COMPARISON OF CANOPY SENSING TECHNOLOGIES FOR CORN NITROGEN MANAGEMENT IN MINNESOTA

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ABSTRACT

Various crop canopy sensing tools are being used to manage nitrogen, but their utility to predict N needs in Minnesota remains unclear. The objectives of this study are to compare the effectiveness of different canopy sensing technologies at predicting corn (*Zea mays* L.) yield at different development stages, and compare their capability to determine in season N deficiency. Six to seven N rates at 35 to 45 kg N ha^{-1} increments were pre-plant applied in six fields throughout Minnesota and a rate of 100 to 125 kg N ha^{-1} split-applied 1/3 pre-plant and 2/3 sidedress at V2, V4, V6, V8, and V12 development stages. Canopy sensing measurements with SPAD, Crop Circle (NDRE) and GreenSeeker (NDVI), were obtained at V4, V8, V12 and R1. Grain yield was determined at harvest. Preliminary results show that sampling earlier than V8, regardless of the tool, resulted in poor yield predictive power and N deficiency detection, likely because of mineralization of soil organic N exceeds plant requirements at early stages. GreenSeeker was well correlated to yield (R^2=0.87) at V8 but index saturation past V8 weakened the correlations. Crop Circle had increasing predictive power until V12 (R^2=0.95); by R1 tassels likely interfered with the measurements. Correlation with SPAD was 0.83 (V8), 0.73 (V12), and 0.94 (R1). Nitrogen deficiency was not detected by GreenSeeker at any stage. At V8, Crop Circle and SPAD underestimated- and at V12 and R1 overestimated-N needed to maximize yield. Sensor relative critical values ranged from 0.98 to 1.00. Using a typical 0.95 critical value at V8 the agronomic optimum rate was underestimated by 99 and 43 Kg N ha^{-1} by SPAD and Crop Circle, respectively. Overall, the later the sensing the higher the yield predictive power, however the potential to improve yields by later N application diminishes, unless irrigation ensures N incorporation into the root zone.

INTRODUCTION

While significant amounts of nitrogen (N) are required for corn production, fertilizer N is subject to environmental losses that may result in environmental degradation, yield reduction, and lower returns on investment. In Minnesota, fertilizer N guidelines are based on the maximum return to N (MRTN) approach (Sawyer et al., 2006). It is known that optimum N rates may greatly vary from year to year as a result of different weather conditions and soil N mineralization (Johnson and Raun, 2003). Therefore, fertilizer N strategies that rely on past years responses are less likely to provide accurate optimum N rate predictions ahead of the growing season. In this matter, various canopy sensing technologies have been proposed as promising tools to tweak N rates. Since measurements are taken in-season they already reflect the plant's response to year-specific environmental conditions at the time of measurement.

Various canopy sensing tools are currently available on the market. The Minolta SPAD 502

(Konica Minolta, Ramsey, NJ) is one of the oldest and most used instruments on plant N status determination studies. The device clamps a leaf section and measures potential photosynthetic activity which is closely related to leaf chlorophyll content and ultimately to plant N status (Peterson et al., 1993). GreenSeeker (Trimble) is another widely used active sensor. It measures at the 650 and 770 nm wavelengths to provide the Normalized Difference Vegetation Index (NDVI), which is the most used vegetative index for assessment of plant N status. Several studies have shown successful use of NDVI to predict yield and help manage fertilizer N (Freeman et al., 2007; Kitchen et al., 2010). RapidSCAN CS-45 (Holland Scientific, Lincoln, Nebraska, USA) is an active handheld sensor that in addition to calculate NDVI uses the red-edge and NIR wavelengths (730 and 780 nm) to provide the Normalized Difference Red Edge (NDRE). The red-edge is known for its higher levels of sensitivity to chlorophyll (Kanke et al., 2012), when compared to NDVI.

While studies showing the benefits of canopy sensors to manage N are prevalent in states located in the Great Plains and southern portions of the US Midwest, there is not a consensus about their effectiveness in Minnesota and other northern portions of the US Midwest. Studies performed by Raun et al., (2002) successfully used of canopy sensors to improve nitrogen use efficiency (NUE) in Oklahoma and Virginia, but results from Steven (2014), in North Dakota found low coefficients of determination when correlating sensor based N rates to optimum N rates.

The objectives of this study are to compare the effectiveness of different canopy sensing technologies at predicting corn yield at different development stages, and compare their capability to determine in season N deficiency under Minnesota conditions.

