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ABSTRACT
The use of optical sensors to detect nitrogen (N) deficiencies and determine in-season fertilizer recommendations has grown. Nitrogen responses are difficult to detect early in the growing season. The objective of this experiment was to determine if different N sources could deliver early season detection of N deficiencies. Four N fertilizer sources were applied at rates of 90 and 180 kg N ha^{-1} across three site-years. A Greenseeker and SPAD sensor were used to measure in-season fertilizer response index (RI). When differences in sensor RI values between N rates were present, they did not occur until the V9/10 growth stage. No specific N source provided superior results that led to a reliable, early season detection of N deficiency. Reliable differences in response index values could be detected beyond the V7/V8 growth stages. For earlier detection of N responsiveness, and potential N deficiency, other management strategies should be investigated.

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corn; nitrogen; fertilizers; precision agriculture

Introduction

With an increasing demand for livestock feed exports and corn (*Zea mays* L.) based ethanol (Wallander, Claassen, and Nickerson 2011) the area of corn production has increased over the last 20 years in the Southern Great Plains of the USA (U.S. Department of Agriculture 2014). Though the irrigated area has remained relatively constant, to meet the increased demand, the rain-fed area planted and harvested has increased in this region (U.S. Department of Agriculture 2014). Average yearly grain yields in the region of North-central Oklahoma for rain-fed corn can range from 3 to 7 Mg ha^{-1} depending on the year (U.S. Department of Agriculture 2014). Even though these values do not rival the yield levels of non-irrigated areas of the Midwestern corn belt of the United States, nitrogen (N) fertilizer production practices that reduce environmental impact and maximize the use of resources should be pursued.

One production practice researchers have investigated that aids in the recovery of more N fertilizer in the grain is a sidedress application of N at the time of maximum N uptake by the corn plant (Welch et al. 1971; Russelle et al. 1981; Olson and Kurtz 1982; Aldrich 1984). It is widely accepted that a sidedress application of N does increase grain N; however, results for the impact of sidedress N on final grain yield have been mixed. Researchers have reported that, averaged over multiple site years, the sidedress application of N increased grain yields compared to a preplant-only application (Stevenson and Baldwin 1969; Walsh et al. 2012). However, others have reported highly variable year-to-year yield improvements or non-improvements that oftentimes cannot be explained (Welch et al. 1971; Bushong et al. 2016).

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Properly determining the appropriate sidedress N fertilizer rate that maximizes corn grain yield and N use efficiency (NUE) has been burdensome. One proposed approach has been the use of ground-based active optical sensors (GBAOS) that detect N deficiency coupled with algorithms that determine the optimum N fertilizer rate (Raun and Schepers 2008). These GBAOS use ratios or normalized difference vegetation indices (NDVI) derived from crop canopy or individual leaf reflectance or transmittance of red and near-infrared wavebands that estimate the crop greenness/chlorophyll content and biomass (Sharma and Franzen 2014). One of the more popular algorithms for determining N recommendations in corn with GBAOS utilizes the measurement of the crop grain yield potential at the time of sensing along with a response index (RI), which is the ratio of the crop sensor value of an N-rich area compared to an area thought to be deficient in N (Raun et al. 2005). These two parameters encompass the theory described by Raun, Solie, and Stone (2011) and Arnall et al. (2013), in that grain yield potential and crop responsiveness to N fertilization are independent of one another and can vary from site to site and year to year at the same site.

As previously stated, in-season grain yield prediction is one of the key components for determining appropriate N rate recommendations from GBAOS algorithms. Researchers have had success by employing GBAOS along with other parameters such as growing degree-days (GDD) and corn height (Teal et al. 2006; Martin, Raun, and Solie 2012; Sharma and Franzen 2014). The grain yield RI concept was first proposed by Johnson and Raun (2003) and was computed as the grain harvest index, which was determined by dividing the maximum grain yield of fertilized plots by the grain yield of unfertilized plots. Because it would be too late to make an in-season management decision by the time of grain harvest, researchers have attempted to predict the harvest ratio in-season. Mullen et al. (2003) employed the theory of Biggs et al. (2002), which compared crop reflectance of an unfertilized or under-fertilized field to a high N reference strip. They reported the ratio of the NDVI of the high N-rich area to the NDVI of the unfertilized area correlated well with the grain harvest index ratio for wheat (*Triticum aestivum* L.) The equations from the relationships between the two RI's could then be used to predict the grain harvest RI value.

