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Nitrogen Fertilization of Potato using Management Zone in Prince Edward Island, Canada

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Abstract.

Potato (Solanum tuberosum L.) is sensible to nitrogen (N) and optimal N fertilization improve the tuber yield and its quality. Potato crop N response varies widely within fields. However, uniform application of N fertilizer is still the most common practice under potato production. The spatial variability within a 8.6 ha field was assessed by measuring elevation, soil apparent electrical conductivity and 2017 tuber yield data. Three management zones (MZs) were judged optimal and designated as $MZ1_{Lowproductivity}$, $MZ2_{Midproductivity}$, and $MZ3_{Highproductivity}$. The objective of this study was to compare the uniform N rate application to variable N rate application based on MZs under potato production (i.e., petiole N concentration, tuber yield, and residual soil inorganic). Two treatments were considered : 1) an uniform N application (total: 150 lbs N $acre^{-1}$) i.e. 40 lbs N $acre^{-1}$ at preplanting with ContaiN urease inhibitor plus the 110 lbs N $acre^{-1}$ applied at planting with urea; 2) a variable rate application of three N rates i.e. 20, 40 and 60 lbs N $acre^{-1}$ applied at preplanting with ContaiN in the $MZ1_{Lowproductivity}$, $MZ2_{Midproductivity}$, and $MZ3_{Highproductivity}$, respectively, plus the 110 lbs N $acre^{-1}$ applied at planting with urea. Thirty-five sampling points in the field representing all situations (treatments, N rates and MZs), were selected and fallowed for petiole N concentration, tuber yield and soil inorganic N content. The results of this study indicated that in average the $MZ2_{Midproductivity}$ and $MZ3_{Highproductivity}$ produced 26% more tuber yield compared to the $MZ1_{Lowproductivity}$ in a dry growing season. Increased N rates (20, 40 and 60 lbs N $acre^{-1}$ urea with ContaiN) might have been desynchronized with the need of the crop coupled with dry field conditions that could have delayed the release of N in the soil and limited the N uptake by the plant. This was confirmed by the low petiole NO3-N concentration measured in the $MZ3_{Highproductivity}$ and the N rate 170 kg N $acre^{-1}$. However this low petiole concentration did not seem to limit the tuber yield. The best N rate for the $MZ2_{Midproductivity}$ and $MZ3_{Highproductivity}$ seems to be 150 kg N $acre^{-1}$ under Prince Edward Island pedoclimatic conditions.

Keywords.
Slow release fertilizer, ContaiN, Urea inhibitor, Soil electrical conductivity, Variable rate application.

Introduction

Potato (*Solanum tuberosum* L.) production in Prince Edward Island (PEI) is one of the major contributors to the Canadian economy. During the two last decades, tuber yield decreased and this is a serious concern for the growers. It is well known that the widely adopted uniform fertilization management leads to reduced productivity, sub-optimal use of resources and adverse impacts on the environment (Lajili et al. 2021). Consequently, producers are evaluating the potential of precision agriculture (PA) to increase revenues and protect the environment through the site-specific fertilization management (Ahmad et al. 2020; Karydas et al. 2020).

Nitrogen (N) and water are two major inputs for improving potato growth and yield but a large proportion of the applied fertilizer N is, however, not used by the crop (Clément et al., 2020; 2021). Urea fertilizer is the predominant form of N fertilizer used in PEI, mainly because of its high N content (46%) and lower cost compared to other N fertilizers. However, its alteration from urea to ammonium and then to nitrate is rapid and nitrate can be lost in the environment. Applying an optimal N rate according to the needs of the crop development is required to prevent N loss in the environment. To better synchronize the needs of the crop and the release of nitrate from the fertilizer, some N sources known as slow release N fertilizer such as ContaiN (urea applied with urea inhibitor; Exclusive AgXplore Technologies, Missouri, US) can slow down the transformation of the fertilizer into nitrate form (Cambouris et al. 2014a).

Potato crop N response varies widely within fields. It is also well recognized that significant spatial and temporal variation in soil N availability occurs within crop fields (Cambouris et al. 2014b). However, uniform application of N fertilizer is still the most common practice under potato production. The management zone (MZ) approach based on soil sensing, topography and tuber yield could be helpful to control one part of the spatial variability by delineating areas in the field with the same yield limitation. Consequently, the goal of this paper is to compare the uniform N rate application to the variable N rate application based on MZs in a potato field under PEI pedoclimatic conditions.

