The Use of Crop Sensors and Variable Rate Technology for Precision Application of Nitrogen to Cotton

A Research Paper Presented for the Master of Science in Agriculture and Natural Resources Degree at The University of Tennessee Martin

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Abstract

The management of nitrogen (N) in the production of cotton (*Gossypium hirsutum* L.) is one of the most important factors producers must consider during the growing season. The under-application of N can result in stunted plants, lower boll production and reduced yield. Too much N applied to a cotton crop under good growing conditions can encourage excessive vegetative growth, restrict boll production, and cause the loss of unused N into the environment. The use of optical crop sensors and normalized difference vegetation index (NDVI) to determine plant health and growth gives producers options to consider when applying N. Environmental conditions and yield potential must also be considered. NDVI readings are used as an input in a N rate algorithm, which matches NDVI ranges with N rates. When combined with a variable rate fertilizer spray system, NDVI algorithms give producers the ability to make an on-the-go N application at early bloom. Such mid-season N applications maintain or increase cotton lint yields by matching crop need and potential with the correct N rate. In this research project, the crop sensor N rate was compared to the farmer’s standard N rate to determine how well it performed. The initial N application was sidedressed and the mid-season application was dribbled. Harvest data was collected with a John Deere cotton picker equipped with a yield monitor. At two of the locations, the crop sensor treatments applied less N and produced equal or greater yields. At one location, the crop sensors improved yield but used twice as much N. The greater the amount of soil variability present in a cotton field, the better the crop sensors can accurately match a crop’s N needs to the correct area of the field. Merging NDVI, past yield history, current seasonal conditions, and yield potential into an on-the-go application of N at early bloom gives producers flexibility and increases efficiency in managing N.
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Chapter 1. Introduction

Nitrogen (N) is a major nutrient in cotton (*Gossypium hirsute* L.) production and one of the most difficult nutrients for producers to manage. Numerous conditions contribute to variability in the temporal use and spatial response of nitrogen. Nitrogen is used to fuel plant growth and directly affects yield. Efficient management of the N used by a cotton crop is difficult to predict and implement. The amount of N being used by a cotton crop varies according to the growth stage of the crop. Environmental conditions during the growing season influence how much N is available, needed, and used at a particular time (National Cotton Council, nd.). Soil moisture and temperature control how well and at what speed a cotton crop develops. In-season monitoring of the crop during the growing season can help producers formulate plans for N needs and timing of applications. This intensive management can help producers match N input to yield potential according to the season (Chua et al., 2003). Soil variability within fields adds another dimension to the equation, because each individual soil type or texture zone can respond differently to environmental conditions. The greater the amount of soil variability, the harder it is for a producer to apply the correct amount of N for a specific part of the field. Spatial variability adds to the difficulty in managing N use and timing for a particular cropping season (Scharf et al., 2002).

Another limiting factor is timeliness. This is the ability of a producer to make a N application at the right time during the growing season. Timeliness can be limited by equipment, labor or inclement weather. A limiting factor can be the number of days that a N application can be made at a particular growth stage. The type of application equipment that producers have influences their ability to make N applications in a timely manner. In a field containing different
soil types or textures, variable rate application equipment is needed to be able to change N rates according to those factors.

Changing environmental conditions during the growing season also have to be considered by producers when managing N. Natural rainfall patterns during a cropping season can cause problems with a N management plan. Extended periods of wet weather may cause losses due to leaching, runoff, or denitrification, while dry weather may slow or halt plant growth, inhibiting N uptake (MSUCares, 2010). Temperature during the growing season is an additional weather factor that influences crop growth. Cool temperatures can slow plant growth and excessively high temperatures can cause a plant to use more resources trying to prevent overheating. Irrigation can alleviate the stress from low moisture availability, but not all fields are irrigated and irrigation management has to be considered in a N management plan.

The common practice for N application by producers is to make a single application to the cotton crop early in the growing season (Scharf and Lory, 2006). This application contains the entire amount of N that the producer feels the cotton crop will need to make the maximum yield under normal growing conditions. After periods of excessive rainfall, producers may apply additional N to offset any possible losses due to leaching or runoff. During extremely dry periods, excess N may remain in the soil and be taken up after moisture becomes available and create problems with excessive growth at the wrong time of the season. Another factor not taken into account by producers is the amount of residual soil N present (Gantz, 2007). Residual N can vary from year to year based on environmental conditions and crop rotations. The amount of N applied to the previous crop the year before can influence the amount of N needed to produce maximum yields in the following cotton crop (Boquet et al., 2009). These factors are usually not taken into consideration when determining the N application rate on a field of cotton. The
efficiency and amount of the N applied and/or available during the growing season for a cotton crop can vary widely from year to year.

