

EVALUATION OF IN-FIELD SENSORS TO MONITOR NITROGEN STATUS IN SOYBEAN

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ABSTRACT

In recent years, active optical crop sensors have been gaining importance to determine in-season nitrogen (N) fertilization requirements for on-the-go variable rate application. Although most of these active in-field crop sensors have been evaluated in corn and wheat crops, they have not yet been evaluated in soybean production systems in North Dakota. Recent research from both South Dakota and North Dakota indicate that in-season N application in soybean can increase soybean yield under certain conditions. This study was conducted to evaluate the use of Ag leader OptRx sensor in soybean production to determine the N need. The data for this research were collected from North Dakota State University, NDSU NW22 plots in Fargo in 2013. A field plot experiment was conducted with 2 drainage treatments, 4 varieties, 6 N treatments and 4 replications. Two OptRx sensors, mounted on a small tractor were used to collect the Vegetation Index (VI) values over the study area on 5 different dates throughout the growing season. Each plot (7.6m x 1.5m) consisted of 4 rows. The sensor data were collected from the middle two rows to eliminate the edge effects. The VI data were exported to ArcGIS to calculate the mean VI for each plot. For the last date (87 Days After Planting [DAP]) of data collection in the growing season, data were also collected with a SPAD meter, hand-held Greenseeker, and Greenindex+ app. The OptRx reading didn't show any significant differences between the N treatments and varieties during early and mid-season (48 and 53 DAP). But later in the growing season (87 DAP), the treatments such as 84 kg/ha at emergence, 28 kg/ha at emergence plus 28 kg/ha at R2-3, and 56 kg/ha at emergence ESN (Environmentally smart nitrogen) exhibited significantly higher VI compared to other N treatments. Also the varieties 6088 and 12R06 showed significantly higher VI than other varieties. For the last date (87 DAP) of data collection, none of the other sensors except OptRx showed any significant difference between the treatments and varieties. Collecting subsequent years of data will be necessary to confirm the response of OptRx sensor to N application in different varieties of soybeans.

Keywords: Precision Agriculture, In-field active optic sensors, Soybeans, Nitrogen, Vegetation Index

INTRODUCTION AND BACKGROUND

Soybean [*Glycine max* (L.) Merr.] is one of the major crops grown in US. It has become an increasingly important crop in North Dakota. There is a demand for soybean produced in the US and around the world with an increase in world population every year. According to United States Department of Agriculture (USDA), the annual production forecast of soybean in the nation was 88.61 million Mg with North Dakota ranking 10th in the nation at an estimated annual production of 3760 Mg (USDA, 2013). The center for agricultural policy and trade studies at NDSU reported that the soybean acreage in North Dakota increased from 243-283 thousand hectares since the late 1980s to early 1990s to 1.9 million hectares in 2012. The share of soybeans in North Dakota's agricultural revenue was around \$646 million during 2000s and during 2008-2012, it increased to \$ 1.45 billion (Richard and Won, 2013). The planting forecast of soybean in 2014 has been increased to 33 million hectares across the nation. In North Dakota the soybean acreage has been projected to increase from 1.88 million hectares in 2013 to 2.29 million hectares in 2014 (USDA, 2014).

In recent years, optical crop sensors have been gaining importance to determine in-season fertilization requirements for variable rate N application, primarily in corn and wheat. Some of the In-field active optical sensors available in the market include Trimble handheld Greenseeker (Trimble Navigation limited, CA, USA), OptRx (Ag leader Technology, Inc., Iowa, USA) and SPAD meter (Minolta SPAD-502; Minolta Corp., Ramsey, NJ, USA). The Trimble greenseeker is an active sensor that emits its own source of red and infrared light and determines NDVI by measuring the reflected light back at the sensor. The OptRx sensor operates similar to the greenseeker sensor but has three channels. The sensor emits light at three wavelengths: 670 and 730 nm in the visible band, and 780 nm in the NIR band. Since this sensor has its own source of light, it is not affected by ambient light conditions and can work both during day and night. This sensor also has the unique ability to provide NDRE (Normalized Difference Vegetation Index Red Edge) values. Based on the real time VI values, Ag leader Direct CommandTM applies variable rate N on-the-go comparing the real time VI value to a reference value.