Material and Methods

Site description

The 8.6 ha field (46°29`44"N, 63°44`34"W) was located in Kensington, PEI (Fig. 1) and was planted with potato (Prospect, cv.) in 2020. The field was seeded with barley (*Hordeum vulgare* L.) and a mixed of millet (*Pennisetum glaucum* L.) and sorghum (*Sorghum x drummundii*) in 2018 and 2019, respectively. The main soil series identified in the field was Charlottetown (Fig. 2) and was classified as Orthic Humo-Ferric Podzol (Soil Classification Working Group 1998). The soil series has a good moisture-holding capacity and is well drained. Soil texture analysis of the field varied from sandy loam to loamy sand and the pH ranged from 5.3 to 6.7 (average 6.0).

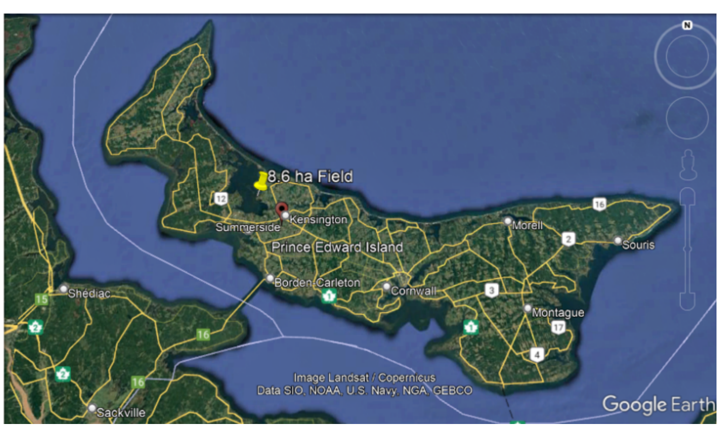

Fig. 1 : Field location (Source : Google Earth®).

Management Zone Description

The spatial variability within the field was previously assessed in August 2019 by measuring elevation and soil apparent electrical conductivity (EC_a) at two different depths (EC_aS: 0-30 cm; ECaD: 0-100 cm; Fig. 3a & b) using soil proximal sensors (VERIS-3100). Yield data of 2017 from the yield monitor was also used to study the spatial variability of the potato crop (Fig.3c). Three MZ (designated at $MZ1_{Lowproductivity}$, $MZ2_{Midproductivity}$, and $MZ3_{Highproductivity}$) were delineated based on soil EC_aS, EC_aD and 2017 yield monitor data using ISODATA function of ArcGIS (Fig. 4a). In average, the $MZ1_{Lowproductivity}$ was located in the area with the lowest altitude, ECaS, ECaD and yield; in contrary, the $MZ3_{Highproductivity}$ was located in the area with the highest altitude, ECaS, ECaD and yield (Table 1).

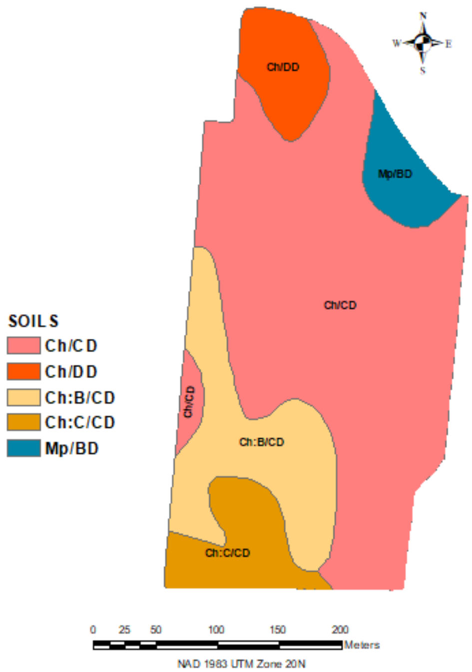

Fig. 2 : Map of the soil series (*Source: CANSIS: https://sis.agr.gc.ca/cansis/nsdb/dss/v3/index.html*). The letters B and C on the numerator indicate a moderately well-drained soil and presence of bedrock less than 50 cm deep, respectively. The first letters B, C, D on denominator correspond to the slope inclination (%) whereas the second letter on denominator corresponds to the dominant soil texture (i.e. D: loamy sand).

