Scientific Research Publishing

Open Journal of Soil Science, 2017, 7, 278-287
http://www.scirp.org/journal/ojss
ISSN Online: 2162-5379
ISSN Print: 2162-5360

Sensor-Based Algorithm for Mid-Season Nitrogen Application in Corn

**Ahmad Khalilian[1]*, Nicholas G. Rogers[1], Phillip B. Williams[1], Young J. Han[1],
Ali Mirzakhani Nafchi[1], Joe Mari Maja[2], Michael W. Marshall[2], Jose O. Payero[2]**

[1]Department of Agricultural Sciences, Clemson University, Clemson, SC, USA
[2]Edisto Research and Education Center, Clemson University, Blackville, SC, USA
Email: *akhlln@clemson.edu, ngroger@g.clemson.edu, pbw@clemson.edu, yhan@clemson.edu, anafchi@clemson.edu, jmaja@clemson.edu, marsha3@clemson.edu, jpayero@clemson.edu

How to cite this paper: Khalilian, A., Rogers, N.G., Williams, P.B., Han, Y.J., Nafchi, A.M., Maja, J.M., Marshall, M.W. and Payero, J.O. (2017) Sensor-Based Algorithm for Mid-Season Nitrogen Application in Corn. *Open Journal of Soil Science*, **7**, 278-287.
https://doi.org/10.4236/ojss.2017.710020

Received: September 21, 2017
Accepted: October 24, 2017
Published: October 27, 2017

Abstract

Applying insufficient nitrogen (N) in a highly responsive crop, such as corn, results in lower grain yield, quality, and profits. On the other hand, when nitrogen is applied in excess of crop needs, profit is reduced and negative environmental consequences are likely. The objective of this study was to develop and employ a sensor-based algorithm to determine the mid-season N requirements for deficit-irrigated corn in Coastal Plain soils. The algorithm was developed using varied prescription rate N plot on two soil types. The test plots received nine different rates of N fertilizer, replicated 5 times in plots of each soil type using a Randomized Complete Block design. A 6-row GreenSeeker optical sensor was used to measure plant NDVI, between the V6 to V8 growth stages. The sensor readings were used to develop an algorithm to be used in the estimation of side-dress N application in corn. The NDVI sensor readings were collected at the V6 to V8 growth stage during the 2015 and 2016 growing seasons correlated with actual corn yields ($R^2 > 0.68$, $p < 0.001$). In-Season Estimated yield (INSEY) was used along with the actual yield to produce a yield potential for each growing season for deficit-irrigated corn crop. In summary, the algorithm developed from the NDVI readings reduced N application rates by 21% and 34% in soil types 1 and 2, respectively, compared to the normal grower practice (226 kg N/ha) with no reduction in corn yields.

Keywords

Algorithms, Corn, Nutrient Management, Precision Agriculture, Normalized Difference Vegetation Index (NDVI), Sensors

1. Introduction

Applying the proper rate of N for a crop is one of the major management decisions for producers. When choosing N rates, farmers need to carefully consider both achieving the most profitable economic return and advancing environmental stewardship. Applying insufficient N for a highly responsive crop, such as corn, results in lower grain yield, quality, and profits. On the other hand, when N is applied in excess of crop needs, profit is reduced and negative environmental consequences are likely. On average, growers in the USA apply about 160 kg N/ha for corn, for a total of 5.6 million metric tons annually [1]. High production costs increasingly motivate growers to reduce crop input costs while maximizing yields to stay competitive in the global market. For example, a 20% reduction in N usage could save corn growers over $1.2 billion annually.

Nitrate-N is highly mobile in soil, especially in the sandy soils of Southeastern Coastal Plain region of the United States, and is a major source of surface and groundwater contamination. Previous experiments [2] [3] reported that when high amounts of N are accumulated in the soil, it becomes highly susceptible to leaching, which could then contaminate the ground water.