The early season N status of a growing corn crop can be greatly affected by the amount and form of available N. The amount and form can be dependent upon the transformation and loss mechanisms of N in the soil. Previous trials from the Midwestern corn belt of the United States have been conducted to determine the adequate quantity of N to establish N-rich reference areas using different N sources (Blackmer and Schepers 1994; Varvel, Schepers, and Francis 1997). However, only Yu et al. (2010) have compared the performance of different N sources at establishing N-rich reference areas. Yu et al. (2010) evaluated the effects of calcium ammonium nitrate, urea ammonium nitrate (UAN), polymer coated urea, environmentally smart N, and urea on corn chlorophyll and photosynthetic properties. They observed that all sources were equally effective at establishing N-rich reference area.

One of the issues with the use of the RI concept in rain-fed corn grown in the Southern Great Plains is that the appearance of an N deficiency does not occur until at least growth stage V7 (Abendroth et al. 2011) and oftentimes later (Teal et al. 2006; Martin et al. 2007), especially when any amount of preplant N fertilizer is applied. With warmer air and soil temperatures that promote rapid growth and the use of shorter season hybrids to avoid reproductive growth during warmer times of the growing season, the time window of opportunity for mid-season N fertilization is rather small. Also, with N deficiency detection typically not apparent until V7 or later, expensive high clearance N applicators would likely be needed for sidedress applications. Thus, methods that would allow for earlier season detection of N deficiency would be beneficial. The objective of this study was to determine if N fertilizer sources that are ammonium- and/or nitrate-based, could provide an earlier season detection of N deficiency in rain-fed corn grown in the Southern Great Plains.

Materials and methods

The experiment was conducted at one location (Lake Carl Blackwell, OK, USA) during the 2012 growing season and at two locations (Lake Carl Blackwell, OK, USA and Hennessey, OK, USA) during the 2013 growing season. Site soil mapping unit descriptions and preplant soil nutrient testing results are provided in Table 1. If required by the regional fertilizer recommendations of Zhang and Raun (2006), the research areas were fertilized prior to planting to 100% sufficient levels based on soil test P and K results. This practice was conducted to insure that N would be the only limiting nutrient.

A randomized complete block design with three replications per site-year was utilized to evaluate the effects of different preplant N fertilizer sources on in-season sensor RI values. Four N fertilizer sources: ammonium sulfate (AS, 180 g N kg^{-1}), urea (450 g N kg^{-1}), urea ammonium nitrate (280 g N kg^{-1}), and calcium nitrate (CN, 155 g N kg^{-1}) were applied at two rates of 90 and 180 kg N ha^{-1}. These plots served as the N-rich plots. An unfertilized check treatment was included in each block. For the Lake Carl Blackwell, OK sites in 2012 and 2013 the fertilizer was broadcast applied and mechanically incorporated. Because the Hennessey site in 2013 was a no-till site, fertilizer was broadcast applied and left on the soil surface prior to planting.

For all three site-years, plot sizes were 3.1 m wide by 6.2 m long. Four rows spaced 76 cm apart were planted per plot. Field activities including N fertilizer application dates, planting dates, corn hybrids, seeding rates, and sensing dates are provided in Table 2. Planting took place in the spring using corn hybrids that are known to express improved drought tolerance. Seeding rates were based on best agronomic practices for rain-fed corn in the Southern Great Plains. Daily rainfall and average temperature were recorded from the nearest climate-monitoring site (Oklahoma Mesonet 2014) for each respective site-year. A summary of the climatic conditions from planting up to reproductive growth for the three site-years is provided in Figure 1.