Table 1. Descriptive statistics of the elevation, soil apparent electrical conductivity at two different depths (ECaS: 0-30 cm; ECaD: 0-100 cm) and the 2017 yield monitor data for the three management zones (MZs).

	MZs	n	Min	Max	Mean	STD	CV (%)
Elevation (m)	1	711	5.20	8.68	6.33	0.65	10.3
	2	553	7.21	11.28	9.14	0.89	9.7
	3	2275	9.85	13.59	11.96	0.67	5.6
ECaS (mS/m)	1	737	0.5	2.4	1.22	0.33	27.0
	2	1943	0.7	3.1	1.86	0.27	14.5
	3	801	1.2	4.1	2.83	0.53	18.7
ECaD (mS/m)	1	659	0.3	3.2	0.98	0.46	46.9
	2	1509	0.3	3.6	1.90	0.43	22.6
	3	1028	0.7	3.8	2.73	0.51	18.7
Yield_2017 (t/ha)	1	1472	17.9	42.9	27.8	4.04	14.5
	2	4567	19.1	54.3	37.8	2.87	7.6
	3	2416	35.0	55.9	45.1	3.36	7.4

a) b) c)

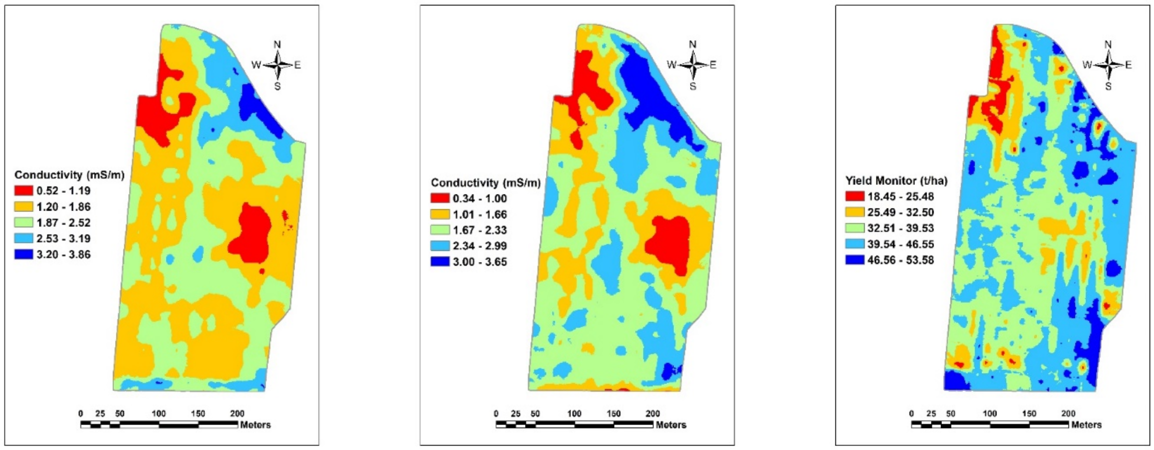

Fig. 3 : Spatial variability maps of the soil apparent electrical conductivity [a) ECaS and (b) ECaD] and (c) 2017 tuber yield monitor.

Experimental design

In spring 2020, the field experiment was laid out into a generalized randomized block design of two treatments and four blocks (Fig. 4b). The two treatments consisted in 1) a uniform N rate application 150 lbs N acre^{-1}) i.e. 40 lbs N acre^{-1} at preplanting with ContaiN urease inhibitor plus the 110 lbs N acre^{-1} applied at planting with urea; 2) a variable rate application of three N rates i.e. 20, 40 and 60 lbs N acre^{-1} applied at preplanting with ContaiN in the MZ1$_{Lowproductivity}$, MZ2$_{Midproductivity}$, and MZ3$_{Highproductivity}$, respectively, plus the 110 lbs N acre^{-1} applied at planting with urea. Potato Prospect *cv.* was planted. Sampling points (35 SP) were selected to capture all different situations represented in the field and used to evaluate in-season plant N status and soil residual N as well as 3 m tuber harvest test at the end of the season [135 days after planting (135DAP)]. A yield monitor (Greentronics) was also used to obtain the potato yields at harvest (142DAP).

a) b)

