Evaluating Remote Sensing Based Adaptive Nitrogen Management for Potato Production

Brian Bohman, Carl Rosen, and David Mulla

Department of Soil, Water, and Climate, University of Minnesota, St. Paul MN

A paper from the Proceedings of the
14th International Conference on Precision Agriculture
June 24 – June 27, 2018
Montreal, Quebec, Canada

Abstract. *Conventional nitrogen (N) management for potato production in the Upper Midwest, USA relies on using split-applications of N fertilizer or a controlled release N product. Using remote sensing to adaptively manage N applications has the potential to improve N use efficiency and reduce losses of nitrate to groundwater, which are important regional concerns. A two-year plot-scale experiment was established to evaluate adaptive N-management using remote sensing compared to conventional practices for Russet Burbank variety potatoes grown on an irrigated, coarse-textured soil in Becker, MN. Nitrogen treatments included (Control) a 45 kg N/ha control treatment, (270 Split) a split-applied urea treatments of 270 kg N/ha, (270 CR) a controlled-release polymer coated urea [PCU] treatments of 270 kg N/ha, and (VR Split) a variable-rate split-applied urea treatment based on remote sensing observations using the MERIS Terrestrial Chlorophyll Index [MTCI] interpreted using the Nitrogen Sufficiency Index [NSI]. Using the CROPSCAN MSR-16R ground-based multispectral radiometer, spectral reflectance measurements were collected weekly during the growing season to monitor crop N status in the variable rate treatment (VR Split) and calculate NSI with 270 CR as the “well-fertilized” reference. If the NSI value immediately prior to scheduled fertilizer application was less than 0.95, then N-fertilizer was applied to VR Split at a rate of 22 kg N/ha. The variable-rate treatment (VR Split) received 248 and 226 kg N/ha in 2016 and 2017 respectively, which is 22 and 44 kg N/ha less than the conventional N management practices (270 Split, 270 CR), and there were no significant differences in the quantity or quality of tuber yield between these treatments. This study demonstrates that adaptive N management using remote sensing is a promising method to optimize N rate and timing to account for spatial and temporal variability in crop N status for potato production.*

Keywords. *Nitrogen sufficiency index, remote sensing, adaptive management.*

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Introduction

The environmental impact of irrigated agriculture on groundwater resources in the Upper Midwest states of Minnesota, Wisconsin, North Dakota, and Michigan has been and continues to be a major area of concern. A small, but significant, fraction of total crop acres, 1% (ND) to 8% (MI), in the Upper Midwest are irrigated (NASS, 2012) – when water sensitive crops, such as vegetables, are grown on sandy soils in humid climates, transient water stress can occur between precipitation events and can reduce yield necessitating supplemental irrigation (Shock, et al., 2007). The management of irrigation has important environmental consequences – improperly applied irrigation can drive percolation below the root zone and the leaching of nitrate into groundwater (Hergert, 1986, Martin, et al., 1991, Quemada, et al., 2013). Surficial sandy aquifers are susceptible to nitrate contamination (Adams, 2016, Best, et al., 2015); when contaminated with nitrate above the EPA designated maximum contamination limit [MCL] of 10 mg N/L, drinking water from these aquifers poses a human health risks (US EPA, 2009). The MCL for nitrate is often exceeded in areas with vulnerable soils and intensive agricultural activity (MDA, 2015, MDH, 2017). Removing nitrate from drinking water is expensive for private well owners, \$130 – \$360 per household per year, and public water suppliers, \$59 – \$2,224 per household per year, with a total cost across Minnesota estimated at \$6 million per year (Keeler, et al., 2016, Lewandowski, et al., 2008).

Potato is an important specialty crop grown in the Upper Midwest with a small geographic footprint ranging from 17,800 ha (MI) to 31,600 ha (WI) but a large economic impact with a production value of \$857 million per year (NASS, 2013). However, potato grown in the Upper Midwest has high nitrogen [N] requirements (Rosen and Bierman, 2008), is especially sensitive to water stress (Shock, et al., 2007), and between 36% (ND) and 100% (WI) of potato production uses supplemental irrigation (NASS, 2013). This leads to conditions that are primed for driving nitrate leaching (Kraft and Stites, 2003) and high rate of groundwater use (Nocco, et al., 2017) leading to public concerns about groundwater quality and quantity.

A key strategy to address contamination of groundwater with nitrate and the responsible use of groundwater resources is developing improved irrigation and nitrogen management practices for producers (Alva, 2010, Meisinger and Delgado, 2002, Quemada, et al., 2013, Zebarth and Rosen, 2007). Nitrogen management in potato is typically conducted with either multiple split-applications with roughly two-third of fertilizer (i.e. urea) applied at emergence and 4 or more fertigation applications throughout the growing season, or as a single application of controlled release fertilizer at emergence. A new approach to manage nitrogen in potato production would be to use remote sensing to determine when a fertigation application is necessary in a split-application system. Using remote sensing to calculate the Nitrogen Sufficiency Index [NSI] and determine the timing of fertigation applications will reduce total fertilizer application rate without negatively impact tuber yield or quality. The objective of this study was to compare agronomic outcomes from nitrogen management using remote sensing based NSI to conventional nitrogen management practice.

