SENSOR BASED NITROGEN MANAGEMENT FOR COTTON PRODUCTION IN COASTAL PLAIN SOILS

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Abstract

Tests were conducted for four years to develop sensor-based algorithms for predicting the mid-season side-dress nitrogen requirements for irrigated and dry land cotton in Coastal Plain soils. The efficacy of the Clemson algorithms was compared to a typical grower's practice and algorithms developed at Oklahoma State University (OSU). In addition, the effects of sensor height, solar radiation, ambient temperature, and measurement time on performance of the GreenSeeker® optical sensor were determined. The results showed that the Clemson algorithms can be used successfully to predict side-dress nitrogen requirements between the time periods of 5 to 7 weeks after plant emergence. For a given NDVI, the estimated yield for irrigated cotton was 1.6 times higher than the dry land cotton. The predictions of yield as a function of NDVI used by the algorithms were cultivar sensitive; however, a combined yield relation provided sufficient accuracy to estimate cotton N fertilizer rates. Soil EC management zones should be used for calculating nitrogen application rates in the Southeastern Coastal Plain region. There was no difference in cotton yield between Clemson and OSU method for dry land cotton; however, the OSU algorithm yielded significantly less than the Clemson & growers' methods for irrigated cotton. The Clemson algorithms applied between 40 to 47% less fertilizer compared to conventional application mode without effecting cotton yields. The GreenSeeker sensor is height sensitive; but, it is not sensitive to ambient temperature or solar radiation. The NDVI data should be collected between the time period of three hours after sunrise and one hour before the sunset.

Introduction

Several researchers across the cotton producing states are developing algorithms for cotton nitrogen fertilization based on optical sensors (Earnest and Varco, 2005; Scharf et al., 2008; Arnall et al., 2008). Due to significant variations in soil type and texture in coastal plain regions, N-application algorithms should be developed specifically for the region to match these conditions. There are high correlations between soil texture (as indicated by soil electrical conductivity - EC) and cotton yields in costal plain soils (Khalilian et al. 2004). In addition, plant demand and response to N changes from year to year and mobile nutrients (such as N) are used, lost, and stored differently as soil texture varies. Soil EC has a significant effect on cotton crop response to applied nitrogen (Khalilian et al., 2008). For example, in low EC areas, seed cotton yield increased as N rates increased. However, in medium and high EC areas there was no yield response above 90 lbs/acre N.

The algorithms developed for coastal plain regions, should be compared to those developed by other researchers to determine their practicality in other areas of USA. The GreenSeeker® RT series, is one of the more widely used active optical sensors to determine the mid-season nitrogen requirement for many crops across the United States including cotton. However, there are no standard recommendations related to sampling time and sensor height for optimum performance of the sensor in cotton production.

The objects of this four year study were: 1) To develop nitrogen-algorithms for irrigated and dry land cotton utilizing plant NDVI and soil electrical conductivity (EC) data (management zones); 2) To compare Clemson algorithms with the algorithm developed at Oklahoma State University and a typical grower's practice; and 3) To determine the effects of sensor height, solar radiation, ambient temperature, and measurement time on performance of the GreenSeeker® sensor.

Materials and Methods

Objective 1:
Tests were conducted for four years (2007-2010) to develop sensor-based algorithms for predicting the mid-season side-dress nitrogen requirements for irrigated and dry land cotton in Coastal Plain soils. Two production fields were used in this study. One field, equipped with an overhead irrigation system, was used during the 2007 and 2010 production seasons to develop the algorithm for irrigated cotton. The second field was used during the 2008 and 2009 seasons for developing the algorithm for dry land cotton nitrogen management. A commercially available soil electrical conductivity (EC) measurement system (Veris Technologies 3100) was used to identify variations in soil texture across the test fields. The test fields were then divided into three management zones based on soil EC data and each zone was divided into 50 ft by 8-row plots.

