REMOTE SENSING OF CORN N STATUS WITH ACTIVE SENSORS

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ABSTRACT

Determining in-season corn (*Zea mays* L.) nitrogen (N) variability has been a research focus of agronomists for quite some time. One of the methods currently available to determine N variability in corn is remote sensing. Studies have shown that remotely sensed imagery can detect N variability in corn. However, this method can have some limitations, such as the timeliness in which this imagery can be acquired. Hand-held active remote sensing devices may overcome these limitations. This study was conducted to test the ability of three sensors to detect N variability in irrigated corn at four N rates (0, 50, 100, and 175 lbs N/acre) across five corn growth stages (V8, V10, V12, V14, and V16). Results show that, depending on corn growth stage, all three of these units accurately quantify corn variability as it's affected by N fertility level and would be a useful tool for in-season N management in irrigated corn.

INTRODUCTION

Determining in-season corn N variability has been a research focus of agronomists for quite some time. Currently there are several methods available to identify in-field nutrient variability. These methods include grid soil sampling and collecting in-season plant samples. These methods are often cost prohibitive, labor intensive, and destructive to the crop (Khosla et al., 1999). Remotely sensed imagery can also provide important information about N variability in corn (Shanahan et al, 2001; Scharf & Lory, 2002; Chang et al, 2003; Sripada et al, 2005). Although very promising, remotely sensed imagery acquired by aircraft or satellite has some significant limitations. The greatest limitation is the timeliness in which imagery can be acquired. Acquiring aerial or satellite imagery at very specific crop growth stages can be limited by weather (i.e., cloud cover) and orbital cycles. Using a hand-held or tractor mounted active remote sensing device, these limitations may be overcome because they can be used on the ground, at any time. Studies have also shown that the vegetation indices calculated by these active remote sensors (NDVI, Normalized Difference Vegetative Index) are well correlated to N variability in corn (Raun et al, 2003, 2004).

The objective of this study was to assess the ability of three commercially available active remote sensors to distinguish in-season N variability in corn across five growth stages and four N rate treatments.

MATERIALS AND METHODS

This study was conducted at the Colorado State University Agricultural Research Development and Education Center (ARDEC) located north of Fort Collins, CO. This site is a continuous corn field under furrow irrigation and conventional tillage management. A Complete Randomized Block (CRB) design was implemented within the field with subplots of different N rates. There were four N rate treatments (0, 50, 100, and 175 lbs N/ac), yielding 16 subplots (each N rate was replicated four times to account for spatial variability). All subplots consisted of four corn rows that were 50ft in length.

Three commercially available active hand-held sensors were selected for this study; NTech's GreenSeeker™ red and green units and Holland Scientific's Crop Circle™. Each of these units determines NDVI using the equation below:

$$NDVI = \frac{\text{Near Infrared Band Reflectance} - \text{Visible Band Reflectance}}{\text{Visible Band Reflectance} - \text{Near Infrared Band Reflectance}}$$

However, each unit calculates NDVI using a different waveband in the visible band:

Green GreenSeeker™ visible band = green (510nm)
Red GreenSeeker™ visible band = red (650nm)
Crop Circle™ visible band = amber (590nm)

Sensor readings were collected at the V8, V10, V12, V14, and V16 corn growth stages with each of the 3 units. However, due to data logger failure in the field, V16 data is not available for the GreenSeeker™ units. Statistical analysis using Proc ANOVA in SAS was performed to determine the significant effect of the N rate treatment. When the treatment effect was significant at the alpha 0.05 level the least significant difference (lsd) value was determined using the means separation procedure.

RESULTS & DISCUSSION

The results of this study show that each of the three commercially available active hand-held sensors studied have the ability to distinguish in-season N variability (dependant on growth stage) in corn. Each sensor yielded different levels of NDVI, however, the overall trend of the NDVI readings for each sensor generally increased with increasing corn growth stage. The results of each individual sensor are presented below:

Crop Circle™ Sensor:

