Nitrogen Management across Site-Specific Management Zones Using Active remote Sensing.

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ABSTRACT

Studies have shown that normalized difference vegetation index (NDVI) from ground-based active remote sensors is highly related with leaf N content in maize (*Zea mays*). Remotely sensed NDVI imagery can provide valuable information about in-field N variability in maize and significant linear relationships between sensor NDVI and maize grain yield have been found suggesting that an N recommendation algorithm based on NDVI could optimize N application. Therefore, a study was conducted using the two most prominent ground-based active sensors (NTech's GreenSeeker™ red and Holland Scientific's Crop Circle™ amber) to develop an N recommendation algorithm for each sensor for use at the V12 maize growth stage. Each sensor's NDVI N recommendation algorithm calculated unbiased N recommendations suggesting that the methodology of algorithm development was valid as was the estimate of required N at maize growth stage V12 and the algorithms developed for each sensor calculated very similar N recommendations. The integration of ground-based sensors and the appropriate N application algorithms into an on-the-go fertilizer application system would increase the spatial accuracy of N application on fields that are spatially variable if these algorithms are shown to be stable over time and space.

INTRODUCTION

Precision farming has been a major research focus of agronomists for over a decade. Much of this research has been directed towards enhancing the efficiency of overall farm inputs (e.g., fertilizers, herbicides, insecticides, water) without negatively impacting farm productivity, profitability and the environment. One way to achieve increased fertilizer efficiency could be through the application of nutrient based on remotely sensed data. An easy and effective way to obtain remotely sensed data is through the use of ground-based active remote sensors that can be used calculate normalized difference vegetation indices (NDVI) and ultimately nutrient recommendations particularly N. Ground-based active sensors allow for the determination of NDVI at specific times and locations throughout the growing season without the need for ambient illumination. Active sensors are relatively small in size and operate by directing sensor produced visible light (VIS) as well as near infrared (NIR) light at the plant canopy of interest. The amount of VIS and NIR light that is reflected off of the plant canopy is collected by the active sensor and a NDVI value is calculated using Equation 1.

$$NDVI = (NIR - VIS) / (NIR + VIS) \qquad \text{[Eq. 1]}$$

where: NIR = near infrared and VIS = visible light wavelength

Work by Raun et al., (2002) has shown that the use of a response index (RI) can be used to estimate N application rates based on yield predictions in winter wheat. This RI uses the

NDVI readings of an N-rich (reference) portion of the field divided by the NDVI readings of a target area of the field to give a normalized response index that can then be used in conjunction with other variables to determine an N recommendation. The RI equation is presented below as Equation 2.

$$RI = NDVI_{Reference} / NDVI_{Target} \quad \text{[Eq. 2]}$$

where: $NDVI_{Reference}$ = NDVI of N-Rich Plot
$NDVI_{Target}$ = NDVI of Managed Plot

Using the RI method an increase in N use efficiency (NUE) of more than 15% was observed over conventional N application methods. By performing this calculation the data is normalized or brought to a similar scale that can be compared. The wider the discrepancy in reflectance values from the reference and target areas the larger the RI resulting in a higher N recommendation based on the RI's relationship with grain yield, plant N or other factors that relate to plant growth. Essentially the RI indicates the difference in maize growth from a well fertilized area of the field and a non-fertilized area of the field and the algorithm estimates the amount of N needed to make up this difference.

Since development of an N recommendation algorithm is our overall goal, we first conducted a study to determine which sensor, amber or red, performed best in our region and at which maize growth stage each sensor performed best. Our results suggest that both the red and amber sensors performed equally in the determination of N variability in maize and that each performed best at the V12 maize growth stage (Shaver, 2009). Therefore, our objectives for this study were: To develop and test an in-season N recommendation algorithm based on NDVI for the red and amber sensors for use at the V12 maize growth stage, which can then be used and further evaluated in farmers field across Colorado.

MATERIALS AND METHODS

Study Sites:

This study was conducted at Colorado State University's Agricultural Research Development and Education Center (ARDEC) located near Fort Collins, Colorado. The field site used was furrow irrigated continuous maize and was classified as a fine-loamy, mixed, superactive, mesic, Aridic Haplustalf (Soil Survey Staff, 1980). Two different locations within the same field were used for this study resulting in two site years.

Sensors:

Two active sensors were used across the two site years. The active sensors tested included the red GreenSeeker™ Model 505 hand held optical sensor unit manufactured by NTech Industries Inc. (NTech Industries, Inc., 2005) and the Holland Scientific Crop Circle™ ACS-210 Plant Canopy Reflectance Sensor (Holland Sci., 2005). The GreenSeeker™ generates a red light (wavelength 660nm). Therefore, the NDVI value calculated by the red GreenSeeker™ will be referred to as "Red NDVI". The Crop Circle™ sensor generates light with a wavelength of 590nm in the visible band which is called "yellow" by the manufacturer but has also been referred to as "amber" in professional circles. Therefore, the index calculated by this sensor will be referred to as "Amber NDVI".