Cotton cultivar Delta Pine 555 was planted during 2007 and 2008 season and Delta Pine 0935 was planted in 2009 and 2010 using recommended practices for seeding, insects, and weed control. Five different rates of nitrogen fertilizer (0, 30, 60, 90, and 120 lbs/acre) were replicated four times in plots of each zone using a Randomized Complete Block (RCB) design arrangement. Plant Normalized Difference Vegetation Index (NDVI) was measured during the growing season using a 6-row sprayer-mounted GreenSeeker® RT-200 mapping system equipped with a NORAC boom-height control system (NORAC Control Systems Saskatoon, SK Canada) to keep the sensor height over canopy constant (Figure 1). The NDVI data were collected 5 times throughout the growing season and were used to develop yield prediction equations. N-application algorithms were developed for all four years, using the same procedures described by Raun et al., 2005 and Khalilian et al., 2008.

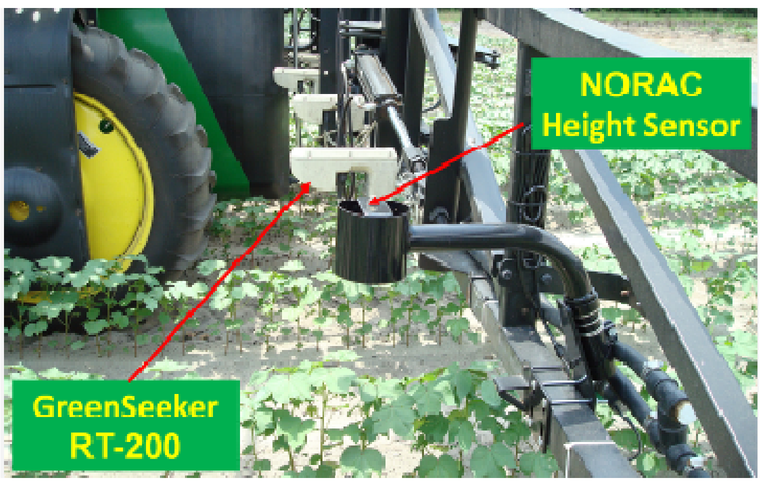

Figure 1: The GreenSeeker RT-200 system with the NORAC height controller.

Objective 2:
Tests were conducted during 2009 and 2010 to determine the effects of three different side-dress nitrogen application methods on cotton yields. The N rates were calculated using the Clemson and Oklahoma State University N-prediction algorithms and conventional growers' practice for the region. The side-dress N treatments were replicated four times in each zone of the test fields using a RCB design arrangement. The OSU algorithm was chosen for comparison to the Clemson algorithm due to the similarities of the two methods. The main difference between the two algorithms is that Clemson uses days after emergence for calculating the predicted yield potential (YP_0) while OSU uses Growing Degree Days (GDD-60). In addition, Clemson algorithm utilizes maximum yield values (Y_{Max}) for each management zone to predict side-dress N requirements.

Three "Nitrogen Ramp Calibration Strips" (N-RCS) were established in each EC zone, to determine the response index (RI) for predicting yield potential when N is applied (YP_N). The N-RCS had 16 rates of N ranging from 0 to 150 lbs/acre on 16.7 ft increment steps. The highest NDVI value from the N-RCS in each zone was used along with the average NDVI from the test plots to calculate RI. All test plots received 30 lbs/acre N at planting followed by side dress nitrogen applications at the optimum time for each algorithm as indicated by Arnall et al. (2008) and Khalilian et al. (2008). The conventional treatment received 60 lbs/acre side-dress N.

Objective 3:
Tests were conducted to determine the effects of sensor height on NDVI readings using the NORAC height controller. Six different heights (20 to 48 inches) above plant canopy were used during this test. In addition, tests were conducted to determine the effects of solar radiation, ambient temperature, and sampling time (the time of day) on performance of the GreenSeeker sensor. To ensure that the variations in NDVI readings were due to plants physiologic properties and not from the sensor itself, one sensor was placed at a standard height above a piece of green cloth and allowed to collect NDVI data from 8 a.m. until 11 p.m. (Figure 2).