Dellinger et al. (2008) used Crop Circle ACS-210 active optical canopy sensor (Holland Scientific, Lincoln, NE) to determine side dress N rate in corn at the V6-V7 growth stages and found that the relative green normalized difference vegetation index (GNDVI) was strongly related to the calculated economic optimum N rate (EONR). Hawkins et al. (2007) conducted a study on in-season N stress in corn and indicated that the N stress can be detected using a SPAD meter. They also reported that N rate algorithms could be developed to make variable rate N applications between the V8-V12 growth stages of corn growth. Scharf et al. (2011) evaluated the performance of sensor-based variable rate N application in corn with respect to the constant N rates chosen by the producer in Missouri. Their results confirmed that sensors N rate algorithm can perform better than the rates chosen by producers.

One of the passive optical sensing methods that was successfully developed for detecting N status of corn is by measuring a GreenIndex using a cell phone camera that was developed into an app by Spectrum Technology (Spectrum Technologies, Inc., IL, USA). Rorie et al. (2011) developed the underlying digital imaging technique to assess leaf N concentration in corn leaves. The pictures of corn leaves from different N treatments were converted into a dark green color index (DGCI). The DGCI values were strongly correlated to SPAD meter readings with $r^2 > 0.91$.

Although N application is not typical in soybean as it is a N fixing plant, past research has shown that N application in soybean can increase crop yield by 2.8 % under tiled drainage (Drury et al. 2009). A research study conducted in Kansas State also showed that late season N fertilization increased yield in irrigated soybeans (Lamond and Wesley, 2001; Wesley et al., 1999). The use of spectral crop sensors may be able to identify the need for N in soybean on a real-time basis, and make appropriate in-season applications of N to avoid plant stress, and thus yield reduction. Currently, many of the commercially available crop sensors have been evaluated and tested in corn and wheat crops. These crop sensors have not yet been evaluated in soybean production systems in North Dakota. The objective of this research was to evaluate OptRx sensor to detect N need in soybeans. This research may provide information about the usefulness of spectral crop sensors in soybean production management.

MATERIALS AND METHODS

Description of study area

The research experiment was conducted at North Dakota State University's research site NW22 (latitude 46°55'57.10" N, longitude 96°51'32.49" W) located in Fargo, North Dakota, USA during the summer 2013 crop season (Figure 1). The soil of the study site was mostly silty clay soil profile up to 1.5 meter with an average growing season rainfall of 406 mm. The annual growing season is from April 1 to September 30 with an average maximum and minimum temperature of 23° C and 10° C respectively. The average air temperature for the study area is about 16° C and the frost-free period is around 130 days.

Design of experiment

The experimental design for the study area was a split plot randomized block design with drainage as the main factor, and N rate x variety as the sub-plot factors. There were a total of 2 drainage treatments (tiled and non-tiled), 6 N treatments, 4 varieties, and 4 replications resulting in a total of 192 plots. The six N rates included 0 kg/ha, 56 kg/ha urea and 84 kg/ha urea at emergence, 56 kg/ha urea at R2-3, 28 kg/ha urea at emergence with 28 kg/ha urea at R2-3, and 56 kg/ha of ESN at emergence. The ESN refers to polymer coated N fertilizer that improves N use efficiency and reduces loss of N to the environment.