In-season sensor RI values were computed by dividing the designated N-rich strip plot sensor value by the farmer practice plot sensor value for each respective block. Sensor measurements were collected at the V6, V8, and V10 growth stages for Lake Carl Blackwell, OK in 2012 and 2013 and at the V5, V7, and V9 growth stages for Hennessey, OK in 2013. All corn growth stages were reported according to Abendroth et al. (2011). Grain yield RI values for the trial area of each site-year were computed by dividing the grain yield of the 180 kg N ha^{-1} AS plots by the unfertilized plots. The high N rate AS plots were chosen, because these were the plots with the highest grain yield for each site-year and this would best represent what would be the most ideal RI to achieve maximum grain yield for each site. As previously stated, the in-season sensor RI and grain yield RI do not have a 1:1 relationship; so simple, linear relationships have been used to estimate one from another. For this trial the following relationship was used:

$$\text{GrainYield RI} = 1.64 \quad (\text{Sensor RI}) - 0.5287 \tag{1}$$

This equation was developed from numerous site-years of regional corn N response trials and is updated regularly with current data (Oklahoma State University 2014).

Two commercially available GBAOS were employed to collect the in-season RI values. A Greenseeker (Trimble, Sunnyvale, CA, USA) crop sensor, which reports NDVI using reflectance values from red (660 nm) and near-infrared (780 nm) wavelengths, was used. Greenseeker measurements were collected over the entire length of the two center rows of the four row plots and the values averaged for each plot. A Minolta SPAD model 502 (Spectrum Technologies, Plainfield, IL, USA) chlorophyll meter, which measures transmittance with red (650 nm) and near-infrared (940 nm) spectral wavebands was employed. SPAD meter measurements were collected on the same day as Greenseeker measurements according to the procedures of Blackmer and Schepers (1995). Readings were collected from ten plants in each of the center two rows and the values averaged for each plot. Measurements were collected on the upper-most collared leaf and obtained midway between the leaf tip and base as well as between the leaf margin and the midrib. Corn leaves that appeared damaged were not measured.

Because the actual grain yield RI was different for each site-year, the three site-years were analyzed separately. The main and interactive effects of N source and N rate for each sensing date were evaluated with analysis of variance techniques. Fisher's protected LSD post-hoc analyses were performed on significant ($alpha = 0.10$) main and interactive treatment effects. All statistical analyses were performed using JMP Pro Version 10.0 (SAS Institute Inc., Cary, NC, USA).

Table 1. Preplant surface (0–15cm) chemical characteristics and soil classification of sites utilized in this study.

Location[a]	Year	Soil mapping unit	Major component(s) soil taxonomic classification	pH[b]	NH_4-N[c]	NO_3-N[c]	P[d]	K[d]	Total N[e]	Organic C[e]
					mg kg^{-1}				g kg^{-1}	
LCB	2012	Pulaski fine sandy loam, 0 to 1% slopes, occasionally flooded	Pulaski: Coarse-loamy, mixed, superactive, thermic Udic Ustifluvents	5.7	9	7	36	139	0.7	8.5
LCB	2013	Port-Oscar complex, 0 to 1% slopes, occasionally flooded	Port: Fine-silty, mixed, superactive, thermic Cumulic Haplustolls Oscar: Fine-silty, mixed, superactive, thermic Typic Nastrustalfs	6.1	6	6	24	139	1.1	9.5
HEN	2013	Bethany silt loam, 0 to 1% slopes	Bethany: Fine, mixed, superactive, thermic Pachic Paleustolls	5.0	8	9	106	240	1.3	13.1

[a]LCB, Oklahoma State University Agriculture Experiment Station near Lake Carl Blackwell, OK; HEN, Oklahoma State University cooperating producer field located near Hennessey, OK
[b]1:1 water
[c]2 *M* KCl extract (Mulvaney 1996)
[d]Mehlich III extract (Mehlich 1984)
[e]Dry combustion (Nelson and Sommers 1996)

Table 2. Field activities for the three site-years utilized in this study.