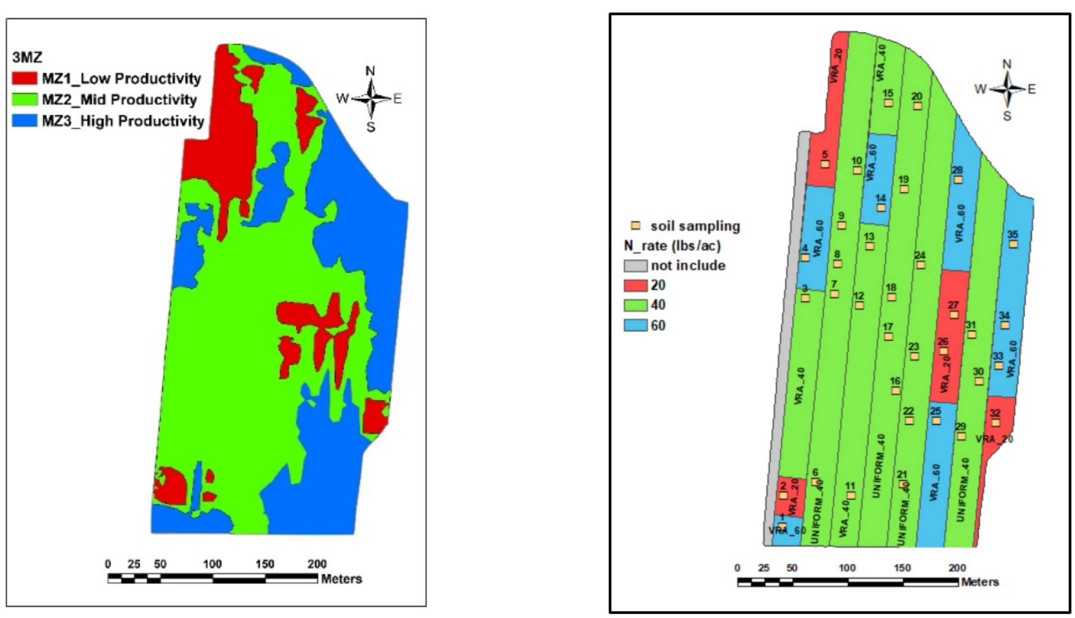

Fig. 4 : Maps of the a) delineation of the three management zones (MZ) and b) experimental design showing the variable N application rates (20, 40 and 60 lbs acre^{-1}, N source (urea mixed with ContaiN) applied at preplanting in the uniform and variable N rate application (VRA) treatments.

Plant and soil sampling analysis

Petiole samples were collected twice during the growing season (62DAP and 77DAP) to determine the plant N status of the crop at all SP and analyzed for nitrate concentrations as described in Zebarth et al. (2012). Briefly, the 4th leaf on the potato stem was collected randomly from 20 plants around a 3 m diameter around the SP and all leaflets were removed and then samples were oven dried at 60°C. Petiole samples were ground to pass a 2 mm mesh screen and the NO3-N content in the plant extracts were quantified with a continuous-flow injection auto-analyzer (QuickChem 8000 FIA+analyzer, Lachat Instruments, Loveland, CO, USA).

Composite soil samples for 0-15 cm and 15-30 cm were collected just after the 3 m tests for tuber yield to determine the soil residual inorganic N (135DAP). Each sample consisted of four soil cores collected randomly within 1.5 m radius around each SP with a 1 inch diameter Dutch auger. Soil NO3-N and NH4-N were extracted with 1 M KCl (1:10 soil: extractant ratio, 30 min shaking time). The NO3 and NH4 concentrations in the soil extracts were quantified with a continuous-flow injection auto-analyzer (QuickChem 8000 FIA+analyzer, Lachat Instruments, Loveland, CO, USA).

Yield Measurements

The 3 m harvest tests for tuber yield were done at 135DAP at all SP and consisted to dig all potato tubers from one row on 3 m length. The mechanical potato harvest was done with the yield monitor on October 7, 2020 (variable referred as tuber yield monitor; 142DAP). The 3 m tests were used to determine total tuber yield. Marketable yield was calculated as total yield minus culls (tubers too small or with external defects). Kriging interpolation method was performed with the yield monitor data measurements using the “Geostatistical Wizard” ArcGIS tool. Then, the kriged resulting map was converted into raster map using the “GA Layer to Grid” ArcGIS tool. This raster map was circumscribed to the field contour using the “Extract by mask” ArcGIS tool. The spatial resolution of the resulting raster map was 1 m^2. Finally, the tuber yield (t ha^{-1}) was extracted within 2 m radius around each SP using the ‘’Extract values to points’’ ArcGIS tool.