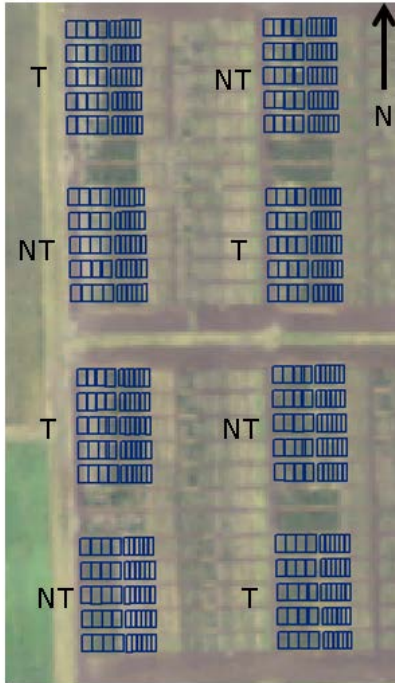


Figure 1. Layout of experimental site NW22 with shapefiles of the plots overlaid on an aerial image. T = Tiled and NT = Non-Tiled.

The four soybean varieties included 04403 (Mustang), 6088 (NuTech), PFS12R06 (Peterson Seed) and 90Y41 (Dupont Pioneer). The study area was planted with four soybean varieties and each experimental unit was 1.5 m wide and 7.6 m long. The crop was planted on May 16, 2013. It emerged on June 11th at 26 DAP and reached R2-3 stage on July 17th at around 62 DAP, and was harvested on October 2nd at 138 DAP. The crop was managed by North Dakota Agriculture Experimental Station (NDAES) and monitored weekly for pests and diseases.

Data collection and analysis

Two Ag leader OptRx sensors (Figure 2) were mounted on a tractor and used to collect the Normalized Difference Red Edge (NDRE) values over the study area on 5 different dates (48 DAP, 53 DAP, 60 DAP, 79 DAP and 87 DAP) throughout the growing season. The sensor data were collected from the middle two rows to eliminate the edge effects. A polygon shape-file of each of the treatment plots was created in ArcGIS using GPS measurements taken over the entire field. The NDRE data collected using OptRx were exported to ArcGIS to calculate the mean NDRE for each experimental unit. For the last date (87 DAP) of data collection in the growing season, other sensors namely hand-held Greenseeker, SPAD meter, and greenindex+ app were also used and compared with OptRx readings. Statistical analysis was performed for each date using the statistical software SAS (version 9.3, SAS Institute, Cary, NC, USA) to evaluate OptRx sensors response to different N application rates and varieties. Both analysis of variance (ANOVA) and mean comparison with LSD test was performed to evaluate treatment effects.



Figure 2. Ag leader OptRx sensors mounted on a tractor.

RESULTS AND DISCUSSION

Active optical sensor data

The OptRx sensor readings showed a distinct difference in average values for different dates in the growing season. The values varied from 0.157 to 0.324 for 48 DAP and 87 DAP respectively. The NDRE values showed a significant difference in drainage treatments early in the season. These values varied from 0.159 to 0.325 for tilled condition and 0.146 to 0.324 for non-tiled condition during the growing season. There was no distinct trend observed for N treatments with different rates applied at different growth stages, but increase in values were observed for different dates ranging from 0.148 to 0.158 at 48 DAP and 0.315 to 0.335 at 87 DAP. The varieties 12R06 and 6088 showed higher NDRE values from 0.155 to 0.336 than varieties 04403 and 90Y41 which varied from 0.149 to 0.316. The P-values for different treatments and dates are summarized in Table 1.

Table 1. ANOVA results for different drainage, N and variety treatments, main and interaction effects on NDRE values.

Days After Planting (DAP)	Sources of variation						
	Drainage (main plot)	N-treatments (Sub-plot)	Variety (Sub-plot)	Drainage × N-treat	Drainage × Variety	Variety × N-treat	Drainage × Variety × N-treat
	<i>P>F</i>						
48 (Jul,3)	<0.001***	0.415	0.479	0.765	0.724	0.937	0.434
53 (Jul,8)	0.092*	0.198	0.632	0.819	0.879	0.204	0.767
60 (Jul,15)	<0.001***	0.027**	0.506	0.401	0.529	0.052*	0.220
79 (Aug,5)	0.857	0.588	0.066*	0.910	0.308	0.995	0.192
87 (Aug,13)	0.765	0.075*	0.029**	0.815	0.703	0.002***	0.460

*Means are significant in 0.1 confidence level.

