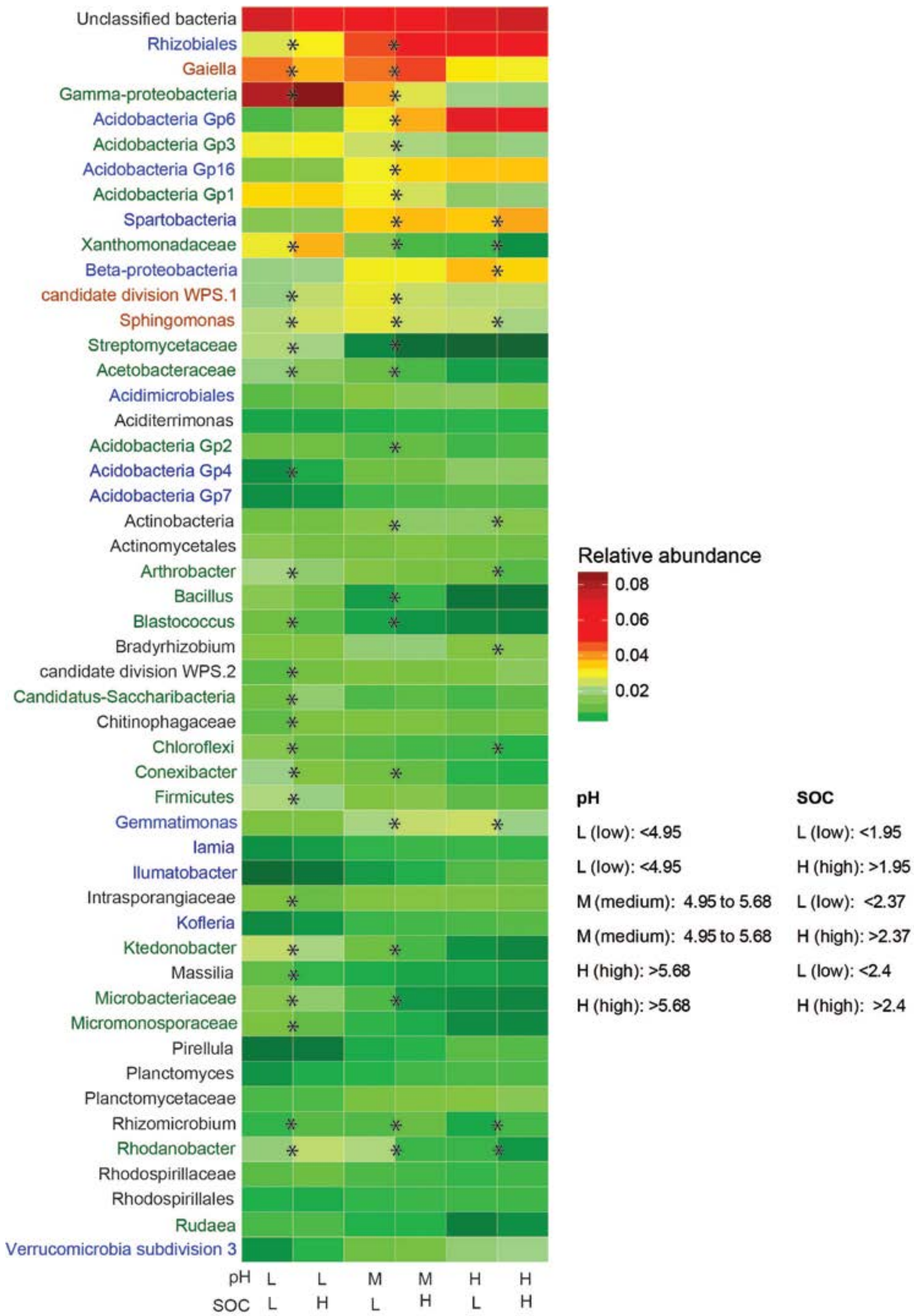

Figure 1. Heatmap of the top 50 abundant OTUs across categories of soil pH and soil organic carbon (SOC) generated using R software with function "heatmap.2". Ranges of pH and SOC were selected to ensure a similar number of samples in each category (i.e., each column shows the results of 13 or 14 samples out of the 83 sampling locations). Bacterial taxonomic assignments are indicated to the genus level when possible or to the closest known taxonomic level. Taxonomic assignments in green, orange and blue color indicate that the relative abundance was greatest at low, medium and high pH, respectively. Asterisks between low (L) and high (H) SOC categories at a given pH indicate differences in the relative abundance.

As indicated previously, it will not be possible to evaluate the effect of compost in commercial fields on soil microbial communities as planned because of problems with field design and error in application rate in the selected fields. Instead, sampling was performed on a new field trial that was established under activity 2.3. The trial was established in the spring on 2016 on a grower field which was known to have a problem with Potato Early Dying (PED). The trial will be conducted over a two-year period with the rotation crop grown in 2017 and potatoes grown in 2018. The trial included three treatments: 1) control, with rotation crop (barley) grown in 2016; 2) chemical fumigation, with chloropicrin applied in the fall of 2016 after harvest of the rotation crop (likely barley); and 3) biofumigation, with mustard grown in 2016 and managed to optimize the biofumigation effect. The treatments were applied to four replicated strips in the field. The effect of the treatments on bacterial and fungal communities, and on the abundance of pathogens causing potato diseases including *Verticillium*, will be measured at selected times during the rotation crop and potato crop growing seasons. Sample collection proceeded as planned in 2016. Sample analyses will be performed at the conclusion of the field experiment.

ii) Effect of compost feedstock on soil microbial communities (NB);

This work used an experimental field was established in October 2014 at the Fredericton Research and Development Centre. The treatments included a no compost control and three composts with varying wood waste as feedstock and carbon to nitrogen ratio. Compost products include a source separated organic compost with negligible wood waste (C:N 10:1), a compost from wood shaving, poultry broiler manure and paper waste (C:N 30:1) and a compost from yard scrapings with wood waste as the dominant feedstock (C:N 55:1). Composts were applied at 45 t ha^{-1} on a dry weight basis. The experiment used a completely randomized block design in four replicates. The field was sampled over four dates including fall 2014 (after compost application), spring (before planting), mid-summer (mid-season) and fall (harvest) 2015. Soil physicochemical properties will be measured. Diversity of microbial communities will be evaluated using next generation sequencing. Samples will be processed this fiscal year.

In 2016, DNA was extracted from soil, the libraries were constructed and the bacterial communities were sequenced. Analyses of soil physico-chemical properties which may influence soil microbial communities (e.g., soil pH, soil texture, soil organic carbon, permanganate oxidizable carbon) are currently on-going.

Preliminary data indicated that the relative abundance of bacterial phyla was changed significantly two weeks after the application of composts compared with soil without compost addition. Bacterial communities were different in soils with different compost feedstock. These results indicated that bacterial communities responded rapidly to addition of compost in the fall and that the communities remained different over the entire potato growing season. Linkages between soil physico-chemical properties and the diversity of bacterial and fungal communities will be determined once all soil analyses are completed. Submission of a scientific publication is planned in 2018-2019.

iii) Effect of fumigation on soil microbial and potato endophyte communities (MB).

A field was chosen in Manitoba that had a known problem with *Verticillium* wilt (Field 2 in activity 1.3bi). Fumigation was done in fall 2015 using Vapam (metam sodium) at the recommended rate. The treatments included three replicate sets of paired fumigated and not-fumigated strips. Four sampling locations were chosen in each strip systematically based on length or to capture the inherent variation in the field. At each location, an area of approximately six rows by eight meters in size was established as a "plot" where sampling occurs.

The field was sampled prior to fumigation in the fall of 2015 after fumigation, and in May, July and September 2016 under the potato crop. Stem and soil sampling occurred at two dates in 2016 under the potato crop, at mid-August and early September. Timing of sampling was chosen to target early and late expression of PED. Soil sampling was also performed in May and October 2017 during the subsequent oat rotation crop to examine longer term responses to fumigation. The samples were received in Fredericton and samples are currently being processed.

Diversity of bacterial and fungal communities will be evaluated using next generation sequencing. The study will evaluate how changes in *Verticillium* induced by soil fumigation (i.e., control vs fumigated strips) influence soil microbial communities, potato gene expression, endophytes and *Verticillium* abundance in stems.

