Evaluating Nitrogen Stress and Yield Impacts from Variable-Rate Nitrogen Applications for Potatoes

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Introduction

- Expansion of intensive, irrigated agriculture in Central Minnesota has led to concerns regarding potential increases in non-point source pollution to surficial aquifers.
- With a goal to improve drinking water quality in this region, which is commonly impaired by nitrate-N, renewed interest has been placed on the role of nitrogen (N) best management practices to meet environmental and agronomic goals.
- Variable-rate N application based on multi-spectral remote sensing is a promising management strategy to maintain maximum yield levels while decreasing risk of N-leaching.

Methods

- This study was conducted in 2016 on Russet Burbank potatoes grown on an irrigated, coarse-textured soil in central Minnesota.
- Six N-treatments, including one variable-rate treatment, were imposed (**Table 3**) using a randomized complete-block design with split-plots. This experiment was part of a larger study which included irrigation [I] treatments (data not presented).
- Remote sensing of crop nitrogen stress was conducted weekly using a CROPSCAN Multispectral Radiometer (MSR-16R) and bi-weekly using a SPAD 502P Chlorophyll Meter.
- Nitrogen stress for each treatment was evaluated using multiple Nitrogen Sufficiency Indices (NSI) which were normalized against N-treatment 5. Indices used in this study (**Table 1**) were previously evaluated for accuracy at predicting N-stress in potatoes by Nigon (2012).

Table 1. Nitrogen Sufficiency Indices

Index	Parameter	Formula†	Source	Calculation
CROPSCAN Indices				
MTCI	Chlorophyll	$\frac{R_{751}-R_{713}}{R_{713}-R_{676}}$	Dash and Curran (2004)	$\frac{\frac{(R_{760}+R_{740})}{2}-R_{710}}{R_{710}-R_{680}}$
SR8	Chlorophyll	$\frac{R_{857}}{R_{554}\times R_{704}}$	Datt (1998)	$\frac{R_{870}}{R_{560}\times R_{710}}$
GRVI	Nitrogen	$\frac{R_{NIR}}{R_G}$	Sripada et al. (2006)	$\frac{R_{760}+R_{810}}{R_{510}+R_{560}}$
SPAD Index				
SPAD	Chlorophyll	$\log\left(\frac{T_{940}}{T_{650}}\right)$	Markwell et al. (1995)	–

†R_n and T_n respectively indicate % Reflectance and % Transmission of given wavelength [nm] of light

- N-fertilizer in the form of simulated fertigation was applied to N-treatment 6 when NSI values indicated a significant deficiency, which approximately occurs at NSI < 0.95.
- Statistical analysis was conducted using R with package lmerTest to create a mixed-effect model and evaluate the response of Yield and NSI to N-treatment.