There are two more factors that can have an influence on a producer’s N management plan: yield potential and economics. If a producer has been farming a particular field or soil type for many seasons he/she has a good idea of the range of yield potential. While extremely low or high yields can occur, producers generally have a target yield in mind before the season begins. This target yield is subject to change as the growing season progresses and the crop reacts to growing conditions. It is also tied to economics, both production costs and potential revenue. Producers have to try to balance expenses to reach a certain yield goal, while being able to react to any extremes; this can make N management very difficult.

Over-application of N by producers occurs often because of the potential of N to limit crop yield and the type of application equipment that is most common and readily available. Any new tools, including practices or technology, that can assist producers with N management, a critical crop production decision, can be of enormous value to them.

**Research Objectives**

The objective of this research project was to facilitate the movement of the research findings and techniques using NDVI crop sensors to apply N at the early bloom stage from the agricultural research station to a commercial cotton field. The basic foundation research that was used to develop the LSU Cotton Nitrogen Algorithm was done at the Macon Ridge and Northeast Research Stations in Northeast Louisiana. The algorithm was established from the data gathered from small plot research conducted by Dr. Brenda Tubana, a soil fertility scientist with the LSU AgCenter, over a period of three years. All data being gathered from continuing on-going research and demonstration plots is used to update the algorithm.
Another goal of this project was to determine how a producer can manage N application to a cotton crop to maximize efficiency and returns. For producers to readily adapt this N management practice, the application has to be made in real time. The applicator has to be equipped with crop sensors and a field computer that can interpret the results and apply a corresponding N rate as the applicator travels across the field. This type of application is known as an on-the-go application. Using this method eliminates any time delay between crop sensing and the actual N application. Time for field operations is always at a premium for producers and making an early bloom N application on-the-go increases their efficiency and the probability that the application method might be adopted by them. The decision of when a field actually reaches early bloom has to be made with the consideration of getting the N application made without being too late for the plants to get the most benefit.

Split applications of N have always been recommended as a management option but the application method has varied between producers (MSUcares, 2010). An objective of this research project was to make this N management strategy practical for Louisiana cotton growers. For producers to adopt a new N management plan a basic application procedure had to be developed that used the production equipment that producers had or was readily available. This project was initiated in 2012 and modified in 2013. This objective was very important because if producers cannot merge the application methods and procedures easily into their production operations, they will be reluctant to use them as a part of their N management plan.
Chapter 2. Literature Review

Nitrogen and Cotton Growth

Nitrogen is a key nutrient that plants use for growth and reproduction. The amount of N used by cotton is dictated by growth stage. During the early season vegetative growth stages, the cotton plants use little N. Beginning about 40 days after planting, N use begins to rise as the cotton plants begin the reproductive stages at first square. This increase continues until about 100 days after planting when the bolls begin opening (Ayala and Doerge, 2001).

Sidedress N applications are the most economical methods of supplying a cotton crop. The initial application of N to a cotton crop should be made early in the growing season to avoid N deficiencies, which cause yield loss. A producer should consider a yield goal to determine the total amount of N that will be applied. Cotton uses 0.22 kilogram (kg) (0.1 pound (lb)) of N per kg (lb) of lint produced (Livingston and Stichler, 1995). For optimum N management, split applications give the most efficient N use by a cotton crop. Applying the amount of N needed by a cotton crop at the growth stage when it can be used makes this method of N management more efficient than single applications (Ayala and Doerge, 2001). Split applications also lower the risk of N loss due to leaching or denitrification.

The N cycle starts when N fertilizer is applied as ammonia or nitrate to the soil for a crop. Part of the N is converted to nitrite and is not available for the plants. Part of it is susceptible to losses from runoff, leaching or denitrification. Leaching is the mixing of N in the soil solution and its loss through downward movement into the soil profile. Denitrification is the conversion of N into a gas and its loss from the soil into the air (MSUcares, 2010). Nitrogen not lost to the environment is readily available to be used by the crop. The longer unused N remains in the soil,
the higher the chances that it will be unavailable as nitrite or lost from the soil profile (O’Leary et al., 1994).

