EVALUATION OF ALGORITHM THRESHOLDS FOR CROP CANOPY SENSOR-BASED IN-SEASON NITROGEN APPLICATION IN CORN

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Abstract

Nitrogen fertilizer is frequently the most limiting nutrient in corn production. Typically most nitrogen is applied before planting. Since nitrogen can leave the soil system fairly easily, the result can be an inefficient use of nitrogen fertilizer. Previous research has shown increased efficiency with no reduction in yield by applying nitrogen later in the season when the crop is actively growing, with rates regulated spatially through the use of active crop canopy sensors. This study evaluated the potential for N cutoff thresholds using a sufficiency index (SI) as the threshold value for areas with poor stand or an unrecoverable N deficiency. In this study the algorithm developed by Solari, et al. (2010) was used. Field scale treatments were imposed on six irrigated fields in south-central and western Nebraska to evaluate performance of the active crop canopy sensor-based in-season N management algorithm with and without predicted permanent yield loss thresholds. The study found no consistent advantage in yield, nitrogen use efficiency, or profit with sensor-based treatments using algorithm thresholds. The uniform, soil-test-based UNL treatment was most often the most profitable treatment. Further research is needed to revise the Solari, et al. (2010) method to account for soil-N supply prior to and following in-season N application.

Introduction

Previous literature suggested the use of variable rate nitrogen application to correct deficiencies, but not to limit the extent of the deficiency. Solari's algorithm focused on applying N to a corn crop that had an SI value of less than 0.97. The assumption was that a more deficient plant will have a lower SI value; therefore, requiring more N to correct the deficiency. Research done by Roberts, (2009) showed that Solari's method was successful when implemented in his research treatments. However, Roberts, (2009) observed N being applied to areas that would not increase yield significantly. These areas included severely nitrogen stressed plants, as well as areas of low plant population, and waterways. Further research is needed to look at the effects of limiting N application on progressively deficient plants. It is thought that there is a point (SI value) at which no additional yield can be captured by applying any additional N. A threshold would also mean N savings. For the Roberts, (2009) study between two sites, N rates were simulated for threshold values from SI values of 0 to 1 in steps of .05.

If the SI value was less than this threshold SI value or greater than a SI value of 0.97, no nitrogen would have been applied. The average rate of N was then determined, which would be lower than the sensor treatment. Savings of nitrogen was calculated and compared to having a no threshold imposed treatment (sensor treatment). Consistent results occurred will all replications in both sites despite contrasting soil properties. The two fields represented fine and coarse-textured soils for as wide of a contrast as possible. Between the two sites, six different sensor treatment strips were analyzed. Relationships of nitrogen savings versus SI values were similar for both sites.

The occurrence of areas where a threshold may need to be imposed is thought to be low, but by successfully implementing a threshold, the approach by Solari, (2010) would be further refined and more efficient.

Objective

The objective of this study was to illustrate performance of the active crop canopy sensor-based in-season N management algorithm with and without imposing permanent yield loss thresholds using a series of field-long strip trials.

Materials and Methods

The research in this study was performed on six different cooperating producer's fields over the course of two growing seasons, 2009 and 2010. Three field sites were used in 2009: Sites 09BR, 09HU, and 09RA. Three different field-sites were used in 2010: Sites 10BR, 10HU, and 10LE. Excerpts from two of these fields that characterize the results will be discussed below.

Each experimental site included five field-long strip treatments in 2009 and six treatments in 2010, with three replications for each treatment in a randomized complete block design (RCBD). The strips were either 8 or 12 rows wide depending on the producer's harvesting width. Treatments in 2009 included: threshold set at a value of 0.65 sufficiency index (SI), threshold set at a value of 0.75 SI, sensor, reference, and UNL nitrogen algorithm. The treatments will be referred to as T65, T75, sensor, reference, and UNL respectfully. In 2010 a third threshold treatment with a value of 0.55 SI (T55) was added; all the other treatments remained the same.

The UNL treatment refers to the algorithm developed at the University of Nebraska-Lincoln for producers in Nebraska applying a uniform rate of nitrogen on a whole field basis.