1.2d: Heat stress and its interaction with drought stress (MB).

A randomized complete block design, with four blocks was planted in 2017 to test the impact of heat and its interaction with water stress on Russet Burbank potatoes at CMCDC-Carberry. A split-plot arrangement for the treatments was used, with three soil moisture levels as the main-plot treatments (irrigation to maintain soil moisture at 80, 60 and 40% plant available water), and heat stress as the sub-plot treatment (heat chamber or ambient temperature). Water stress levels were maintained throughout the field season with overhead irrigation, and Watermark sensors installed in all plots were used to make irrigation decisions. Rectangular heat chambers were installed and removed in sub-plots at various points in the growing season to test intermittent heat stress on potato yield and quality and gene expression at pre-selected time periods. The goal was to raise ambient temperatures by a few degrees Celsius for approximately 24 hours at a time. The chambers were installed for approximately 24 hours, removed, and leaf disc samples collected immediately after removal for gene expression analysis using transcriptome sequencing.

Analysis of yield and quality factors has begun on the 2017 data. Initial analysis indicates that the 40% plant available water treatment had significantly lower gross tuber yields (485 cwt/ac) compared to the 60 and 80% water treatments (539 and 524 cwt/ac, respectively). Water and heat treatments did not significantly impact specific gravity, tuber size profile, or fry color. Previous work at CMCDC-Carberry has shown that patterns in fry quality impact of in-season water stress can develop over time in storage. In this study, fry colors were determined immediately after harvest, and harvest sample areas in this study were not large enough to store and fry test tubers at later time periods. We did not observe significant impacts ($P<0.05$) of the heat stress treatments, or the interaction of water and heat stress, on the measured yield or quality values. Gene expression leaf disc samples are in the laboratory for analysis.

<u>1.3. Mitigation practices to overcome yield limitations.</u>

1.3a: Compost application to increase potato productivity:

i) Field scale evaluation (NB)

Field-scale trials were conducted on commercial potato fields to evaluate the use of compost. In each field, paired strips were established with or without compost application. In all cases, Envirem hen compost was used. Compost was applied at a rate of approximately 45 t/ha on a fresh weight basis.

In 2015, a field-scale evaluation of compost application was conducted on six commercial fields, including two fields with detailed sampling. In each case, compost had been applied once in the fall of 2014.

In 2016, a field-scale evaluation of compost application was conducted on three commercial fields. In two fields, paired treatment strips were established which either received no compost, or had compost applied three times (spring of 2014, fall of 2014, fall of 2015). The third field had similar paired treatment strips, but compost was applied twice (fall of 2014, fall of 2015).

In 2017, a field-scale evaluation of compost application was conducted on four commercial fields. In each field, compost had been applies three times (fall of 2014, fall of 2015 and fall of 2016).

Overall, there were inconsistent benefits to compost application on tuber yield and quality. Fields ranged from no benefit to a modest benefit in terms of tuber yield. There was no consistent pattern as to which fields had a yield benefit, and there was no obvious benefit to multiple applications of compost as compared to a single application. Any yield benefit of compost application was relatively small compared with the cost of compost application, suggesting that this is not an economically viable practice in the short term. It may be beneficial to target compost application to specific areas of a field which require improvement.

It is possible that the limited response to compost use may in part reflect the choice of compost used. This compost has high ash content and low dry matter content, which resulted in a lower total quantity of organic matter added. In addition, the compost had wood products as a primary feedstock, and it is possible that the compost did not result in as large of an increase in soil biological activity as might have occurred if the primary feedstock had more labile carbon sources.

ii) Effect of compost feedstock in small plots trials (NB)

This work was done MSc student Carolyn Wilson (Dalhousie University), supervised by Bernie Zebarth (AAFC) and David Burton (Dalhousie University). This work included two field trials and one growth room trial at the Fredericton Research and Development Centre. The overall objective was to assess the effect of diverse compost products for their suitability for use within potato rotations in NB. Trials were performed with cultivar Shepody because of its greater susceptibility to soil-borne diseases.

The first field trial was initiated in the fall of 2014 to compare compost products with diverse feedstocks for their effects on tuber yield and quality, indices of soil health, and for their effects on soil-borne diseases. The six treatments included a no compost control, and application of five compost products at a rate of 45 t/ha on a dry weight basis: Envirem hen compost (C:N ~ 27), marine-based compost with shells (C:N ~ 23), poultry manure compost (C:N ~ 19), forestry residues compost (C:N ~ 63), and source separated organics compost (C:N ~ 10). Each treatment received the recommended fertilizer application, not corrected for compost application. Tuber total and marketable yield were determined and graded according to a processing potato contract. A series of indices of soil quality were assessed. Tubers were also assessed for the presence of soil-borne diseases. Compost was applied again in the fall of 2015 to the same plots and at the same rate, and a potato crop grown in 2016. Similar measurements were made. The potato crop data is currently being summarized. A series of physical, chemical and biological indices of soil health were assessed on samples from both years (Figure 1).

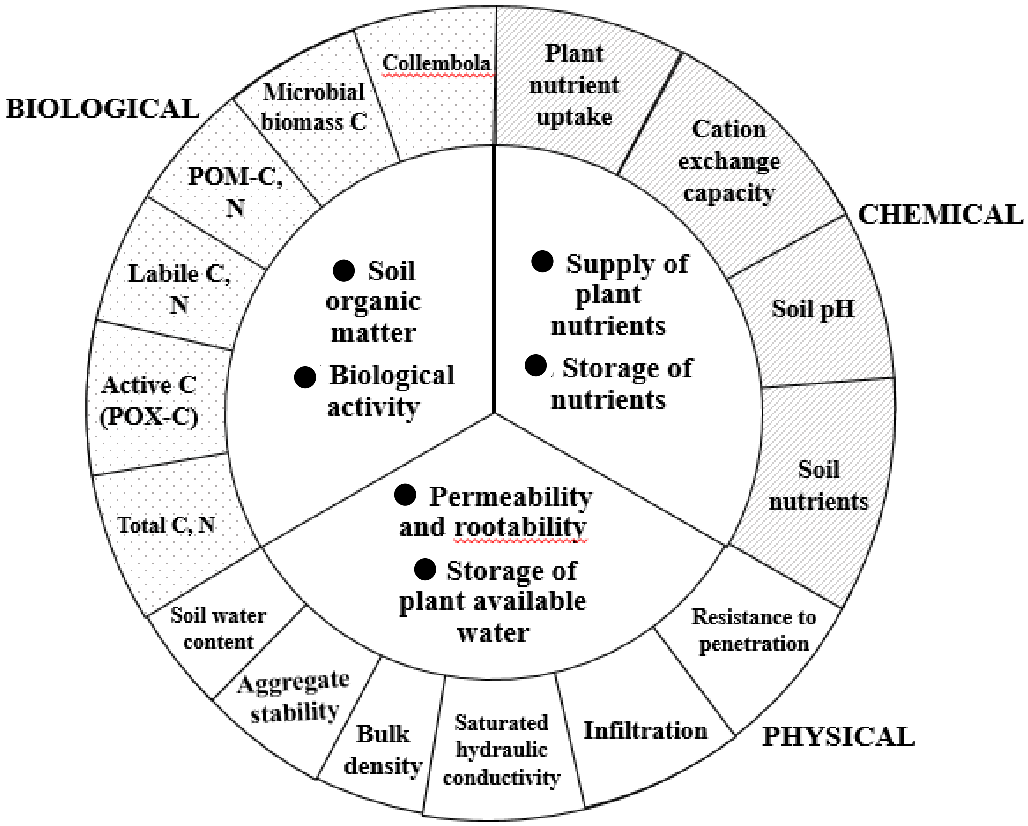

Figure 1. Physical, chemical and biological indices of soil health being determined.

The second field trial was performed similar to the first, except that no mineral fertilizer was applied. This trial included whole plant sampling to assess the apparent availability of NPK in the compost products. This trial was also repeated a second time to assess the effects of a single compost application, and of two successive compost applications. Most analyses have been completed and the data is being summarized.

One growth room experiment was performed in 2015, and repeated in 2016, to determine the effect of diverse compost products on disease severity of tubers. Soil was collected from a field site at the Fredericton Research and Development Centre which has elevated populations of common scab (*Streptomyces scabies*), powdery scab (*Spongospora subterranea* f. sp. *subterranea*) and *Verticillium* wilt. The experiment included eight compost treatments, including the six treatments listed above plus a lobster shell compost (C:N ~) and a "sea" compost (C:N ~). Each compost was mixed with the collected soil, and maintained under high and low water regimes to favour different soil-borne diseases. Tubers were then assessed for the incidence and severity of diseases.