MATERIALS AND METHODS

This study was conducted in six locations throughout Minnesota, five in corn-corn and one in corn-soybeans rotation. The locations were near: Becker, (45.392359N, -93.882602W) on a Hubbard loamy sand; Lamberton (44.247250N, -95.310285W) on a Ves loam; Waseca (44.0597235N, -93.5249851W) on Nicollet clay loam-Webster silty clay loam (Waseca I), and (44.071767N, -93.521239W) Webster silty clay loam-Canisteo clay loam (Waseca II); Theilman (44.287343N, -92.181478W) on a Fayette silt loam; and Clara City (44.970618N, -95.373577W) on a Colvin-Quam complex silty clay loam.

Treatments consisted of six to seven N rates at 35 to 45 kg N ha^{-1} increments pre-plant applied as urea, and a rate of 100 to 125 kg N ha^{-1} split-applied 1/3 pre-plant urea and 2/3 sidedress urea plus Agrotain at V2, V4, V6, V8, and V12 development stages. Pre-plant fertilizer broadcast was followed by field cultivation. Becker was an irrigated site and irrigation was applied based on soil water balance calculations.

The 2014 growing season was challenging for planting due to cooler and wetter than normal conditions. Corn hybrid Pioneer P9917AMX was planted in Becker on May 14th, in Lamberton on May 30th, and in Theilman on May 22th. Corn hybrid Dekalb DKC53-56RIB was planted in Waseca on May 30th (Waseca I) and May 11th (Waseca II). Corn hybrid Dekalb DKC44-13RIB was planted in Clara City on May 30th. Other than N management, each location was managed according to best management practices to maximize productivity.

Canopy sensing measurements were performed with Minolta SPAD 502 (Konica Minolta, Ramsey, NJ), GreenSeeker (Trimble) and RapidSCAN CS-45 (Holland Scientific) at V4, V8, V12 and R1 development stages. NDVI and NDRE indices were calculated from data collected with the GreenSeeker and RapidSCAN, respectively. SPAD readings were collected from 30 representative plants in the middle rows of each plot from the upper most developed leaf during vegetative stages and the ear-leaf at R1. Each reading was taken halfway between the stalk and the leaf tip and midway between the midrib and the leaf margin. GreenSeeker and Crop Circle were mounted on poles and carried manually while sensing on top of the two center rows of each plot. Grain yield was determined at harvest from the two center rows used for canopy sensing and adjusted to 155 g kg^{-1} moisture content.

Statistical analyses were done using SAS software (SAS Institute, 2011). The NLIN procedure was used to fit regression models for N rate and grain yield, and for sensor readings and grain yield. The model that was statistically significant and with the highest R^2 was selected. The agronomic optimum N rate (AONR) was determined at the point where increasing N rates did not translate into higher yields. For locations with linear yield response to N, AONR was the highest N rate applied. The nitrogen difference (ND) (AONR minus N rate applied) was then calculated for each N rate within each location. Relative sensor readings (RSR) were computed by dividing the readings of each individual treatment plot by the average (n=4) reading of the highest N rate treatment. To determine the relationship between ND and RSR, values were regressed against the corresponding ND for each location, using NLIN. Differences in yield for the different split application timings were analyzed using PROC Anova and the Tukey HSD test at the 95% confidence level.

RESULTS AND DISCUSSION

Since these data are only from one year and the study is still being conducted, this section can only be considered as preliminary information. The effectiveness of the tools to predict corn yield varied greatly between locations and stages (Table 1). In general, correlation increased with later development stages, but there were some inconsistencies in this pattern, especially for NDVI readings with the GreenSeeker. For individual locations, such as Clara City, Lamberton, and Waseca I, correlation values were sometimes high for the different instruments at the V4 development stage. However, across locations, sensing at V4 vegetative stage proved to have limited predictive capacity compared to later development stages. These results highlight the fact that sensing technologies may have limited utility early in development, when nitrogen management decisions need to be made before the rapid nitrogen uptake phase starts and while the plants are short enough to allow ease of nitrogen application. The generally low correlation observed at V4 is likely because nitrogen supply from mineralization of soil organic matter is ample in most cases relative to the small nitrogen requirements of the crop at this stage of development. Typically by the V6 development stage less than 10% of the total nitrogen required by the corn crop has been taken (Abendroth et al., 2011).