Producers make management decisions on N rates according to several factors. The first is application timing: all N applied at one time or in split applications. The other factors include a yield goal and soil type. How much N is required for a particular soil type to produce a particular yield? The degree of management and input levels can influence the yield goal. Is the producer’s management style high or low input? Is the field irrigated or not? Is the rest of the field’s fertility balanced with the crop needs for the yield goal? All of these factors affect the amount and timing of nitrogen fertilizer applications (Snyder, 2006).

Environmental Concerns and Economics

Nitrogen use by producers has become a focal point for environmental groups in recent years. Available soil N along with applied N can be in excess of what a crop can use efficiently and effectively during a growing season. Even though production methods have evolved and crop management has intensified, approximately 50% of the N applied during the growing season is not used (Wiesler et al., 2001). The potential for N leaching into groundwater and runoff is one of the major concerns of environmental groups. Legal action has been taken to try and regulate the amount of N present in water bodies (National Cotton Council, 2012). The outcome of legal cases could potentially have an impact on future N use by producers with respect to the amount and timing of fertilizer applications not only on cotton but on all crops that use supplemental N.

Another factor linked with the amount and timing of N applications is fertilizer cost. A common blend of N fertilizer applied today is 30-0-0-2, a mix of 30% N, 0% phosphorus, 0% potassium and 2% sulfur in a liquid state, which costs about $1.27 per kg ($0.57 per lb) of N
University recommendations vary from state to state but, in general, 22.7 to 36.4 kg (50 to 80 lbs) of N is required to produce 1 bale of cotton (MSUcares, 2010). Therefore, the cost of N to produce 1 bale of cotton ranges from $28.83 to $46.23 (2013). The input cost of N has a significant effect on a producer’s profitability. Matching potential yield to the sufficient N rate is crucial. The use of management zones and crop sensors may not reduce the total amount of N applied to a field, but matching N rates to the parts of the field where the highest returns can be made will increase overall profitability.

The standard early season application of the entire N requirement exposes it to losses by leaching, runoff, or volatilization. Leaching is the loss of N dissolved in water down into the soil profile (Johnson et al., 2005). Volatilization is the conversion of N to a gas, which is lost into the air. Nitrogen use by cotton plants early in the season is limited because of small root systems. As a more extensive root system is developed and the plants began to fruit, N use rises with peak use at approximately 100 days after planting (Ayala and Doerge, 2001). Applying N in two separate applications allows the producer to adjust the amount of N applied to the crop according to the potential yield for that year. Approximately one-half of the anticipated N is applied during the early vegetative stages. This initial N application will fuel plant growth until early bloom when the need for additional N will increase as plants begin the reproductive phase of growth. The second N application is usually applied as a granular or a liquid dribble. Both application methods require the addition of a urease inhibitor to stabilize the N and rainfall or irrigation to incorporate into the soil. The urease inhibitor contains a substrate for the biological enzyme that converts urea to ammonia leading to potential loss through denitrification. This inhibitor can slow down or stop the conversion process (Mullen and Lentz, 2011). Better N efficiency correlates to higher profitability for producers.
The Application Process

Traditionally, producers have applied N to cotton using a side-dress application rig, which injects the liquid carrier into the soil next to the crop row to minimize losses due to volatilization (MSUcares, 2010). Producers apply a single rate across the entire field regardless of soil type, irrigation, or other factors. The first step to improve N use efficiency beyond a single application rate is the division of fields into management zones. The establishment of zones can be based on one or several overlapping factors, including USDA digital soil maps, soil electrical conductivity, irrigation, and elevation. The use of different factors to establish management zones reflects how their interaction affects the productivity of the field (Terra et al., 2006). Combining these factors in the management zones makes possible a more complete analysis of yield data. Producers can compare the analysis of how different treatments respond over the whole field and by management zone.