Data Analysis and Statistics

Statistical analyses of NO3-N at two periods (66DAP and 77DAP), NO3-N and NH4-N measured at harvest as well as all variables related to the tuber yield were performed with PROC MIX in SAS. The model was a generalized completed block design. The treatments [uniform and variable rate application (VRA)] and the MZ were considered as fixed effects and the blocks as a random effect. In addition to that, all comparisons were done with *a priori* contrast. A Pearson correlation analysis was also performed to identify the relationships between the tuber yield from the yield monitor and the 3 m harvest tests.

Result and discussion

Climatic conditions

The 2017 and 2020 seasons were drier than the 30-year average. In 2017, the months of June to August and October were particularly dry whereas in 2020, it was, the months of May to July (Table 2). Total precipitation for the 2017 and 2020 growing seasons was 413 mm and 378 mm, respectively compared to 537 mm for the 30 year average. In general, the 2017 and 2020 mean air temperature was also higher than the 30 year average.

Table 2. Mean air temperature (°C) and total precipitation (mm) per month in 2017 and 2020 compared with the 30-year average (1981–2010) in Summerside, Prince Edward Island (46°26'28''N, 63°50'17''W).

	Mean air temperature (^{O}C)			Total precipitation (mm)		
Month	2017	2020	30 years	2017	2020	30 years
May	10.0	9.16	9.50	148.4	59.0	94.9
June	15.7	16.35	14.70	69.0	16.7	91.3
July	19.2	19.78	19.20	25.6	31.6	74.1
August	18.6	20.14	18.60	45.1	95.0	92.7
September	15.8	14.61	14.10	79.5	92.0	96.8
October	11.5	8.98	8.40	45.4	83.4	87.0

Summerside, PEI: (Environment and Natural Resources, Canada, #8300596)

Petiole N Status

Petiole nitrate concentrations are commonly used to establish the plant N status of the crop. Specific standard curve for petiole NO3-N concentration for Prospect cultivar does not exist. However, the average petiole NO3-N concentration determined at 62DAP and 77DAP was 20797 ppm and 22280 ppm, respectively for the entire field. At 62DAP, a significant effect of the MZs (Fig. 5a), a quadratic relationship between the N rates in the VRA treatment (Fig. 5b) and a strong tendency for the interaction MZ*N_rate*TRT (Fig. 6) were observed. In fact, petiole NO3-N concentration in the $MZ1_{Lowproductivity}$ and $MZ2_{Midproductivity}$ presented a higher concentration that in the $MZ3_{Highproductivity}$. This was also observed in the $MZ3_{Highproductivity}$ for each treatment but the difference was more obvious in the $MZ3_{Highproductivity}$ with the N rate 170 lbs acre^{-1}. Porter and Sisson (1991) demonstrated that, around 77DAP, the petiole NO3−N concentration showed strong relationship with the nitrogen rate regardless of cultivars, growing season, and cropping system. However, in our case study, petiole NO3-N concentration seems to be affected by the proportion of the N rate mixed with the ContaiN applied to the $MZ3_{Highproductivity}$. At 77DAP, only significant effect was observed with the MZs. The concentration of petiole NO3-N in the $MZ1_{Lowproductivity}$ (24470 ppm) was higher than the one measured in the $MZ2_{Midproductivity}$ (20255 ppm). In general, the petiole NO3-N concentration measured at the potato tuber bulking stage (around 77DAP) is considered sufficient at a value > 15000 ppm (Westermann, 1993). In our case study, the lowest NO3-N concentration measured was 17711 ppm for all situations (MZs, treatments and N rates) at 77DAP.