The Crop Circle™ sensor was able to distinguish significant N variability at all measured crop growth stages ($P < 0.05$) (Figure 1). At the V8 corn growth stage the sensor was only able to distinguish the 0 lbs N/ac rate as the other rates most likely supplied sufficient N for the corn at this stage resulting in no detectable variability between the 50, 100, and 175 lbs N/ac rates. This was also the case for the V10 corn growth stage. The Crop Circle™ sensor did not differentiate ($P > 0.05$) between the 100 and 175 lbs N/ac rates at any growth stage. This suggests that the crop had sufficient levels of N when it reached the 100 lb N rate. Significant differences between the 0, 50, and 100 lbs N/ac rates were detectable at the V12, V14, and V16 corn growth stages with the Crop Circle™ sensor. Generally NDVI increased with increasing N rate. This is directly related to increased leaf area and increased leaf N content of the corn leaf with increasing N application rate. Greater corn leaf area and corn leaf N content lead to increased surface area for sensor light reflection and therefore, increased NDVI. This increase in leaf surface area also leads to less soil exposure and therefore less soil interference on the sensor.

Significant differences in NDVI were also detectable across corn growth stage at all N treatment rates (Table 1). Generally as corn growth stage increased within N rate so did NDVI. As the corn grows and matures the growth stage increases and the canopy fills in creating more leaf area. This creates more area for sensor light reflection and leads to greater NDVI levels at all N rates.