The reference strip is a uniformly applied high rate nitrogen strip to ensure nitrogen is not a yield-limiting factor. The reference strip received adequate amounts of N, so as not to be limiting during sensing operations. The reference strip is the foundation for active sensor treatments, which will be explained in greater detail below.

The sensor treatment refers to a variable rate approach for applying nitrogen using crop-canopy sensors. The three different threshold treatments are variations of the same method used in the original sensor treatment.

The sensor-based treatment has the ability to vary the rate of nitrogen (N) application spatially via a crop-canopy sensor with associated software and hardware. The Holland Scientific ACS-210 Crop Circle active canopy sensor (Holland Scientific, Inc., Lincoln, NE) was used to determine the crop N status. The sensor measures reflectance in two different wavelengths (bands). One band is in the visible electromagnetic spectrum centered at 590±5.5 nm. The other band is in the near infrared (NIR) portion of the spectrum located centered at 880±10 nm. These two bands are combined to create the Chlorophyll Index (CI) (Gitelson et al., 2003, 2005) by dividing the NIR band over the visible band and subtracting 1 from that ratio.

The CI is utilized in conjunction with the high nitrogen reference treatment. One CI value for each replication of the reference strip was obtained by averaging the values sampled previously to create a reference CI for the individual replication. The reference CI was then used as the denominator in calculating SI (Equation 1).

Equation 1

$$SI_{Sensor}=CI_{Treatment}/CI_{Reference}$$

The numerator for calculating SI is $CI_{Treatment}$. This is the CI sensed over the separate treatments. The SI indicates how relatively deficient in chlorophyll the treatment area is compared to the reference. Solari et al., (2010) utilized this relationship and developed an algorithm to produce a rate of nitrogen that could be varied throughout a field or treatment. This "nitrogen algorithm" (Equation 2) is used in conjunction with the ACS-210 sensor.

Equation 2

$$\text{N rate}=370*\sqrt{0.97-SI_{Sensor}}$$

The current practice of using the current N algorithm approach presented an opportunity to explore whether N application was warranted at lower SI values. Hypothetically, if a lower SI value is observed, then the chlorophyll concentration is lower, which means the need for more nitrogen. The lower the SI value the higher the application rate of nitrogen. At what point does more deficient corn (lower SI) not recover yield enough to justify applying the extra nitrogen? The threshold treatment utilized this question by cutting off any N below the threshold SI value, but above the threshold SI value, the treatment functioned the same way as a sensor treatment.

Roberts (2009) showed that SI values less than 0.45 typically do not exist; therefore, 0.65 and 0.75 were chosen as starting points to test threshold values. Values were chosen from past experience of visual nitrogen deficiencies at these SI values.

The sensor and threshold treatment strips received 84 kg ha^{-1} of nitrogen early in the growing season when the corn was around the third leaf stage (V3), while the reference and UNL treatments received their respective total N rate except for Sites 09BR where applications were limited to 84 kg ha^{-1} and 112 kg ha^{-1} for the UNL and reference treatments respectfully. These treatment strips would not receive another application of nitrogen until the corn reached the eleventh leaf stage (V11). At V11 the sensors were used to acquire the reference strip CI. The treatments that did not receive a uniform nitrogen application then utilized the nitrogen algorithm in conjunction with the reference CI. Those treatments included the sensor, T65, and T75. The UNL and reference treatments received an additional uniform rate of nitrogen to reach the recommended rate for each. Site 09BR received the remaining N at this stage.

Nitrogen was applied via a John Deere high clearance sprayer that had been specially customized with the ability to change rates rapidly. Yield data was collected by cooperating producers. Duncan Multiple Range Tests were performed using the PROC GLM in SAS 9.2 to determine significant differences between variables including yield and N rate.

Results and Discussion

In 2009 each site had unique responses to treatments. The reference treatment for Site 09BR yielded statistically higher than all other treatments (Figure 1).