Figure 2: Sensor test using a green cloth

Results and Discussion

Objective 1:
The coefficients of determination for yield prediction equations during 2007 to 2010, ranged from 0.83 to 0.91. The prediction equations were based on in season estimated yield or INESY, which was calculated by dividing the NDVI values by the days after emergence (or DAE).The results showed that the algorithms were cultivar sensitive; however, a combined algorithm can be used successfully to predict the side-dress N fertilizer rates in cotton production. Soil EC management zones should be used for calculating nitrogen application rates in the Southeastern Coastal Plain region.

For a given NDVI value, the algorithm for irrigated cotton, predicted higher yields than the one developed for the dry land cotton. Therefore, data were combined into two groups "irrigated" and "dry land" (Figure 3). This resulted in an algorithm with lower coefficients of determination than the individual yield prediction equation for each year (R^2 = 0.856 for irrigated and 0.763 for dry land cotton). However, it is still good enough for practical use by growers for managing side dress nitrogen applications in cotton. The results also showed that, averaged over four years, irrigation increased cotton yields by 60% in Coastal Plain soils.

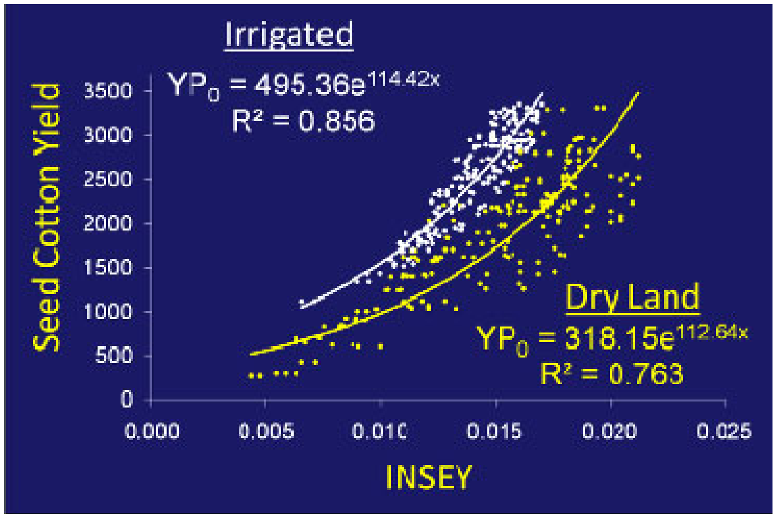

Figure 3: Yield Prediction Equations for irrigated and dry land cotton.

The results showed that the Clemson algorithms can be used successfully to predict side-dress nitrogen requirements between the time periods of 5 to 7 weeks after cotton plant emergence, which is the optimum time for side dress nitrogen application in coastal plain regions. The algorithms also had higher coefficients of determination during this period. Tissue analysis tests were performed on the cotton seeds from the variable rate nitrogen plots in 2009 and 2010, to determine the of nitrogen application rates on cotton seed nitrogen content. This information is needed for calculating side-dress nitrogen rates. A very strong correlation ($R^2 > 0.96$) was found between the percent nitrogen in harvested cotton seeds and nitrogen application rates, with an average value of 2.5% over two years.

Objective 2:

The Clemson algorithm recommended 24 lb/acre N across all zones plus the 30 lbs/acre at planting (total 54 lbs/ac) for the 2009 dry land test, while the OSU algorithm called for 47 in zone 1, 24 in zone 2, and 0 in zone three plus the 30 lbs/ac at planting. The results showed that there were no significant differences in yield between the two algorithms and normal farmer practice for the dry land cotton (Figure 4). The main difference in cotton yield was due to soil EC zones. The two algorithms were able to lower nitrogen use across the entire field by 40% without affecting cotton yields.

