# COMPARISON OF THREE CANOPY REFLECTANCE SENSORS FOR VARIABLE-RATE NITROGEN APPLICATION IN CORN

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## ABSTRACT

In recent years, canopy reflectance sensing has been investigated for in-season assessment of crop nitrogen (N) health and subsequent control of N fertilization. The several sensor systems that are now commercially available have design and operational differences. One difference is the sensed wavelengths, although these typically include wavelengths in both the visible and near-infrared ranges. Another difference is orientation – the sensors most commonly used in the US are designed to operate with a nadir (vertical) view of the crop, while some sensors developed in Europe and now becoming available in the US are designed to view the crop obliquely. Data comparing the different sensor designs is lacking. Thus, the objective of this research was to evaluate three different commercial canopy reflectance sensors used for N fertilization control in corn. Two units of each of three commercial sensors – GreenSeeker, Crop Circle, and CropSpec – were mounted to a high-clearance applicator for field data collection and operated according to manufacturer recommendations. Data were collected from five field experiments in 2009. Multiple blocks of randomized N rate response plots traversed each field. Each block consisted of 8 N treatments from 0 to 235 kg N $ha^{-1}$. Crop canopy reflectance sensor measurements were obtained from the N response blocks at the time of side-dress N application. At one site, additional sensor measurements were obtained over a range of growth stages after N application. NDVI data from GreenSeeker and Crop Circle sensors were highly correlated at most field sites and overall, while data from those two sensors were less strongly related to CropSpec data. CropSpec NDVI was more strongly related to SPAD and leaf N content, while the other two sensors were more affected by crop height variations. For multiple data collection runs in a single day, less run-to-run variation was seen with the CropSpec. For best results, users need to take into account the differences among these commercial sensors, particularly between the two small-footprint nadir sensors (Crop Circle and GreenSeeker) and the large-footprint, oblique sensor (CropSpec).

**Keywords:** variable-rate nitrogen, crop canopy sensor, reflectance

## INTRODUCTION

Crop canopy reflectance sensing for nitrogen (N) status assessment and subsequent control of N fertilization has been widely researched and is becoming an accepted practice. Farm magazines describe producer experiences with this technology and in at least one US state (Missouri), farmers can receive government payments for using canopy sensor-controlled N application (USDA-NRCS, 2009). Initial systems, both in the US (Stone et al., 1996) and abroad (Heege and Reusch, 1996) used passive radiometers that were dependent on ambient sunlight for illumination. Difficulties in compensating for spatiotemporal variation in ambient illumination (Souza et al., 2010) led to the development of active sensors with their own illumination source, designed so that the sensor would respond only to reflectance based on the active illumination and not on sunlight.

Several active canopy reflectance sensors designed for N application control are commercially available. Considerable research has been directed toward developing algorithms to translate commercial sensor output into N-rate control decisions for crops such as wheat (Raun et al., 2002), corn (Kitchen et al., 2010; Solari et al., 2008) and cotton (Olivera, 2008). These efforts have generally been sensor-dependent in that one particular sensor has been used in the research and the findings are specific to that sensor. Some sensor-comparison work has been done (Solari, 2006; Olivera, 2008; Tremblay et al., 2009) and algorithm conversions have been established in some cases (USDA-NRCS, 2009). However, additional documentation and comparison of the operational characteristics of active crop canopy sensors is desirable.

## OBJECTIVE

The objective of this research was to evaluate the operation of three commercial canopy reflectance sensors during applicator-based data collection on a corn crop. Specific parameters investigated were correlation of NDVI obtained by the different sensors, the relationship of sensor data to crop variables, and temporal variation in sensor readings.

## MATERIALS AND METHODS

### Field Sites

Data were collected at five field sites. One site, at the University of Missouri South Farm (SF) was designated specifically for sensor field testing. At this site, six blocks of response plots were established, with three blocks designated to receive N at planting and the other three at sidedress. Each block consisted of 8 randomly assigned N treatments from 0 to 235 kg N $ha^{-1}$ on 34 kg N $ha^{-1}$ increments. The 8 plots within each block were 6 rows wide (4.5 m on 76 cm row spacing) and 10 m long, with the total block being 18 m wide and 20 m long. Between blocks, a high-N area 18 m wide and 10 m long was established. These high-N areas were also designated to receive N at planting. Planting of this site was on 1 June 2009; however due to precipitation immediately afterward, the “at planting" N application was done on 22 June with corn plants approximately 10 cm tall. Sidedress N application was on 10 July with plants approximately 60 cm tall. Application of N was with a modified AGCO Spra-Coupe, as described by Kitchen et al. (2010). In both cases incorporating rainfall was received within 5 days or less of application.