Field Activity	2012 LCB[a]	2013 LCB	2013 HEN[a]
Preplant N fertilization date	4 April	18 March	1 April
Planting date	10 April	20 March	1 April
Corn hybrid	P0876HR	DKC 63-55	P08676HR
Previous crop	wheat[b]	wheat	sorghum[b]
Tillage system	conventional	conventional	no-tillage
Seeding rate (seeds ha^{-1})	49,400	54,300	44,800
Sensing date – V5/6	16 May	18 May	20 May
Sensing date – V7/8	23 May	27 May	29 May
Sensing date – V9/10	29 May	6 Jun	10 June
Grain Yield RI	1.29	1.38	1.63

[a]LCB, Lake Carl Blackwell, OK; HEN, Hennessey, OK
[b]wheat, *Triticum aestivum* L.; sorghum, *Sorghum bicolor* (L.) Moench.

Results

Lake carl blackwell, OK (2012)

Of the three site-years analyzed, Lake Carl Blackwell, OK (2012) had the highest average air temperature from planting to maturity along with the lowest amount of rainfall (Figure 1). Analysis of variance showed no interaction for N rate and N source on in-season sensor RI values for both the Greenseeker and SPAD sensors at all three sensing dates (Tables 3 and 4). No significant effect of N rate was observed for the Greenseeker sensor; however, a decreasing trend in the P-value, denoting differences between N rates, appeared to develop from V6 to V10 (Table 3). This same trend was observed for the SPAD sensor with the only difference being that the 180 kg N ha^{-1} treatments had significantly higher RI values than the 90 kg N ha^{-1} at the V10 growth stage (Table 4). For the Greenseeker sensor, the only growth stage in which statistical differences in RI values between N sources were observed, occurred at the V10 growth stage (Table 3). Regardless of growth stage, the CN treatments displayed the highest RI values when sensed with the Greenseeker sensor (Figure 2). The same trend was observed for the SPAD sensor RI values, with the CN RI values at the V6 and V10 growth stages being statistically higher than the other three N sources (Figure 2). The actual grain yield RI value for this site was determined to be 1.29. The value when converted to the adjusted in-season sensor RI value was determined to be 1.11. Maximum grain yields for this site were about 5.4 Mg ha^{-1} with check grain yields of about 4.3 Mg ha^{-1}. The use of the Greenseeker sensor provided sensor RI values, averaged across N rate and source, at or above the grain yield RI value at the V6 and V10 growth stage, but not the V8 growth stage (Figure 2). One observation noted was that the AS treatment RI values measured with the Greenseeker sensor were numerically lower than the grain yield RI values for all growth stages. The in-season sensor RI values measured with the SPAD sensor never exceeded the grain yield RI value for the site for any of the three growth stages (Figure 2). The only N source to appear to come close, to this mark was the CN treatment at the V6 and V10 growth stages (Figure 2).

Lake carl blackwell, OK (2013)

Of the three site-years analyzed, Lake Carl Blackwell, OK (2013) had the highest amount of rainfall from planting to crop maturity (Figure 1). Analysis of variance revealed there to be no interactive effect of N rate and N source on in-season sensor RI values for both the Greenseeker and SPAD sensors at all three sensing dates (Tables 3 and 4). A decreasing trend in the P-values, denoting differences between N rates, appeared to be developing from V6 to V10 for both sensors, with the Greenseeker sensor displaying a statistically significant difference between the 90 and 180 kg N ha^{-1} treatments (Tables 3 and 4). Regardless of sensor, no significant differences were observed between different N sources for all three growth stages evaluated (Tables 3 and 4). The actual grain yield RI value for this site was determined to be 1.38. The value when converted to the adjusted in-season sensor RI value was determined

