A VARIABLE-RATE NUTRIENT MANAGEMENT TECHNIQUE FOR OVERHEAD SPRINKLER IRRIGATION SYSTEMS

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Abstract

Applying a proper rate of fertilizer for a crop is one of the major management decisions for producers in the southeastern USA. Since 1997, irrigated acreage in South Carolina has increased at a rate of about 10,000 acres per year. Currently there are no practical decision making tools or equipment available for variable-rate application of nitrogen through overhead sprinkler irrigation systems, the predominantly adopted irrigation system in South Carolina. Therefore, the primary goal of my study was to develop and test technologies and concepts for a sensor-based, variable-rate nutrient management program for overhead sprinkler irrigation systems, to provide site-specific application of fertilizers only where needed within individual fields. A 250-ft long linear-move irrigation system was modified to apply variable-rate nitrogen (VRN) with low energy precision application (LEPA) drops. The results showed that the VRN system performed satisfactory with an average application rate error of less than 1.8% for all N rates. There was a strong correlation (R^2 = 0.9996) between the target and actual nitrogen application rates. There was no difference in cotton yields between 90 and 120 lbs. /acre nitrogen applications in either management zone. There were no differences in yield between sensor-based and conventional nitrogen management techniques. Applying N in 3 or 4 applications, statistically increased yields compared to single or split side-dress applications in both 2016 and 2017. Averaged over 4 treatments, sensor-based nitrogen applications reduced fertilizer requirement by 69% in 2016 and 57% in 2017, compared to growers' conventional method. Also, multiple (3 or 4) applications, increased N rates by 20 lbs./acre in 2016 and 23 lbs./acre in 2017 compared to single or split side-dress applications, but increased the cotton lint yields by 243 and 124 lbs./acre, for 2016 and 2017, respectively.

Introduction

Applying a proper rate of fertilizer for a crop is one of the major management decisions for producers in the southeastern USA. In this region, considerable soil variation occurs within production fields in soil texture and other characteristics, which could have significant impacts on fertilizer management strategies. On average, our growers apply about 90 lbs. /acre N for cotton for a total of 28 million lbs. annually just for South Carolina. High production costs make it increasingly important for our growers to reduce crop input costs while maximizing yields to stay competitive in the global market. For example, a 20% reduction in nitrogen usage could save South Carolina cotton growers over $3.7 million annually. Therefore, uniform application of N fertilizer over the entire field can be both costly and environmentally questionable (Nafchi et al., 2017). Scientists at Clemson University have successfully developed cost-effective "sensor-based nitrogen application" systems for dryland and irrigated cotton (Porter et al, 2010; Khalilian et al. 2008 and 2011). These algorithms, which calculate side-dress nitrogen requirements based on an optical sensor, are specifically designed for Coastal Plain region, to account for soil and climatic variables characteristic of this region. These technologies are currently being transferred to South Carolina farmers through on-farm research and Extension activities. Testing this technology on 13 growers' farms during 2015 to 2017 has shown that the sensor-based N management saved cotton farmers between $27 and $60 per acre, by applying less nitrogen. Additionally, if each acre were to have 50 pounds less nitrogen fertilizers on 300,000 acres, this will result in 15 million lbs. less nitrogen applied to the state's cotton fields. Using EPA 10 ppm nitrogen limit, we would have 180 billion gallons of nitrogen free water in South Carolina.

During the past 10 years, irrigated crop acreages have increased significantly in South Carolina. The irrigated cotton acreage increased by 93% from 2002 to 2012 (USDA, 2002-2013), and as a result, our growers are expecting us to develop practical and affordable tools for site-specific nitrogen management through sprinkler irrigation systems. However, currently there are no practical decision making tools or equipment available for variable-rate application of nitrogen through center pivot irrigation systems, the predominantly adopted irrigation system in South Carolina.

The objectives of this study were a) to develop and test technologies for a sensor-based, variable-rate nutrient management program for overhead sprinkler irrigation systems, to provide site-specific application of fertilizers only where needed within individual fields; b) to adapt Clemson sensor-based nitrogen recommendation algorithm from single side-dress application to multiple split-applications through a center pivot in cotton production.

Materials and Methods

The test field was equipped with a 250-ft long linear-move irrigation system, which was modified to apply variable-rate nitrogen (VRN) with low energy precision application (LEPA) drops. The irrigation system was also capable of applying water site-specifically (variable-rate) to different part of the field based on a prescription map (Han et al., 2009).