Four other sites were established in producer fields, PB, PN, PS, and PR. Layout of response plot blocks was the same as at SF, with 6 to 12 blocks of N response plots in each field. At the producer sites, the high-N areas were applied at or near planting, while N was applied to the response plots at sidedress.

## Canopy Reflectance Sensors

Data were collected with three commercial sensors – Holland Scientific Crop Circle ACS-210 (Holland Scientific, Lincoln, NE), N-Tech GreenSeeker Model 505 (Trimble Navigation, Sunnyvale, CA), and Topcon CropSpec (Topcon Precision Agriculture, Mawson Lakes, SA, Australia). All three are active sensors, meaning that they have their own light source(s) and use detection technology that minimizes the effect of changes in ambient light on sensor readings. Each sensor emits and measures reflected light at two different wavelengths, although the specific wavelengths vary among the sensors (Table 1).

The Crop Circle sensor uses a single polychromatic light-emitting diode (LED) for illumination and two separate detectors. Designed for nadir sensing, it has a field of view proportional to height above target (Table 1), and response was described as relatively constant over the field of view (Holland et al., 2005). The GreenSeeker sensor, developed based on initial work by Stone et al. (1996) uses a separate LED for each wavelength and a single detector. The GreenSeeker field of view is approximately constant over its operating height range; however, Solari (2006) showed that a larger portion of its response comes from the center of the field of view.

The CropSpec sensor, based on initial research by Heege and Reusch (1996), is designed to view a larger area of crop obliquely (Table 1). The CropSpec sensor uses two pulsed laser diodes for illumination and a single detector. In contrast to the other two sensors that sense red and amber light, the visible channel of the CropSpec senses the "red edge" of the spectrum, where the reflectance of green vegetation transitions from low (~ 5%) in the visible range to relatively high (~ 30 to 50%) in the near-infrared range.

The GreenSeeker and Crop Circle sensors were mounted to a frame on the front of the applicator above rows 2 and 5 of the six-row corn strip (Fig. 1). This frame allowed adjustment of the height of the sensors to maintain their position relative to the crop. The two CropSpec sensors were affixed to the top of the Spra-Coupe cab (Fig. 1), with one positioned to view each adjoining 6-row data pass.

## Data Collection

Sensor data were collected from the four producer fields at the time of sidedress N application, when corn was between 0.75 and 1.5 m tall. Data were collected multiple times at the SF site (Table 2). Data were collected as the Spra-Coupe drove through the plots at approximately 2 to 3 m $s^{-1}$. Data from the

**Table 1. Manufacturer's stated operational characteristics of the crop canopy sensors used in this study.**

| | Holland Scientific Crop Circle ACS-210 | NTech Industries GreenSeeker Model 505 | Topcon CropSpec |
|---|---|---|---|
| Visible wavelength | 590 ± 5.5 nm | 660 ± 15 nm | 735 ± 5 nm |
| NIR wavelength | 880 ± 10 nm | 770 ± 15 nm | 805 ± 5 nm |
| Height above target | 0.25 to 2.1 m | 0.6 to 1.6 m | 2 to 4 m |
| View direction | Nadir | Nadir | Oblique, 45 to 55º |
| Field of view / sensing footprint | 32º x 6º | 61 x 1.5 cm (~ constant over height range) | 2 to 4 m wide (~ proportional to height above target) |

GreenSeeker and Crop Circle sensors, along with GPS coordinates, were recorded on a tablet computer at 10 Hz for further processing. CropSpec data were collected on a separate tablet computer at 1 Hz. All sensor data were post-processed to account for sensor and GPS antenna offset, and for the CropSpec, to align with the proper swath. Sensor data from the center 5 m of each 10-m-long plot were averaged to represent the plot.