**Means are significant in 0.05 confidence level.

***Means are significant in 0.01 confidence level.

OptRx sensor response to treatments

The NDRE measured with OptRx sensor did not show a response to N treatments or varieties early or mid-season at around 48 DAP and 79 DAP respectively (Table 2 and 3). This might be due to the fact that early in the season, more bare soil was visible to the sensor compared to crop canopy. But, significant difference was noted for tilled and non-tilled plots at 48, 53, and 60 DAP (Figure 3). The oxygen supply is reduced and affects the final yield under waterlogging conditions (Russell, 1977) and hinders root growth and nodulation in soybeans (Sallam and Scott, 1987). The NDRE values were significantly higher in tilled plots compared to non-tilled plots because of better crop growth due to better soil aeration and oxygen balance in the root zone. The result agreed with the findings of Board and Harville (1996), who reported that the crop growth rate in a drained site increased for stress free soybean.

There was significant difference observed only between some of the varieties for August 05 (79 DAP) and August 13 (87 DAP) in NDRE values which might be due to the difference in canopy development among the varieties (Figure 4). The crop growth rate is influenced by soybean varieties at different growth stages (Ruhul Amin et al. 2009; Futuless et al. 2011). At around 60 and 87 DAP, significant differences were observed between some of the N treatments (Figure 5). The p-values for different N treatments and varieties at different DAPs are shown in Table 2 and 3. It is evident that the sensor did show differences between the treatments and varieties during the late season when the plants were close to complete canopy closure.