In the Coastal Plain region, considerable soil variation occurs within production fields in soil texture, water holding capacity, and other characteristics, which could have a significant impact on fertilizer management strategies. Field variation affects the growth and development of plants, and a tremendous amount of growth variability is often correlated with changes in soil characteristics across the production field. In Coastal Plain soils, the yield response to N fertilizer also varies significantly among different sections of a production field, even in small fields [4] and high correlations have been observed between soil electrical conductivity (EC) and crop yields [5]. Therefore, uniform application of N fertilizer over the entire field can be both costly and environmentally questionable [6]. The solution lies in matching field variability with the appropriate N-rate. One way of maintaining adequate soil N fertility levels without exceeding crop N requirements is to tailor N inputs to meet the specific crop N requirements [2]. The technology to do this is known as variable-rate, sensor-based nutrient management.

Several researchers have developed algorithms for N fertilization based on optical sensors [4] [7] [8] [9]. However, due to higher annual precipitation, significant variation in soil type and texture, low soil organic matter content, and low nutrient holding capacity of soils in the Coastal Plain region, N-application algorithms developed in other regions, either under- or over-estimate N rates for crop production. During a three-year study at Clemson [4] [10], N fertilizer applied based on the algorithm developed at the Oklahoma State University (OSU) [9], reduced irrigated cotton yields by 15% compared to standard farmer practices (one uniform N rate across the entire field). The OSU algorithm, recommended 66% less N. During a 2013 study at Clemson, the algorithm developed at OSU [11], overestimated N rates by 11% in winter wheat production, without affecting crop yields. Therefore, there is a need to develop sensor-based nitrogen-algorithms for corn, specifically designed for Coastal Plain region, to account for soil and climatic variables characteristic of this region.

2. Objectives

The objectives of this study were to: 1) develop/refine an algorithm for prediction of side-dress N requirements for deficit-irrigated corn utilizing the plant Normalized Difference Vegetation Index (NDVI) and soil electrical conductivity data, and 2) compare the Clemson algorithm to a typical grower's practice in terms of effects on corn yields and plant N requirements.

3. Methodology

Replicated field studies were conducted during the 2015 and 2016 growing seasons, at the Clemson University's Edisto Research and Education Center (34˚17'19.2"N, 79˚44'37.7"W). The 1.6-ha test field was irrigated following a deficit-irrigation strategy using a lateral move irrigation system (76 m long). Irrigation was applied only during conditions where it was required to keep from incurring losses. Total rain plus irrigation was 60 cm and 54 cm during 2015 and 2016 growing seasons, respectively.

The soil type in the test field was Varina loamy sand (Fine, kaolinitic, thermic Plinthic Paleudults), a typical Coastal Plain soil. A commercially available Veris 3100 soil electrical conductivity meter (Veris Technologies, Inc., Salina, KS, USA) [12] was used to measure soil-texture variability of the test field. The test field was then divided into two management zones (soil types) based on the soil EC data and USDA soil texture map [13]. The main differences between two management zones were soil EC and percent slope. The percent slope for zone one was 0 to 2 percent (VaA) and for zone two was 2 to 6 percent (VaB). Each zone was then divided into 45 plots (8-row by 18 m). The test plots were arranged in a randomized complete block design, and 9 N treatment rates (0, 22.5, 45, 90, 135, 180, 225, 270, and 292 kg N/ha) were replicated 5 times in plots of each zone. A modified multi-boom applicator (**Figure 1(A)**) was used to apply different N rates to the test plots. This system (called a RAMP applicator) was capable of applying 16 different N rates (0 to 300 kg/ha). The RAMP applicator was equipped with four sets of nozzles (booms) selected to apply 1×, 2×, 4×, and 8× rates, with 4 independent pumps for controlling nitrogen rates. The rate controller (developed at Clemson University) selected combinations of these nozzles to apply the desired application rate (**Figure 1(B)**). Ground radar sensors were used to adjust the desired length over which each application rate was applied.