Across locations, the GreenSeeker had the best coefficient of determination at V8 (0.87), but index saturation past this stage weakened the correlations (Table 1). These results agree with Gitelson (2004), who stated that NDVI approaches saturation under moderate-to-high biomass conditions. Out of the three technologies evaluated, the GreenSeeker was overall the most inconsistent at correlating with yield. Our results contrast those of Tubaña et al. (2008) that found the GreenSeeker to be well correlated to corn yield. Across all locations the Crop Circle NDRE measurements provided the most consistent increase in predictive power with increasing development stages until V12 (R^2=0.95), but correlation decreased at R1 likely because tassels may have interfered with the measurements. Overall, the SPAD meter had the best correlation to yield at R1 (R^2=0.94), as opposed to R^2=0.89 for the Crop Circle and R^2=0.60 for the GreenSeeker. This likely illustrates the fact that nitrogen concentration of the ear-leaf is typically well correlated to yield. Unfortunately, at R1 the Crop Circle and GreenSeeker are measuring mostly the upper canopy and cannot conduct a direct measurement of the ear-leaf. This follows findings from Steven (2014) who indicated that since the chlorophyll meter can be positioned on the ear-leaf this instrument obtains better readings of nitrogen status and overall plant yield potential than an active sensor can gather during reproductive development stages.

At the AONR (ND equal zero), the regression model showed that relative SPAD readings ranged from 1.00 to 0.98 (Table 2 and Figure 1). These results are similar to values observed by Hawkins et al., (2006) who found 1.00 at V8, 0.99 at V15 and R1 and 0.98 at R3, but are greater than 0.95 found by Petterson et al., (1993). Relative NDRE readings at AONR were consistently 0.98 for all development stages (Table 2). There was no relationship to nitrogen rate with the GreenSeeker for any of the development stages we measured (data not shown).

Using the typical 0.95 relative value to trigger N application would have underestimated nitrogen application between 43 and 99 Kg N ha^{-1} relative to the actual AONR (Table 2). This was observed for all development stages regardless of the instrument used (SPAD or Crop Circle-NDRE). Similar relative SPAD value (47 Kg N ha^{-1} below AONR) when using the 0.95 critical value was found by Hawkins et al. (2006). At V8 both SPAD and NDRE reached a plateau at a nitrogen rate lower than the AONR (ND=0) but the plateau was greater than the AONR at V12 and R1 (Table 2 and Figure 1). At V8 SPAD underestimated nitrogen needs by 14 Kg N ha^{-1} and NDRE underestimated nitrogen needs by18 kg N ha^{-1}. Whereas at V12 and R1 both tools overestimated N needs to maximize yield anywhere from 31 to 80 kg N ha^{-1}. The fact that nitrogen needs are underestimated at V8 may be a reflection that at this stage the crop is not showing nitrogen stress because it has an ample supply of nitrogen, but the supply is eventually exhausted later in the season when the crop uptake is high, but our ability to supply additional N may be limited.

Across all five locations with fine textured soils, split applications of N produced similar yields to a single pre-plant application (Figure 2). It was also observed that delaying sidedress application to V8 or V12, even when 1/3 of the N was supplied pre-plant, may result in greater yield loss than earlier applications. According to Peterson et al., (1993), if a corn plant experiences moderate to severe nitrogen stress in the early growth stages, the size of the ear and number of kernels may have already been compromised, so that later applications of N will not allow complete yield recovery. At Lamberton, where the soil became dry later in the season the delayed application was especially detrimental relative to a single pre-plant application as there was no sufficient moisture to move the applied nitrogen into the root zone (data not shown). While agronomist often focus on the risk of nitrogen loss when this nutrient is applied at pre-plant, it is important to note that sidedress applications also carry a risk when the nutrient is not available at the time when the crop needs it. In addition, if the nitrogen supplied at sidedress is not used by the crop, it is subject to eventual loss to the environment, similar to when pre-plant nitrogen is lost early in the spring.

In contrast to the fine-textured soils, in the coarse texture soils at Becker, where irrigation was available to incorporate nitrogen into the root zone, there was a positive yield response to split applications compared to a single pre-plant application (Figure 2). In 2014, there was high leaching potential early in the season, and even early split-applications were subject to loss. Conversely, the later applications (V6, V8 and V12) provided nitrogen to the crop after the risk for nitrogen loss diminished.

SUMMARY

Overall, early-season measurements of the crop canopy resulted in poor yield predictive power and N deficiency detection. This is likely the result of adequate supply of N from fertilizer (even at small rates of application) and soil organic matter and the relatively small requirements of corn early in the season. As the season progresses, canopy sensors are better able to predict yield, but may overestimate nitrogen needs. In non-irrigated fine-textured soils one of the most important challenges may be that once the canopy sensors start to detect nitrogen deficiency it may be too late to supply the additional nitrogen. In contrast, in irrigated coarse-textured soils later sidedress applications may actually be more effective than single pre-plant applications and the use of canopy sensors may hold greater promise. This is only preliminary information. This study is currently being repeated during 2015.