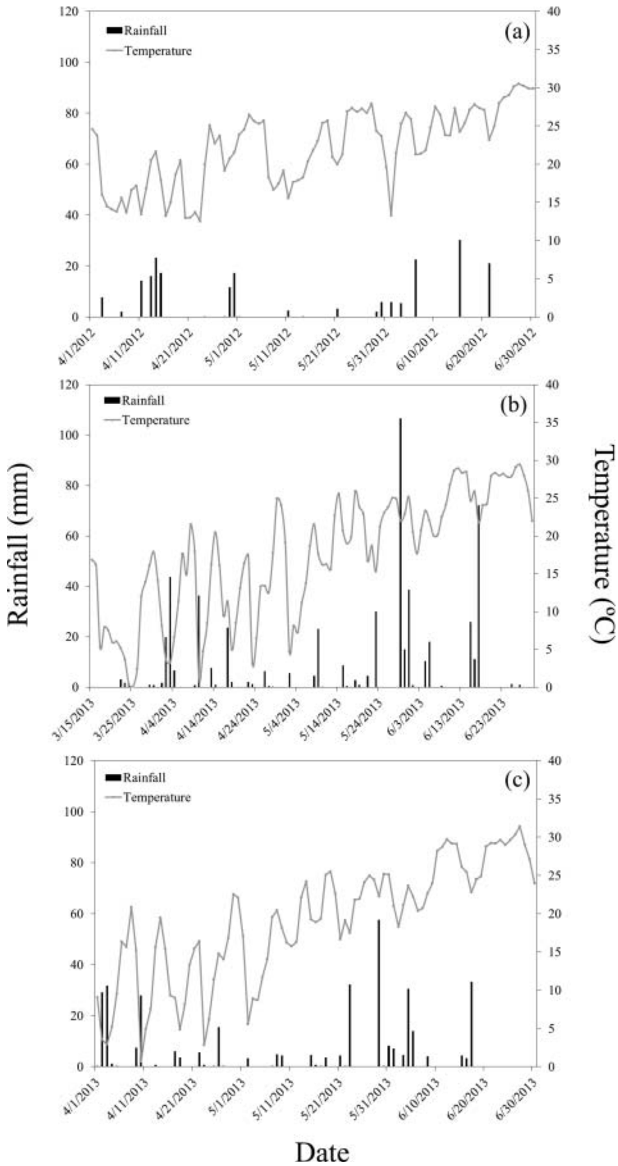

Figure 1. Daily rainfall and average temperature for Lake Carl Blackwell, OK – 2012 (a), Lake Carl Blackwell, OK – 2013 (b), and Hennessey, OK – 2013 (c). Data downloaded from nearest Oklahoma climate-monitoring site (Oklahoma Mesonet 2014).

to be 1.16. Maximum grain yields for this site were about 3.8 Mg ha^{-1} with farmer practice grain yields of about 2.7 Mg ha^{-1}. The Greenseeker in-season sensor RI values were numerically lower than the adjusted grain yield RI value for the V6 and V8 growth stages. At the V10 growth stage the values for the AS and UAN treatments were at or slightly exceeded the adjusted grain yield RI value (Figure 3). The SPAD sensor in-season RI values were numerically lower at all growth stages compared to the adjusted grain yield RI value for the site (Figure 3).

Hennessey, OK (2013)

Total rainfall for this site fell in between the other two site-years in this study and was characterized as having the highest amount of rainfall in the first two weeks after planting (Figure 1). Analysis of variance revealed there to be no interactive effect of N rate and N source on in-season sensor RI values for

Table 3. Analysis of variance results for the effects of N rate and N source and the interaction of the two on response index values determined with a Greenseeker sensor. Values reported are the probability >F.

Source	N rate	N source	N rate X N source
LCB[a]2012			
V6	0.823	0.108	0.847
V8	0.721	0.425	0.936
V10	0.290	**0.025**[b]	0.505
LCB[a]2013			
V6	0.222	0.556	0.468
V8	0.155	0.253	0.374
V10	**0.036**	0.276	0.404
HEN[a]2013			
V5	0.403	0.825	0.783
V7	0.268	0.963	0.619
V9	0.229	0.571	**0.045**

[a]LCB, Lake Carl Blackwell, OK; HEN, Hennessey, OK
[b]Values in bold are significant at $P < 0.10$