A commercially available optical sensor, the GreenSeeker$^{®}$ RT-200 mapping system (NTech Industries, Inc. Ukiha, CA, USA), was utilized during the 2015 and 2016 growing seasons to measure corn plant's NDVI, between the V6 to V8 growth stages. The GreenSeeker optical sensor is an active sensor that emits two bands of light, red and Near Infrared (NIR), and measures the amount of reflectance. The value reported from this measurement is the indices termed Normalized Difference Vegetation Index (NDVI) [11]:

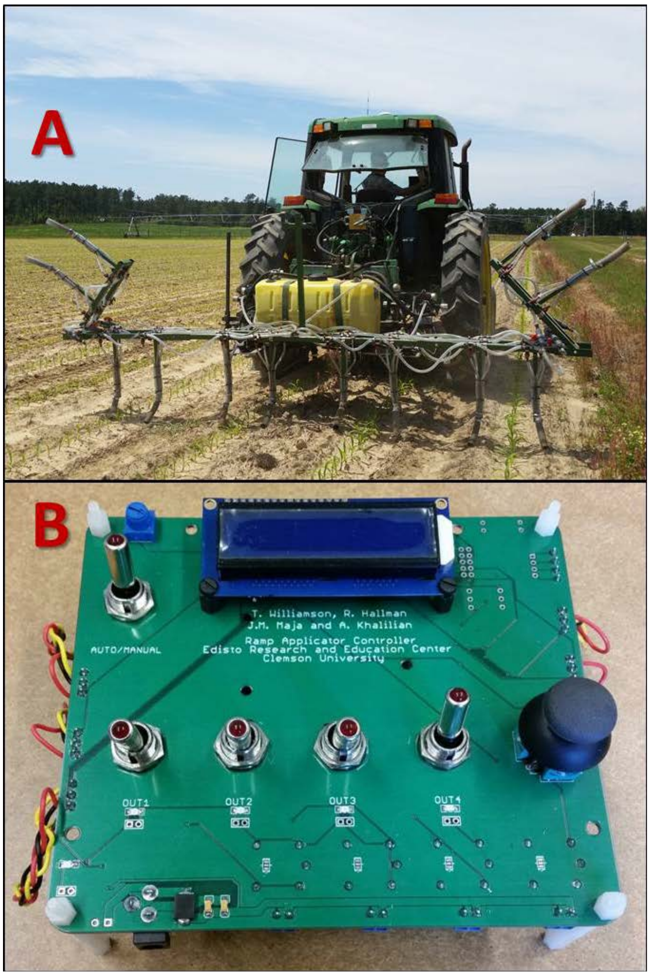

Figure 1. The clemson ramp applicator used to apply different N rates to test plots (A) and the controller system (B).

$$\text{NDVI} = \frac{\text{NIR}_{\text{reflectance}} - \text{Red}_{\text{reflectance}}}{\text{NIR}_{\text{reflectance}} + \text{Red}_{\text{reflectance}}} \tag{1}$$

The RT-200 mapping system (Trimble Inc., Sunnyvale, CA, USA) utilizes six separate optical sensors that were retrofitted to a John Deere 6700 Hi-Boy self-propelled sprayer (John Deere Co., Moline, IL, USA) (**Figure 2**) and could map the center six rows of the eight-row plots. Sensor data were logged on a 1 Hz cycle, and were captured and stored on a Trimble Nomad handheld onboard computer that was also linked to a Trimble Differential GPS receiver (Trimble Inc., Sunnyvale, CA, USA). The NDVI data were transformed and stored as a shape file that could be exported to any GIS software, to be analyzed and averaged based on plot design.

The sensor readings were used to develop the algorithm to be used in the estimation of side-dress N application for deficit-irrigated corn. The collected NDVI data were used to calculate the In-Season Estimated Yield (INSEY) [11]:

$$\text{INSEY} = \frac{\text{NDVI}}{\#\ \text{of days after planting}} \tag{2}$$

Figure 2. The sprayer-mounted GreenSeeker® RT-200 system.

To determine the relationship between the actual corn yield and the INSEY, both linear and non-linear regression models were utilized to determine the yield potential (YP_0) and the N prediction algorithm.