Materials and Methods

A plot-scale field experiment was conducted in 2016-17 on irrigated plots at the Sand Plain Research Farm [SPRF] in Becker, MN (45º 23’ N, 93º 53’ W). Mean temperature at this station is 7.1 ºC and mean annual precipitation is 31.9 mm (Arguez, et al., 2010). The soil at this station was characterized as a Hubbard loamy sand (Sandy, mixed, frigid Entic Hapludolls) and excessively well drained with low available water holding capacity of 0.098 cm cm-1 for 0-90 cm depth (Hansen and Giencke, 1988, Natural Resources Conservation Service, 2013). Russet Burbank potato, a processing variety common to the region, was grown each year following a previous crop of rye. Pre-plant soil samples were collected at 0-15 cm and analyzed for standard macro- and micro-nutrient content (Nathan and Gelderman, 2015) and collected at 0-60 cm to be analyzed for inorganic N content using conductimetric analysis (Carlson, et al., 1990) (Table 1). Apart from experimental nitrogen and irrigation treatments, all management and cultural practices were managed by the staff at the SPRF in accordance with common practices for the region (Egel, 2017) and other macro-nutrients were applied based on soil samples and University recommended methods. A weather station (Campbell Scientific, Logan, UT) located at the SPRF recorded measurements of precipitation, maximum and minimum temperature, solar radiation, relative humidity, and wind speed every hour.

Table 1. Soil properties before spring planting

	0–15 cm				0–60 cm	
Year	pH	OM	Bray-P	K	NO_3^-–N	NH_4^+–N
		%	mg kg^{-1}			
2016	5.9	1.8	34	136	2.0	1.3
2017	6.1	1.9	35	165	2.3	1.0

This study was established as a randomized complete block design with a split-plot restriction on randomization and four replicates. Irrigation rate and timing was the whole plot treatment (with two treatments) and nitrogen rate, source, and timing as the sub-plot treatment (with six treatments). Each replicate was separated by a 15.2 m buffer of rye and irrigation blocks within replicates are separated by a 9.1 m buffer alley. Experimental plots were 6.4 m wide (7 x 0.9 m rows) and 6.1 m long with an additional 1.5 m buffer for plots located at the edge of the irrigation block. A 3.1 m buffer separated split-plots within whole plots that were co-located in the same set of 7 rows. Whole "B" seeds were planted on 22 April 2016 and 29 April 2017 with a one-foot spacing between seeds. Vines were killed with a mechanical flail mower on 14 September 2016 and 13 September 2017 and tubers were mechanically harvested from rows 4 and 5 on 30 September 2016 and 27 September 2017.

Irrigation was managed using methods common for the region (Steele, et al., 2010, Wright, 2002) by the staff at the SPRF for an available water holding capacity of 4.6 cm over a rooting depth of 60 cm and management allowable depletion of 30%.

Nitrogen treatments included (Control) a 45 kg N/ha control treatment, (270 Split) a split-applied urea treatments of 270 kg N/ha, (270 CR) a controlled-release polymer coated urea [PCU] treatments of 270 kg N/ha, and (VR Split) a variable-rate split-applied urea treatment based on remote sensing observations paired with the Nitrogen Sufficiency Index [NSI] (Blackmer and Schepers, 1995) with 270 CR as the well-fertilized reference (Table 2). Fertilizer at planting was diammonium phosphate applied uniformly to all N-treatments at a rate of 45 kg N/ha. Emergence fertilizer was urea for 270 Split, and VR Split and Environmentally Smart Nitrogen (Agrium Inc., Calgary, AB) for 270 CR at various rates. Treatment 270 Split received four scheduled post-hilling applications of UAN-28 in the form of simulated fertigation on a 1- to 2-week basis.

Table 2. Rate and timing of nitrogen (N) fertilizer treatments

	2016	22 Apr	1 June	23 June	14 July	21 July	27 July	
	2017	29 Apr	30 May	28 June	10 July	20 July	27 July	
		Planting	Emergence	Post-Emergence				Total
Nitrogen		kg. N ha^{-1}						
Control		45 DAP	-	-	-	-	-	45
270 Split		45 DAP	135 Urea	22 UAN	22 UAN	22 UAN	22 UAN	270
270 CR		45 DAP	225 ESN	-	-	-	-	270
VR Split		45 DAP	135 Urea	?	?	?	?	?

