More Research Needed On Remote Sensing For Nitrogen Management

Current algorithm development methodology has proven sound and should be researched further for accuracy.

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The Fluid Journal • Official Journal of the Fluid Fertilizer Foundation • Spring 2011 • Vol. 19, No. 3, Issue #73

***Summary:** The remotely sensed normalized difference vegetation index (NDVI) can provide valuable information about in-field nitrogen (N) variability in maize. Significant relationships between sensor NDVI and maize grain yield have been found, suggesting that an N recommendation algorithm based on NDVI could optimize N application. Algorithms were developed for the GreenSeeker™ and Crop Circle™ sensors and the methodology of algorithm development was proven valid, as was the estimate of required N at maize growth stage V12. The algorithms developed for each sensor calculated very similar N recommendations. Our expectations are the integration of crop canopy 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.*

Precision farming has been a major research focus of agronomists for over a decade. Much of this research has been directed toward 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 nutrients based on remotely sensed data.

An easy and effective way to obtain remotely sensed data is through the use of crop canopy sensors that can be used to calculate NDVI and ultimately nutrient recommendations, particularly N. Crop canopy sensors allow for the determination of NDVI at specific times and locations throughout the growing season without the need for ambient illumination. These 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. The amount of VIS and NIR light that is reflected off the plant canopy is collected by the sensor and an NDVI value is calculated using Equation 1: $NDVI = (NIR - VIS)/(NIR + VIS)$.

Research has shown that a response index (RI) can be used to estimate N application rates. This RI uses the NDVI readings of an N-rich (reference) portion of the field divided by the NDVI of a target area of the field to give a response index that can then be used to determine an N recommendation. The RI equation is presented as Equation 2: $RI = NDVI_{Reference}/NDVI_{Target}$, where $NDVI_{Reference}$ = NDVI of N-rich plot, and $NDVI_{Target}$ = NDVI of managed plot.

The wider the discrepancy in reflectance values from the reference and target areas the larger the RI, resulting in a higher N recommendation. Essentially, the RI indicates the difference in maize growth from a well-fertilized area of the field compared to a non-fertilized area of the field. The algorithm estimates the amount of N needed to make up this difference.

Development of an N recommendation algorithm is the overall goal. However, initially we conducted a study to determine which sensor--Crop Circle (amber wavelength) or Green Seeker (red wavelength)--performed best in the semi-arid region of Colorado, and at