Yield was measured during the end of each growing season using an Ag Leader Yield Monitor (Ag Leader Technology, Ames, IA, USA) retrofitted on a John Deere 4 row combine (John Deere Co., Moline, IL, USA). During the 2015 growing season the yield data were used to develop the N algorithm. The 2016 growing season yield was used to further refine the 2015 algorithm.

In addition, in 2016, the efficacy of the Clemson algorithm (developed during 2015 and 2016) was determined by comparing the sensor-based N application method to a typical grower's practice (224 kg N/ha) under deficit-irrigation corn production. Replicated tests were conducted to compare these two systems (sensor-base and conventional practices) in terms of effects on corn yields and N requirements. The experimental design was a randomized completer block design with 5 replications in each zone. A Nitrogen-Rich-Calibration-Strip (NRCS) was established using a pre-plant N application rate where N will not be limiting throughout the season (292 kg N/ha), was established in each management zone of the test field. The NRCS was 18m long by eight rows of corn. The Response Index (RI), the extent in which the crop will respond to additional N [11], was calculated as:

$$\text{RI} = \frac{\text{NDVI}_{\text{NRCS}}}{\text{NDVI}_{\text{FIELD}}} \tag{3}$$

where $\text{NDVI}_{\text{NRCS}}$ = highest NDVI reading from the NRCS, and $\text{NDVI}_{\text{FIELD}}$ = NDVI reading from plots of each management zone. The predicted attainable yield (YP_N) with added N was calculated as [11]:

$$YP_N = RI * YP_0 \tag{4}$$

where YP_0 is predicted yield, calculated from the algorithm developed during 2015 and 2016 (Equation (8)).

The predicted attainable yield should not exceed the maximum corn yield

(YP_{MAX}) for the given region and management practices. In this case the YP_{MAX} was set at 12,565 kg/ha for deficit-irrigated field conditions in the Coastal Plain Region of South Carolina. The N fertilizer rate was then determined as:

$$N_{\text{Rate}} = \frac{\left(YP_N - YP_0\right) * \%N}{\text{NUE}} \quad (5)$$

where YP_0 = the predicted yield, $\%N$ = the percentage of N in crop seeds after harvest (1.25% for corn), and NUE = N use efficiency (60% for corn) [14].

4. Results

In-Season Estimated Yield (*INSEY)* was used along with the actual yield to produce a yield potential for each growing season for deficit-irrigated corn. There were good correlations between sensor readings collected during the 2015 and 2016 growing seasons (V6 to V8 stage) and actual corn yields. As days after planning increased, the correlations between the *INSEY* and actual corn yields became stronger up to 49 days in 2015 and up to 54 days in 2016. The coefficients of determinations decreased after these days.

Figure 3 shows the yield prediction equation developed from the 2015 growing season data. The yield prediction algorithm for 2015 is given in equation 6. There was a high correlation ($R^2 = 0.6914$, $P < 0.001$) between *INSEY* and actual corn yield.

$$YP_o = 3987.9\text{e}^{112.65x} \quad (6)$$

where x is *INSEY* and YP_0 is predicted corn yield.

Figure 4 shows the yield prediction equation developed from the 2016 growing season data. There was a higher correlation ($R^2 = 0.7106$, $P < 0.001$) between *INSEY* and actual corn yields compared to 2015. The yield prediction algorithm for 2016 is given in Equation (7).