Results

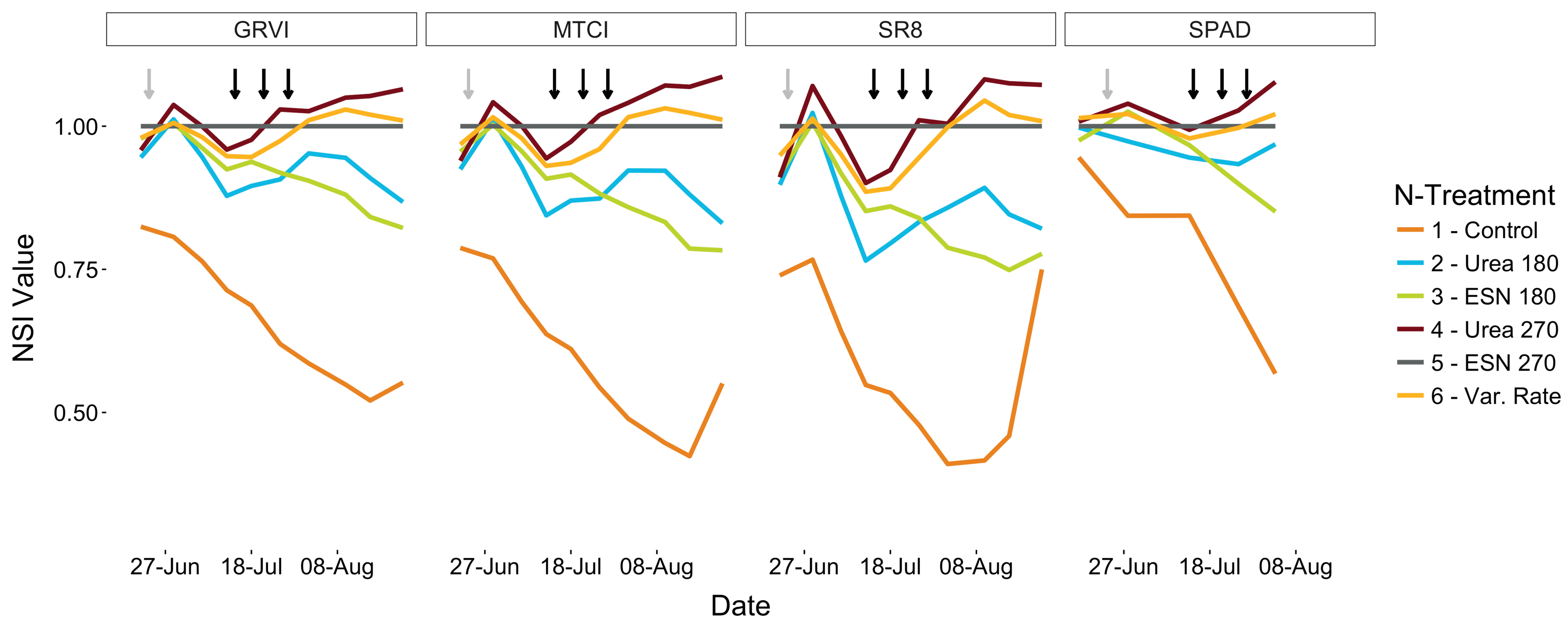

Figure 1. Comparison of NSI values from CROPSCAN and SPAD over time for each N-treatment. Black arrows indicate dates when post-hilling fertilizer was applied to N-treatments 2, 4, and 6. Grey arrows indicate application only to N-treatments 2 and 4.

Table 2. NSI values for N-Treatment 6 given with level of significance for comparison against reference†

Index	21 June	29 June	6 July	12 July	18 July	25 July	1 August	10 August	16 August	24 August
	NSI Value									
GRVI	0.97	1.017	0.979	0.931 ***	0.936 ***	0.960 **	1.016	1.031	1.023	1.011
MTCI	0.98	1.008	0.981 *	0.948 ***	0.946 ***	0.974	1.010	1.029 *	1.020	1.010
SR8	0.95	1.019	0.951	0.886 ***	0.892 ***	0.945 ***	0.999	1.045 *	1.020	1.008

Index	16 June	28 June	13 July	25 July	3 August
	NSI Value				
SPAD	1.014	1.021	0.979	0.997	1.021

***, **, * – Significant difference at $p < 0.001$, 0.01, 0.05 respectively
† N-Treatment 5 is the “well-fertilized” reference used for calculation of NSI, and by definition has a constant NSI value of 1.000

Table 3. Rate and timing of N-fertilizer treatments

N-Treatment†	Planting 22 April	Emergence 1 June	Post-Emergence 23 June	Post-Emergence 14 July	Post-Emergence 21 July	Post-Emergence 27 July	Total‡
	kg N ha^{-1}						
1 – Control	45 DAP	–	–	–	–	–	45
2 – Urea 180	45 DAP	67 Urea	17 UAN	17 UAN	17 UAN	17 UAN	180
3 – ESN 180	45 DAP	135 ESN	–	–	–	–	180
4 – Urea 270	45 DAP	135 Urea	23 UAN	23 UAN	23 UAN	23 UAN	270
5 – ESN 270	45 DAP	225 ESN	–	–	–	–	270
6 – Var. Rate	45 DAP	135 Urea	–	23 UAN	23 UAN	23 UAN	247

† DAP: Diammonium Phosphate, ESN: “Environmentally Smart Nitrogen”, UAN: Urea + Ammonium Nitrate
‡ N-fertilizer rates rounded, and may not sum exactly across N-treatments

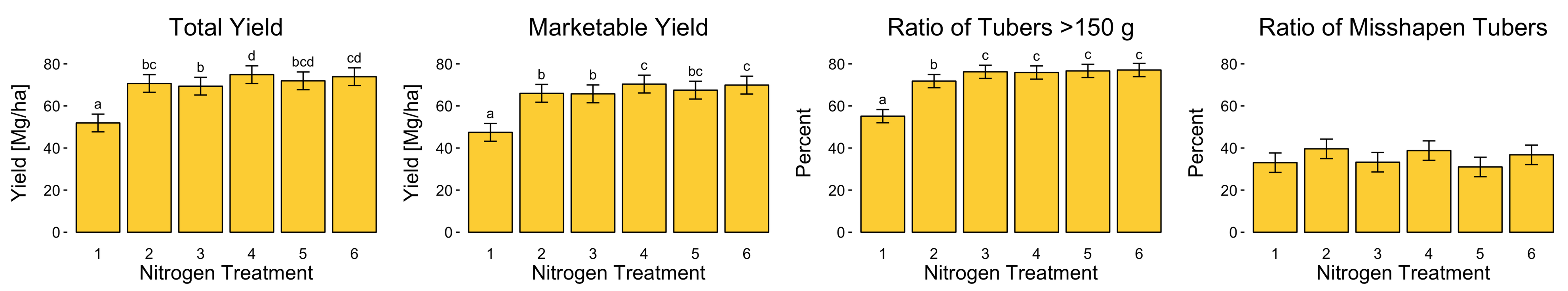

Figure 2. Yield quantity and quality parameters for each N-treatment. Error bars represent confidence intervals about the mean (α = 0.05). Treatments labeled with different letters are have a statistically significant difference (α = 0.05).