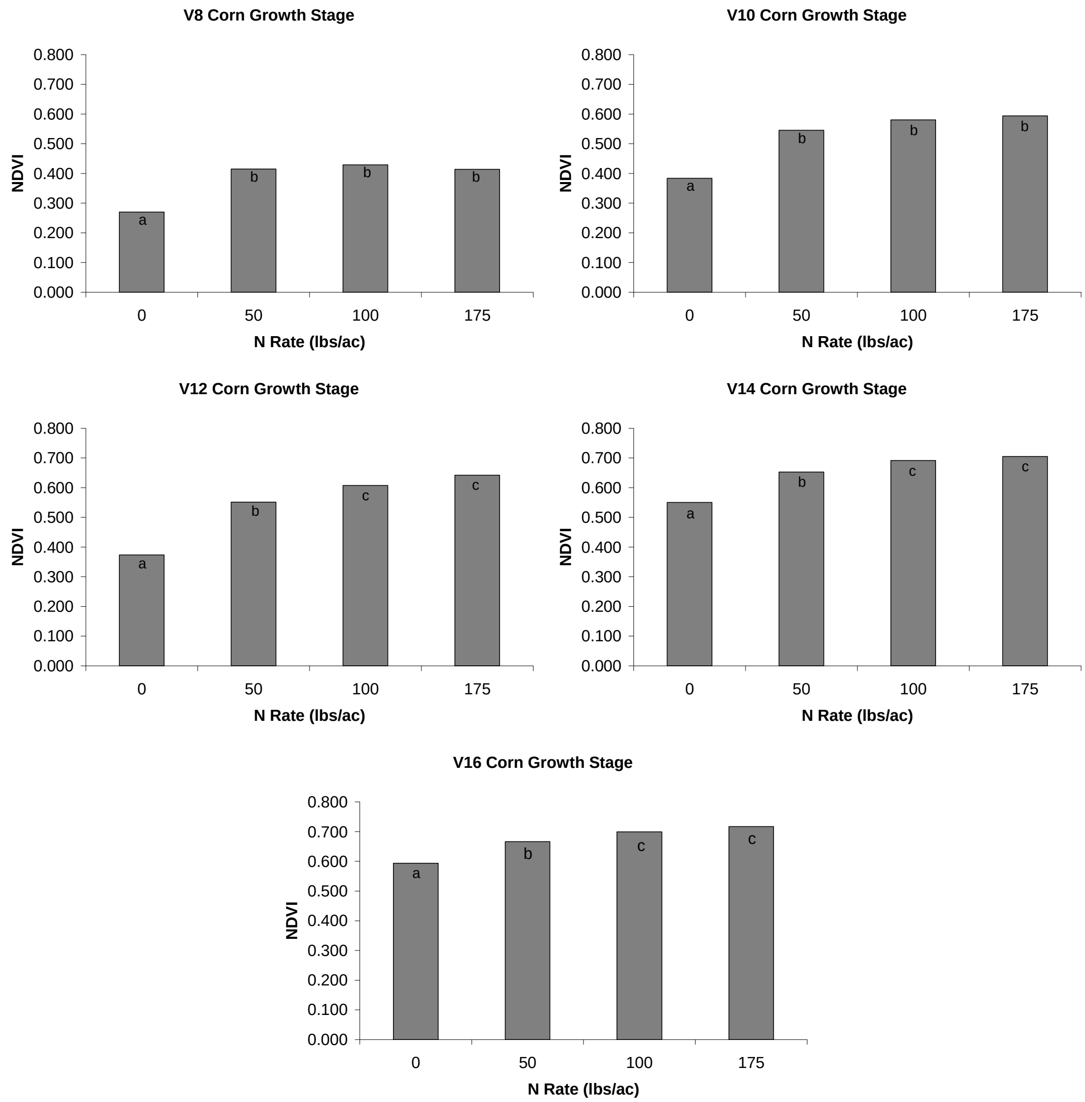

Figure 1. Crop Circle™ sensorcorn NDVI readings at growth stage V8, V10, V12, V14, andV16 as affected by 0, 50, 100, and 175 lbs N/ac N application rates.

Table 1. Crop Circle™ sensor NDVI readings across corn growth stages V8, V10, V12, V14, and V16 within 0, 50, 100, and 175 lbs N/ac N application rates.

	Corn Growth Stage						
	V8	V10	V12	V14	V16		
N Rate(lbs/ac)	-----------------------	Crop Circle NDVI	-----------------------			p-value	LSD**$_{0.05}$
175	0.414a*	0.594b	0.642c	0.705d	0.717d	<0.0001	0.027
100	0.429a	0.581b	0.607b	0.691c	0.699c	<0.0001	0.033
50	0.415a	0.545b	0.552b	0.653c	0.667c	<0.0001	0.046
0	0.270a	0.384b	0.374b	0.550c	0.594d	<0.0001	0.027

*Different letters across growth stage indicate significant differences

**LSD = least significant difference

Red GreenSeeker™ Sensor:

The red GreenSeeker™ sensor was able to distinguish significant N variability in irrigated corn (Figure 2). The red GreenSeeker™ unit only detected differences at the 0 lbs N/ac rate at the V8 and V10 growth stages as the corn plants had sufficient N at the 50, 100, and 175 lbs N/ac rates. The red GreenSeeker™ sensor could not distinguish between the 100 and 175 lbs N/ac rates at any growth stage again suggesting that the crop N needs were met at the 100 lbs N/ac rate. The red GreenSeeker™ unit also had some limitation in distinguishing between the 100 and 50 lb N rates in the V12 growth stage but was able to make this determination at the V14 stage. This suggests that the differences in the leaf area and leaf N content of corn plants between the 50 and 100 lbs N/ac rates were not yet pronounced enough at the V12 stage for this unit to detect differences. At the V14 growth stage the differences in leaf area and leaf N content were large enough to lead to greater amounts of sensor light reflection in the 100 lbs N/ac rate than in the 50 lbs N/ac rate.

The red GreenSeeker™ unit also detected N variability across all growth stages (V8, V10, V12, & V14) at all N treatment rates (Table 2). As growth stage increased within N rate red GreenSeeker™ NDVI also increased significantly in all cases tested. This is due to larger corn leaf area and greater leaf N content in the corn as growth stage progresses, leading to larger surface area for sensor light reflection, and higher NDVI values in the later corn growth stages. This relationship held within each N rate treatment because regardless of N rate the corn increased in leaf area with growth stage leading to increased NDVI.