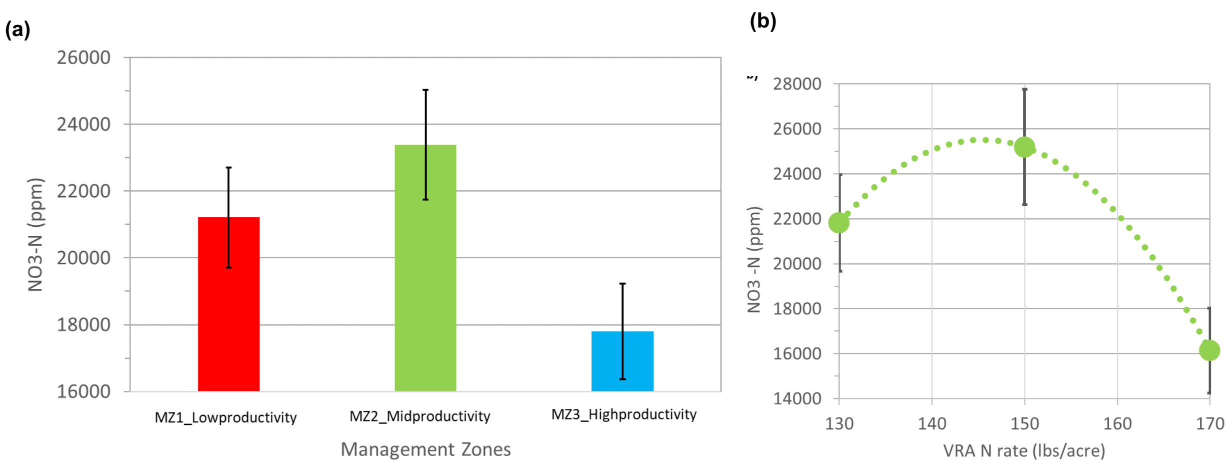

Fig 5. Effect of (a) the management zone on the petiole NO3-N concentration (NO3-N ppm) and (b) the quadratic effect of the N rate in the variable rate application (VRA) treatment at 62 days after planting on the petiole NO3-N concentration (NO3-N ppm).

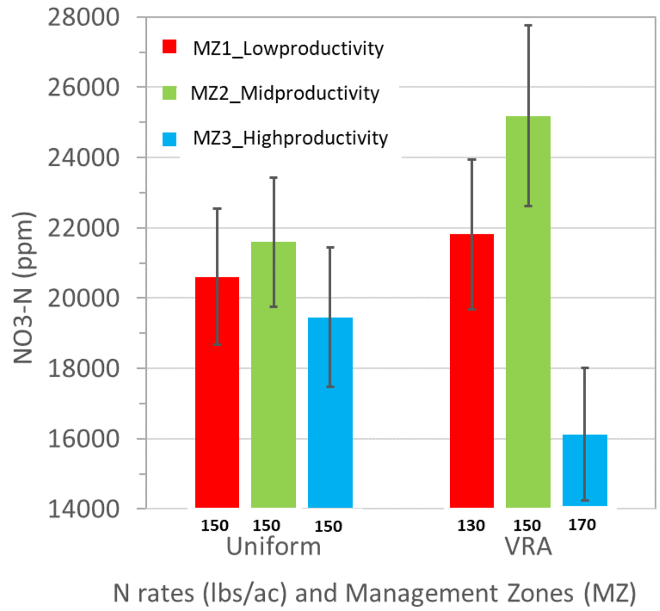

Fig. 6. Effect of the management zones and the N rates in the uniform and variable rate application (VRA) treatments on the petiole NO3-N concentration (NO3-N ppm) at 66 days after planting.

Potato tuber yield

The tuber yield monitor and the total yield from the 3 m harvest test shown a significant correlation (r= 0.71). The significant effects obtained with the data from the yield monitor reflected the observed effects in the total and the marketable yield (Table 2). The increasing N rates in the VRA treatment increased linearly with tuber yield. The tuber yield from $MZ3_{Highproductivity}$ and $MZ2_{Midproductivity}$ was significantly higher than the one observed in the $MZ1_{Lowproductivity}$. In average the $MZ3_{Highproductivity}$ and $MZ2_{Midproductivity}$ tuber yield difference was 7.8 t ha^{-1} compared the tuber yield in the $MZ1_{Lowproductivity}$ (Fig. 7). This difference might be attributed to the better soil growing conditions for the potato in these two MZs (higher average ECaS and ECaD). Soil ECa is linked to the soil humidity and the soil texture (McCutcheon et al. 2006). The higher was the ECa, the better was the growing conditions for potato (Cambouris et al. 2006) and this is especially true for a dry growing season because tuber potato production needs high quantity of water.