The development of management zones was possible with the use of a global positioning system (GPS), which uses a signal from satellites to locate and fix the equipment’s position in the field. Geographic information service (GIS) software is used to create spatial areas in a field that became the management zones. Nitrogen rates or other production inputs could be assigned to these zones for application to the field (Roberts et al., 2006). The next piece of needed equipment is a variable rate controller. A variable rate controller uses management zone information, GPS location, and speed to control the actual application for a specific rate of fertilizer. Changes in the applicator speed can change the actual applied rate, and the controller adjusts continuously to maintain the target rate. Yield monitors on harvest equipment give producers another option in creating management zones. Yield data could be collected and analyzed to create management zones according to yield potential (Roberts et al., 2006).
Regardless of the technique used, each management zone can be assigned a N rate and, using a variable rate controller, the producer can make a site-specific N application. While this is a better choice than making a single application of the total season’s N, it could still result in the over or under application of N with regard to how the growing season progresses.

**Equipment Required for Precision Agriculture**

The continuing advancement of precision agriculture technology and equipment has made it possible to scan a plant at a specified growth stage, determine the plant’s health and vigor, calculate a N rate, and deliver it as the application equipment passes over the field. This is known as an on-the-go application and it facilitates better crop stage application timing and increases application cost efficiency (Luccio, 2013). The crop sensors that scan the crop and deliver a reading to a field computer are the third part of the equipment needed for site specific on-the-go applications. Crop sensors use reflected light to measure normalized difference vegetation index (NDVI) (Taylor and Fulton, 2010). NDVI is an index that is a measure of plant biomass, an indicator of plant health, based on the spectral reflectance. Knowing the health of a crop in the field helps a producer estimate the possible yield potential.

The NDVI reference number is determined by using a N calibration ramp strip located in the field. The N calibration ramp strip is a fertilizer strip containing a range of N rates that are applied while the cotton is still small (Bronson et al., 2012). These strips are scanned by the crop sensor and two readings are taken as part of the calibration process. For each N rate, the maximum and minimum NDVI readings are recorded and averaged. These readings are entered into an algorithm to determine target application rates for N based on the NDVI index. N is applied by a variable rate controlled applicator as it passes through the field (Roberson, 2009). Numerous algorithms have been developed for several crops, such as corn (*Zea mays*), wheat
"Triticum aestivum" and cotton (Lukina et al., 2001). The field computer contains software that can use the data produced by an algorithm to determine a target rate for application. The target rate is sent to a variable rate controller for the actual application. This type of site specific application, in which the correct amount of N needed is applied and placed correctly in the field, increases crop use efficiency and optimizes potential yield based on how the plant has developed during the growing season.

Continuing advances in precision agriculture technology and equipment has allowed researchers to explore and develop production practices for managing N use more efficiently. These practices include mid-season N applications at a specific growth stage when the cotton plants are able to utilize the additional N. Agricultural researchers have worked to determine the correct growth stage for a mid-season N application. For cotton it is at seven weeks after planting (Griffin, 2010). The highest yield response can be gained from additional N applications at these specific growth stages.

Producers have difficulty with a mid-season application when trying to use conventional side-dress equipment. In the early season, this equipment does not affect the cotton or cause any damage during normal operation. At mid-season, the cotton is too large to get conventional equipment through the field without causing unnecessary mechanical damage to the cotton. One solution for this problem is to use a high-clearance sprayer equipped with nozzles specifically designed for fertilizer applications. The fertilizer is dribbled on the ground between the cotton rows using two nozzles per row middle. To alleviate losses from N volatilization, a urease inhibitor is added to the fertilizer before application. The inhibitor restricts soil microbial activity on the N fertilizer and reduces losses without affecting N availability to the crop (Singh and Verma, 2007).
There has been extensive research on mid-season N applications using crop sensors in wheat, corn, and cotton (Lukina et al., 2007; Raun et al., 2002; Vellidis et al., 2011). The calibration ramp method for determining crop health is an integral part of the algorithm that determines the optimum N rate to be applied (Raun et al., 2008). This research has proven its use and has become standard practice in some regions of the United States. Algorithms have been developed to determine the correct N rate to be applied at mid-season for maximum yield based on the crop conditions and yield goals. Several universities have developed algorithms for N rate calculations that take into account local conditions along with local yield goals (Thomason et al., 2011).

The development and implementation of crop sensors for monitoring crop health during the season has a large impact on the management of inputs. These inputs include not only N use, but also irrigation timing (Bajwa and Vories, 2007), and use of plant growth regulators (Schrimpf, 2008). Both of these inputs correlate with N rates, especially if the rate is excessive in relation to growing season conditions. Crop sensing technology can also be used to determine maturity (Gwathmey et al., 2010). This type of use will grow as producers learn more about using it.