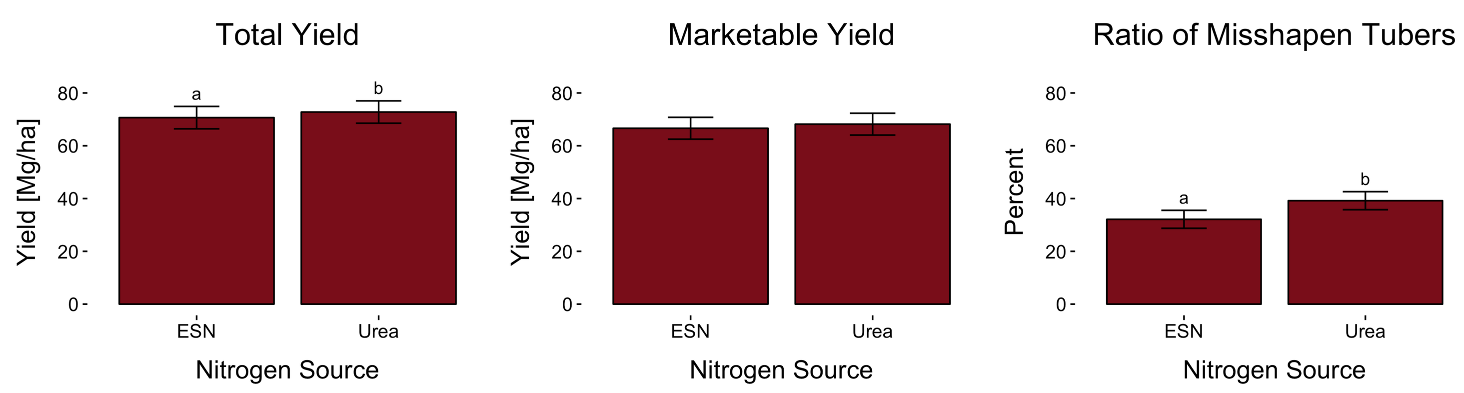

Figure 3. Analysis of yield quality and quantity response across the N-rate and N-source factorial found in N-treatments 2, 3, 4, and 5. Error and significance are indicated in the same manner as Figure 2.

Image 1. Assortment of tubers harvested from this study

Discussion

- NSI values calculated from CROPSCAN and SPAD varied by date, N-treatment, and calculation method (**Figure 1**). The control N-treatment produced significant N-stress. N-stress became more severe later in the season for N-treatments 2 and 3. Limited N-stress was detected in N-treatments receiving the highest rates of N (4, 5, and 6).
- CROPSCAN NSI method was capable of timely detection of statistically significant N-stress in N-treatment 6 while SPAD NSI was not (**Table 2**). Variable-rate nitrogen application reduced total N-application by 23 kg N/ha relative to the recommended rate of 270 kg N/ha (**Table 3**), with a non-significant impact on yield quantity and quality.
- Nitrogen treatment had a significant effect on most yield parameters (**Figure 2**). Overall, yield was high with the exception of the control N-treatment. Treatments with high N-rate (4, 5, and 6) produced significantly greater Total Yield and Marketable Yield than low N-rate treatments (1, 2, and 3).
- N-Source had a significant effect on yield quality and quantity. Urea produced the highest Total Yield, while ESN had the lowest ratio of Misshapen Tubers. Marketable yield was not affected by N-source (**Figure 3**).
- These results potentially indicate that utilizing CROPSCAN NSI is an effective strategy to reduce N-rate without impacting tuber yield. This may ultimately reduce the risk of N-leaching.

Image 2. Data collection on 18 July 2016 using CROPSCAN MSR-16R

Citations

- Nigon T.J. (2012). Aerial Imagery and Other Non-Invasive Approaches to Detect Nitrogen and Water Stress in a Potato Crop, University of Minnesota.
- Dash, J., & Curran, P. J. (2004). The MERIS terrestrial chlorophyll index. *International Journal of Remote Sensing*, 25, 5403-5413.
- Datt, B. (1998). Remote sensing of chlorophyll a, chlorophyll b, chlorophyll a b, and total carotenoid content in eucalyptus leaves. *Remote Sensing of Environment*, 66, 111-121.
- Sripada, R. P., Heiniger, R. W., White, J. G., & Meijer, A. D. (2006). Aerial color infrared photography for determining early in-season nitrogen requirements in corn. *Agronomy Journal*, 98, 968-977.
- Markwell, J., J.C. Osternman, and J.L. Mitchell. 1995. Calibration of the Minolta SPAD-502 leaf chlorophyll meter. *Photosynth. Res.* 46:467–472.