$$YP_0 = 84.225\text{e}^{336.95x} \quad (7)$$

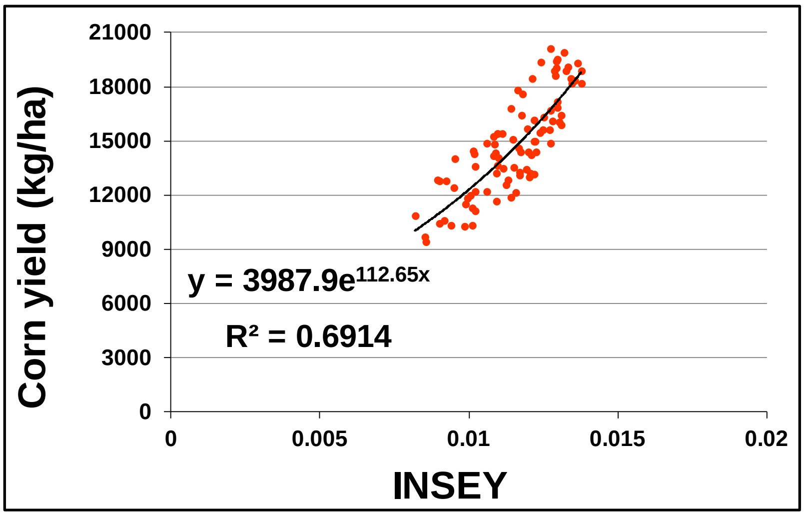

Figure 3. Yield prediction equation from 2015 (All soil EC zones combined).

Figure 5 shows the algorithm developed using data from 2015 and 2016. The combined algorithm still had a good correlation ($R^2 = 0.6789$, $P < 0.001$) between the *INSEY* values and actual corn yields, that could accurately predict the mid-season N requirements for corn production. Therefore, the final yield prediction equation (using two years data) for corn under deficit irrigation in Coastal Plain soils is:

$$YP_o = 407.8e^{219.56x} \tag{8}$$

In the Coastal Plain Region of South Carolina, the typical farmer practice for corn under irrigation is to apply a flat rate of 226 kg N/ha. During 2016 growing season, the Clemson sensor-based algorithm was compared to a typical grower's practice in terms of effects on corn yields and N requirements. The results (Figure 6) showed that the sensor-based nutrient management reduced N rates by 21% and 34% in zones one and two, respectively, compared to traditional farmer's fixed rate practice without any reduction in corn yields. Applying side-dress N

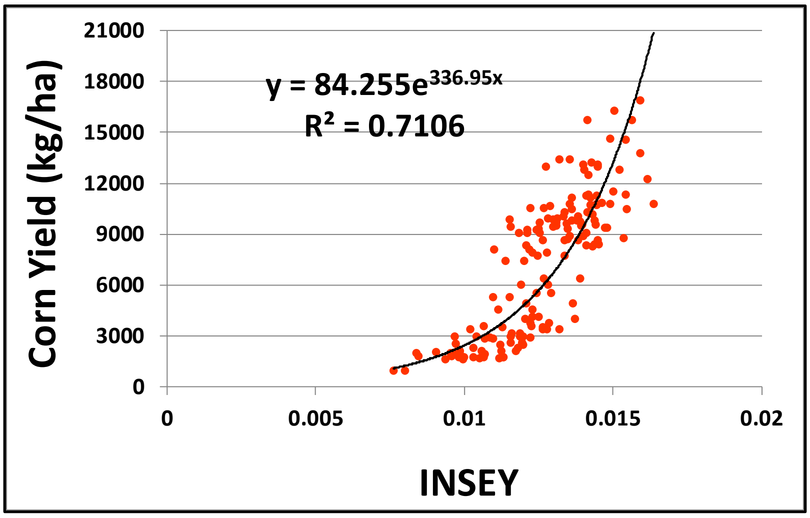

Figure 4. Yield prediction equation from 2016 (all soil EC zones combined).