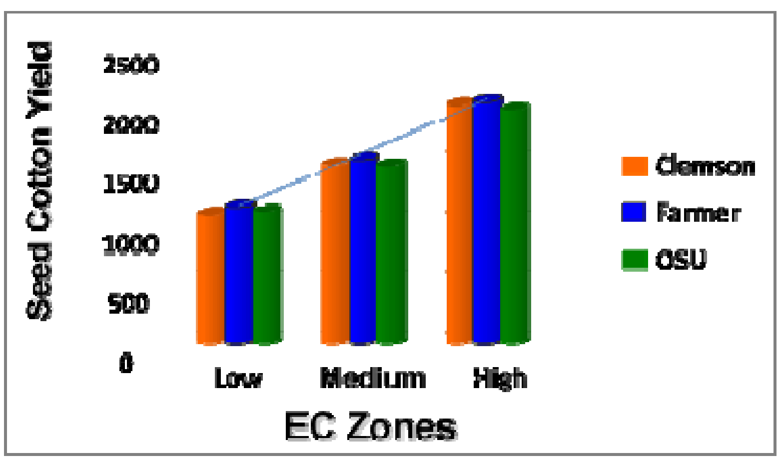

Figure 4: Effects of nitrogen management methods on dry land cotton yield (2009).

For the irrigated test in 2010, the Clemson algorithm recommended 24, 17, and 11 lbs/acre for the zones 1 to 3, respectively. However, the side dress nitrogen rate based on Oklahoma algorithm was zero lbs/acre for all zones. All treatments received 30 lbs/ac at planting. The OSU method yielded significantly less than the Clemson & growers' methods in all three zones for the irrigated cotton (Figure 5). In 2010, reductions in N use were 66% & 47% for OSU & Clemson methods, respectively.

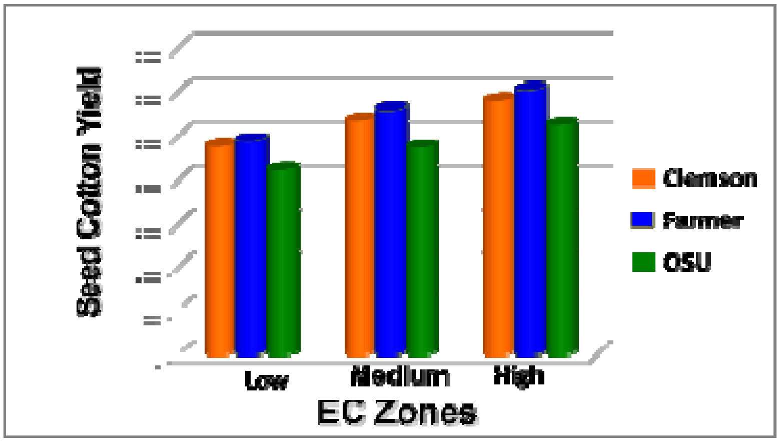

Figure 5: Effects of nitrogen management methods on irrigated cotton yield (2010).

Objective 3:
The results of sensor height tests showed that the GreenSeeker sensors are height sensitive and the NDVI values decreases as the height above canopy increased (Figure 6). The optimum height, based on four years observation, appeared to be 36 inches above the plant canopy (NTech recommends height be limited between 32 and 48 inches above the canopy). This will prevent sensor saturation, which happens when the sensor is too close to the plant canopy. Sensor heights above 36 inches, results in NDVI measurements from row middles at the early stages of plant growth, and later in the season, it is restricted by the equipment (sprayer) limitations to accomplish heights above 36 inches.