Additional data were obtained at the SF site on three dates (10, 16, and 20 July) for comparison with sensor data. Leaf chlorophyll content was quantified with a Minolta 502 SPAD meter. The SPAD meter was clamped onto the most recently collared leaf, mid-way along the blade of 16 randomly selected plants and the 16 readings were averaged to get an overall plot value. Eight plants were selected from each of rows 2 and 5, the same rows sensed by GreenSeeker and Crop Circle. Mean crop height was calculated from height to the whorl of 3 (10 July) or 6 (16 and 20 July) randomly selected plants. On 20 July, leaf tissue samples were obtained from the same plants used for SPAD data collection. These were combined into a single sample per plot and total N content was determined with dry combustion (900ºC) using a LECO Tru-Spec C/N Analyzer (LECO Corp., St. Joseph, MI).

**Table 2. Data collection information for the SF site.**

| Date | Time of day | Days after planting | Plant height, mean and (std. dev.) (m) | SPAD reading, mean and (std. dev.) |
|---|---|---|---|---|
| 22 June 2009 | 1045 | 21 | | |
| 9 July 2009 | 1015 | 38 | | |
| 10 July 2009 | 1530 | 39 | 0.65 (0.15) | 47.2 (7.8) |
| 16 July 2009 | * | 45 | 1.00 (0.20) | 52.7 (6.9) |
| 17 July 2009 | 1015 | 46 | | |
| 17 July 2009 | 1320 | 46 | | |
| 17 July 2009 | 1415 | 46 | | |
| 17 July 2009 | 1600 | 46 | | |
| 20 July 2009 | 0800 | 49 | 1.12 (0.19) | 48.7 (5.5) |
| 22 July 2009 | 1100 | 51 | | |

* Canopy sensor data unusable due to missing GPS data. Data from 1015 run on 17 July used for comparison to plant height and SPAD data.