**On-Farm Demonstration and Research Trials**

The transfer of research to production agricultural operations is the goal of agricultural scientists. Participating in on-farm trials and demonstrations gives producers the ideal stage for doing this. Large on-farm trials take place under conditions that have greater variability than small research plots and give scientists additional information that can be used to refine production methods. Demonstration trials give producers hands-on experience with what the research scientists have been developing (Hancock, 1997). On-farm demonstration trials also
serve to promote the technology involved with on-the-go application. Producers cooperate and use their side-dress equipment for the initial N side-dress application. Harvest is conducted by the producers using their equipment, which is outfitted with yield monitors. Producers who already have yield monitors and variable rate application equipment are prime candidates for integrating crop sensor technology into their crop production methods. For producers who have some precision agriculture equipment and experience, a demonstration trial is a stepping stone to the next level. Producers get the opportunity to observe the crop sensors working and how they interact with the variable rate controllers in large field situations. These producers are often already using technology and precision agriculture techniques in their present operations (Larson et al., 2008). Presentations given on the methods and results of these trials through field day tours, newspaper articles, and talks at local and regional meetings expand producers’ interest in the technology and methods.

**Cotton Production in Tensas Parish**

Cotton is an important crop to the economy of Tensas Parish, LA. There are three cotton gins and a cotton warehouse located in the parish. The gins are owned by local farmers and the warehouse is owned by the cotton gins. Cotton acreage has dropped significantly in Louisiana since 2000 and Tensas has been the largest cotton producing parish in Louisiana since 2001. Cotton has remained an integral part of the crop mix in Tensas even though corn and soybean acreage was greater than cotton acreage in 2013 (LSU Agcenter, 2000, 2001, 2013).

One reason that cotton remains a viable crop for Tensas producers is its growth nature. Cotton is a perennial which is grown as an annual: it has a lot of flexibility in its ability to compensate for poor or good growing conditions (Wright et al., 2011). Cotton can survive during bad growing conditions and then respond if conditions improve. Cotton can have a
positive response to irrigation but can also produce an excellent yield under dryland conditions (Burns and Blanche, 2012). This ability gives cotton an advantage over corn or soybeans on non-irrigated heavy clay soils.

The Louisiana State University Agricultural Center has developed management practices and guidelines for producing a cotton crop. These guidelines cover a variety of input practices such as variety information and fertilizer rates. The recommended fertilizer rates vary according to soil type. On silt loam soils, the recommendation is 67 to 101 kilograms of N per hectare; on clay soils, 101 to 134 kilograms of N per hectare are recommended (Lofton et al., 2014). Cotton varieties have been developed that contain genes for Lepidoptera control and herbicide tolerance. Some varieties are tolerant to glyphosate and glufosinate herbicides (Myers et al., 2014).

The majority of the cotton in Tensas Parish is produced using minimum tillage with some conventional tillage every year. Significant yield losses can be caused by several insects, including tarnished plant bugs, spider mites, budworms and bollworms (Roberson, 2014). Herbicide resistant weeds, such as palmer amaranth and Italian ryegrass, have caused producers to modify their herbicides programs to control these weeds (Schultz, 2013).

Improved varieties have been responsible for a steady increase in average cotton yields in Tensas Parish. In 2008 the parish average yield was 784 pounds per acre and in 2013 it was 1392 pounds. Traditionally a bale of cotton was considered to weigh 500 pounds but the USDA defines a standard bale of upland cotton as 480 pounds. Since 2008, yields have risen more than 1 bale per acre (LSU AgCenter, 2008, 2013).
Chapter 3. Materials and Methods

In 2012, a trial working with mid-season N application using crop sensors on cotton was initiated in Tensas Parish, Louisiana (Figure 1). Tensas Parish (County) is located in Northeast Louisiana and is bordered on the east by the Mississippi River. The parish is made up of highly fertile alluvial soils. These soils range in type from light silt loams to heavy clays. There is also some variation in soil texture within a soil type. Cotton and corn are two of the major crops grown in Tensas Parish. These crops are normally grown in a one year rotation and the use of N on both crops has created speculation as to how much N is being carried over from year to year and how this affects the following crop. Preplant N analysis of soil samples in the trial fields in both 2012 and 2013 showed available residual N levels that ranged from 0 to 30 lbs across the trial fields.