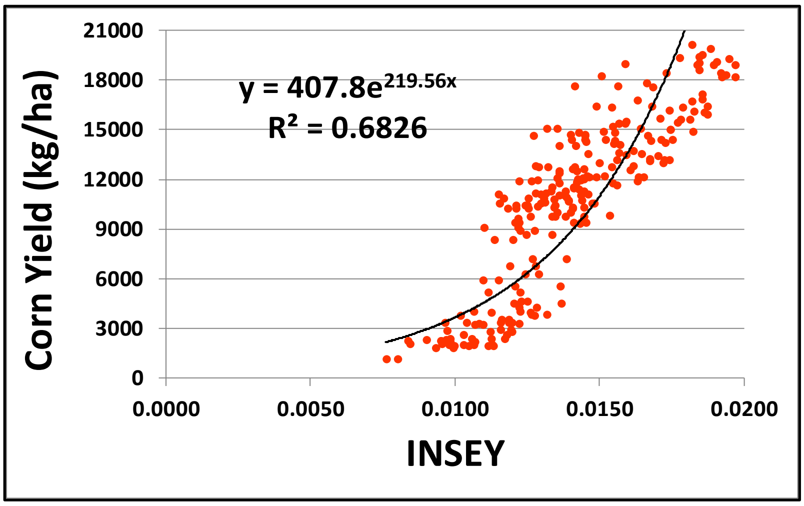

Figure 5. Combined 2015 and 2016 yield prediction equations.

based on Clemson algorithm and the GreenSeeker optical sensor data, increased corn yields by 12% and 5% in zones one and two, respectively, compared to grower's standard production method (**Figure 7**). However, the yield increases were not statistically significant.

5. Conclusion

Overall, there was a good correlation between combined sensor readings collected during 2015 and 2016 growing seasons (V6 to V8 stage) and actual corn yields ($R^2 > 0.68$). In-Season Estimated Yield was used along with the actual yield to produce a yield potential for each growing season for deficit irrigated corn crop. The Clemson algorithm, reduced rates of N, 21% and 34% in soil types 1 and 2, respectively, compared to the grower standard practice program (226 kg N/ha) with no reduction in corn yields. This technology has a potential to apply N where it is needed in the field at an optimum rate, which will help our growers to reduce production costs, increase farm profits, while enhancing

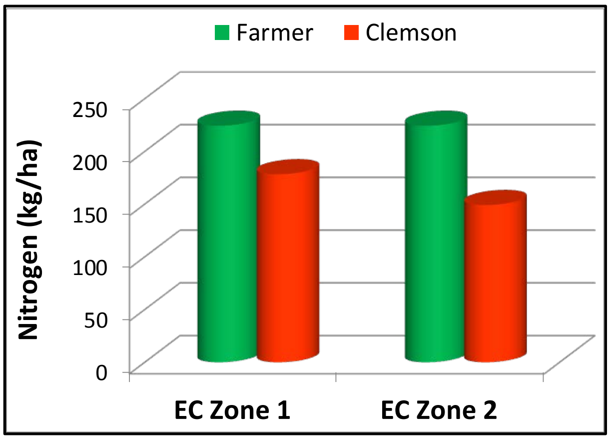

Figure 6. Corn nitrogen usage (Clemson N algorithm vs. farmer standard N program).

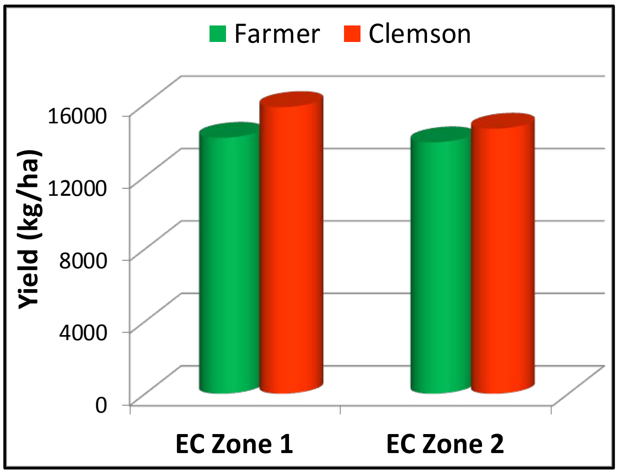

Figure 7. Effects of nitrogen management systems on corn yields.

environmental quality. Future research could include further refining the Clemson algorithm by testing over multiple growing seasons to improve its correlation to actual yield.

Acknowledgements

Technical Contribution No. 6587 of the Clemson University Experiment Station. This material is based upon work supported by NIFA/USDA, under project number SC-1700540. The authors also acknowledge the funding support of the Clemson Public Service Activities.

Disclaimer

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

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