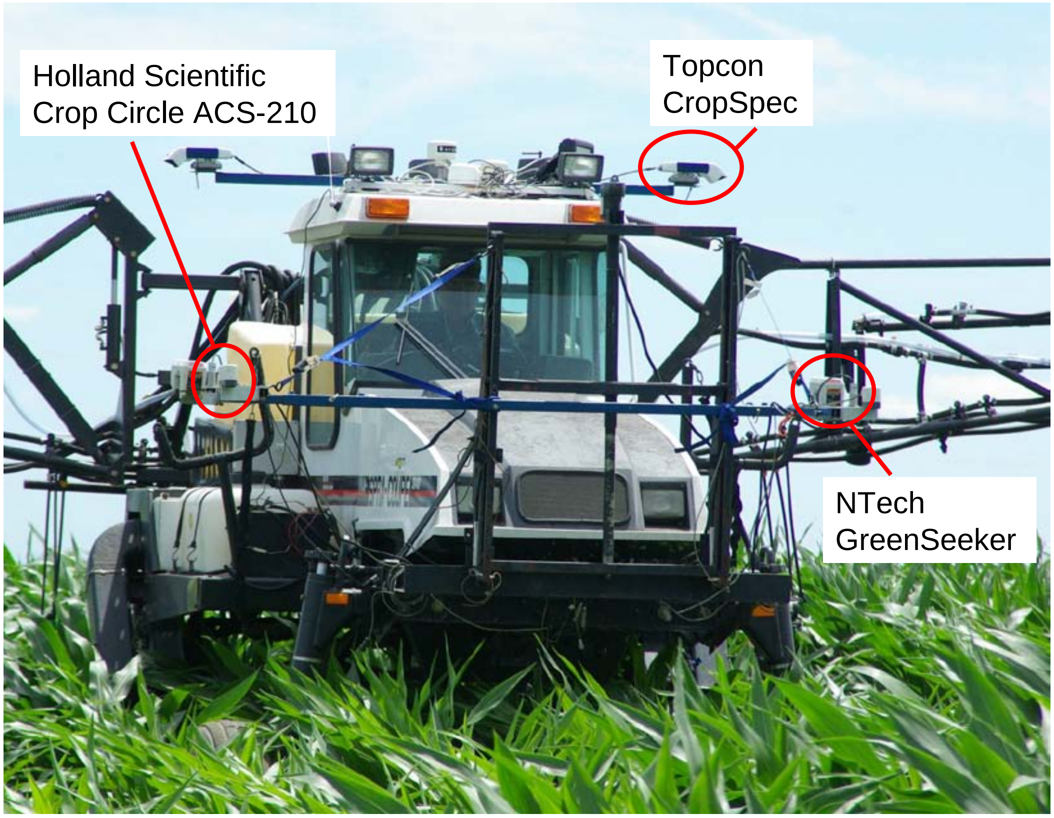


**Fig. 1. Crop canopy sensors mounted to Spra-Coupe for field data collection.**

## RESULTS AND DISCUSSION

### NDVI Differences among Sensors

Response of the different sensors was compared on the basis of normalized difference vegetative index (NDVI), an index commonly used in sensor-based variable N algorithms. Other algorithms use the simple ratio (SR) of the NIR to the visible channel, or the inverse simple ratio (ISR). These can be easily calculated from NDVI, as ISR = (1 – NDVI)/(1 + NDVI). Means of the two sensors of each type were used in the comparison, after pre-screening of individual sensor data streams to eliminate any spurious, out-of range data (<< 1% of data points were eliminated). Previous research (Roberts et al., 2009) showed an advantage to using mean data from multiple sensors to guide a single application rate in contrast to controlling multiple boom sections individually, each based on a single sensor reading.

Plot-average NDVI comparisons for the four producer sites are shown in Fig. 2 (left). As might be expected, readings from the two nadir-looking, small-footprint sensors (GreenSeeker and Crop Circle) were most closely related, with $R^2$ = 0.79, while a much weaker relationship was seen with either of the nadir sensors and the oblique, large-footprint sensor (CropSpec). Similar results were found for the SF site (Fig. 2, right). Differences between GreenSeeker and Crop Circle NDVI were consistent with our previous research as embodied in NRCS guidance to Missouri producers for use of these sensors in variable-rate N application (USDA-NRCS, 2009).

Within-site correlations between Crop Circle and GreenSeeker (Table 3) were generally better than those of either with CropSpec. Correlations of Crop Circle to CropSpec were lower, with correlations of GreenSeeker to CropSpec lowest and more variable among sites. These differences are likely due, at least in part, to the differences in sensing geometry between the three sensors, with higher correlations observed between sensor pairs with more similar sensing footprints (Table 1). Differences in signal-to-noise ratio among the sensors (Solari, 2006) may have been another contributor.

## Sensor Estimates of Chlorophyll and Nitrogen

As has also been reported by others (e.g., Blackmer et al., 1994), there was a strong relationship between SPAD reading measured and leaf N content sampled 49 days after planting on 20 July ($R^2 = 0.84$). CropSpec NDVI was predictive of both SPAD and leaf N ($R^2 = 0.62$; Fig. 3). Data from Crop Circle and GreenSeeker were not predictive of either SPAD or leaf N ($R^2 \leq 0.06$) from that date. Data from the canopy sensors were generally more correlated to SPAD at earlier measurement dates. Overall, highest correlations to SPAD were with CropSpec, then Crop Circle, and the lowest correlations with GreenSeeker (Table 4). Although differences between the sensors were less at the earlier measurement dates, CropSpec was always more than twice as good at representing variance in SPAD (Table 4). On the other hand, correlations with crop height were much more similar across the three canopy sensors, with each sensor having the highest correlation for one of the measurement dates (Table 4).

In this study, data from the small-footprint canopy sensors (GreenSeeker and Crop Circle) were much more strongly related to crop height (i.e., biomass) than to leaf N content (or SPAD). Solari (2006) also reported GreenSeeker and Crop Circle data were highly affected by biomass and crop height. Inclusion of auxiliary data on crop height may make chlorophyll estimaties with these sensors more accurate. Jones et al. (2007) reported chlorophyll estimates from NDVI were improved when height measured by an ultrasonic distance sensor was included as a second term in a linear regression.