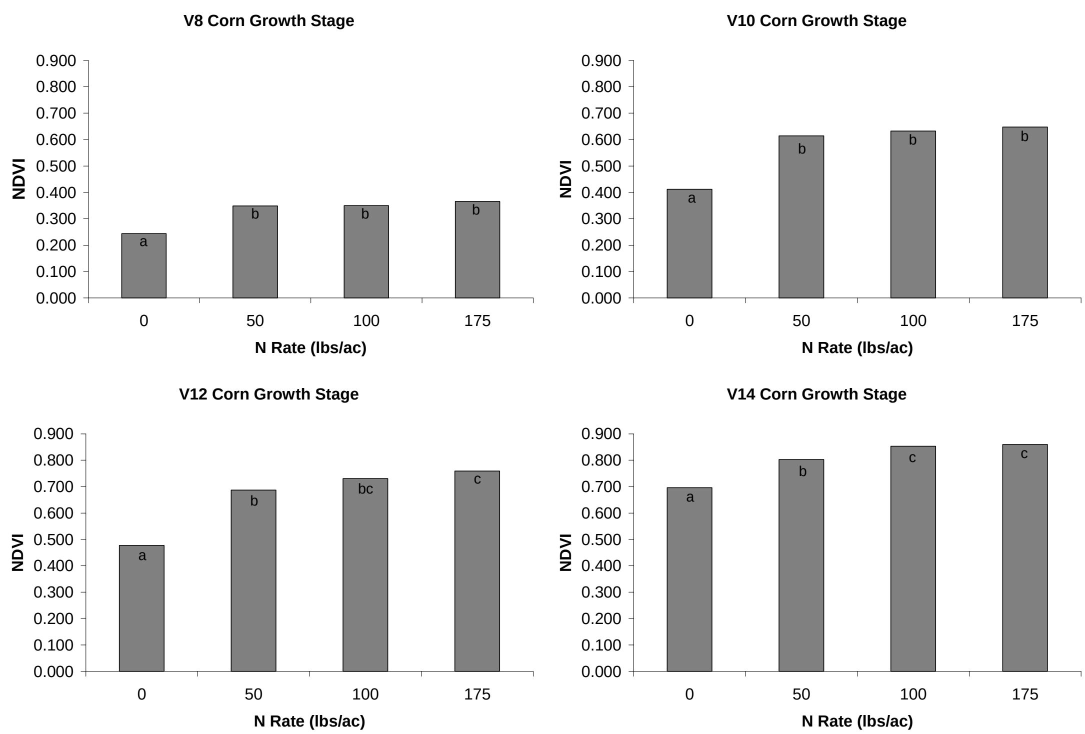

Figure 2. Red GreenSeeker™ sensor corn NDVI readings at growth stage V8, V10, V12, and V14 as affected by 0, 50, 100, and 175 lbs N/ac. N application rates.

Table 2. Red GreenSeeker™ sensor corn NDVI readings across corn growth stages V8, V10, V12, and V14 within 0, 50, 100, and 175 lbs N/ac N application rates.

	Corn Growth Stage					
	V8	V10	V12	V14		
N Rate(lbs/ac)	Red GS NDVI				p-value	$LSD^{**}_{0.05}$
175	0.365a	0.647b	0.759c	0.860d	<0.0001	0.041
100	0.340a	0.632b	0.731c	0.853d	<0.0001	0.034
50	0.348a	0.614b	0.687c	0.803d	<0.0001	0.044
0	0.244a	0.412b	0.477c	0.696d	<0.0001	0.033

*Different letters across growth stage indicate significant differences

**LSD = least significant difference

Green Greenseeker™ Sensor:

Significant differences in NDVI were detected across corn growth stage within N rate with the green GreenSeeker™ sensor (Table 3). However, the green GreenSeeker™ unit did not detect significant differences between the V10 and V12 growth stages at any level of N rate. The corn plant leaf area and leaf N content differences were not great enough between these growth stages for the green GreenSeeker™ unit to detect. Also, the levels of NDVI dropped significantly from the V12 to the V14 growth stage. The reasons for this drop in NDVI from growth stage V12 to growth stage V14 is not immediately apparent. The explanation may lie with the sensor itself. The sensor may have an upper limit of effectiveness (in this case growth stage V12). However, previous studies have not shown this to be true. Another possible explanation could lie with the data logger system used to collect the NDVI readings. This system is prone to crashing and errors, which we experienced numerous times throughout the study.

The green GreenSeeker™ only appeared to be able to determine differences in N variability at the V10 and V12 corn growth stages (Figure 3). At the V10 corn growth stage this sensor could detect differences in corn variability between the 0 lbs N/ac rate and the 50, 100, and 175 lbs N/ac rates. This suggests that corn N requirements were met by all N rates except 0 lbs N/ac at the V10 stage. At the V12 stage differences in variability were detectable at all N rates except between the 100 and 175 lbs N/ac rates. No significant differences in NDVI were detected with the green GreenSeeker™ sensor at the V8 or V14 corn growth stages.

Table 3. Green GreenSeeker™ sensor NDVI readings across corn growth stages V8, V10, V12, and V14 within 0, 50, 100, and 175 lbs N/ac N application rates.