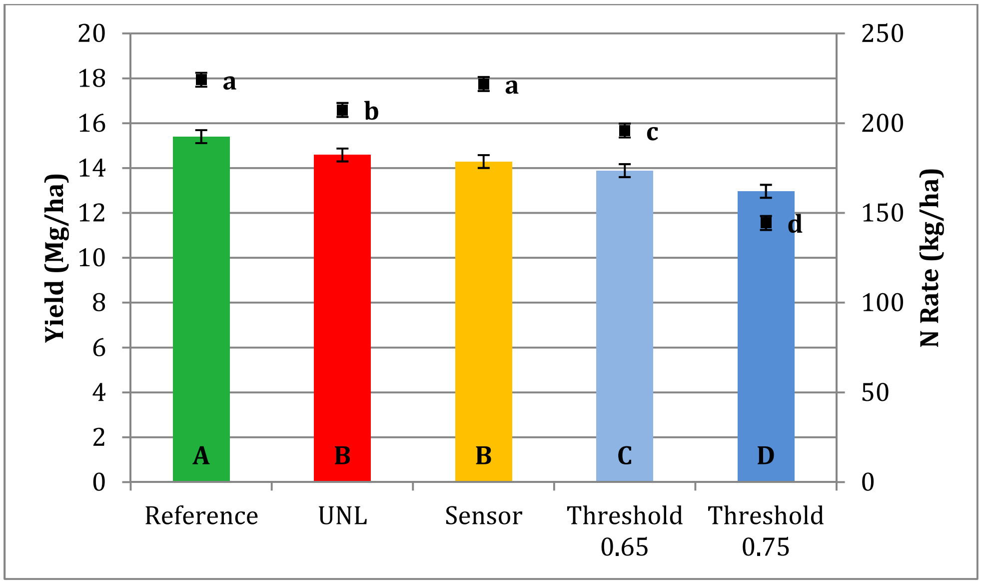

Figure 1: Whole strip treatment values for 09BR by treatment for grain yield in bar format on the primary axis. Values by treatment for the total nitrogen received in point format on the secondary axis. Error bars represent the Duncan multiple range test separation value. Means with the same letter are not statistically different (p=0.05).

The sensor-based treatment yielded similarly to the UNL treatment, but received significantly more N. Each threshold treatment received significantly less nitrogen and yielded significantly less than the other treatments.

To examine impacts of threshold implementation in detail where crop conditions were less ideal, we extracted data occurrences only in the direct area where the threshold treatments were imposed. Treatment values for UNL, reference, and sensor treatments were extracted. This approach resulted in different responses for Site 09BR from the whole strip means, particularly the sensor treatment. In (Figure 2) grain yields for all treatments tended to follow the same trend as the field length strips, but the total N applied in the sensor treatment was significantly higher than any of the other treatments, while yielding less than the reference treatment and similar to UNL.