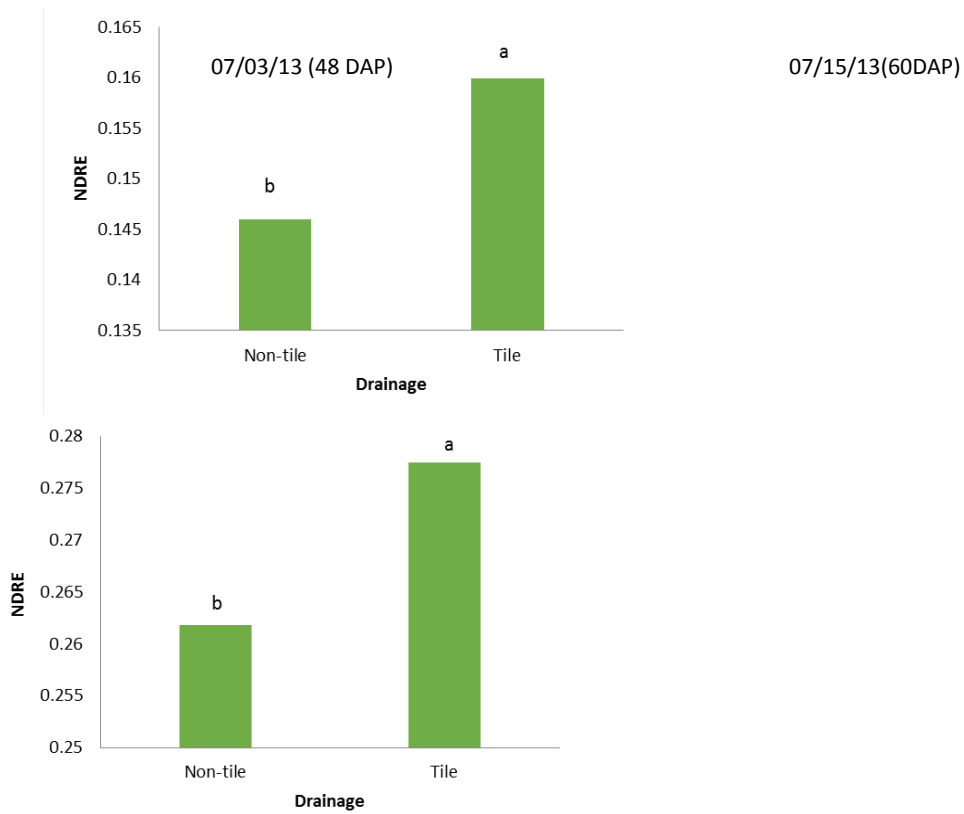


Figure 3. NDRE response to tiled and non-tiled drainage treatments. Means with different letters are significantly different ($\alpha= 0.05$) between main treatments for 48 DAP or 60 DAP.

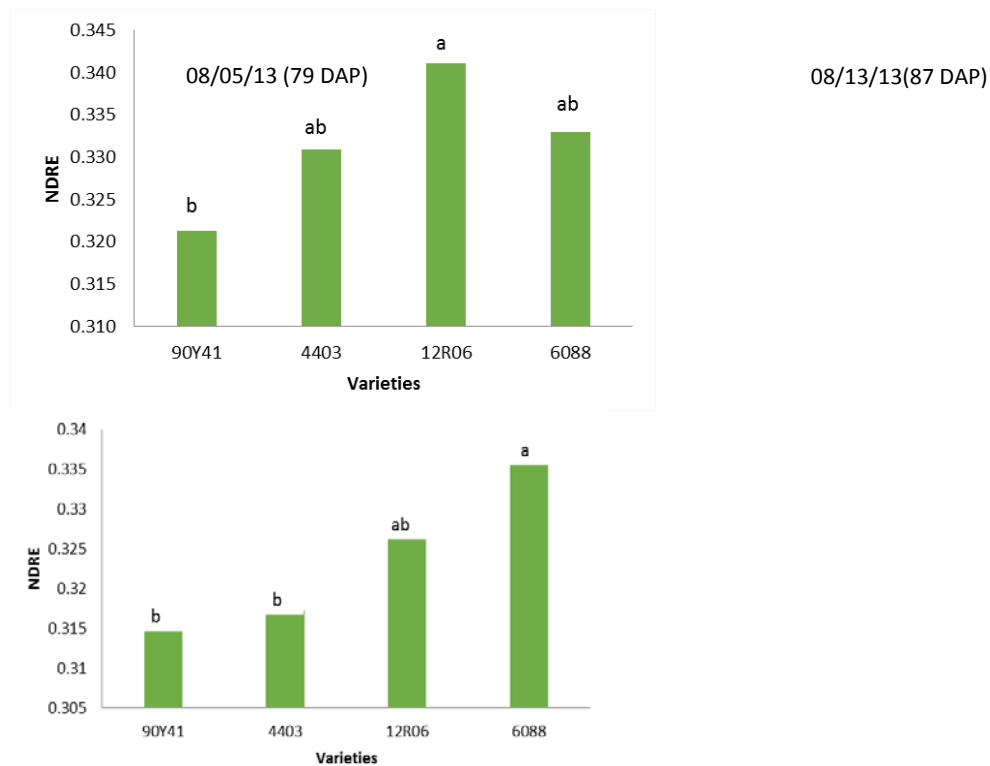


Figure 4. OptRx response to different varieties. Means with the same letter are not significantly different ($\alpha= 0.05$) between varieties.