One additional field trial was initiated in the spring of 2014. This trial used the same compost product as the field scale trials. Treatments included application of approximately 0, 0.5, 1.0 or 1.5 times that used in the field scale trial, where compost was applied in spring of 2014, fall of 2014, and fall of 2015 to reflect the timing used in the field scale trials initiated in 2014. Whole plant samples were collected in 2014, 2015 and 2016 to assess the NPK availability of the applied compost.

Preliminary results suggest that significant improvements in soil quality can be obtained through application of compost. The compost results in improvements in soil permeability, and in the quantity and quality of soil carbon. Improved soil quality has been previously shown to result in "non-nutrient" yield benefits. However, the improved soil quality did not translate into improved yield in the current study.

Preliminary results also indicate that for the compost products assessed, although in some cases there was a significant effect on N availability, that in general they had limited effects on soil nutrient availability in the short term. This may due in part to the application of the compost in the fall, such that effects on nutrient availability to the subsequent potato crop may be reduced. Compost will, however, benefit nutrient availability in the longer term by increasing soil organic matter content.

Preliminary results suggest that compost application may have some minor effects on soil-borne diseases. However, the effects of the compost were generally small in magnitude and inconsistent among years and trials.

A scientific article summarizing the effects of compost products on soil-borne diseases of potato in field and laboratory trials is currently in press. A scientific article summarizing the effects of compost products on soil physical, chemical and biological indices of soil health is currently under review. A scientific manuscript summarizing the effects of compost application on crop yield and nutrient status is currently in preparation.

1.3b: Fumigation to increase potato productivity:

i) Field scale evaluation (MB)

A series of trials were conducted on commercial fields to assess the effect of soil fumigation with Vapam with grower and processor cooperation. Three trials had fumigation treatments applied in the fall of 2015 prior to a 2016 potato crop, and two trials had fumigation treatments applied in the fall of 2016 prior to a 2017 potato crop. Fields were planted to Russet Burbank potatoes, with replicated treatment strips of a non-fumigated control or fall-applied Vapam (i.e., applied the fall just prior to the potato crop) at the recommended application rate. A minimum of 12 paired (fumigated vs. non-fumigated) sampling points were established per field, with multiple paired sampling points in each field strip replication. At the paired sampling points, plant and yield sampling, along with disease assessments were carried out in the potato crop. Soil and plant samples were collected to assess *Verticillium dahliae* levels in soil and plants. *Verticillium* soil densities were assessed with plate counting and molecular real time PCR assay on fall-pre-treatment, spring-post-treatment and fall-post-treatment soil samples. Species identification was done by PCR assay. In selected study fields, gene expression leaf disc samples (activity 1.2bii), potato stem and soil endophyte samples (activity 1.2ciii) were also collected for additional activities within the overall project.

In 2015, Field 2 was identified to be used for more detailed study including examination of soil microbial communities (activity 1.2ciii), effects on gene expression analyses, and post-potato phase soil *Verticillium* analysis. This field was pre-selected based on previous field history, and suspected high levels of soil *Verticillium* levels. Strong visual treatment effects were present in this field starting in mid-August 2016.

For the 2016 field sites, one of three fields (Field 2) had very high *V. dahliae* soil levels prior to treatment (the pre-selected field for long-term soil microbial analysis). Fumigation reduced soil *V. dahliae* levels in two of the three fields in 2016. However, only Field 2, with very high pre-treatment levels of *V. dahliae*, had a significant reduction in visual disease and concurrent increase in yield (net yields of 458 cwt/ac vs. 372 cwt/ac for fumigated vs. non-fumigated, respectively). In Field 2, there was a 19% yield loss due to Early Dying from *Verticillium*. Spring 2017 analysis of soil from Field 2 shows that the soil *Verticillium* levels bounced back in the year following potato.

For the 2017 field sites, *V. dahliae* analysis was completed on fall-pre-treatment samples. Analysis of the spring- and fall-post-treatment soil samples, yield and visual disease ratings is ongoing.

Results from the study indicate that fumigation may rescue fields with high *Verticillium* levels, but that fumigation in other fields is not likely to yield a return on investment. *Verticillium* levels in the soil bounce back in the year following the potato crop, and as a result further work is needed to determine if fumigation is required every year for fields with very high pathogen levels.

ii) Field scale evaluation (NB)

A field-scale evaluation of soil fumigation was conducted on a number of commercial fields in each year 2015-2017. Fields were selected based on visual evidence of disease in prior potato crops and on grower interest. Each field had paired treatments strips, with or without fumigation, applied in the fall prior to the potato crop. Potato hills were formed, and the fumigation applied as bands into the hills. Tuber yield and quality were assessed in the following potato crop.

A field-scale evaluation of soil fumigation was conducted on three commercial fields in 2015. For two trials, soil samples taken at planting and in August were used to assess populations of root-lesion nematodes and *Verticillium* propagules. Stem samples to assess severity of *Verticillium* were also collected in August from these two trials. Root lesion nematodes measured in the spring of 2015 in the two fumigated fields averaged 70 and 77% of the nematode counts in the non-fumigated control. Similarly, root lesion nematodes measured in August 2015 averaged 75 and 84% of that in the non-fumigated control. *Verticillium* wilt quantified for these two fields by plate count by the University of Manitoba in spring of 2015 was substantially lower for the fumigated treatment strips (14 and 2 propagules/g soil) compared with the control treatment strip (66 and 56 propagules/g soil). Similarly, *Verticillium* wilt quantified for the same two fields by plate count by the University of Manitoba in August of 2015 was substantially lower for the fumigated treatment strips (64 and 1 propagules/g soil) compared with the control treatment strip (1275 and 307 propagules/g soil).

In 2016, a field-scale evaluation of soil fumigation was conducted on seven commercial fields. For two fields, the GPS locations for yield were not recorded. The effect of fumigation on *Verticillium dahlia* and *Verticillium albo-atrum* and nematodes was evaluated in four of these fields, and also in a newly broken field which was in its first year of potato production. Samples were collected in the week of September 5, 2016. Out of the four fields assessed, two fields showed an important decrease in root-lesion nematodes, while the other two fields had no significant differences in nematodes number. The same two fields which had a significant reduction in root-lesion nematodes also had substantial reductions in *Verticillium* wilt as quantified by plate count by A&L Laboratories.

In 2017, a field-scale evaluation of soil fumigation was conducted on ten commercial fields. Samples were collected from four fields for quantification of root-lesion nematodes and *Verticillium* wilt. Root-lesion nematodes measured in spring of 2017 were generally low, and were reduced by fumigation at two of the four field sites. Quantification of *Verticillium* wilt for fields sampled in 2017 is on-going.

Overall, soil fumigation resulted in a yield increase in all fields tested. The yield response is attributed primarily to a reduction in Potato Early Dying (PED) complex, which is a combination of the fungal pathogen *Verticillium* wilt and parasitic nematodes. This conclusion is consistent with the measureable reductions in pathogen levels at several of the field sites. In fields where there was a yield response, but not necessarily a measureable change in pathogen levels, the yield response may also be due to other soil-borne diseases.

The consistent response to fumigation, and in some cases large tuber yield responses to fumigation, indicate that PED is a significant yield limiting factor in NB. The yield increase associated with fumigation was not always sufficient to cover the cost of fumigation. This suggests that any fumigation treatments should be targeted to fields, or to areas within fields, where pathogen levels are high. Reliable economic threshold levels for *Verticillium* wilt and parasitic nematodes are needed to guide grower decisions on soil fumigation.

The fumigation trials have been critical in identifying the importance of PED as a yield limiting factor in NB. These findings indicate it will be critical to manage PED in order to maintain high productivity in NB potato production. Soil fumigation can be an effective control for PED in the short term. The potential effects of soil fumigation on soil health, particularly on soil biology, remain unclear. There are, however, few reliable alternative practices for control of PED. As a result, the best approach to manage PED in NB potato fields remains unclear, and requires further study.