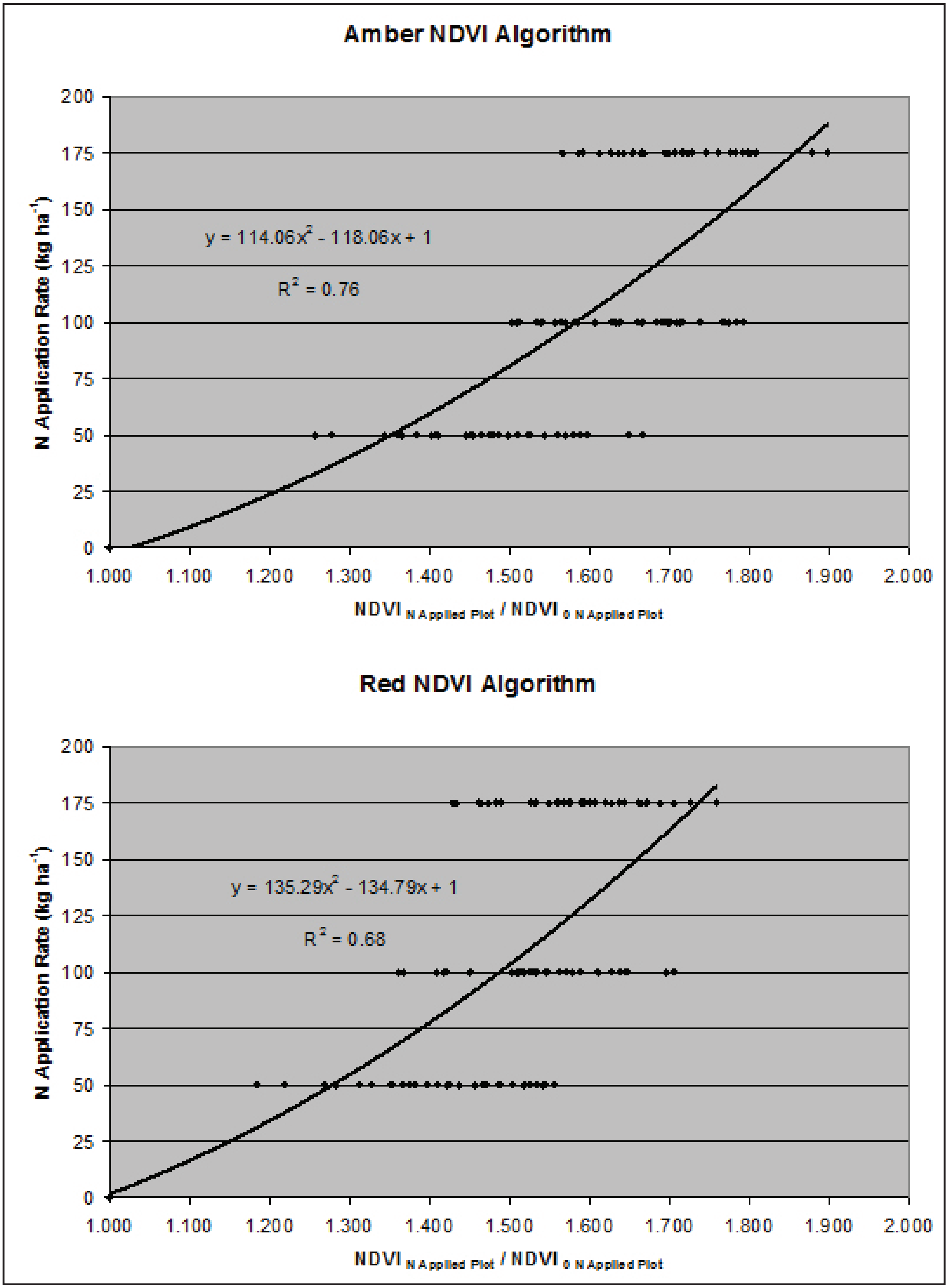

Figure 1. *Amber and red NDVI nitrogen (N) application algorithm based on V12 maize growth N response to N application rates of 175. 100, 50, and 0 lbs/A.*

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.

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' fields across Colorado.

Methodology

Study site was the Agricultural Research Development and Education Center (ARDEC) at Colorado State University. The site was furrow irrigated, continuous maize, and classified as a fine-loamy, mixed, super-active, mesic, Aridic Haplustalf. Two different locations within the same field were used for this study, resulting in two site years.

Sensors included GreenSeeker™ (red) and Crop Circle™ (amber). Sensor readings were collected across four N application rates at the V12 maize growth stage for site years 1 and 2. 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™ to record NDVI values. The amber sensor was connected to a GeoSCOUT GLS 400 data logger to record all NDVI values.

N application. Nitrogen was applied as 32-0-0 urea-ammonium-nitrate (UAN) at maize emergence (no preplant N), using a 4-row sidedress 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/A.

Plot design. Subplots 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 subplots within each site year. Each plot was 4 maize rows in width (30-inch row spacing) and 50 feet long. Site years 1 and 2 had not received applied N for two years prior to this study.

N algorithm. The 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/A N plots in site years 1 and 2. The algorithm was created at the V12 growth stage because maximum N variability was recorded by the sensors at the V12 growth stage. Additionally at V12 the maize is still small enough to allow N application implements into the field. The overall idea with this algorithm is that an 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.

"Crop sensors help calculate nutrient recommendations"

Data analysis. All statistical analysis was performed using the Statistical Analysis System (SAS). All regressions were performed using the REG procedure in SAS. The bootstrapping process was accomplished 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.

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

	N applied at corn emergence (lbs/A)			
	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 2				
N recommended by amber algorithm	122	29	8	5
N recommended by red algorithm	116	26	7	7

Results promising

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/A N application rates produced equal yields, suggesting that the 100-lb/A rate supplied sufficient N for maximum yield. All applied N rates yielded significantly more than the check. Yields in site-year 2 were similar to those in site-year 1, and again, the 175- and 100-lb/A N rates produced the same yield. This again suggests that the N sufficiency level was reached at the 100 lb/A rate.

Algorithm premise. Previous studies suggest that both sensors perform equally well. The N recommendation algorithms (NRA) were therefore developed for each sensor using the same methodology. As with other NRA our amber and red sensor NRA were based on an RI. One method for determining RI is presented in Equation 2 (see earlier, above, in introduction). Equation 2 is also the format used to determine RI in the algorithms presented in this article. An RI was calculated over a range of N application differences (175, 100, and 50 lbs/A) 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) sensors.

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. Our data clearly show that the amber and red sensor algorithms 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.

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