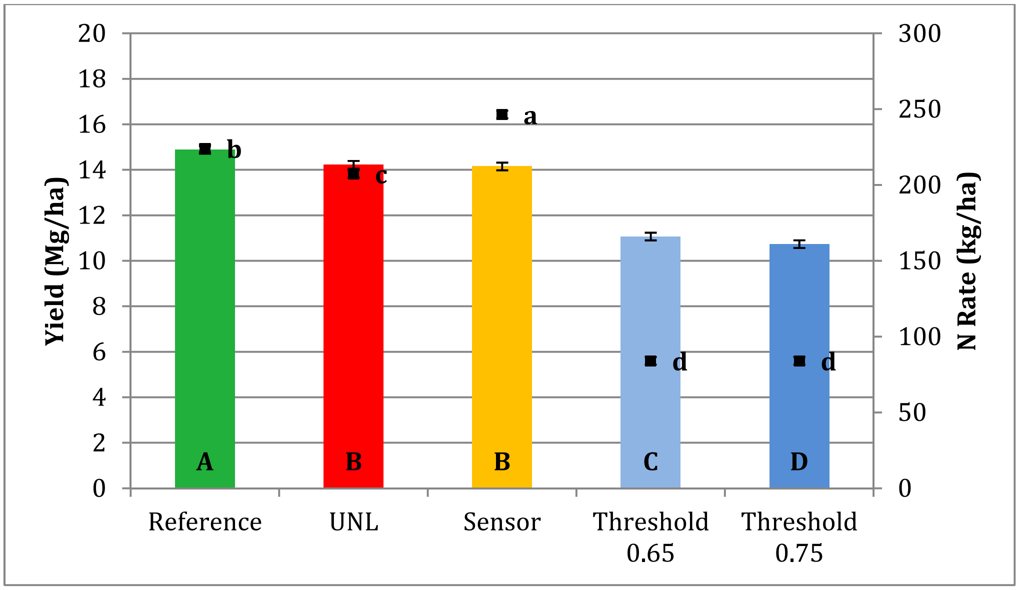

Figure 2: Combined imposed threshold values for 09BR by treatment for grain yield in bar format on the primary axis. Values by treatment for the total nitrogen received in point format on the secondary axis. Error bars represent the Duncan multiple range test separation value. Means with the same letter are not statistically different (p=0.05).

The threshold treatments yielded significantly lower than other treatments and received significantly less N as well. Site 10HU had a typical response of grain yield to N (Figure 3).

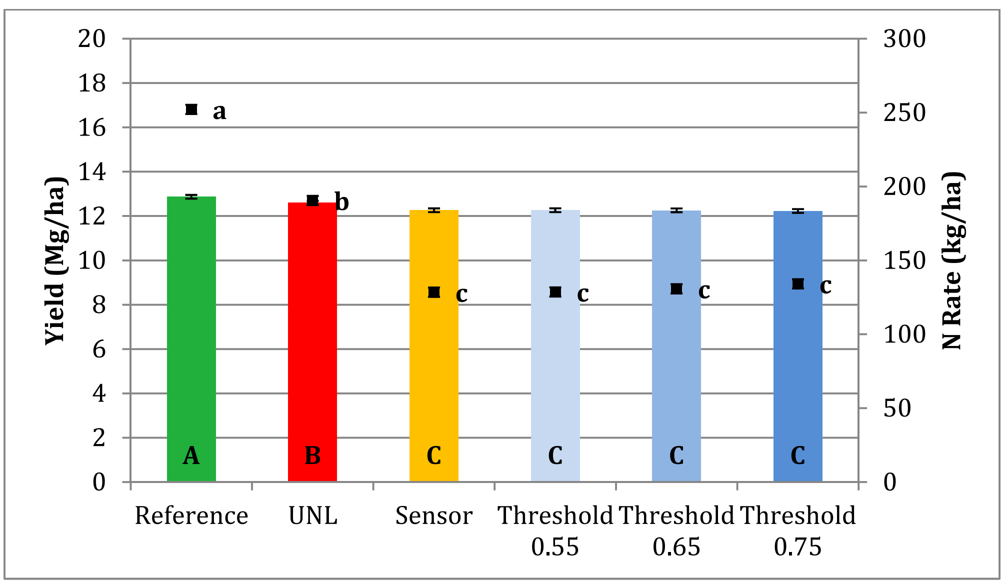

Figure 3: Whole strip treatment values for 10HU by treatment for grain yield in bar format on the primary axis. Values by treatment for the total nitrogen received in point format on the secondary axis. Error bars represent the Duncan multiple range test separation value. Means with the same letter are not statistically different (p=0.05).

The reference treatment's grain yield was significantly higher than all other treatments and received the most N followed by a lower grain yield and N rate for the UNL treatment. The sensor treatment and all threshold treatments yielded similarly and received similar amounts of N; all less than the UNL treatment. The sensor treatment had a significantly higher SI value than all threshold treatments. Threshold 0.55 had a significantly lower SI value than either the T65 or T75 treatments. Site 10HU also showed a different response for combined threshold location compared to the field length strip values. At this site, there was relatively little yield response to N (Figure 4).