	Corn Growth Stage					
	V8	V10	V12	V14		
N Rate(lbs/ac)	Green GS NDVI				p-value	$LSD^{**}_{0.05}$
175	0.423a	0.603b	0.614b	0.502c	<0.0001	0.049
100	0.392a	0.573b	0.613b	0.503c	<0.0001	0.050
50	0.426a	0.563b	0.573b	0.488c	0.0001	0.044
0	0.362a	0.456b	0.416b	0.503c	0.0005	0.047

*Different letters across growth stage indicate significant differences

**LSD = least significant difference

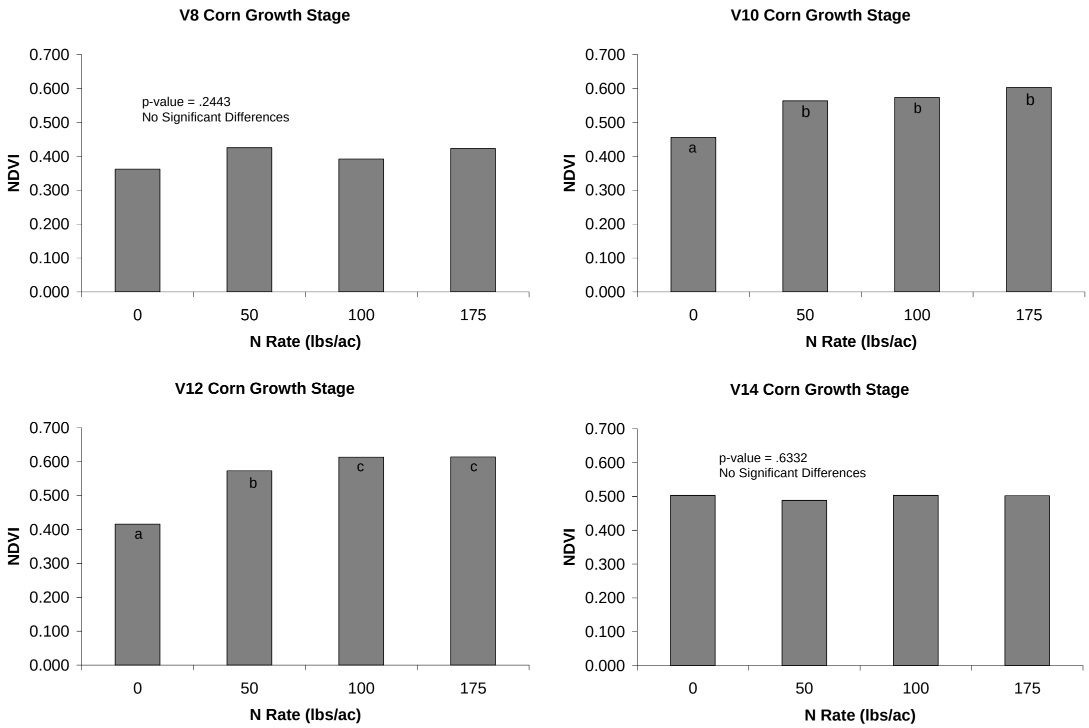

Figure 3. Green GreenSeeker™ sensor corn NDVI readings at growth stage V8, V10, V12, and V14 as affected by 0, 50, 100, and 175 lbs N/ac. N application rates.

CONCLUSIONS

This study was conducted to determine the ability of three commercially available active remote sensors to determine N variability in corn across four different N rate treatments and across five corn growth stages based on sensor measured NDVI readings. The Holland Scientific Crop Circle™ and NTech red GreenSeeker™ remote NDVI sensors make significant in-season NDVI estimates in irrigated corn when compared across 0, 50, 100, and 175 lbs N/ac N application rates. All three sensors were able to detect corn variability across corn growth stage with NDVI generally increasing with advancing growth stage. The red GreenSeeker™ unit was most effective showing significant differences across all growth stages within each level of N fertility. Overall all three of these sensors accurately quantify corn variability as affected by N fertility level and would be a useful tool for in-season N management in irrigated corn. However, the Crop Circle™ and red GreenSeeker™ sensors appear to have an advantage over the green GreenSeeker™ sensor due to its ability to only quantify this variability at the V10 and V12 growth stages.

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Volume 7

MARCH 8-9, 2007
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