Table 2. Multiple comparison results (Pr>F) done with *a priori* contrast on 3 m tuber yield (total and marketable) and tuber yield from the yield monitor (tuber yield monitor) at season 2020.

A priori contrasts	--------------------Tuber Yield----------------------		
	Monitor	Total	Marketable
	Pr>F	Pr>F	Pr>F
$MZ1_{Lowproductivity}$ vs $MZ2_{Midproductivity}$	**0.0020**	**0.0867**	**0.0927**
$MZ1_{Lowproductivity}$ vs $MZ3_{Highproductivity}$	**0.0006**	**0.0680**	**0.0674**
$MZ2_{Midproductivity}$ vs $MZ3_{Highproductivity}$	0.4711	0.8817	0.8409
N_rate=130 vs N_rate=150 (TRT=V)	**0.0044**	**0.0584**	**0.0439**
N_rate=130 vs N_rate=170 (TRT=V)	**0.0027**	**0.0294**	**0.0286**
N_rate=150 vs N_rate=170 (TRT=V)	0.8751	0.9225	0.9641
TRT=U vs TRT=V (N_rate=150)	**0.0215**	0.2708	0.2407
N linear (TRT= V)	**0.0027**	**0.0294**	**0.0286**
N quadratic (TRT=V)	**0.0539**	0.2636	0.2036

Significant at P = 0.10 and less in bold.

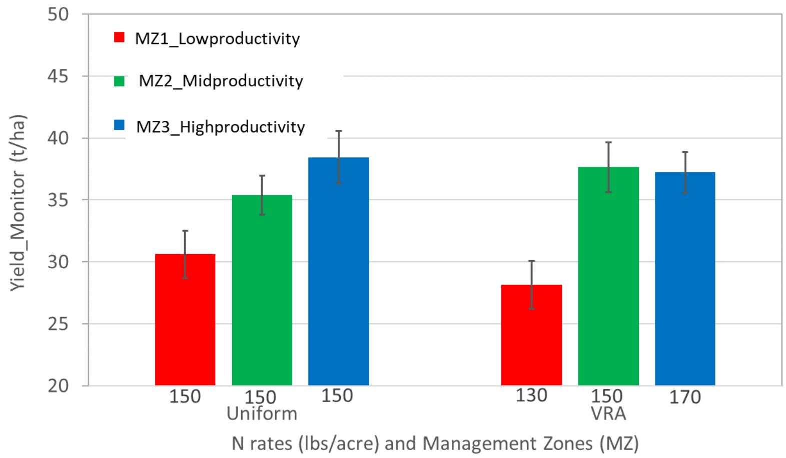

Fig. 6. Effect of the management zones and the N rates in the uniform and variable rate application (VRA) treatments on the tuber yield monitor.

Residual soil N at Harvest

The concentrations of NO3-N and NH4-N measured at 135DAP in the layers 0-15 and 15-30 cm were not significant in the MZs, treatments, N rates or for any interaction. In average, NO3-N concentrations of 27.1 and 23.8 mg kg^{-1} were observed for the 0-15 and 15-30 cm layers, respectively. For the NH4-N concentrations, the average was 7.4 and 11.0 mg kg^{-1} for the 0-15 and 15-30 cm layers, respectively. Based on an average bulk density of 1.36 g cm^{-3} for the Charlottetown soil series, the soil mineral N content was estimated at 140 kg N ha^{-1} in the 0-30 cm soil layer. This quantity was about the double of the average residual soil N of 67.5 kg N ha^{-1} measured in similar soil conditions (e.g. same soil series, PEI location, 150 lbs N $acre^{-1}$; Liang et al. 2019). In this PA study, the uniform or VRA treatments left a high inorganic N concentration in the 30 cm top layer that can be leached after harvest.

Conclusion

High precision data from soil ECa and 2017 tuber yield made it possible to delineate three MZs that reflected the productivity of the field, *i.e.* low, mid and high productivity. The dry climatic conditions may have slowed soil N release from fertilizer and soil mineralization as well as crop uptake and minimized the effect of the highest rate in the $MZ3_{Highproductivity}$. Further studies using the proposed AP approach should be done to confirm the impact of the VRA of a slow release fertilizer applied at preplanting with other growing seasons in the PEI pedoclimatic conditions.

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