1.3c: Variable-rate irrigation to overcome yield limitations (MB)

Two years of Variable Rate Irrigation (VRI) vs. Uniform Rate Irrigation (URI) study were completed by the end of 2017 to compare current performance and management of VRI systems on potato yield and quality. Based on the topography, soil test and remote sensing data, VRI prescription zone maps were developed at four different test fields across the two years of testing: small-plot trials located at the CMCDC-Carberry research facility, and commercial-scale testing located on a commercial farm operating a VRI system. Prescription VRI maps for CMCDC-Carberry were developed by the project lead with consultation from an industry agronomist. The prescription maps for the commercial fields were developed by the farm agronomist. In both years, following the development of the prescription maps, replicated, paired comparison plots were identified within the study areas to test VRI management against Uniform Rate Irrigation (URI). The plots were located to capture yield and crop data across different irrigation management zones from the VRI prescription maps.

Continuous soil moisture monitoring was carried out in selected plots and zones at the study sites using Decagon field dataloggers and EC-5 and 5TM soil moisture sensors installed within potato rows at multiple depths. Tuber yield and quality analysis and post-harvest soil sampling were carried out for site characterization.

The VRI systems either had no impact, or improved yield or quality profile above URI management across the four site-years. At the CMCDC-Carberry research site, there was no yield difference between the irrigation treatments in either year. However, VRI management did improve the quality profile of the yields. In 2016, the CMCDC-Carberry VRI plots had fewer total culls/tares than the URI plots, while in 2017, the VRI plots had 24 cwt/ac less yield in the <6 oz size category compared to the URI plots.

In 2016, the commercial VRI field had 32 cwt/ac higher tuber yields under VRI management, but no differences in culls or overall quality. No differences were observed between the irrigation treatments in 2017. Low rainfall amounts in July and August 2017 meant very high crop irrigation water demands. Heavy irrigation water demand, combined with an early vine die-off in the commercial field may have contributed to the non-significant results in that field in 2017.

It was hypothesized that VRI systems of water management would produce variable results, as each season and field have different weather conditions, abiotic and biotic stresses. The type and magnitude of the stresses can impact the effectiveness of a variable water management system. Results from this project indicate that VRI systems can improve potato yield or quality profile in some situations, but growing conditions may impact the effectiveness of the technology. Further study on production fields has been proposed in the upcoming Potato Cluster to assist in determining the level of variability on which return on investment could be expected.

1.3d: Use of nurse crops to protect the soil and enhance potato productivity:

i) Field scale evaluation (NB)

A field-scale evaluation of nurse crops was conducted on four commercial fields in 2015. A detailed evaluation of the use of nurse crops was conducted on two of these fields. In each case, the fields had paired treatment strips, which either received no nurse crop, or had a nurse crop seeded around the time of potato planting. Sampling was performed in each field site according to plan. In addition, a device used to test for soil infiltration rate was used at selected locations at the two details sites. Samples were collected at the same locations and times for determination of soil bulk density and to perform the Solvita test as a measure of soil quality.

In 2016, a field-scale evaluation of nurse crops was conducted on two commercial fields. On one field, paired treatment strips were established which either received no nurse crop, or had a nurse crop seeded around the time of potato planting. The second field had a similar design except there was an additional treatment strip where the nurse crop was desiccated early. Sampling was performed in each field site according to plan. In addition, soil cores for lab-based determination of soil permeability were collected before and after hilling from selected locations from each treatment strip. These cores were also used to measure soil bulk density, and to perform a Solvita test.

In 2017, a field-scale evaluation of nurse crops was conducted on four commercial fields. In each case, the fields had paired treatment strips, which either received no nurse crop, or had a nurse crop seeded around the time of potato planting. No infiltration measurements were performed in 2017.

Overall, nurse crops grew rapidly and were effective in protecting the soil from erosion prior to emergence of the potato crop. In many cases, the cover crops produced a large quantity of root biomass that improved the condition of the surface soil. Nurse crop species like winter rye grew quickly and produced more biomass than other nurse crop species, but could in some cases become a weed in subsequent crop years. In comparison, a nurse crop species like barley grew well, and was easier to kill. Termination of the nurse crop using an herbicide was generally preferable to ensure that the nurse crop growth was controlled and did not compete with the potato crop, as control of the nurse crop through tillage is not always successful. The effect of a nurse crop in improving water infiltration was generally inconsistent. A modest tuber yield benefit was obtained with use of a nurse crop in some fields and years, but this response was not consistent. There was the potential for a reduction in yield if the nurse crop was not effectively terminated.

ii) Nurse crop species and management small plot trials (NB)

In the spring of 2017, two nurse crop trials were established at the Fredericton Research and Development Centre. The objectives of the trials were to incorporate of the outcomes of the 2016 nurse crop trials while also evaluating the effectiveness of herbicide application prior to potato hilling.

The first trial (NC Pea/Rye) was a repeat of the 2016 nurse crop trial. The trial was a randomized complete block design with three replicates. The trial compared a no nurse crop control with two nurse crop species (winter rye and field pea). Two seeding rates were tested for each nurse crop: winter rye (100 vs 150 lb/acre), field pea (75 vs 140 lb/acre). Two herbicide treatments were established for each combination of nurse crop and seeding rate: kill (Prism herbicide application pre-hilling at 20 DAP); and no-kill (no herbicide application). This resulted in a total of 27 experimental units for the trial. All experimental units measured 7m x 10m with 6 potato rows per plot.

The second trial (NC Bar/Rye) was developed in conjunction with Judith Nyiraneza from AAFC-Charlottetown and Sherry Fillmore (Bioinformatics) and paired sites were established between Fredericton and Charlottetown. The NC Bar/Rye trial consisted of a Latinized block design with four replicates. Two nurse crops were evaluated (spring barley and winter rye) in comparison with the no nurse crop control with single seeding rates selected for the nurse crops (spring barley 200 lb/acre; winter rye 175 lb/acre). Two herbicide treatments (Paraquat and Prism) were also evaluated at the pre-hilling stage of the potato crop (15 DAP for Paraquat and 20 DAP for Prism). This resulted in a total of 36 experimental units measuring 7 m x 10 m with 6 potato rows per plot.

Both nurse crop trials were established in May of 2017 and all nurse crops in NC Pea/Rye and NC Bar/Rye were planted via grain drill 2 days prior to potato planting. Russet Burbank Elite II cut potato seed (54-60 g/seed piece) was machine planted at 15" spacing then treated in the open row with Admire using commercial scale equipment during row closure. All treatments received 170 kg N/ha as 17:17:17 fertilizer banded at planting.

Planting one of the nurse crop plots with the grain drill (left) and plots after nurse crop seeding and potato planting (right).

Soil data were collected from each plot at 0-15 cm and 15-30 cm depth for soil physical and chemical analyses. Soil analyses are currently on-going. Soil moisture and temperature were monitored throughout the growing season using HOBO EM50 dataloggers installed at two soil depths (15 and 30 cm) in two row locations (potato hill and furrow) within each treatment combination.

Sampling for nurse crop biomass was performed prior to herbicide treatment and potato hilling for all nurse crop treatments. This included sampling above- and below-ground tissue to determine biomass and nutrient concentrations. Determination of petiole nitrate concentration was done on three dates. Potato biomass sampling was performed prior to topkill application. Tuber total and marketable yield, size distribution and tuber defects were determined.

Results from 2015 (Table 1) indicate that there was a limited effect of nurse crop species, seeding rate or killing method on tuber size categories. The exception was a lower yield of cull tubers for lower nurse crop seeding rates.

In 2016, there was a significant crop species by kill treatment interaction for Grade A tubers, where no kill resulted in greater grade A tubers than kill for field peas, but not for winter rye. There was also a significant main effect of nurse crop species on grade A tubers, with greater yield for a field pea than for a winter rye nurse crop. There was a nurse crop species by seeding rate interaction on 10 oz tubers, where the lower seeding rate for winter rye increased 10 oz tubers compared with the increased seeding rate, whereas there was a limited effect of seeding rate on 10 oz tubers for a field pea nurse crop.

Table 1. Potato harvest and grading results for the NC Pea/Rye trial in 2015 and 2016.