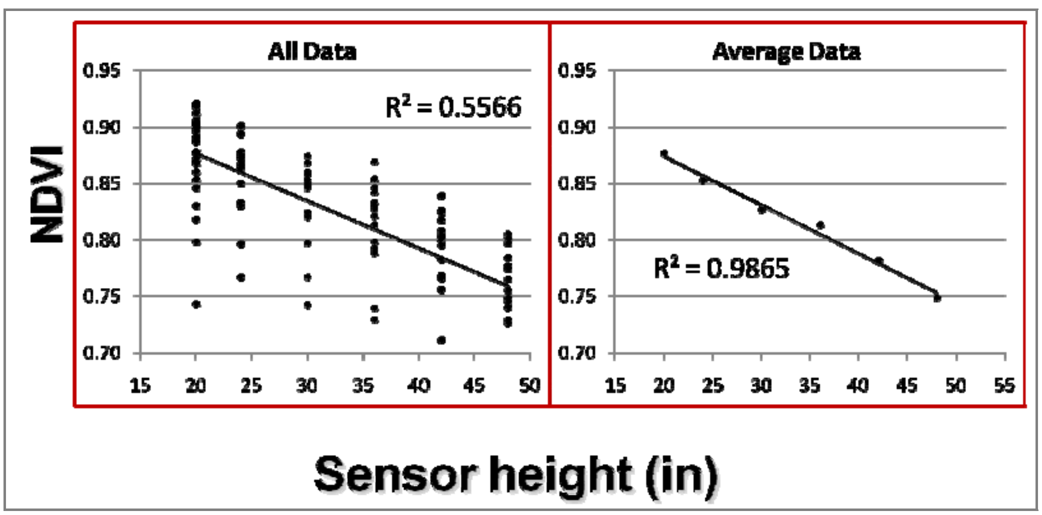

Figure 6: Effects of Sensor Height on Plant NDVI (individual plants: left and average values: right).

Measurement time affected the sensor output. The values were higher early in the morning and dropped after sunset (Figure 7). The NDVI data collected using the Green Cloth did not follow the same patterns as cotton plant, which confirm that the variation in NDVI is due to plants physiologic properties and not from the sensor itself. The results suggested that optimum sampling time for NDVI measurements is about three hours after sunrise until one hour before sunset. Solar radiation and ambient temperature did not have any effects on sensor readings.

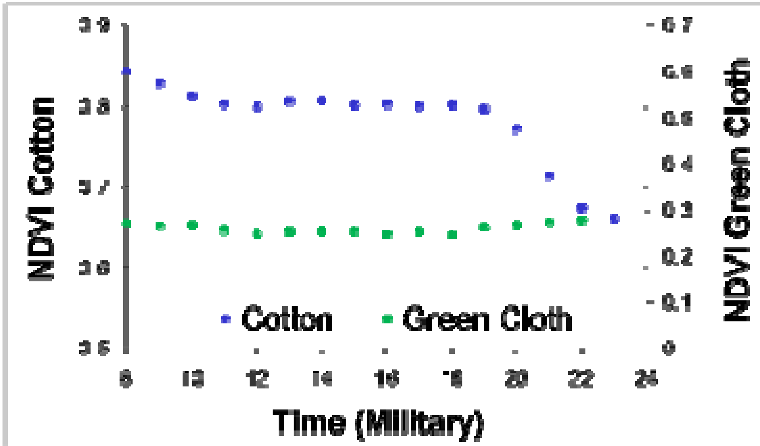

Figure 7: Effects of sampling time on plant NDVI.

Summary

- The Clemson algorithms can be used successfully to predict side-dress nitrogen requirements between the time periods of 5 to 7 weeks after plant emergence.
- For a given NDVI, the estimated yield for irrigated cotton was 1.6 times higher than the dry land cotton.
- The N algorithms are cultivar sensitive. However, a combined algorithm can be used successfully to predict the side-dress N fertilizer in cotton production.
- Soil EC management zones should be considered in determining nitrogen application rates in the Southeastern Coastal Plain region.
- There was no difference in cotton yield between Clemson and OSU method for dry land cotton; however, the OSU algorithm yielded significantly less than the Clemson & growers' methods for irrigated cotton.
- The Clemson algorithms applied between 40 to 47% less fertilizer compared to conventional application mode without effecting cotton yields.
- The GreenSeeker sensor is height sensitive; but, it is not sensitive to ambient temperature or solar radiation.
- The NDVI data should be collected between the time period of three hours after sunrise and one hour before the sunset.

Acknowledgements

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Disclaimer

Mention of a trade name does not imply endorsement or aversion of the product by Clemson University to the exclusion of others that might be available.

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