A special trailer was designed to carry the fertilizer tank and pump alongside of the irrigation system (Figure 1-A). One side of this trailer was supported using two wheels, while the other side was attached to the irrigation system using two heavy duty hinges, which allowed the trailer to pivot when moving on uneven ground with respect to the lateral system. The fertilizer injection system consisted of a 330-gal tank; a roller pump (Hypro Pumps, New Brighton, MN) that was powered by an electric motor (Leeson Electric, Grafton, WI); and electronic control system. The roller pump was rotated using chains and gears to set the proper RPM of the system.

The irrigation system was divided into 10 zones with four irrigation drops in each zone. The N application rate of these zones could be controlled independently. Nitrogen was distributed to 10 manifolds through a 0.75-in PVC pipe that spans the length of the irrigation system. Ten normally closed, 3-way, 24V electric solenoid valves were used to control N rates. Each solenoid valve was attached to a manifold with four outlets (Figure 1-B), which injected nitrogen into four irrigation drop nozzles. Therefore, each solenoid covered 8 rows of cotton.

The variable-rate nitrogen application system uses the pulse system described by Perry et al. (2003), which cycle individual or groups of N injection solenoid valves OFF and ON, to achieve desired fertilizer rates within each management zone. With this arrangement, it was difficult to keep the line pressure constant, while injection nozzles were pulsing. Therefore, a 30-gallon bladder tank (WaterWorker) was installed between the pump and the main N line, which kept nitrogen pressure constant throughout the irrigation system. A pressure cut-off switch was also installed at the pump to shut off the motor when line pressure exceeded 60 psi, and turn the pump back on when pressure dropped below 50 psi. Also, a flow divider (Prince Hydraulics, North Sioux City, SD) was installed between the bladder tank and the main nitrogen line, which made it possible to increase or decrease maximum nitrogen rate throughout the system sending any excess flow back to the tank. A pressure gauge was installed after the flow divider to monitor system pressure.

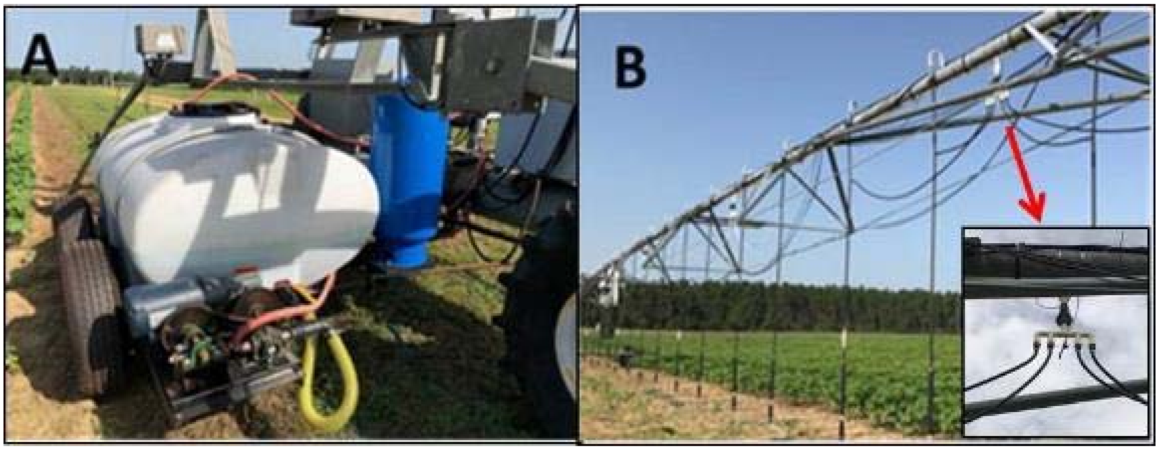

Figure 1: Fertilizer tank and trailer (A) and nitrogen injection manifolds (B).

The electrical signals, sent to the solenoids to inject N, were controlled by a solid-state relay board (SSR-RACK24, Measurement Computing, Middleboro, MA, Fig. 2) with AC-switch solid-state relays (SSR-OAC-05, Measurement Computing). A laptop computer, equipped with a data acquisition and control adaptor (MiniLab-1008, Measurement Computing), was used to control 24 lines of digital output to the solid-state relay board. A GPS antenna was installed on top of the lateral and was connected to a receiver (AgGPS, Trimble Navigation Limited, Sunnydale, CA) mounted inside a weatherproof box. A set of custom software, previously developed to support the Clemson variable-rate lateral irrigation system (Han et al., 2009), was modified to use for the VRN application system. The first software (Field Configuration Utility) collects the field information, including the length and width of the field, its GPS coordinates and the orientation of the lateral, number of nitrogen control sections and zones. The second software (Clemson Lateral Nitrogen Control), utilizes the nitrogen application map prescribed by the "Field Configuration Utility" and actually controls the variable-rate N application system.