**Table 3. Pearson correlation coefficients between sensor NDVI readings for individual site and combined datasets.**

| Dataset | Correlation coefficient (r) | | |
|---|---|---|---|
| | CropSpec vs. Crop Circle | Crop Circle vs. GreenSeeker | CropSpec vs. GreenSeeker |
| PB | 0.86 | 0.95 | 0.80 |
| PN | 0.58 | 0.79 | 0.37 |
| PS | 0.75 | 0.93 | 0.74 |
| PR | 0.71 | 0.72 | 0.51 |
| All producer | 0.81 | 0.89 | 0.59 |
| SF | 0.77 | 0.93 | 0.60 |
| All sites | 0.76 | 0.86 | 0.46 |

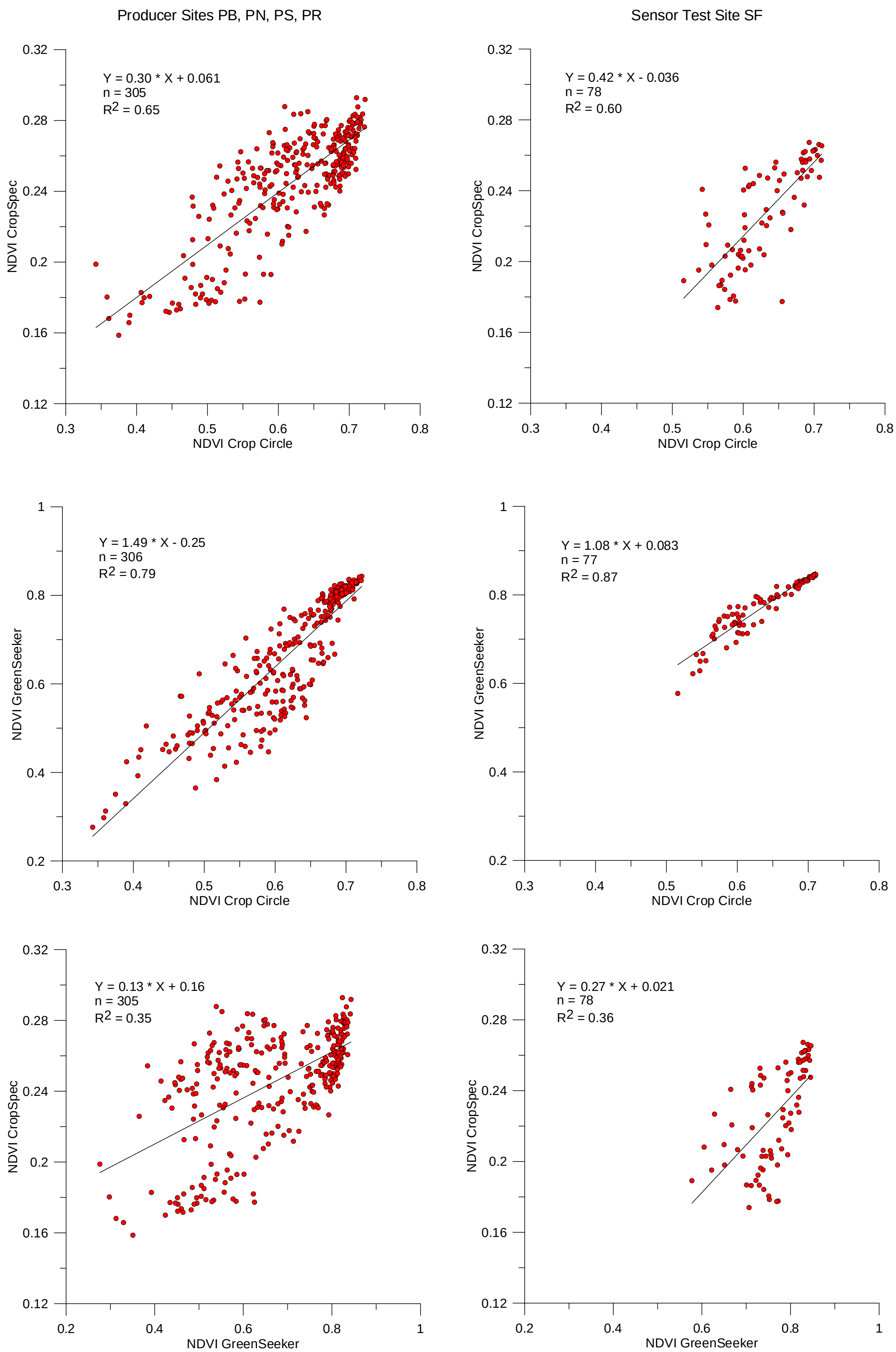


**Fig. 2. Relationships among NDVI measured at sidedress for GreenSeeker, Crop Circle, and CropSpec canopy sensors. Graphs show data combined for four producer sites (left) and for the sensor test site (right).**