Weekly measurements of multispectral reflectance (MSR-16R, CROPSCAN, Inc., Rochester, MN) were used to calculate the MERIS Terrestrial Chlorophyll Index [MTCI] (Dash and Curran, 2004), which had previously been identified as best able to detect N-stress in potato (Nigon, et al., 2015). Remote sensing data was collected on a weekly basis on 10 dates between 21 June 2016 and 24 August 2016 and on 11 dates between 1 June 2017 and 23 August 2017. Four subsamples were collected from each plot at a height of 1.8 m, giving a diameter of view of approximately 0.9 m. Post-hilling fertilizer applications in the form of 22 kg N/ha of UAN-28 were applied as simulated fertigation to N6 when the NSI value was less than 0.95 prior to the scheduled application date (Table 3).

Table 3. Nitrogen Sufficiency Indices

Index		Formula[†]	Source
MERIS Terrestrial Chlorophyll Index	MTCI	$\frac{R_{751}-R_{713}}{R_{713}-R_{676}}$	Dash and Curran (2004)
Nitrogen Sufficiency Index	NSI	$\frac{VI_{N(i)}}{VI_{270\ Split}}$	Peterson *et al.* (1993)

[†] R_n indicate % Reflectance of given wavelength [nm] of light

Harvested tubers were mechanically sorted into weight classes (0-85 g, 85-170 g, 170-284 oz., 284-397 oz., and >397 oz.) and graded (US No. 1 and No. 2) (USDA, 1997). A subsample of harvested tubers was then evaluated for scab infection, hollow heart internal defects, and specific gravity. Response variables to be assessed include total tuber yield, Grade A tuber yield, ratio of misshapen tubers, ratio of tubers greater than 170 g, ratio of hollow heart defects, and tuber specific gravity.

Statistical analysis was conducted using SAS PROC GLIMMIX (SAS Institute, 2013) to test the fixed effects of study year, irrigation treatment, nitrogen treatment, and their interactions. The overall significance, and multiple comparisons between treatments were conducted for each response variable with significance set at $P < 0.10$, and protected multiple comparisons between treatments were conducted with significance set at $P < 0.05$ for each response variable with a significant overall effect.

Results and Discussion

Remote Sensing and Variable Rate N Treatment

Overall, remote sensing using CROPSCAN could identify significant differences between N-treatments. Remote sensing measurements of VR Split N-treatment taken prior to scheduled post-emergence fertilizer applications were below the 95% NSI threshold using MTCI on 2 dates in 2016 and 2 dates in 2017 (Figure 1). Following these dates, 22 kg N/ha were subsequently applied to the VR Split treatment on those applications dates (Table 4). There was one exception – on the fourth application date in 2016, fertilizer was applied to VR Split although the NSI value using MTCI was not less than 95%. This decision was made to apply fertilizer at this time because there would be no subsequent opportunities to apply N-fertilizer and it was expected that the NSI value would drop below 95% within a few days following the scheduled fertilizer application date. In total 3 post-emergence N-fertilizer applications were applied to VR Split in 2016. Relative to the 270 Split treatment, N fertilizer application rate for the VR Split treatment was reduced by 22 and 44 kg N/ha in 2016 and 2017, respectively.

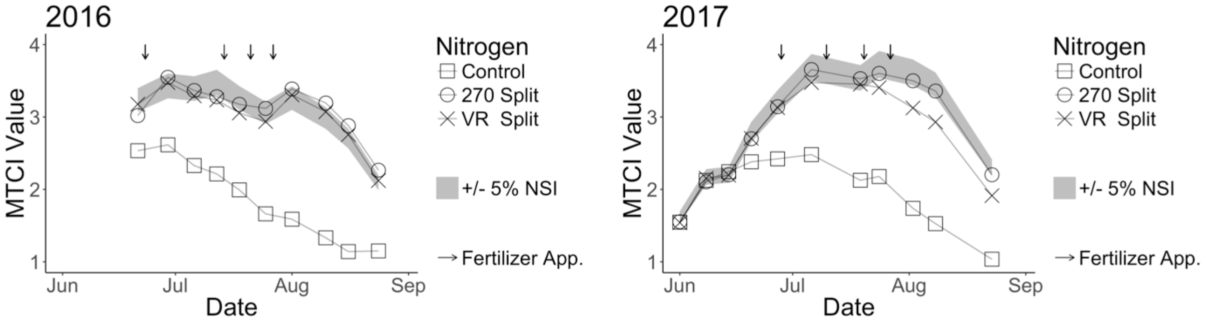

Figure 1. Crop N-status evaluated using the MTCI calculated from the CROPSCAN and NSI

Table 4. Monitoring in-season crop N-status for main effect of VR Split N-Treatment

Decision Date	2016				2017			
	23 June	14 July	21 July	27 July	28 June	10 July	20 July	27 July
Fertilizer Applied to VR Split	kg N/acre							
	0	22	22	22	0	22	0	22
CROPSCAN	21 June	12 July	18 July	25 July	27 June	6 July	19 July	24 July
	NSI Value							
MTCI	0.9818[†]	**0.9303**	**0.9359**	0.9602	0.9745	**0.9430**	0.9756	**0.9141**

[†] **Bold** values indicate an identified N-deficiency for a given VI on a given date. Shaded values indicate that a fertilizer application was made on the corresponding decision date.