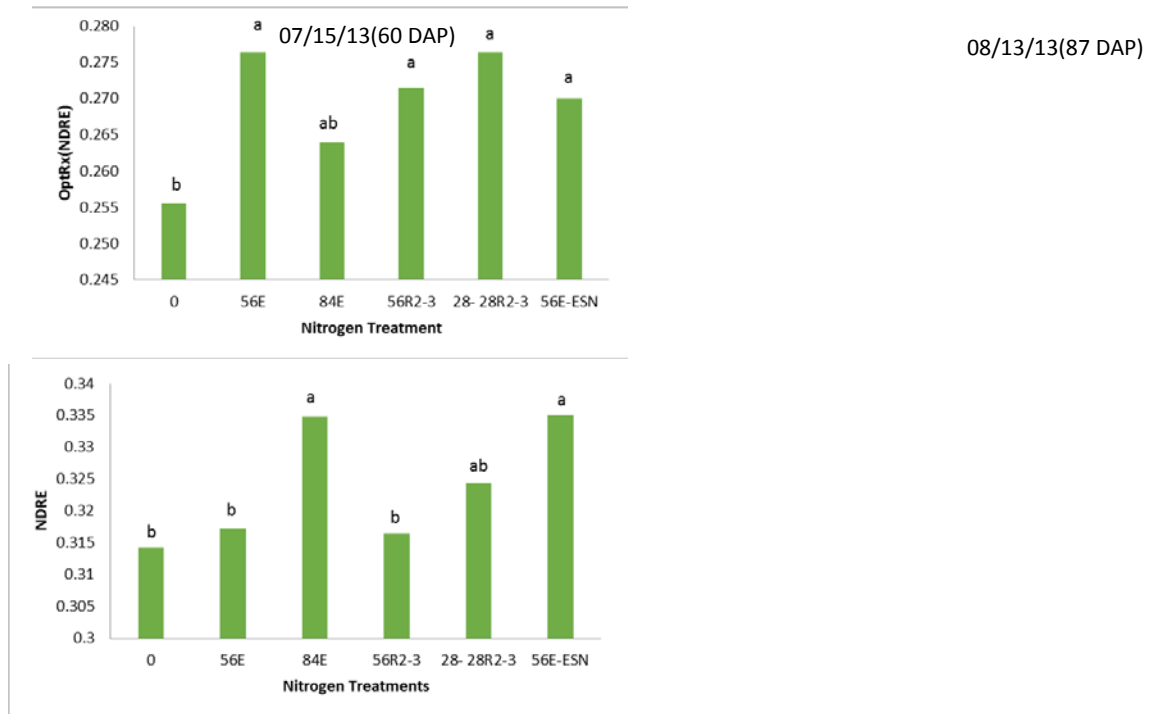


Figure 5. OptRx response to different N treatments. Means with the same letter are not significantly different ($\alpha= 0.05$) between N treatments.

Table 2. Mean NDRE values for different N treatments and plant growth stages.

N-Treat	Days After Planting(DAP)			
	48	60	79	87
0	0.156 ^{a*}	0.256 ^b	0.326 ^a	0.315 ^b
56E	0.153 ^a	0.276 ^a	0.328 ^a	0.317 ^b
84E	0.148 ^a	0.264 ^{ab}	0.326 ^a	0.335 ^a
56R2-3	0.152 ^a	0.271 ^a	0.332 ^a	0.316 ^b
28E- 28R2-3	0.158 ^a	0.276 ^a	0.338 ^a	0.324 ^{ab}
56E-ESN	0.150 ^a	0.270 ^a	0.338 ^a	0.335 ^a

*-Means in the column with same letter are not significantly different at $p<0.05$.

Table 3. Mean NDRE values for different Varieties and plant growth stages.

	Days After Planting(DAP)
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Variety	48	60	79	87
90Y41	0.151 ^{a*}	0.274 ^a	0.321 ^b	0.316 ^b
4403	0.150 ^a	0.265 ^a	0.331 ^{ab}	0.317 ^b
12R06	0.154 ^a	0.268 ^a	0.341 ^a	0.327 ^{ab}
6088	0.156 ^a	0.270 ^a	0.333 ^{ab}	0.336 ^a

*-Means in the column with same letter are not significantly different at $p < 0.05$.