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Table 1: Quadratic model correlation values (R^2) for the relationship between grain yield and sensor readings at various development stages and locations throughout Minnesota.

Location	Stage	Equipment/index		
		SPAD	NDVI†	NDRE‡
Becker	V4	n.c. §	0.45	n.c.
	V8	0.53	---	n.c.
	V12	n.c.	0.61	0.87
	R1	0.88	0.83	0.90
Clara City	V4	0.88	0.79	0.82
	V8	0.8	0.94	0.93
	V12	0.63	---	0.97
	R1	0.91	0.97	0.97
Lamberton	V4	0.75	0.77	0.96
	V8	0.76	0.87	0.98
	V12	0.97	0.22	0.98
	R1	0.97	n.c.	0.69
Theilman	V4	0.39	0.35	0.65
	V8	0.96	0.74	0.95
	V12	0.89	n.c.	0.94
	R1	0.91	0.51	0.92
Waseca I	V4	0.92	0.57	0.52
	V8	0.96	0.94	0.98
	V12	0.96	0.97	0.97
	R1	0.98	0.39	0.92
Waseca II	V4	n.c.	---	0.88
	V8	0.97	0.86	0.85
	V12	0.93	---	0.96
	R1	0.98	0.89	0.92
Mean across locations	V4	0.49	0.58	0.64
	V8	0.83	0.87	0.78
	V12	0.73	0.45	0.95
	R1	0.94	0.60	0.89

† NDVI obtained from GreenSeeker.

‡ NDRE obtained from Crop Circle.

§ Not correlated.

--- Not sampled.

Table 2: Statistically significant (p<0.1) quadratic-plateau regression models for the relationship between the relative sensor readings (RSR) and N rate difference from AONR (ND). Average values across Theilman, Lamberton and Waseca II locations.

Equipment/ Index	Stage	Regression model	Join point†	Plateau	R^2	P-value	ND at 0.95‡
SPAD	V8	$y = 1.00 - 0.00022x - 0.00000811x^2$	-14	1.01	0.95	0.068	-99
	V12	$y = 0.98 + 0.000514x - 0.00000321x^2$	80*	1.00	1.00	0.001	-51
	R1	$y = 0.98 + 0.000432x - 0.00000528x^2$	41	1.01	0.97	0.035	-62
NDRE§	V8	$y = 0.98 - 0.0004x - 0.00001x^2$	-18	0.98	0.98	0.013	-43
	V12	$y = 0.98 + 0.000372x - 0.00000599x^2$	31	0.99	0.98	0.021	-87
	R1	$y = 0.98 + 0.00051x - 0.00000349x^2$	73*	1.00	0.99	0.012	-87

†ND (Kg N ha^{-1}) where the quadratic equation joins the canopy index plateau value.
‡ND (Kg N ha^{-1}) where canopy index is equal to 0.95
* Indicate estimate beyond data.
§NDRE obtained from Crop Circle

Figure 1: Quadratic-plateau regression models for the relationship between a) relative SPAD sensor readings or b) relative NDRE readings and N rate difference from AONR (ND). Average values across Theilman, Lamberton and Waseca II sites in 2014. Regression curves were generated from regression models given in Table 2. Relative SPAD and NDRE values were computed by dividing the readings of each individual treatment plot by the average reading of the highest N rate treatment.