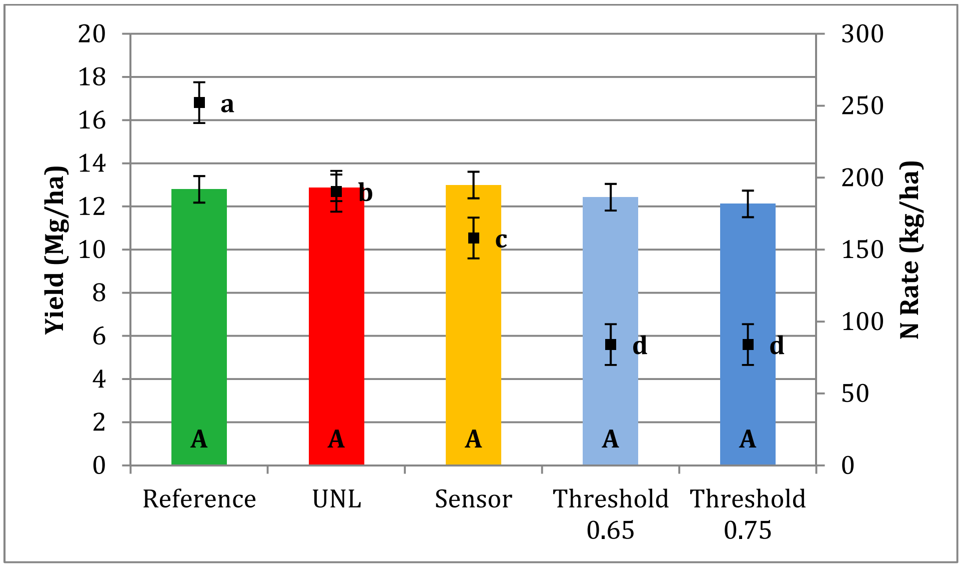

Figure 4: Combined imposed threshold values for 10HU by treatment for grain yield in bar format on the primary axis. Values by treatment for the total nitrogen received in point format on the secondary axis. Error bars represent the Duncan multiple range test separation value. Means with the same letter are not statistically different (p=0.05).

All treatments yielded similarly, but received significantly different amounts of nitrogen. The threshold treatments received the least amount of nitrogen. The associated grain yields for the threshold treatment tended to be lower than the other treatments, but not significantly. The combined threshold location SI values for Site 10HU show that the SI values are significantly different for each treatment, but yield is not different (Figure 5).

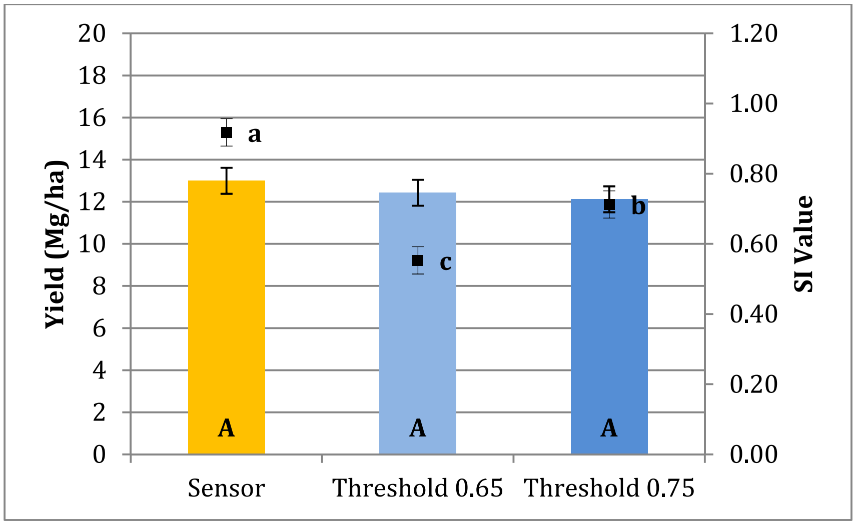

Figure 5: Combined imposed threshold values for 10HU by treatment for grain yield in bar format on the primary axis. Values by treatment for the SI value at time of sensing (V11) in point format on the secondary axis. Error bars represent the Duncan multiple range test separation value. Means with the same letter are not statistically different (p=0.05).

Discussion

Field length strips grain yield responses to treatments for Site 09BR was as expected, the higher the N rate, the higher the grain yield. Threshold treatments yielded significantly lower than any of the other treatments, which suggests this method was ineffective for this site. However, for the combined threshold location values, we saw a different outcome. The sensor treatment received a significantly higher N rate than any other treatment while grain yield was not significantly higher as a result. The combined threshold location SI value for the sensor treatment was 0.73 (Figure 6).