OptRx Vs. Other active sensors

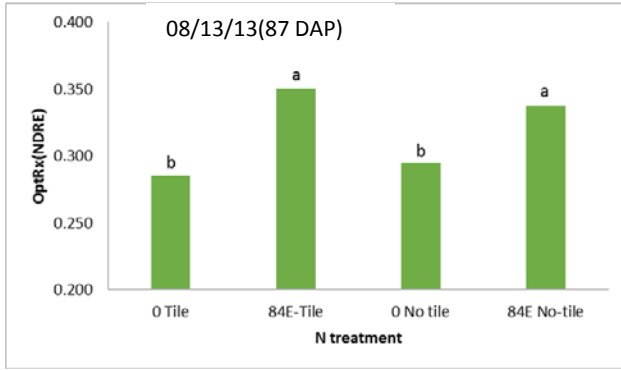
For the last date at 87 DAP, few other sensors (Greenseeker, Spadmeter 502 and greenindex+ smartphone app) were used and compared with OptRx readings. Specific plots with two different N rates for a specific variety (90Y41) were chosen to collect data using the above mentioned sensors in both tiled and non-tiled conditions. The results (Table 4) show no significant difference between the N treatments for all the sensors except OptRx (Figure 6-7). The OptRx sensor uses red edge light wave technology which works better later in the growing season with an increasing canopy cover. It has been reported that the red edge wavebands have greater sensitivity at higher chlorophyll content and biomass. These wavebands are influenced by plant chlorophyll content, leaf structure and leaf area index (LAI) (Meer and Jong, 2006). The NDVI values computed from optical sensors such as greenseeker that use red wavelength is reported to be unresponsive with greater canopy cover. Leaf orientation at different growth stages, decrease in chlorophyll content at senescence and increase in soil moisture could cause low sensitivity of NDVI (Gitelson et al., 2001). Figure 8 shows the correlation between yield and NDRE values for August 13 at around 87 DAP. There was a low but significant correlation between yield and NDRE for 90Y41 variety compared to others in both tiled ($r = 0.53$) and non-tiled plots ($r = 0.46$).

Table 4. Mean output values for different in-field sensors evaluated in different N and drainage conditions (87 DAP).

Treatment	Sensor			
	OptRx (NDRE)	DGCI	Green Seeker (NDVI)	Spadmeter502 (SPAD)
0 Tile	0.285 ^{a*}	0.655 ^a	0.82 ^a	46.9 ^a
84E-Tile [†]	0.350 ^b	0.663 ^a	0.83 ^a	48.2 ^a
0 No-tile	0.295 ^a	0.648 ^a	0.82 ^a	47.5 ^a
84E No-tile	0.338 ^b	0.648 ^a	0.84 ^a	47.7 ^a

*-Means in the column with same letter are not significantly different at $p < 0.05$.

[†] 84 kg N at emergence.



08/13/13(87 DAP)

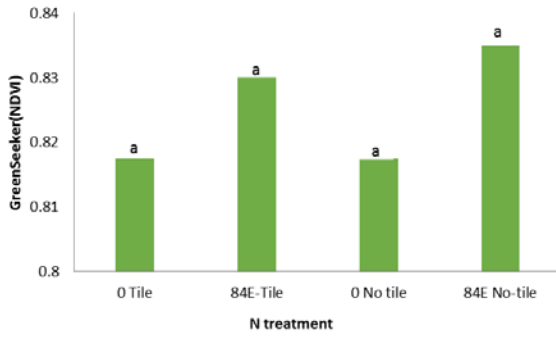
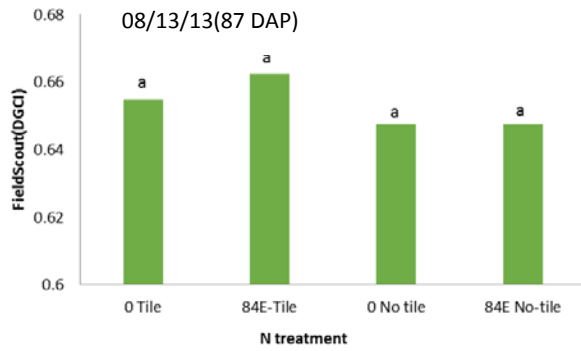


Figure 6. OptRx and GreenSeeker response to N treatments with tiled and non-tiled conditions. Means with the same letter are not significantly different ($\alpha= 0.05$) between treatments.