Sensor readings were collected across four N application rates at the V12 maize growth stage for site years 1 and 2. Active sensors were mounted on a telescoping boom allowing readings to be collected at the proper height above the maize canopy. The red sensor was connected to a Compaq Ipaq™ hand-held computer to record NDVI values. The amber sensor was connected to Holland Scientific's GeoSCOUT GLS-400 data logger (Holland Sci., 2006) to record all NDVI values.

Nitrogen Application and Plot Design:

Nitrogen was applied as 32-0-0 urea-ammonium-nitrate (UAN) at maize emergence (no pre-plant N was applied) using a 4-row side-dress applicator with variable rate capabilities. This applicator applied liquid N below and to the side of the maize plant. The N was applied as close to a scheduled irrigation event as possible to reduce potential N losses due to volatilization. Four N rates were applied; 0, 50, 100, and 175 lbs N ac^{-1}. Sub-plots of each N application rate were set up at two different locations (site years 1 and 2) at ARDEC and each N rate was replicated four times at each site year in a complete randomized block (CRB) design. This resulted in 16 sub-plots within each site year. Each plot was 4 maize rows in width (30 inches row spacing) and 50 feet long. Site years 1 and 2 had not received applied N for two years prior to this study.

NDVI Based Nitrogen Algorithm Development:

Our NDVI based N estimation algorithms for the amber and red sensors were created by using the maize growth stage V12 NDVI readings from the 0, 50, 100 and 175 lbs ac^{-1} N plots in site-years 1 and 2. This algorithm was created at the V12 growth stage because maximum N variability was recorded by the active sensors at the V12 growth stage (Shaver, 2009) and the maize is still small enough to allow N application implements into the field. To create the algorithms, a wide range of NDVI RI's were created by dividing the NDVI of an N applied plot by the NDVI of a 0 lbs ac^{-1} plot. This RI will be referred to as the $RI_{Algorithm}$ as it was used to create the algorithms and is different from the RI presented in Equation 2 which is used in the algorithms to estimate crop N need. The $RI_{Algorithm}$ equation is presented as Equation 3.

$$RI_{Algorithm} = NDVI_{N\ plot} / NDVI_{0\ N\ plot} \qquad [Eq.\ 3]$$

where: $NDVI_{N\ plot}$ = NDVI readings from N applied plots (50, 100 and 175 lbs ac^{-1})
$NDVI_{0\ N\ plot}$ = NDVI readings from 0 lbs ac^{-1} plot

The calculated $RI_{Algorithm}$ values were then plotted against the N application rate difference that created that RI (50, 100 or 175 lbs ac^{-1}). The overall idea with this algorithm is that a RI can be based on N application differences. If we know the difference in N application rates and the resulting RI this information can be plotted and an N prediction equation can be formulated through linear regression. This process was repeated for all possible $RI_{Algorithm}$ values across 50, 100, and 175 lbs ac^{-1} N application rates. An RI of 1.0 was used at the 0 lbs ac^{-1} N application rate assuming that if the $NDVI_{Reference}$ was divided by the $NDVI_{Target}$ (Equation 2) and a RI of 1.0 was recorded no additional N would be needed because the target area and reference area would have the same N status.

The $RI_{Algorithm}$ values were then regressed on applied N using polynomial regression and an N recommendation prediction equation was formulated. The intercept for the regression equation was set at 1.0 because this is the lower limit of the RI (at 1.0 no N is needed). After algorithm development validation was required.

Data Analysis:

All statistical analysis was performed using the Statistical Analysis System (SAS) (SAS Institute, 2006). All regressions were performed using the REG procedure in SAS. The bootstrapping process was done using a bootstrapping macro in SAS. Proc MEANS was used for all means calculations and the CLM option was used in Proc MEANS for all confidence interval calculations. Analysis of variance was performed using Proc Anova.

RESULTS AND DISCUSSION

Maize Grain Yield:

Grain yield was significantly increased by applied N fertilizer in both site years. Yields were highest in site-year 1 relative to site-year 2, and the 175 and 100 lbs ac^{-1} N application rates produced equal yields suggesting that the 100 lbs ac^{-1} rate supplied sufficient N for maximum yield. All applied N rates yielded significantly more than the check (0 lbs ac^{-1}). Yields in site-year 2 were similar to those in site-year 1, and again the 175 and 100 lbs ac^{-1} N rates produced the same yield. This again suggests that the N sufficiency level was reached at the 100 kg ha^{-1} rate.