	Mean value							
	2015				2016			
Source of Variation	Small Tuber Yield (kg/ha)	Grade A Tuber Yield (kg/ha)	10oz Tuber Yield (kg/ha)	Cull Tuber Yield (kg/ha)	Small Tuber Yield (kg/ha)	Grade A Tuber Yield (kg/ha)	10oz Tuber Yield (kg/ha)	Cull Tuber Yield (kg/ha)
Treatments								
Control	9677	9989	1214	1279	8385	14731	3402	9697
Field Pea - Low Rate - Kill	5453	4053	0	419	8419	15736	1811	6554
Field Pea - Low Rate - No Kill	10066	7401	1412	531	10614	20419	1691	5610
Field Pea - High Rate - Kill	6733	5637	727	905	9965	15584	2963	10535
Field Pea - High Rate - No Kill	6739	7082	1446	1213	11013	18141	1698	6314
Winter Rye - Low Rate - Kill	6112	8173	1566	505.3	10738	17010	2482	11618
Winter Rye - Low Rate - No Kill	4946	4465	479.4	116.7	8317	13751	2772	9390
Winter Rye - High Rate - Kill	6927	5806	649.3	862.1	11214	13269	1312	11607
Winter Rye - High Rate - No Kill	9492	7743	1040	662.1	8866	13470	1158	7138
Analysis of Variance								
Interaction Effects								
*Crop*Rate*Kill*	0.084	ns	ns	ns	ns	ns	ns	ns
*Rate*Kill*	ns	ns	ns	ns	ns	ns	ns	ns
*Crop*Kill*	ns	ns	0.100	ns	0.085	0.042	ns	ns
*Crop*Rate*	ns	ns	ns	ns	ns	ns	0.035	0.099
Main Effects								
Crop	ns	ns	ns	ns	ns	0.018	ns	0.016
Rate	ns	ns	ns	0.026	ns	ns	ns	ns
Kill	ns	ns	ns	ns	ns	ns	ns	0.009

There was no significant effect of nurse crop species, seeding rate or killing method on total or marketable yield in 2015 (Table 2). In 2016, there was a significant effect of nurse crop species on marketable yield, where yield was greater for a field pea than for a winter rye nurse crop. For total yield in 2016, there was a significant nurse crop species by kill method interaction, and a significant nurse crop species by seeding rate interaction. The former interaction reflected greater total yield when the winter rye nurse crop was killed vs not killed, whereas this response was not evident for a field pea nurse crop. The latter interaction reflected greater total yield for a field pea nurse crop for the greater seeding rate, but greater total yield with a winter rye nurse crop with a lower seeding rate.

Data analysis is currently underway for the NC Pea/Rye trial for 2015-2017 and for the NC Bar/Rye trial for 2017. Preliminary results of the NC Bar/Rye potato harvest and grading can be found in Table 3.

Imagery was captured to quantify the soil coverage provided by the nurse crops for all experimental units in the NC Pea/Rye and NC Bar/Rye trials. An example of the setup and resulting imagery can be found below. A macro is currently under development and will automate the processing and analysis of the soil coverage for images captured in the 2015-2017 field seasons.

Table 2. Potato total and marketable yield for the NC Pea/Rye trial in 2015 and 2016.

	Mean value			
	2015		2016	
Source of Variation	Marketable Yield (kg/ha)	Total Yield (kg/ha)	Marketable Yield (kg/ha)	Total Yield (kg/ha)
Treatments				
Control	11203	22158	11847	38305
Field Pea - Low Rate - Kill	4053	9925	13607	33587
Field Pea - Low Rate - No Kill	8812	19409	15072	39024
Field Pea - High Rate - Kill	6364	14001	13422	40747
Field Pea - High Rate - No Kill	8528	16480	15762	38392
Winter Rye - Low Rate - Kill	9740	16357	11770	43087
Winter Rye - Low Rate - No Kill	4944	10007	12083	36557
Winter Rye - High Rate - Kill	6456	14244	9749	38326
Winter Rye - High Rate - No Kill	8783	18937	8851	31397
Analysis of Variance				
Interaction Effects				
*Crop*Rate*Kill*	ns	0.093	ns	ns
*Rate*Kill*	ns	ns	ns	ns
*Crop*Kill*	ns	ns	ns	0.047
*Crop*Rate*	ns	ns	ns	0.048
Main Effects				
Crop	ns	ns	0.002	ns
Rate	ns	ns	ns	ns
Kill	ns	ns	ns	ns

Table 3. Potato harvest and grading results for the NC Bar/Rye trial in 2017.

	Mean value					
	2017					
Source of Variation	Small Tuber Yield (kg/ha)	Grade A Tuber Yield (kg/ha)	10oz Tuber Yield (kg/ha)	Cull Tuber Yield (kg/ha)	Marketable Tuber Yield (kg/ha)	Total Tuber Yield (kg/ha)
Treatments						
Control - No Kill	11919	16241	2542	3685	18783	34387
Spring Barley - No Kill	11178	12737	4174	6452	16911	34541
Winter Rye - No Kill	9244	17387	4127	5378	21514	36136
Control - Prism	7549	15860	5065	4887	20925	33360
Spring Barley - Prism	7571	20285	6511	7608	26796	41975
Winter Rye - Prism	7885	19593	9310	8496	28903	45283
Control - Paraquet	8683	12944	4181	5545	17125	31352
Spring Barley - Paraquet	9993	12766	7440	9132	20207	39332
Winter Rye - Paraquet	8190	30808	4136	2933	34944	46067

Tripod set-up used to capture aerial picture of nurse crop (left); and resulting image used to quantify soil cover (right).

iii) Plot scale evaluation (PEI)

The soil cropped to potato is subject to erosion between seeding and potato emergence, and the soil loss can be high in areas with significant slope. This 3 year study explored mechanisms to protect the soil in the period between seeding and emergence by using different nurse crops intercropped with potato. Lessons learned from year one were used to set up the trial in a subsequent year, and thus this study is different from most conventional studies where the treatments are defined from the beginning and are repeated across years. The study aimed to provide preliminary information on what nurse crop species may be suitable, and what is the appropriate method to stop nurse crop growth, in potato production in PEI.

Trials were conducted at Harrington research farm in 2015, 2016 and 2017. The experimental details are summarized in Tables 1 to 3.

Table 1. Nurse crop screening trial at Harrington in 2015	
Treatments and seeding rates and dates	
Control	
Buckwheat	65 lb/ac
Winter rye	130 lb/ac
Oats	120 lb/ac
Brown mustard	10 lb/ac
All nurse crops were direct seeded before potatoes were planted	
Planting date nurse crop	June 9
Planting date potatoes	June 9, fertilized with 17-17-17 at 1000 lbs/ac

Table 2. Nurse crop trial at Harrington in 2016	
Treatments and seeding rates and dates	
Control	
Winter rye	130 lbs/ac
Root max ryegrass	18 lbs/ac
Planting dates	
Planting date nurse crop	May 26
Planting date potatoes	May 26, fertilized with 17-17-17 at 1000 lbs/ac
Herbicide application time	
First spray at 35 DAP	Poast, 800 ml ha^{-1}
Second spray at 77 DAP	Poast, 800 ml ha^{-1}
All nurse crops were direct seeded before potatoes were planted	

Table 3. Nurse crop trial at Harrington in 2017	
Treatments and seeding rates and dates	
Control	
Winter rye	175 lb/ac
Spring barley	200 lb/ac
Planting dates	
Planting date nurse crop	
Planting date potatoes	May 25, fertilized with 17-17-17 @ 1000 lbs/ac
Herbicide application time	
Non-selective at 17 DAP	Paraquat (Gramoxone 1.5 L/ha)
Grass-selective at 26 DAP	Sencor (150 g/ha) + Prism (24 g/ha)
All nurse crops were direct seeded before potatoes were planted	

A screening phase for testing different species as nurse crops was initiated in 2015. Four nurse crop species (buckwheat, winter rye, oat and brown mustard) were compared with a no nurse crop control in a randomized block design replicated four times. Nurse crop growth was stopped mechanically with hilling.

In 2016, nurse crop growth was controlled with hilling as well as a grass selective herbicide to stop the nurse crop growth after potato emergence. Two nurse crop species (winter rye and root max ryegrass), and two ways of controlling nurse crop growth (mechanical control through hilling and the use of a grass selective herbicide) were compared with a no nurse crop control.