Figure 2: Variable-rate nitrogen control system (GPS receiver; control PC; and solid-state relay board).

Tests were conducted to determine the uniformity of the variable-rate nitrogen application system. The first test was to evaluate the system's uniformity across the width of the irrigation system (250 ft.). The Quadspray nozzles were removed from each irrigation drop, and a 0.75 gal the bottles were installed at the end of drop, using custom designed bottle caps, mounted at the end of each drop (Figure 3). The tests were repeated four times using four N rates (28, 52, 78, and 100 lbs. /acre). The second test was performed to ensure that the nozzle-pulsing technique produced the desired amount of nitrogen. Tests were run for 100%, 75%, 50%, and 25% nozzle ON times based on a 60-s on/off cycle. For example, at 25% rate, nozzles would pulse 15 s ON and 45 s OFF. As the nozzles were pulsed on and off, samples were collected from all drops (for 10 ft.) along the direction of the irrigation system's movement. These tests we repeated five times.

The 4-acre test field was divided into two management zones, based-on soil EC data and each zone then was divided into 60-ft by 8-row plots. Replicated tests were conducted during 2016 and 2017 growing seasons, to develop guidelines for adapting the Clemson sensor-based nitrogen recommendation algorithms from single side-dress application to multiple split-applications through a center pivot irrigation system. For this purpose, the following six N treatments were replicated 7 times in plots of each management zones, using a randomized complete block arrangement:

1. One side dress N application based-on optical sensor data (NDVI).
2. Two side dress N applications based-on optical sensor data (NDVI).
3. Three side dress N applications based-on optical sensor data (NDVI).
4. Four side dress N applications based-on optical sensor data (NDVI).
5. Farmer method (90 lbs. N/acre dry land recommendation).
6. Farmer method (120 lbs. N/acre irrigated recommendation).

Cotton (DP-1646-B2XF) was planted around Mid-May and Temik 15G, (5 lbs./acre) was applied at planting for controlling nematodes and thrips. Cotton was carried to yield using recommended practices for fertilization and insect and weed control. A Nitrogen Rich Strip (NRS) 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. A nitrogen Rich Strip (NRS) was established in each management zone and was used as a guideline for calculating the side-dress N requirements based on sensor data. For treatments 1 to 4, a commercially available optical sensor, the GreenSeeker® RT-200 mapping system (Trimble Inc., Sunnyvale, CA, USA), was utilized to measure cotton plant's NDVI, from test plots and the NRS, before each side-dress N applications. The Clemson N calculator for cotton (http://www.clemsonnitrogencalculator.com/) was used to calculate N rates for each treatment. Plant data (biomass, leaf nitrogen contents, boll counts, and plant height) were measured during the growing seasons. The crop was harvested with a 4-row cotton picker, equipped with weighing baskets for each row around Mid-October.

Figure 3: Uniformity tests sample collection apparatus.

Results and Discussion

Figure 4 shows system uniformity for four selected nitrogen rates of 28, 52, 78, and 100 lbs. /acre. Application rates were adjusted by changing the speed of the irrigation system. As shown in Figure 4, the max application error was 9% for 52 lbs. /acre nitrogen rate. Surprisingly, the average error for all rates was 0%.

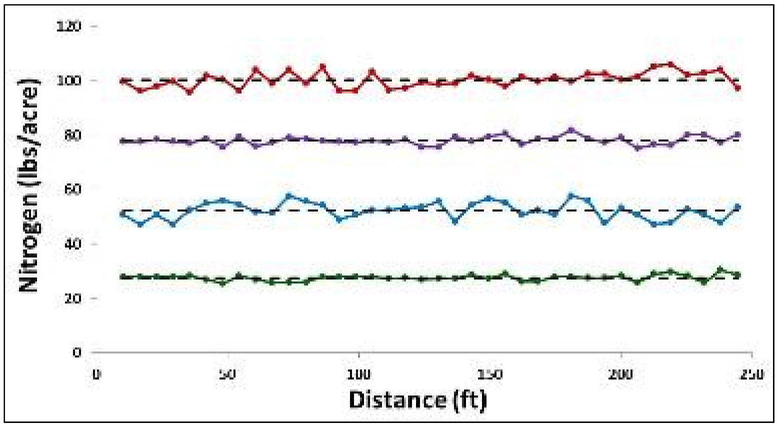

Figure 4: Application uniformity across the width of the irrigation system.