08/13/13(87 DAP)

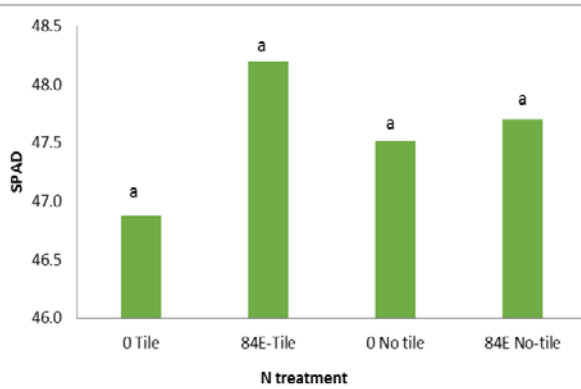


Figure 7. Dark green color index (DGCI) and Spadmeter response to N treatments with tilled and non-tiled conditions. Means with the same letter are not significantly different ($\alpha=0.05$) between treatments.

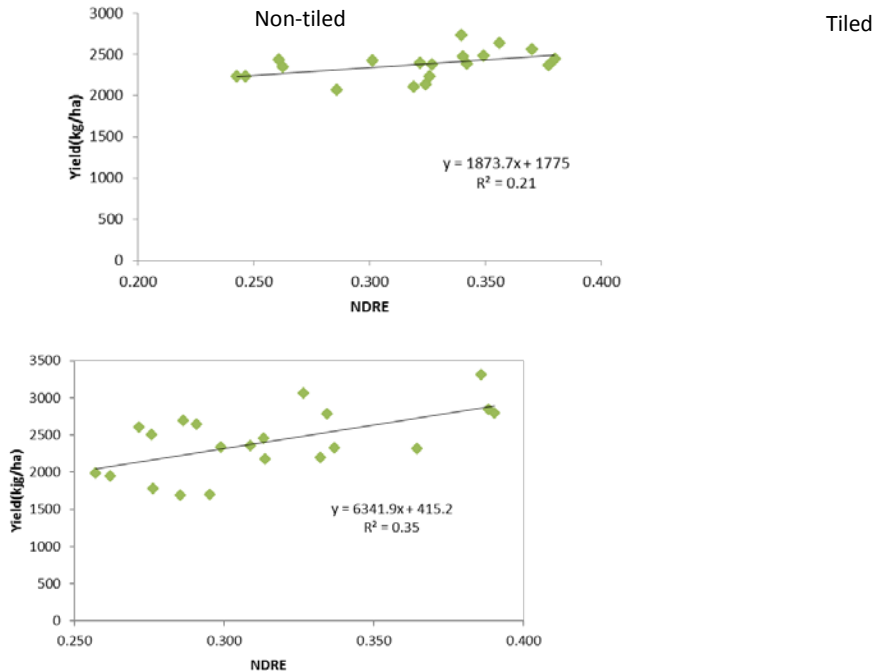


Figure 8. Relationship between yield and NDRE for soybean variety 90Y41 (87 DAP).

SUMMARY AND CONCLUSION

This paper investigated the potential use of active optical sensors in soybean production systems in North Dakota to detect N status of the plants. Early to mid-season, the N treatments and varieties did not influence NDRE. Similar trend was observed for dates 53 DAP and 60 DAP respectively. The NDRE were significantly different between tilled and non-tilled plots in early and mid-season. At later stages, sensor readings showed significant difference between the N treatments and varieties. Significant correlation existed between NDRE and the final yield for variety 90Y41 compared to other varieties. This study shows that the OptRx sensor has the potential to detect N treatment differences later in the season. Further research is needed to confirm the use of OptRx sensor for variable rate in-season N application in soybeans. Also, more investigation needs to be performed regarding the response of the OptRx sensor with different soybean varieties.

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