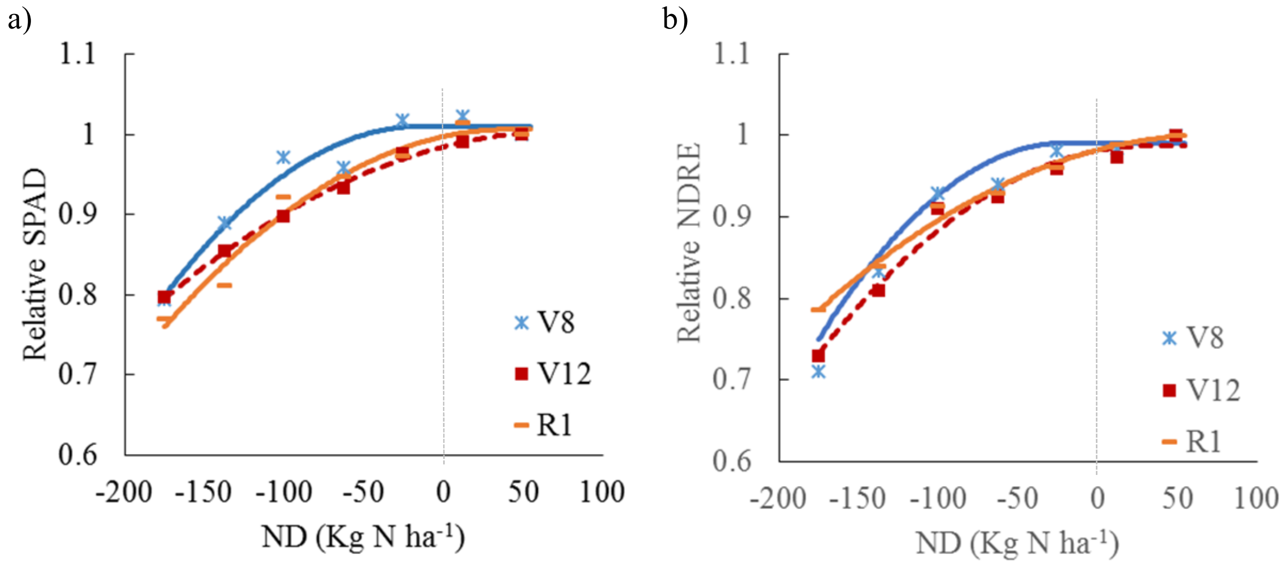
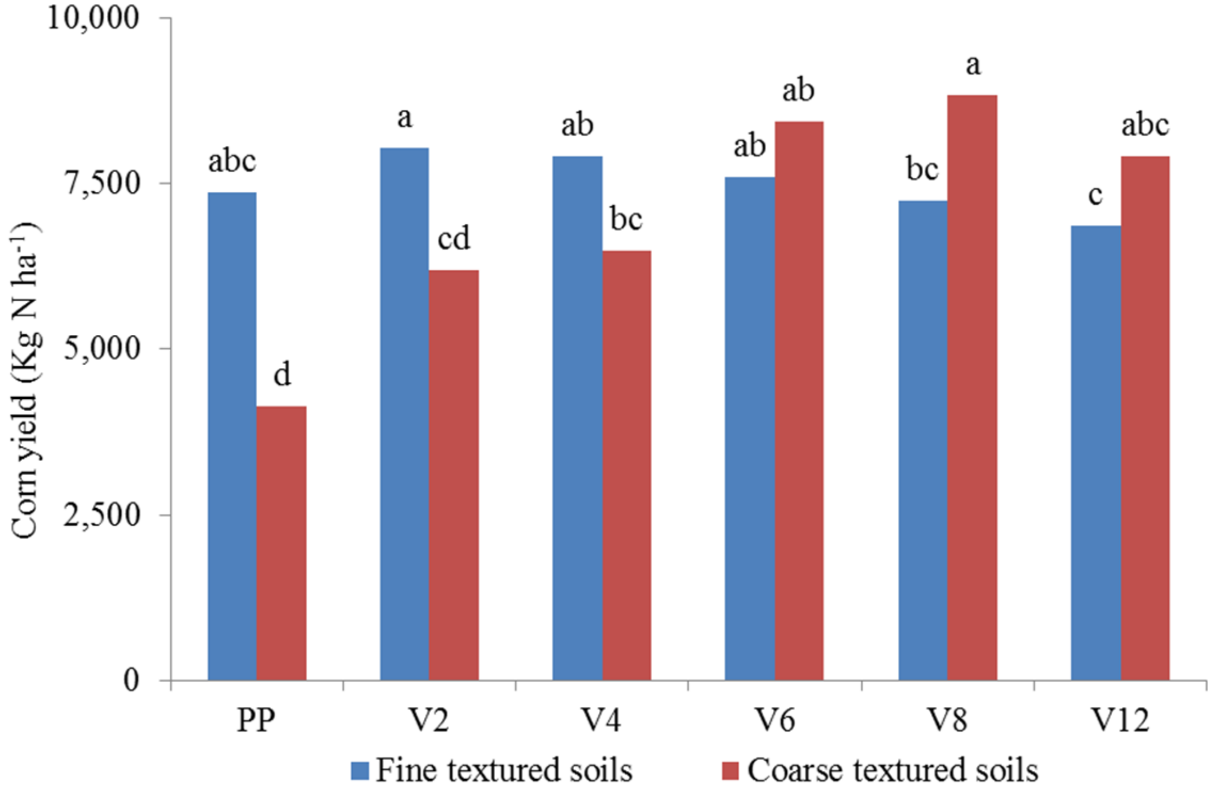


Figure 2: Grain yield at pre-plant (PP) and different sidedress timings with 100 to 125 kg N ha^{-1} in a coarse-textured soil and fine-textured soils (mean of 5 locations). Within texture-soil type, bars followed by the same letter are not significantly different (P>0.05).



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