Data from the large-footprint sensor (CropSpec) was more strongly related to leaf N content (or SPAD) and less related to crop height. It may be that unique operational characteristics of the CropSpec (e.g., large sensing footprint, oblique viewing angle) may have made data from this instrument more strongly related to the plot-average leaf N and SPAD data obtained in this study. Alternatively, it may be that inclusion of the red edge (735 nm) data made this sensor more sensitive to chlorophyll. Hatfield et al. (2008) noted that a reflectance index combining NIR and red edge data had the lowest error in estimating leaf chlorophyll content compared to all other visible wavelengths. According to their data, indices using the visible wavelengths embodied in the other sensors might have as much as 2 to 3 times greater error in estimating chlorophyll content. It is worth noting that these results were with the chlorophyll index (CI = NIR/VIS - 1), which has been shown to be superior to NDVI using the same wavelengths for chlorophyll estimation (Solari et al., 2008). Application of CI to these data and a subsequent sensor comparison would be desirable.

## Temporal Stability

The four sets of data collected on 17 July allowed assessment of the temporal variation in sensor readings (Fig. 4). When using the first run of the day as a reference, the three successive runs fell near the 1:1 line for the CropSpec, but were more widely dispersed for the other two sensors. Correlations between individual runs ranged between 0.84 and 0.98 for the CropSpec, between 0.67 and 0.80 for the GreenSeeker, and between 0.56 and 0.72 for the Crop Circle. It seems likely that the larger sensing footprint of the CropSpec was less affected by run-to-run variations in driving position relative to the crop rows, plant movement due to wind, and other potential sources of variability. Relative positioning of the sensor with respect to the crop rows would be expected to have a much larger effect on the small-footprint sensors.

**Table 4. Correlation of canopy sensor data with SPAD and crop height at three measurement dates.**

| Dataset | Canopy sensor | | |
|---|---|---|---|
| | Crop Circle | CropSpec | GreenSeeker |
| SPAD | | | |
| 10 July | 0.56 | 0.85 | 0.25 |
| 16 July | 0.40 | 0.88 | 0.33 |
| 20 July | 0.22 | 0.79 | 0.22 |
| Crop height | | | |
| 10 July | 0.73 | 0.83 | 0.71 |
| 16 July | 0.56 | 0.67 | 0.63 |
| 20 July | 0.64 | 0.54 | 0.71 |