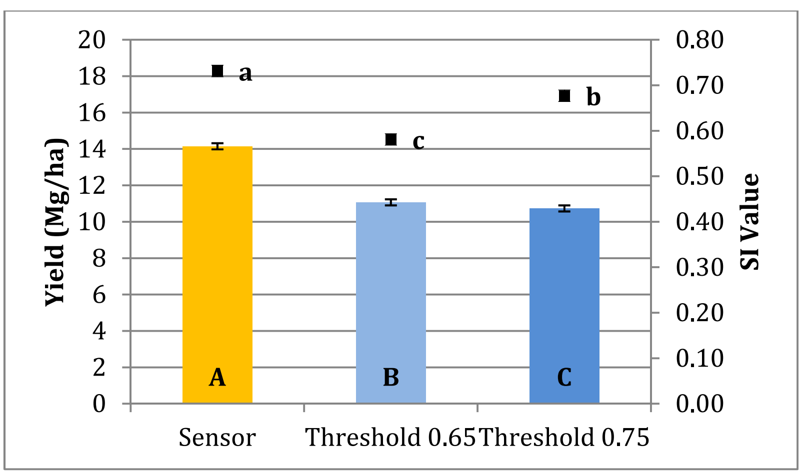

Figure 6: Combined imposed threshold values for 09BR by treatment for grain yield in bar format on the primary axis. Values by treatment for the SI value at time of sensing (V11) in point

format on the secondary axis. Error bars represent the Duncan multiple range test separation value. Means with the same letter are not statistically different (p=0.05).

This is a fairly low SI value, approaching the first threshold of 0.75. The low SI value resulted in a higher average N rate, but there was not the same response in grain yield as the UNL treatment. This is likely because the UNL treatment received more N earlier in the growing season. Inadequate N supply early in the season for all sensor-based treatments may have resulted in unrecoverable N stress relative to the UNL treatment at this site. This site's low soil organic matter, 1.20%, and coarse textured soil make early season fertilizer N supply more critical to protecting yield potential.

Site 10HU had a typical response of grain yield to N (Figure 3). The sensor treatment and threshold treatments all yielded similarly and received similar amounts of N. More than half of the application data points for the sensor treatment had SI values above 0.97. This supports that the reference strip was sufficient at the time of application, and that the reference treatment had sufficient nitrogen applied to supply the crop for the rest of the season. This suggests that the sensor and threshold treatments, however, did not. The 84 kg ha^{-1} of nitrogen applied supplied this crop at least up to the sensing application, but the nitrogen supply must have run out somewhere beyond this time point, which caused a deficiency and ultimately a loss of yield as a result.

Conclusion

Evaluation of SI thresholds was confounded by the unexpected response of the sensor treatment. Since the threshold treatments were based on the sensor treatment, we wanted to be able to compare the threshold treatment response with the response of the sensor treatment. In many cases the uniform application for either the UNL or reference treatments yielded better than the sensor based treatments (sensor and thresholds). If we were only comparing the effectiveness of the threshold treatments, we have found that the thresholds were largely ineffective. At Site 09BR the response of the sensor based treatments was affected by a more deficient plant at sensing time. The initial application of N to the treatments did not provide enough N supply to prevent an irrecoverable deficiency, or that the deficiency was so great that the amount of N required to compensate for the deficiency was greater than had a uniform application been applied instead. The opposite conclusion can be drawn from the fine-textured Site 10HU. The initial application of N to the treatments provided a supply of N that extended at least until the point of sensing and application. This allowed for a higher SI value at the time of sensing, but the initial supply of N did not provide enough N for the rest of the season. As a result, the crop became deficient and yield suffered. Analysis of the combined imposed threshold location was used to eliminate spatial variability, but the results suggest that there was significant variability at this scale. This was shown by comparing the SI values of the sensor based treatments for each site. If there was a lack of spatial variability, the SI values would be statistically similar, and this was not the case.

Further research is needed to refine the current approach to account for the site's soil mineralization potential as it occurs spatially. Different initial rates of N fertilizer are needed for different soil types, and more than one sensing application may be needed.

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