In 2017, two nurse crop species (winter rye and spring barley) and three ways of controlling nurse crop growth were compared with a no nurse crop control. Methods to control nurse crop growth included: 1) mechanical control with hilling; 2) a non-selective contact herbicide that has to be applied before potato emergence, and which was applied at 15 days after planting at the latest; and 3) a grass selective herbicide. Because of the use of an herbicide as early as 15 days after planting, the nurse crop seeding rate was slightly increased to allow good ground cover to be established after 2 weeks.

In 2015, a no nurse crop control and winter rye nurse crop treatments had comparable marketable tuber yields. In comparison, nurse crops of brown mustard, buckwheat and oats resulted in significantly lower marketable yields than the control and winter rye treatments (Figure 1). We observed that hilling did not control completely nurse crop growth. This resulted in significant competition with the potato crop by oats, brown mustard and buckwheat nurse crops. Additionally, brown mustard and buckwheat plants that were not completely killed went to seed, and may represent a risk of increased weed pressure for the subsequent crop.

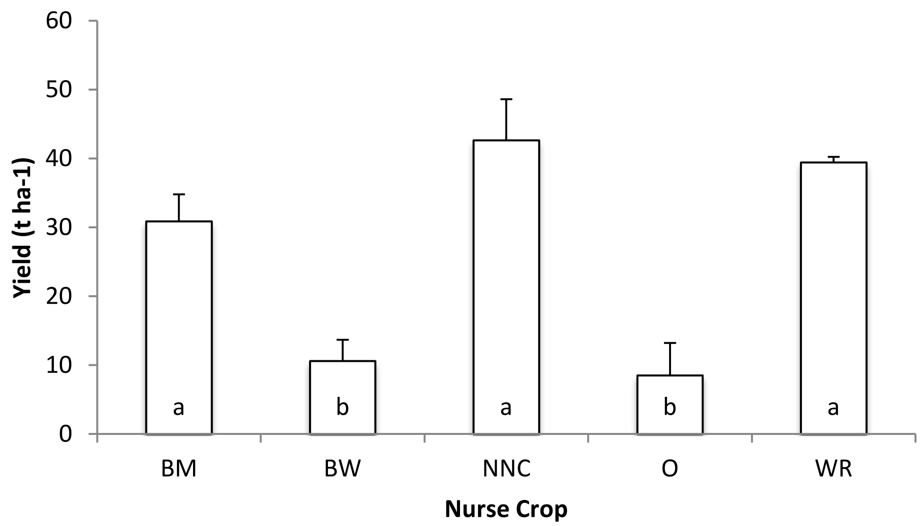

Figure 1. Effect of nurse crop on potato marketable yield. BM, brown mustard; BW, buckwheat; NNC, no nurse crop control; O, oats; WR, winter rye. Columns with different letters are statistically different at 0.05 probability level.

In 2016, marketable (Table 4) and total (data not presented) yield were similar for the winter rye and root max ryegrass nurse crops, and lower for the nurse crops compared with the no nurse crop control. The method of controlling nurse crop growth had no significant effects on total or marketable yield. Therefore, a grass selective herbicide was as inefficient as a mechanical control with hilling in stopping nurse crop growth.

Table 4. Effect of different methods of controlling nurse crop growth and effects of nurse crop grown on marketable yield, specific gravity and total N accumulation before vine senescence in 2016.			
Source of variation	**Marketable yield ($Mg\ ha^{-1}$)**	**Specific gravity**	**Total N accumulation ($kg\ N\ ha^{-1}$)**
Method of controlling nurse crop growth			
Grass selective herbicide	30	1.089	101
Mechanical	28	1.091	110
Nurse crop species			
Control	44a	1.092	154a
Root max annual ryegrass	19b	1.090	77b
Winter rye	24b	1.088	85b
Analysis of Variance			
Method effect	NS	NS	NS
Nurse crop effect	***	NS	****
Method x nurse crop	NS	NS	NS

NS, ***, not significant at 5% probability level and significant at 0.001 probability level

In 2017, there was a significant nurse crop treatment by method to control nurse crop growth interaction on total and marketable yield. Nurse crops of spring barley and winter rye were associated with lower yield than the no nurse crop control when mechanical control or a grass selective herbicide was used to control nurse crop growth (Figure 2). In contrast, there was no significant difference in yield among nurse crop treatments when a non-selective herbicide was used to control nurse crop growth.

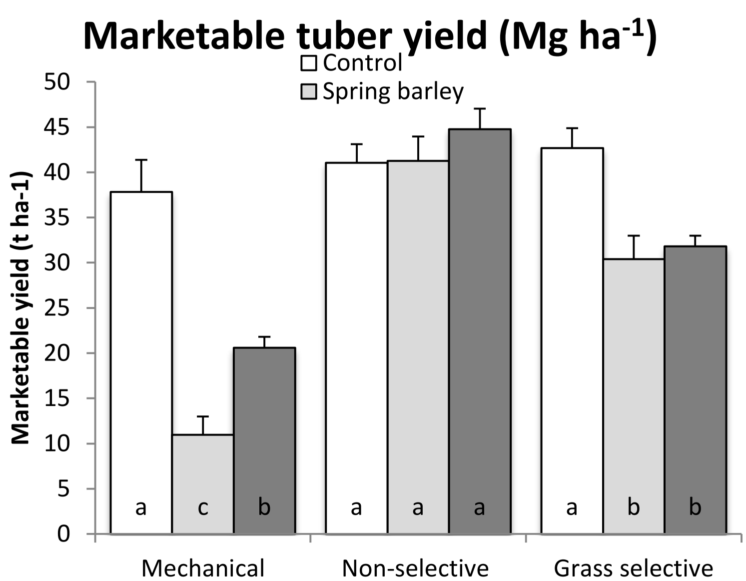

Figure 2. Effects of different methods of terminating nurse crop growth and nurse crop species on potato marketable yield in 2017 at Harrington.

Overall, we have learned that hilling alone is not efficient to stop nurse crop growth, and an herbicide is needed to stop nurse crop growth. Hilling controls very well the nurse crops between potato rows but not those crops on rows. For these reasons, nurse crops that are expected to represent a risk of weed pressure (e.g., brown mustard, buckwheat) for the next crop should not be used. There is a chance to observe a regrowth of the nurse crop when a grass selective herbicide is used, depending on the seeding rate and on the growth stage of the nurse crop. Preliminary results suggest that winter rye and winter barley are suitable candidates to be used as nurse crop, and that a non-selective herbicide is more efficient than the grass selective herbicide in stopping nurse crop growth. Future studies should test different nurse crop seeding rates and different timings to stop nurse crop growth to identify the rate and time that would increase potato yield over a no nurse crop control. A relatively small increase in tuber yield increase would be sufficient to justify the extra cost associated with growing nurse crops, and would protect the soil during this vulnerable period prior to emergence of the potato crop.

*Nurse crop treatments at Harrington Farm in 2017***.**

July 24 - Barley – mechanical control

July 24 - Winter Rye – mechanical control

July 24 - Barley – non selective herbicide

July 24 - Winter Rye – non selective herbicide

iv) Field scale evaluation (PEI)

In 2015, we did not find volunteers who were willing to test nurse crops in commercial fields. In 2016 and 2017, one grower accepted to establish a trial in their field, and the information on the trials is provided in Tables 1 and 2. Given that the nurse crop treatment strips were not replicated, 4 transects within each treatment strip were established and were used as replications. In both years, a grass selective herbicide was used to stop nurse crop growth.

Table 1. Nurse crop trial in commercial field in 2016	
Treatments and seeding rates and dates	
Control	
Winter rye	80 lb/ac
Winter rye	120 lb/ac
All nurse crops were direct seeded before potatoes were planted	
Planting date nurse crop	June 4
Planting date potatoes	June 4
Grass selective herbicide application	
1st application at 33 DAP	Sencor 75 g/ac + Prism 25 g/ac in 25 gallons water
2nd application at 46 DAP	Sencor 125 g/ac+ Prism 25 g/ac in 25 gallons water

Table 2. Nurse crop trial in commercial field in 2017	
Treatments and seeding rates and dates	
Control	
Winter rye	150 lb/ac
Spring barley	200 lb/ac
All nurse crops were direct seeded before potatoes were planted	
Planting date nurse crop	June 12
Planting date potatoes	June 12
Grass selective herbicide application	
One application at 22 DAP	Sencor 150 g/ha + Prism 24 g/ha

In both years, total and marketable yields were not significantly different among nurse crop treatments (Tables 3 and 4). Tuber yields were numerically similar among treatments in 2016. In contrast in 2017, fall rye and barley had 25 and 11% lower marketable yield, respectively, than the no nurse crop control.