Tuber Yield and Quality

Significant differences in total yield and Grade A yield were observed as a response to N treatment (Table 5). As expected, the Control treatment resulted in significantly less tuber yield compared to the fertilized treatments. The interaction of Year x Nitrogen was significant for both Total and Grade A yield, which is attributable to a greater tuber yield from the Control treatment in 2017 compared to 2016. There was no significant difference in either total or Grade A yield between the controlled-release and split-applied N treatments. The total and Grade A yield of the variable rate N treatment were not significantly different from the conventional best management practice N treatments. Significant differences in the ratio of tubers greater than 170 g were observed in response to Nitrogen and Year. Tuber size was larger in 2017 than 2016; additionally, the Control treatment had significantly smaller tubers compared to the fertilized treatments. There was no significant difference in the proportion of tubers greater than 170 g between the controlled-release and split-applied N treatments. The ratio of tubers greater than 170 g for the variable rate N treatment was not significantly different from that of the conventional best management practice N treatments. Significant differences in the ratio of misshapen tubers were found in response to Nitrogen and Year. The Control treatment had significantly more misshapen tubers than the fertilized treatments and the Source of N fertilizer caused significant differences with the CR treatments having fewer misshapen tubers than the Split treatments. More tubers were misshapen in 2016 than 2017. The interaction of Year x Nitrogen was significant for misshapen tubers which is attributable to a greater proportion of misshapen tubers yield from the control treatment in 2017 compared to 2016.

Table 5. Tuber Yield and Quality

		Total Yield	Grade A Yield	Tubers > 170 g	Misshapen Tubers
Year		Mg ha^{-1}		%	
2016		68.8	64.4	72.1 B[†]	35.4 A
2017		68.1	66.4	82.9 A	17.2 B
Nitrogen					
Control		54.2 B	50.9 B	62.2 B	31.1 A
270 Split		73.4 A	70.3 A	81.6 A	26.7 B
270 CR		71.5 A	68.5 A	81.6 A	24.0 B
VR Split		72.2 A	69.5 A	82.3 A	25.3 B
Main Effect	Year [Y]	[‡] –	–	***	***
Main Effect	Nitrogen [N]	***	***	***	**
Interaction	Y x N	*	*	–	***

[†] Means followed by the same letter within a main effect are not significantly different using the Fischer Least Significant Difference procedure for protected post-hoc multiple comparison at α=0.05

[‡] ***, **, *, +, and – denote significance for p(>F) of less than 0.001, 0.01, 0.05, 0.10 and greater than 0.10, respectively

Conclusions

Overall, results of this study suggest using adaptive nitrogen management is an effective practice to maintain optimal agronomic outcomes in potato production. It is notable that the respective reductions in N rate of 22 and 44 kg N/ha in 2016 and 2017 that were associated with the VR Split treatment had no significant impacts on agronomic outcomes. This suggests that producers should be able to use a remote sensing based NSI approach to determine the timing of post-emergence fertilizer applications for potato, and that this approach may be able to reduce unnecessary fertilizer applications. Before the NSI approach based on MTCI that was used in this study can be widely adopted, hyperspectral remote sensing needs to become commercially available. Additionally, the NSI approach depends on a well-fertilized reference strip. The reference strip normalizes the remote sensing measurements to provide useful information on crop nitrogen statue. However, the information produced in an NSI approach is still a relative measurement because it does not provide an absolute assessment of crop nitrogen status (i.e. mg N/kg biomass). This means the NSI approach used in this study is unable to directly determine an appropriate N rate and may still need to be combined with ground truth measurements such as petiole nitrate concentration.

Future work for this study includes an analysis of additional nitrogen and irrigation treatments from the field study that were not included in this paper, nitrogen uptake and nitrogen use efficiency, nitrate leaching, a comparison of methods to make N fertilizer decisions between conventional methods such as petiole nitrate concentration and NSI using the SPAD meter, and an economic analysis. Finally, data from this study will be further utilized to calibrate and validate the biophysical simulation model EPIC to explore the agronomic and environmental impacts of alternative management practices.

Acknowledgements

This project was supported with funding from the Minnesota Area II Potato Growers Association, the Minnesota Department of Agriculture, and MnDRIVE Global Food Ventures Program.

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