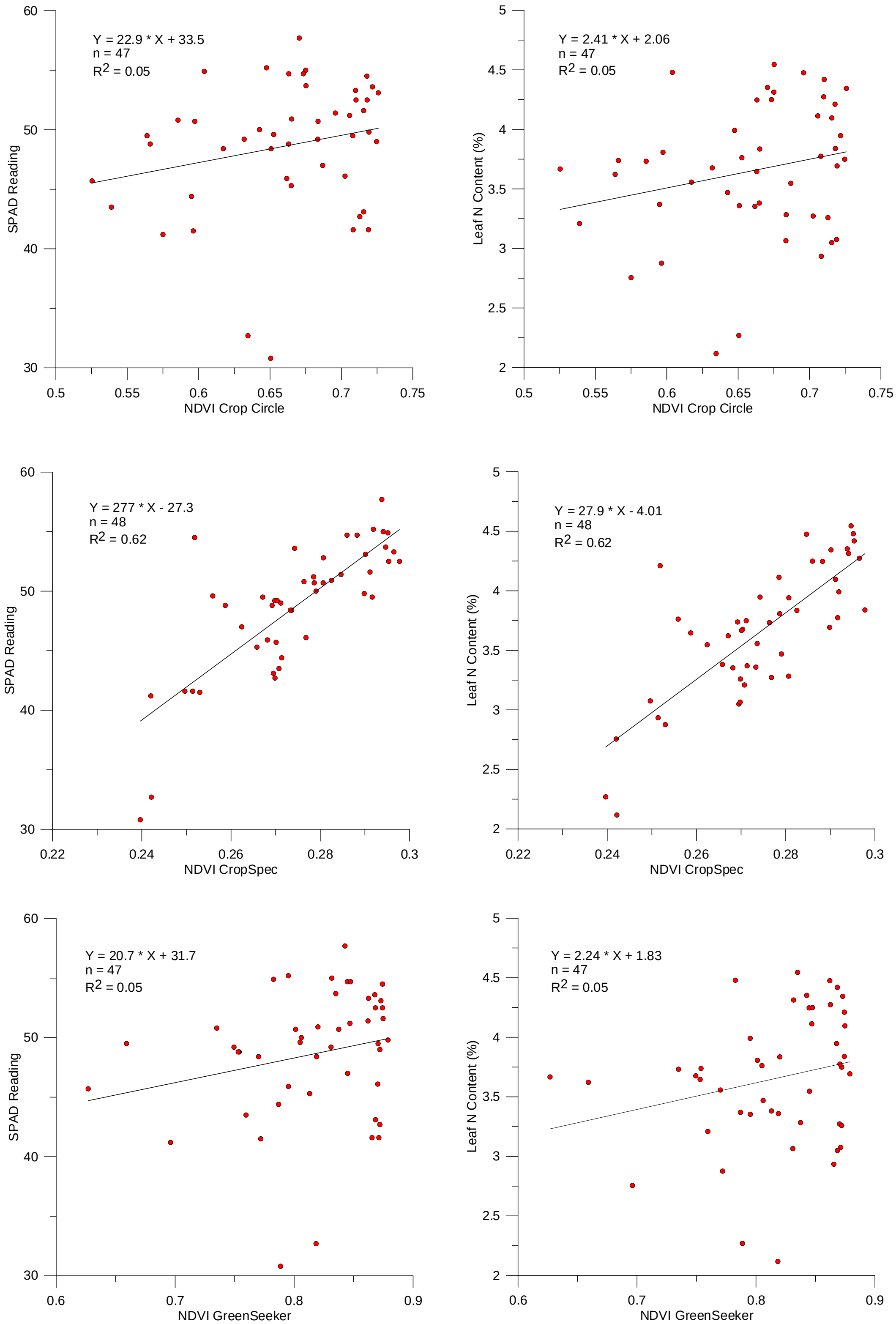


**Fig. 3. Relationship of SPAD reading (left) and leaf N content (right) to NDVI measured 49 days after planting by GreenSeeker, Crop Circle, and CropSpec canopy sensors.**