Table 3. Effect of nurse crop on total and marketable yield and specific gravity in a commercial field in 2016.			
Treatment	**Total yield ($Mg\ ha^{-1}$)**	**Marketable yield ($Mg\ ha^{-1}$)**	**Specific gravity**
Control	33.1	32.3	1.074b
Winter rye 80 lb/ac	32.3	31.9	1.073b
Winter rye 120 lb/ac	29.7	29.3	1.077a
Analyses of Variance			
Treatment effect	NS	NS	S

Table 4. Effect of nurse crop on total and marketable yield and specific gravity in commercial field in 2017.			
Treatment	**Total yield ($Mg\ ha^{-1}$)**	**Marketable yield ($Mg\ ha^{-1}$)**	**Specific gravity**
Control	61	60	1.089
Spring barley	55	54	1.091
Winter rye	48	47	1.092
Analyses of Variance			
Treatment effect	NS	NS	S

1.3e: Fall tillage and cover crop management to protect soil from wind and water erosion:

i) Fall cover crop screening trial (PEI)

Potato harvest results in significant soil disturbance that exposes soil to erosion, and the lack of a growing crop after harvest increases the risk of leaching of residual soil nitrate during the fall and winter period. Winter cover cropping would be a good option for protecting the soil from erosion and reducing nitrate leaching, but the short growing season and late maturing potato varieties grown represent a challenge to successful winter cover cropping. These trials explored opportunities to grow winter cover crops after potato harvest in Prince Edward Island, with the main objective of identifying the suitable species to be grown, and to examine how late a winter cover crop can be seeded.

The trials were conducted at Harrington Research Farm in PEI. A screening trial was conducted in 2015 to select which winter cover crop species to focus on (Table 1). Three winter cover crop species (winter wheat, winter rye and spring barley) were examined in more detail in 2016 (Table 2) and 2017 (Table 3).

Table 1. Details of winter cover cropping screening trial at Harrington in 2015.
Treatments/seeding rates
Winter rye as a reference (137 lb/ac)
Winter peas (50 lb/ac) + winter wheat (100 lb/ac)
Winter rapeseed (6 lb/ac)
Tillage RootMax annual rye grass (18 lb/ac)
Tillage radish (6 lb/ac) + winter rapeseed (6 lb/ac) + oats (50 lb/ac) + peas (50 lb/ac)
Italian ryegrass (18 lb/ac)
All plots with mixtures were seeded separately
No fertility was added
Early seeding date September 29
Late seeding date October 13

Table 2. Details of winter cover cropping trial at Harrington in 2016.
Treatments/seeding rates
Winter wheat (134 lb/ac)
Winter rye (134 lb/ac)
Spring barley (90 lb/ac)
Control (no winter cover crop)
No fertility added
Early seeding date September 27
Late seeding date October 4
June, top dressing N fertilizer in winter cereal at 100 lb/ac
Cereal harvested August 30

Table 3. Details for winter cover cropping trial at Harrington in 2017.
Treatments, seeding rates and times
Winter wheat (134 lb/ac)
Winter rye (134 lb/ac)
Spring barley (90 lb/ac)
Control (no winter cover crop)
No fertility added at seeding time
Early seeding date September
Late seeding date October 4
Plan to topdress N fertilizer in winter cereal at 100 lb/ac in June 2018

During the screening phase in 2015 at Harrington, two seeding dates were compared: September 29 and October 13. The following species were compared: Italian ryegrass, tillage radish/winter rapeseed/oats/peas; tillage root max annual ryegrass; winter peas/winter rye; winter rapeseed and winter rye (Table 1). We observed a poor emergence for the late seeding date (Figure 1). Only winter rye emergence was not affected by seeding date (Figure 1).

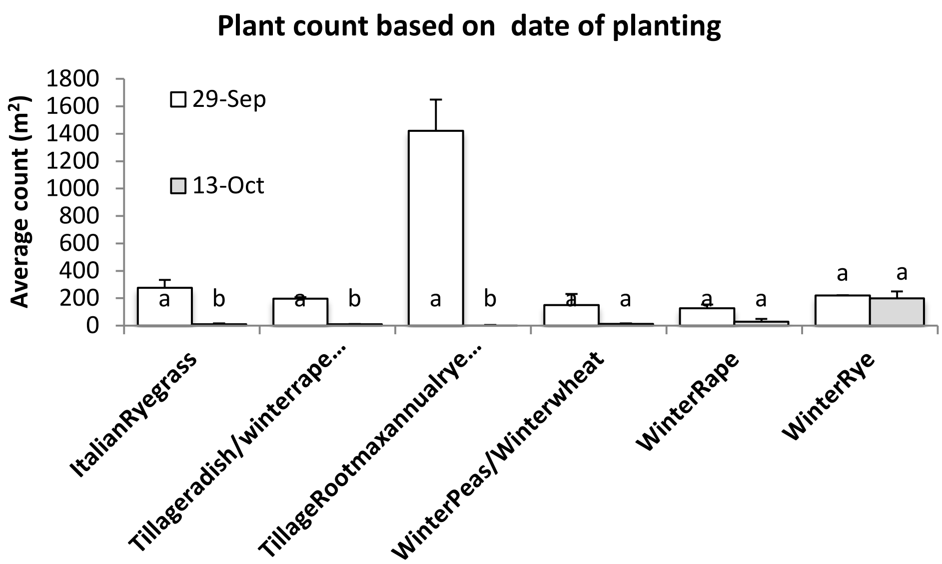

Figure 1. Effects of winter cover crops seeded at two dates on plant counts at Harrington in 2015.

After a discussion with members of the PEI Potato Board, the latest seeding date for trials planted in 2016 and 2017 was set to no later than the first week of October. In 2016, only 4 treatments were compared: spring barley, winter rye, winter wheat and a no winter cover control. Spring barley was included for its fast germination, whereas winter wheat and winter rye represent extra revenue for growers and their winter survival is guaranteed. Based on the plant count, spring barley and winter rye were comparable for early and late seeding dates (Figure 2), whereas plant counts associated with winter wheat seeded late was significantly lower than the early seeding date. No effect of seeding time was observed on winter cereal yield related parameters (Table 4). Grain yield and thousand kernel weight were significantly higher for winter wheat than winter rye, whereas the reverse trend was observed for straw dry matter yield (Table 4).

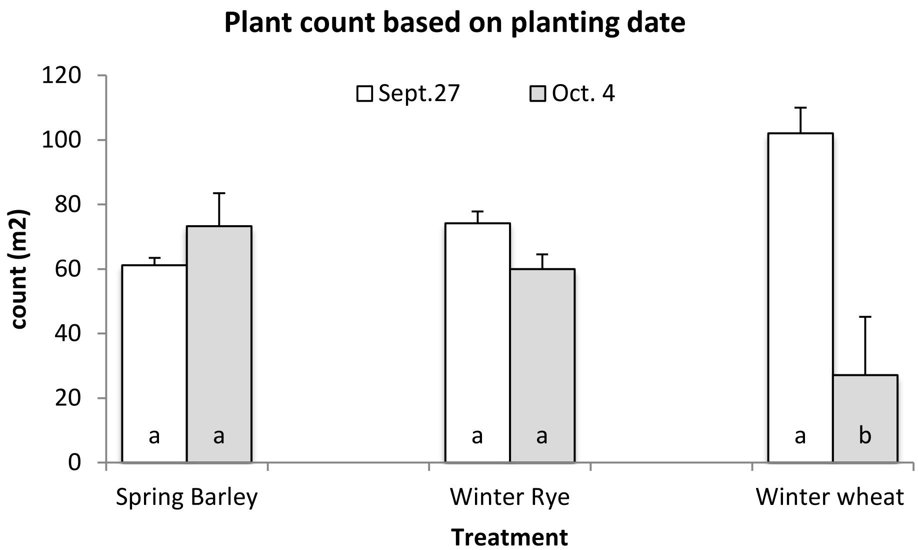

Figure 2. Effect of winter cover crops seeded at two dates on plant counts at Harrington in 2016.

Table 4. Effect of planting dates and winter cover crop species on grain yield, straw dry matter and thousand kernel weight (TKW) in 2016 at Harrington.