the Greenseeker and SPAD sensors at the V5 and V7 growth stages, but there was a significant interaction observed for both sensors at the V9 growth stage (Tables 3 and 4). No discernable patterns between N rate and source were observed for either sensor except that the 180 kg N ha^{-1} CN treatment had a significantly higher RI value than the 90 kg N ha^{-1} CN treatment for both sensors (Figure 4). No significant effect of N rate was observed for the Greenseeker sensor; however, a decreasing trend in the P-value, denoting differences between N rates, appeared to be developing from V5 to V9 (Table 3). This was observed for the SPAD sensor between the V7 and V9 growth stages with a statistical difference between the 180 kg N ha^{-1} RI values compared to the 90 kg N ha^{-1} RI values at the V9 growth stage (Table 4). Regardless of sensor, no significant differences were observed between different N sources at the V5 and V7 growth stages (Tables 3 and 4). The actual grain yield RI value for this site was determined to be 1.63. The value when converted to the adjusted in-season sensor RI value was determined to be 1.32. Maximum grain yields for this site were about 4.1 Mg ha^{-1} with check grain yields of about 2.5 Mg ha^{-1}. Regardless of sensor, at the V5 and V7 growth stages the in-season sensor RI values were numerically lower than the adjusted grain yield RI value. This was the largest difference observed between the sensor RI and grain yield RI values of any of the site-years evaluated (Figure 5). At the V9 growth stage, Greenseeker sensor RI values were near to or exceeded adjusted grain yield RI values

Table 4. Analysis of variance results for the effects of N rate and N source and the interaction of the two on response index values determined with a SPAD meter. Values reported are the probability >F.

Source	N rate	N source	N rate X N source
LCB[a]2012			
V6	0.704	**0.001**[b]	0.986
V8	0.318	0.337	0.707
V10	**0.056**	**0.001**	0.769
LCB[a]2013			
V6	0.919	0.998	0.277
V8	0.618	0.284	0.935
V10	0.444	0.234	0.913
HEN[a]2013			
V5	0.375	0.259	0.737
V7	0.435	0.443	0.684
V9	**0.036**	0.234	**0.091**

[a]LCB, Lake Carl Blackwell, OK; HEN, Hennessey, OK
[b]Values in bold are significant at $P < 0.10$

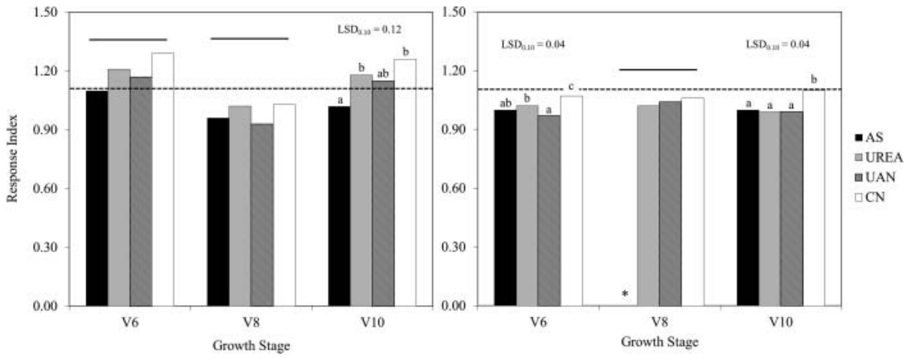

Figure 2. Lake Carl Blackwell, OK-2012 effect of N source on in-season response index values determined with a Greenseeker (left) and SPAD (right) sensor. Dashed line represents the adjusted grain yield response index for this site-year. Solid line above growth stage groupings denotes no statistical (*alpha* = 0.10) difference among N source treatments. Asterisk (*) denotes error in data recording, data not analyzed, or presented.

(Figure 4). The SPAD sensor RI values were higher at the V9 growth stage compared to the V5 and V7 growth stages, but the only treatments that were within a RI value of 0.1 to the adjusted grain yield RI values were the AS treatments and the higher N rate urea and CN treatments (Figure 4).

Discussion

Variability in both the in-season sensor RI values and grain yield RI values was expected. The observed differing levels of N fertilizer responsiveness for the three site-years support the concept outlined by Johnson and Raun (2003), in which the level of fertilizer response is not consistent year-by-year for a specific site and can be unpredictable. These varying degrees in N fertilizer response can dictate how much N is required to achieve optimal agronomic and/or economic yield and should be taken into account when making N fertilizer recommendations as proposed by Raun, Solie, and Stone (2011) and Arnall et al. (2013).