Nitrogen Recommendation Algorithm:

Previous study results suggest that both sensors perform equally well (Shaver, 2009). The N recommendation algorithms were therefore developed for each sensor using the same methodology. As with other N recommendation algorithms our amber and red sensor N recommendation algorithms were based on an RI. One method for determining RI is presented above in Equation 2. This RI normalizes NDVI data. Equation 2 is also the format used to determine RI in the algorithms presented in this paper. An RI was calculated over a range of N application differences (175, 100 and 50 lbs ac^{-1}) and then was regressed over the N application difference that created that particular RI. This regression was then used to calculate an N recommendation quadratic equation that predicts crop N need for the amber and red (Figure 1) NDVI sensors. The resulting N recommendation algorithms for each active sensor are as follows:

Amber Sensor:

$$\text{N Rate (kg ha}^{-1}) = (114.1 \times (NDVI_{Reference} / NDVI_{Target})^2) - (118.1 \times (NDVI_{Reference} / NDVI_{Target})) + 1 \quad \text{[Eq. 4]}$$

Red Sensor:

$$\text{N Rate (kg ha}^{-1}) = (135.3 \times (NDVI_{Reference} / NDVI_{Target})^2) - (134.8 \times (NDVI_{Reference} / NDVI_{Target})) + 1 \quad \text{[Eq. 5]}$$

The premise for the algorithm methodology we used was that RI is directly related to N differences in the crop. The RI can therefore be used to predict the amount of N it would take to make up this difference, which can be used as the N recommendation. This methodology shares aspects from an algorithm developed by Varvel et al., 2007. Both the amber and red NDVI algorithms presented in Equations 4 and 5 were unbiased based on the confidence interval fitting process.

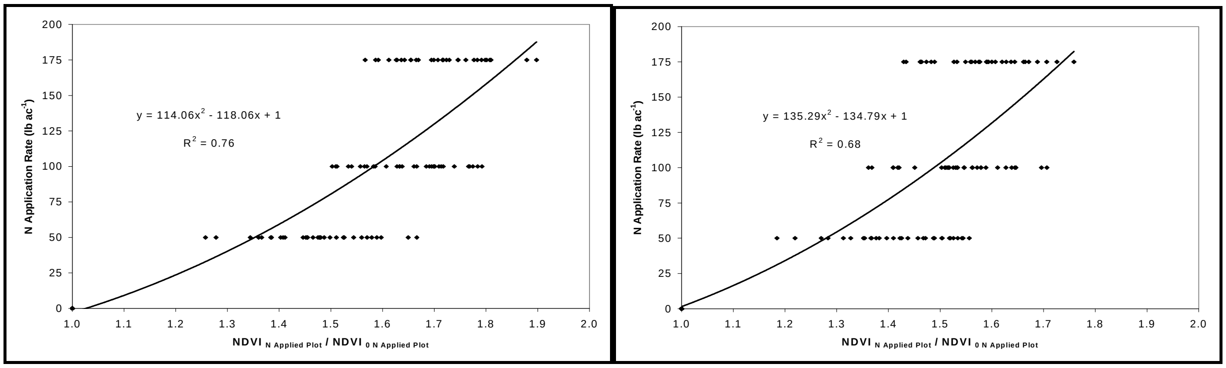

Figure 1. Amber and Red NDVI N application algorithm based on V12 maize growth N response to N application rates of 175, 100, 50 and 0 lbs ac^{-1}.

Our data clearly show that the amber and red sensor algorithms presented in Equations 5 and 6 are unbiased and are a sound methodology for determining NDVI based N recommendation algorithms (Table 1). This process represents a good first step for algorithm development in Colorado.

Table 1. Amber and red NDVI algorithm based N recommendations at maize growth stage V12 across 4 N application rates for the two site years

	----------- N applied at corn emergence (lbs/ac)----------			
	0	**50**	**100**	**175**
Site Year 1				
N recommended by Amber Algorithm	130	28	13	6
N recommended by Red Algorithm	124	28	14	8
Site Year II				
N recommended by Amber Algorithm	122	29	8	5
N recommended by Red Algorithm	116	26	7	7

CONCLUSIONS

The amber and red N recommendation algorithms developed in this study both proved to be unbiased in their N recommendations. This suggests that the NDVI N algorithm development methodology presented here is sound and should be researched further to determine their accuracy over a larger data base that includes more spatial and temporal variability. However, the amount of variability in the $RI_{Algorithm}$ portion of the equation is a concern and further testing is needed to determine how much the recommendation equations are affected by this variability.

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