Figure 5-left shows individual nozzle output at different pulsing rates. The nozzles produced an average N rates of 25, 50, 75, and 100 lbs./acre for 25%, 50%, 75%, and 100% of nozzle ON time, respectively. Errors for each nozzle output were calculated by subtracting the measured value (actual) from the target value then divided by the target values. The average nitrogen application rate error was less than 1.8% for all rates, with maximum absolute error of 5%. There was a strong correlation (R^2 = 0.9996) between the target and actual nitrogen application rates (Figure 5-right).

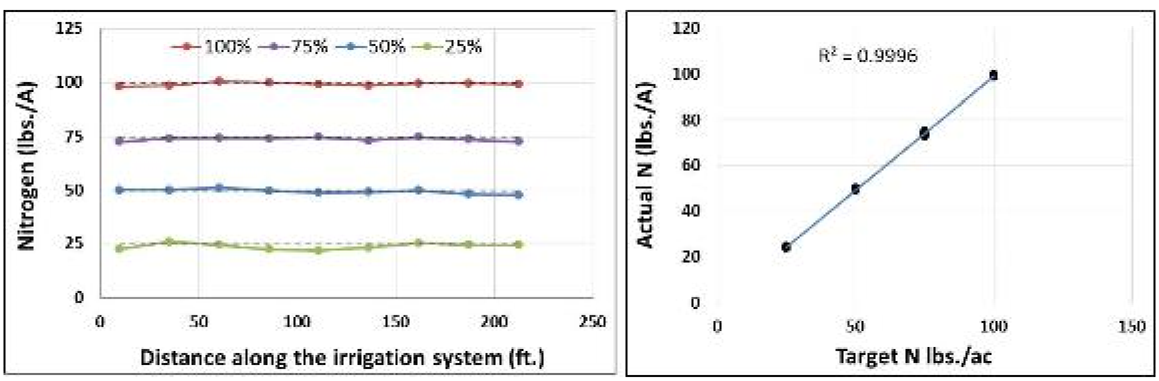

Figure 5: Application uniformity along the direction of lateral irrigation movement (left) and target vs. actual N rates (Right).

Figure 6 shows the effects of nitrogen application system on N requirement (Left) and cotton lint yields (right), for 2016 growing season. There was no difference in cotton yields between 90 and 120 lbs. /acre nitrogen applications in either management zone. There were no differences in yield between sensor-based and conventional nitrogen management techniques. Applying N in 3 or 4 split-applications, statistically increased yields compared to single or split side-dress applications. The average cotton lint yields were 1,039 and 927 lbs. /acre, for multiple applications and single or split applications, respectively. Averaged over 4 treatments, sensor-based nitrogen applications reduced fertilizer requirement by 69% compared to growers' conventional method (90 vs. 28 lbs. /acre). Also, multiple (3 or 4) applications, increased N rates by 20 lbs./acre compared to single or split side-dress applications, but increased the seed cotton yields by 243 lbs./acre.

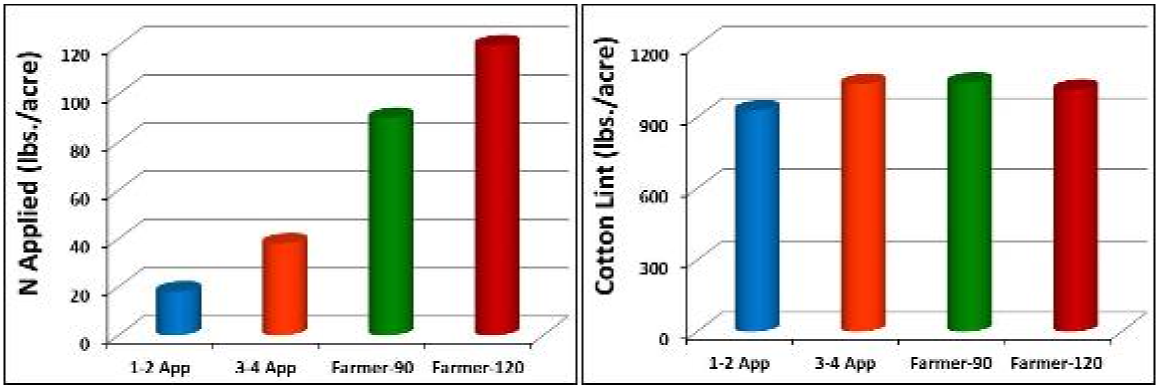

Figure 6: Effects of nitrogen application system on N requirement (Left) and cotton lint yields (right), 2016.