For a sensor RI measurement early in the corn growing season to be a reliable tool for determining N fertilizer recommendations, sensor RI values need to remain consistent through later vegetative growth stages. Lake Carl Blackwell, OK in 2013 was the only one of the three site-years that provided a consistent in-season sensor RI value across all three sampling times regardless of sensor (Figure 3). At Lake Carl Blackwell, OK in 2012 the Greenseeker sensor RI values at the V6 and V10 were similar, but were lower for the V8 growth stage, whereas the SPAD sensor tended to have more consistent RI values across the three growth stages (Figure 2). At

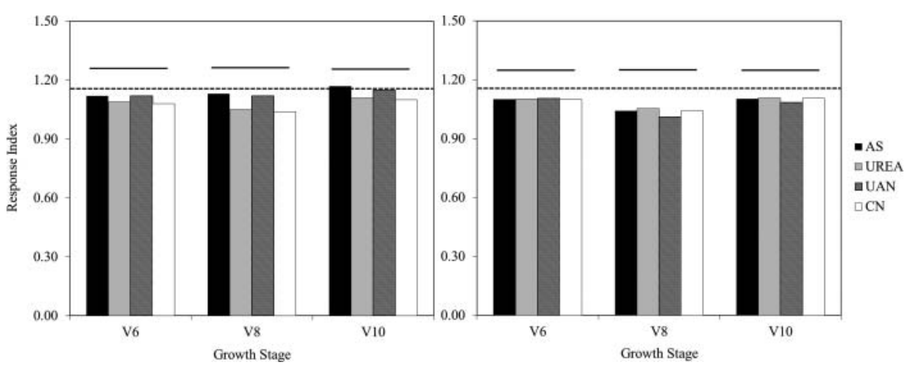

Figure 3. Lake Carl Blackwell, OK-2013 effect of N source on in-season response index values determined with a Greenseeker (left) and SPAD (right) sensor. Dashed line represents the adjusted grain yield response index for this site-year. Solid line above growth stage groupings denotes no statistical (*alpha* = 0.10) difference among N-source treatments.

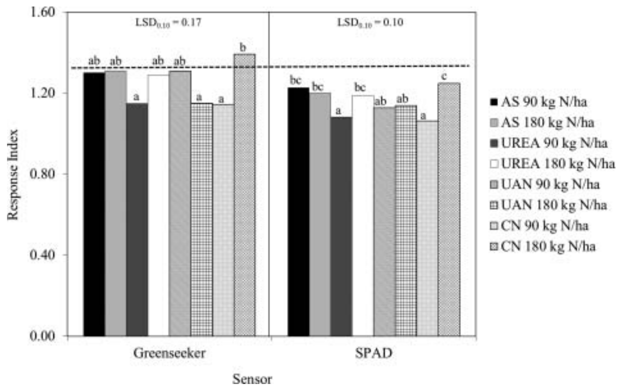

Figure 4. Hennessey, OK-2013 interaction effect of N rate and N source on in-season response index values measured at the V9 growth stage. Dashed line represents the adjusted grain yield response index for this site-year.

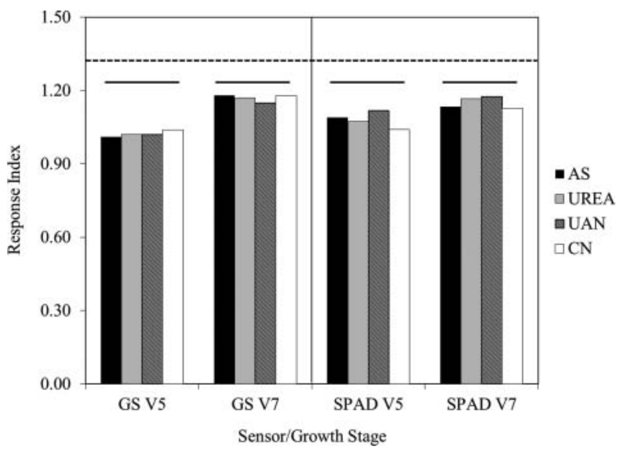

Figure 5. Hennessey, OK-2013 effect of N source on in-season response index values determined with a Greenseeker (GS, left) and SPAD (right) sensor. Dashed line represents the adjusted grain yield response index for this site-year. Solid line above growth stage groupings denotes no statistical (*alpha* = 0.10) difference among N-source treatments.