Source of variation	Grain yield ($Mg\ ha^{-1}$)	Straw dry matter yield ($Mg\ ha^{-1}$)	Thousand kernel Weight (g)
Seeding time			
Early	5.5	2.8	39b
Late	6.3	3.0	41a
Crop species			
Winter rye	4.9b	3.2a	39a
Winter wheat	6.9a	2.5b	41b
Analysis of Variance			
Seeding date [S]	NS	NS	*
Crop species [C]	**	**	**
S x C interaction	NS	NS	NS

A second cycle of winter cover cropping was established at Harrington in fall 2017 after potato harvest. The same parameters will be measured as for the 2016 trial.

ii) Field scale evaluation of fall cover crops (PEI)

The first trial established in commercial field started in 2016 where a grower had seeded winter rye and winter wheat in two different fields after potato harvest, and where a control strip was included as a control in each field (Table 1).

Table 1. Winter cover cropping trial in commercial field in 2016.
Treatments/seeding rates
Winter wheat (134 lb/ac)
Winter rye (134 lb/ac)
Control
No Fertility added at seeding time on October 4
June 2017, top dressing N fertilizer in winter cereal at 100 lb/ac

Four transects were established across the strips and used as replications. In 2017, the same grower established winter cover cropping but forgot to leave a control strip. Plant counts and fall rye and winter wheat yield are presented in Table 2. Fall rye yield and winter wheat was of 3.2 and of 4.4 Mg ha^{-1} in commercial fields, in comparison with 4.9 and 6.9 Mg ha^{-1} at Harrington for winter rye and winter wheat, respectively.

Table 2. Winter cover crop trial in commercial field in 2016: effect on plant count and total yield.

	Plant count on Oct. 24	**Grain Yield (Mg ha^{-1})**
Fall rye	1280	3.2
Winter wheat	1148	4.4

Table 3. Winter cover crop trial in commercial field in 2016: effect on soil nitrate measured at different periods and on anion exchange membranes (AEM) over winter.

	Soil nitrate concentration at two soil depths on four sampling dates (mg N kg^{-1})								AEM over winter
	Oct. 6, 2016		Nov. 7, 2016		May 8, 2017		Sept. 14, 2017		
Control versus winter rye									
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm	µg cm^{-2} day^{-1}
Control	40.2a	33.4a	13.7a	14.7a	29.2a	20.3a	5.15b	4.4a	0.39a
Winter rye	29.4b	23.6b	10.3a	9.4b	19.8b	11.6b	12.03a	7.8b	0.20b
Control versus winter wheat									
Control	46.6a	39.6a	11.6a	12.5a	35.7a	31.6a	5.3a	5.8	0.87a
Winter wheat	25.9b	24.6b	15.6a	15a	30.8a	24.2b	8.4a	8.1	0.65b

Note: values within a group with different letters are statistically significant at 0.05 probability level.

In both fields seeded to winter wheat and winter rye, we observed a trend towards higher nitrate in the control treatment than with winter cereal (Table 3).

Overall, winter cereals (winter rye or winter wheat) were the most suitable winter cover crops after early potato harvest. Spring barley could represent an interesting option due to its fast germination if the main objective is to establish a ground cover. We observed a trend towards reduced soil nitrate concentrations when winter cover crops were established compared to a no winter cover control, implying that winter cereals are good scavengers of residual soil nitrate after potato harvest and thus could offer economic and environmental benefits to growers. Seeding as early as end of September or by the first week of October would allow good emergence and good yield of winter cereals.

November 7, 2016
Winter Rye

October 24, 2016
Winter Wheat

iii) Fall tillage practices in the forage phase of potato rotations (PEI)

The trial was repeated for a final year on three new fields, each field on a different farm. Each field was split into three plots. On each field the three plots received one of three treatments: 1) mouldboard plow performed in fall, 2) conservation tillage performed in the fall, and 3) conservation tillage performed in the spring prior to planting. As in the previous years, on all fields, the mouldboard plow treatment resulted in less than 2% residue cover, the conservation tillage performed in fall resulted in 12-15% residue cover, and the conservation tillage performed in spring resulted in 12-15% residue cover.

Conservation tillage as performed in this trial resulted in only 12-15% residue cover, which is less than the recommended 30% to result in effective erosion control. Performing the conservation tillage in the fall leaves the soil exposed through winter until the potatoes are planted in spring. Waiting until late fall or early winter as weather permits at least reduces the number of days of exposed soil before snow fall. However, it does mean there is exposed soil during the spring freshet. Waiting until spring to perform the conservation tillage pass results in approximately 80% cover through fall and winter and into spring, including through the freshet. The spring tillage pass typically occurs immediately preceding planting, meaning there are fewer than two days of exposed soil between the forage crop and planting. It is common for the tillage pass to occur on the day of planting.

The low residue cover achieved may be a result of the depth of tillage (producers set the implement as deep as is possible as a rule). A future trial could explore how tillage depth impacts the residue left on the surface.

A small number of fields experienced an increase in scab in the potato year (2017) following the conservation tillage done in spring. It is unclear at this point whether there is a causal effect, but the question is being explored in an upcoming project by Dr. Rick Peters.

Overall, this trial calls into question whether the expense of the implement justifies the result.

iv) Fall tillage in the potato phase of rotations (PEI)

This work included a comparison of options for fall tillage practices after potato harvest to reduce soil erosion over the subsequent fall and winter period. Three options were considered: 1) Lemken Karat with rolling baskets ; 2) Lemken Karat with packing; 3) Custom made chisel plough with paddle wheeled “dammer dyker” wheels.

Two field were established in the fall of 2015. Fall conditions in the fall of 2016 prevented establishment of field sites in that year. No grower collaborators were identified for the fall of 2017.

The following general observations can be taken from this activity:

- The Lemken with the packing wheels demonstrated better erosion control (visually), due to a number of reasons:
    - Greater initial residue after tillage
    - The “roughness effect” was sufficient as to hold more snow on the soil surface
    - The compaction by the rollers seemed to hold the soil better
- The Lemken with the rolling baskets seemed more prone to rill and sheet erosion, probably due to the fact of the looseness of the soil after tillage, and less residue at the surface.
- The modified chisel plough suffered from excess rill erosion, which we have seen in previous studies of dammer dyker technology. Initially, the divots provide good erosion control, but after they fill up with sediment they are relatively ineffective.

- Sections of the field with no treatment showed typical soil erosion losses, with the major contributing factor being loose soil in the potato hills intermixed with compacted tire tracks from trucks and tractors.

Lemken Karat with rolling baskets

Lemken Karat with packing wheels

Custom made chisel plough with paddle wheeled "dammer dykers"

1.3f: Furrow de-compaction to increase potato productivity (NB)

In 2015, a field-scale evaluation of in-furrow de-compaction was conducted on one commercial field. The de-compaction was performed two weeks after planting and to a depth of 20 cm. In 2016, a field-scale evaluation of in-furrow de-compaction was conducted on two commercial fields, using an approach similar to 2015. In 2017, a field-scale evaluation of in-furrow de-compaction was conducted on two commercial fields.

Overall, there was an inconsistent response to in-furrow de-compaction. The response varied from modest increases in tuber yield to modest decreases in tuber yield. It is likely that the potential benefit from in-furrow de-compaction will be very situation specific, where a benefit will be realized only under a certain combination of soil and climate conditions. Thus, like many other tillage practices, this practice is appropriate for site specific zone management, and will vary from year to year depending on conditions.

There is evidence from other projects that soil compaction can be an important yield limiting factor. Rather than de-compaction of furrows, it may be more beneficial to move towards using a controlled traffic approach, particularly at potato harvest, and followed by de-compaction only where the heavy traffic occurred.

1.4: Transfer project findings to producers and encourage producers to adopt new technologies and practices

1.4a: Transfer research findings to grower, industry and the scientific community

Project outputs are listed in a separate document. Outputs from the project will continue to be produced after the end of the project. To date, the outputs include three scientific manuscripts published or submitted, 25 oral or poster presentations at international or national scientific conferences, and 40 presentations at regional meetings or on tours. Five field days were held. There were 22 articles in the print media includes newspapers and trade journals (e.g., SpudSmart, Top Crop Manager).

1.4b: Share the results of the project, in both official languages, with all provincial potato associations

Key findings of the project will be summarized in both official languages and distributed to provincial potato boards across Canada.