Similar results were obtained in 2017 (Figure 7). Again, there was no difference in cotton yields between 90 and 120 lbs. /acre nitrogen applications in either management zone. There were no differences in yield between sensor-based and conventional nitrogen management techniques. Applying N in 4 split-applications, statistically increased yields compared to single, split, or three side-dress applications. The average cotton lint yields were 1,154 and 957 lbs. /acre, for four and single application, respectively. Averaged over 4 treatments, sensor-based nitrogen applications reduced fertilizer requirement by 57% compared to growers' conventional method (90 vs. 38 lbs. /acre). Also, multiple (3 or 4) applications, increased N rates by 23 lbs./acre compared to single or split side-dress applications, but increased the cotton lint yields by 124 lbs./acre.

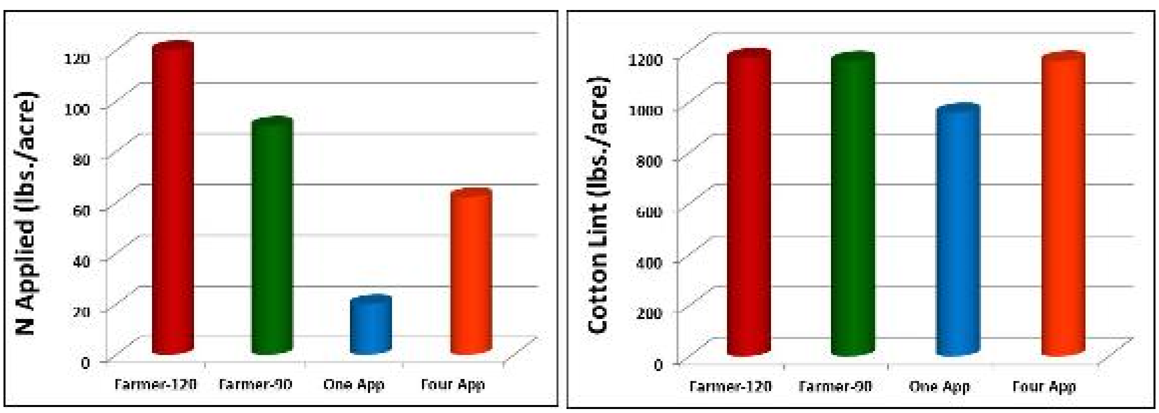

Figure 7: Effects of nitrogen application system on N requirement (Left) and cotton lint yields (right), 2017.

Summary

A 250-ft long linear-move irrigation system was modified to apply variable-rate nitrogen (VRN) with low energy precision application (LEPA) drops. A special trailer was designed to carry the fertilizer tank and pump alongside of the irrigation system. The fertilizer injection system consisted of a nitrogen tank; a roller pump, and electronic control system. The VRN application system uses the pulse system, which cycle individual or groups of N injection solenoid valves OFF and ON, to achieve desired fertilizer rates within each management zone. The electrical signals, sent to the solenoids to inject N, were controlled by a solid-state relay board with AC-switch solid-state relays. A laptop computer, equipped with a data acquisition and control adaptor, was used to control 24 lines of digital output to the solid-state relay board. A GPS antenna was installed on top of the lateral and was connected to a receiver mounted inside a weatherproof box. A set of custom software, previously developed to support the Clemson variable-rate lateral irrigation system, was modified to use for the VRN application system. Replicated tests were conducted during 2016 and 2017 growing seasons, to develop guidelines for adapting the Clemson sensor-based nitrogen recommendation algorithms from single side-dress application to multiple split-applications through a center pivot irrigation system.

The results showed that the VRN system performed satisfactory with an average application rate error of less than 1.8% for all N rates. There was a strong correlation ($R^2 = 0.9996$) between the target and actual nitrogen application rates. There was no difference in cotton yields between 90 and 120 lbs. /acre nitrogen applications in either management zone. There were no differences in yield between sensor-based and conventional nitrogen management techniques. Applying N in 3 or 4 applications, statistically increased yields compared to single or split side-dress applications in both 2016 and 2017. Averaged over 4 treatments, sensor-based nitrogen applications reduced fertilizer requirement by 69% in 2016 and 57% in 2017, compared to growers' conventional method. Also, multiple (3 or 4) applications, increased N rates by 20 lbs./acre in 2016 and 23 lbs./acre in 2017 compared to single or split side-dress applications, but increased the cotton lint yields by 243 and 124 lbs./acre, for 2016 and 2017, respectively.

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