Hennessey, OK in 2013, the Greenseeker sensor RI values increased from earlier to later growth stages; however, the SPAD sensor RI values were slightly lower at the V5 growth stage, but were more consistent between the V7 and V9 growth stage (Figures 4 and 5). Some of these inconsistencies may be due to differences in plant growth and/or nutrient uptake for each of the three sites-years.

Current, non-sensor-based, N-rate recommendations for rain-fed corn in this region are 18 kg N applied for each 1000 kg of grain produced (Zhang and Raun 2006). Current N-rate recommendations for N-rich strips in corn are to be applied at least 85 kg N ha^{-1} above the check (Arnall and Raun 2014). In these experiments, the 90 kg N ha^{-1} fertilizer rate was sufficient for determining a difference between the N-rich strip and the check treatment for the growth stages prior to the V9/V10 growth stage. At the later growth stages, the effects of potential early season N loss may begin to become more evident, so importance needs to be placed on proper N-rich strip rates, if RI values are to be collected later in the growing season. It should be noted that for the three site-years used in this trial no preplant N fertilizer was applied to the check plots. This practice was conducted to maximize the presence of a difference between the N-rich strip and the check. This is a potential, but not likely, N fertilizer management practice for corn production in the region of this trial. For fields that require phosphorus (P) fertilization, the most common commercial P sources contain N, and this should be taken into account when determining suitable N rates for N-rich strips.

None of the four N fertilizer sources utilized in this trial delivered consistent RI value results that would lead us to conclude one source should be preferred to another. The CN treatments did have a numerically, and sometimes statistically, higher RI value at the V9/10 growth stages when compared to the other N sources at Lake Carl Blackwell in 2012 and Hennessey in 2013; however, this trend was not consistent across the three site-years. These results are similar to those that were observed by Yu et al. (2010) in which they observed no differences in photosynthetic performance among different N sources for the establishment of N-rich reference plots in corn.

The Greenseeker and SPAD sensor, as well as other crop sensors, have proven to be dependable methods for improving in-season N-rate recommendations in corn (Scharf, Brouder, and Hoeft 2006; Tubana et al. 2008; Barker and Sawyer 2010). One trend observed across all three site-years was that when the RI values for the two sensors were compared to one another, the SPAD sensor RI values were typically lower. These results are similar to what other researchers (Shanahan et al. 2008) have reported when comparing these two specific crop sensors in corn. Equations that predict the final grain yield RI based on the in-season sensor RI should be developed for each specific crop sensor.

Conclusions

The objective of this trial was to determine whether different N fertilizer sources would provide an early season detection of N fertilizer response in rain-fed corn grown in the Southern Great Plains in the USA. Developing an earlier N fertilizer management practice could widen the window of opportunity to conduct sidedress applications in corn and potentially negate the need for expensive high clearance fertilizer application equipment. Current recommendations for N rates necessary for developing an N-rich area within a corn field are accurate up to at least the V7/8 growth stage. However, if sensor readings and N fertilizer applications are to occur at the V9/10 growth stage or later, managers should make certain that they have supplied enough preplant N so that the designated N-rich area will not be N-deficient. Based upon the results, no particular N source provided superior results that would lead to a reliable recognition of N deficiency earlier in the growing season. Results were similar to what previous researchers in the region have reported. Differences that are reliable enough to make accurate sensor-based N fertilizer recommendations between N-rich strip areas and check areas were not detectable until at or past the V7/8 growth stage. In summary, alternate management strategies should be investigated that can discern N deficiencies earlier in the growing season so as to deliver more accurate sidedress N fertilizer recommendations.

Abbreviations

AS	ammonium sulfate
CN	calcium nitrate
GBAOS	ground-based active optical sensors
GDD	growing degree day
N	nitrogen
NUE	nitrogen use efficiency
NDVI	normalized difference vegetation index
RI	response index
UAN	urea ammonium nitrate

Conflict of interest

The mention of any trademarked products or equipment utilized in this experiment was for research purposes only and does not act as an endorsement by Oklahoma State University. The authors and Oklahoma State University have no direct financial relation with any of the named manufacturers, thus the authors declare there is no conflict of interest regarding the publication of this manuscript.

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