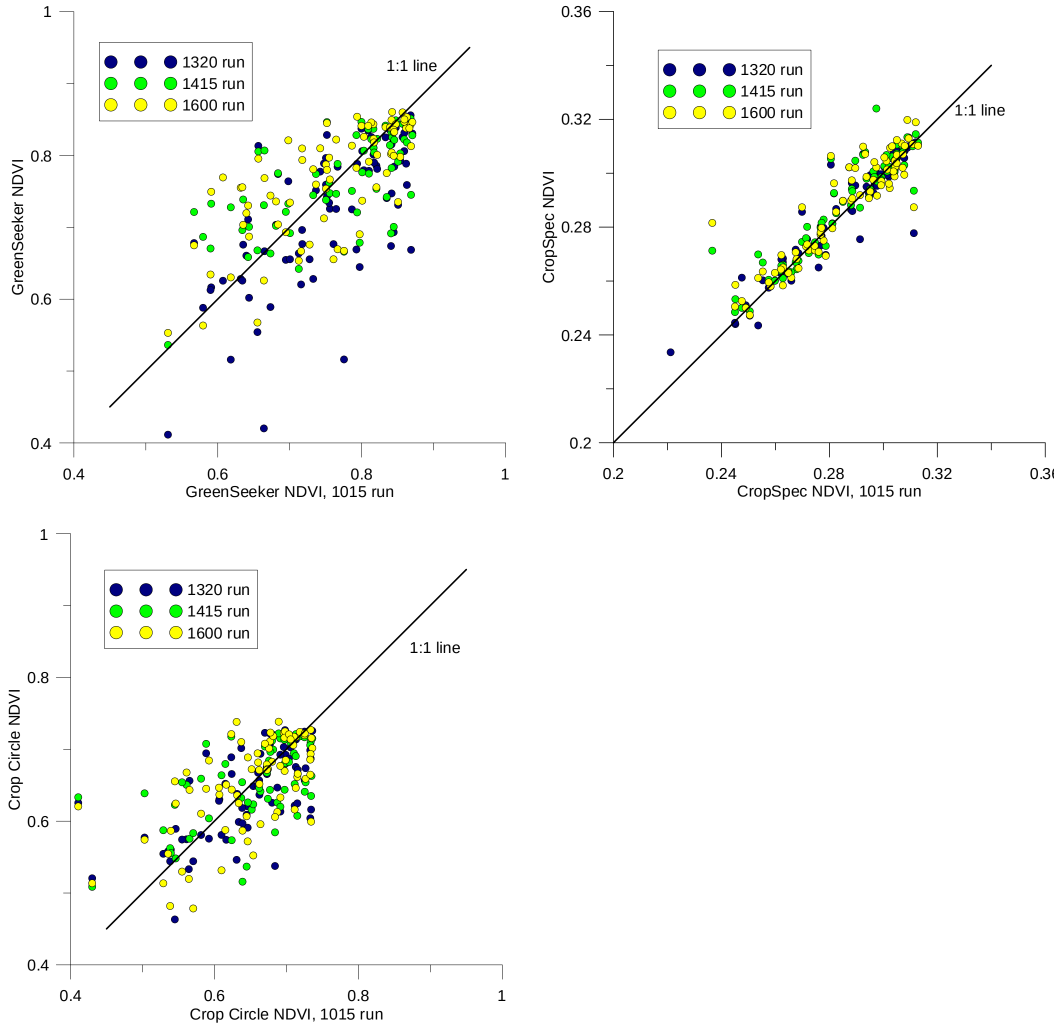


**Fig. 4. Temporal stability of plot-average canopy sensor readings. Second, third, and fourth data runs on 17 July are shown as a function of the first run.**

It is well known that vegetative indices from passive (i.e., based on ambient light) sensors can vary widely over the course of a day, even if the sensor is stationary above the canopy (e.g., Souza et al., 2010). Variation in active sensor (Crop Circle and GreenSeeker) vegetation indices has also been reported (Olivera, 2008). It is unknown if the source of variation is the sensor (e.g., influence of variations in ambient light), external plant considerations (e.g., leaf surface moisture, plant movement), physiological changes in the plant itself, or some combination thereof. It is likely that the different active sensors in this study may have been affected by these issues, and possibly to different degrees. Further research directed toward understanding the relative effect of various error sources on mobilized sensor data collection would be warranted.

## CONCLUSIONS

In this study, three different commercial crop canopy sensors were evaluated for their ability to discriminate reflectance differences related to corn N health. Reflectance data were processed to plot-average (~ 3.6 x 5 m) NDVI values for analysis. Data from GreenSeeker and Crop Circle sensors were highly correlated at most field sites and overall, while data from those two sensors were less strongly related to CropSpec data. While substitution between GreenSeeker and Crop Circle data is feasible (and has been done) in N recommendation algorithms, it may be unreliable to make a similar substitution with CropSpec data. CropSpec NDVI was more strongly related to SPAD and leaf N content, while the other two sensors were more affected by crop height variations. The possibility of improving these correlations through inclusion of crop height data (e.g., from an ultrasonic distance sensor) should be investigated. For multiple data collection runs in a single day, less run-to-run variation was seen with the CropSpec. This was likely due to the averaging effects of its larger sensing footprint which would be less sensitive to driving inaccuracies, crop movement, and small-scale variability. For best results, users need to take into account the differences among these three commercial sensors, particularly between the two small-footprint nadir sensors (Crop Circle and GreenSeeker) and the large-footprint, oblique sensor (CropSpec).

## ACKNOWLEDGEMENTS AND DISCLAIMER

We acknowledge the following for assistance in data collection: Bob Mahurin, Kurt Holiman, Matt Volkmann, Eric Allphin, Alec Sheridan, and Anna Hodge.

Mention of trade names or commercial products in this paper is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the United States Department of Agriculture.

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