The cooperating producers for these trials were Hardwick Planting Company on Somerset Plantation in Newellton, Balmoral Planting Company on Crimea Plantation in St. Joseph, and Crigler Farms on Sunnyside Plantation in St. Joseph (Figure 2). The trial locations

Figure 1. The location of Tensas Parish in Louisiana.  
Figure 2. NDVI trial locations and soil types for Tensas Parish in 2013.
on these farms represented the different soil types that are present in Tensas Parish. In 2013, two of the three locations were irrigated, Crigler by center pivot and Hardwick by furrow. The non-irrigated site, Panola, was also the least variable in soil type and texture of the three locations.

The trial had three treatments in 2012; only two treatments were used in 2013. Treatment 1 was the Farmer Standard (FS). This is the normal rate of N that the individual cooperating producer would use in the trial field. The producer sidedressed the cotton crop with 100% of the N rate before the cotton was 6 inches tall. Treatment 2 (CS), was one-half of the Farmer Standard rate sidedressed at the same time as FS plus additional N applied using the crop sensors at early bloom. Treatment 3 was CS plus 34 kg/ha (30 lbs/ac) of additional N applied as a prescription in potentially higher yielding parts of the field. These areas were defined by Deep Electrical Conductivity (Ec) zones or management zones from previous years’ cotton yield maps. Ec is the measurement of an electrical charge that travels through the soil. The electrical charge is transmitted through the soil texture zones at different rates allowing them to be delineated into separate Ec zones. There are two depths in which Ec zones can be defined: the shallow, which is 0 to 30.5 cm (0 to 12 inches), and the deep, which is 0 to 40.3 cm (0 to 36 inches). In 2012, Treatment 3 was applied at all three locations but it produced the lowest lint yields at all the locations. Based on the results from 2012, FS and CS were the only treatments applied in 2013.

The sidedress applications were done with coulter rigs (Figure 3) which injected a liquid solution of 30-0-0-2 into the soil approximately 15.2 cm (6 inches) away from the cotton plants. Both the full rate and the half rate treatment applications were done by the producers with their equipment according to their own schedules.

The early bloom N application was done with a high-clearance sprayer using a variable rate spray system and Trimble Greenseeker NDVI sensors. NDVI readings and the LSU Cotton
Nitrogen Algorithm were used to determine the N rate to apply to the cotton crop at the early bloom stage. NDVI readings by the Trimble Greenseekers are taken at a specific height range (Figure 4) above the cotton crop: 61 to 122 cm (24 to 36 inches). A key component of using the Greenseekers to determine N rate was the N calibration strips that were placed in the fields at the time of the sidedress application. These were two 6 row strips of different N rates that included 56, 112, and 168 kg/ha (50, 100 and 150 lbs/acre). The N rates were applied in segments at least 30.5 meters (100 feet) long (Figure 5). The purpose of the calibration strips is to determine the maximum NDVI reading of the cotton. A variety of N rates is used because the maximum NDVI reading is not always in the highest N rate segment. The different segments are scattered across the length of the field to try and determine the maximum NDVI reading. The second NDVI
Figure 4. Adjusting the Greenseekers to the correct working height. From left to right, R.L. Frazier, Dennis Burns, and Dr. Brenda Tubana.

Figure 5. The calibration ramp for the Crigler trial site showing the 56, 112 and 168 kg/ha (50, 100 and 150 lbs/acre) strips.
reading required for calibration is the average of the half rate application, CS. This was obtained by sensing the full length of 6 rows of a CS plot (Figure 6). These two NDVI readings are required for the LSU Cotton Nitrogen Algorithm to be able to predict the N rates to be applied. The algorithm produces a range of NDVI values that correspond to different kilograms per hectare of N to be applied. N rate has to be converted from kilograms per hectare to liter per hectare for the variable rate spray system. The type of fertilizer applied to all the trial locations was 30-0-0-2, which weighed 1.3 kg/liter (10.85 lbs/gallon). The N rate in kilograms per hectare was divided by 0.39 kg/liter (3.26 lbs/gallon) of N to convert the N rate to liters per hectare.

The high clearance applicator’s spray system was controlled by a Trimble FMX Field computer. The NDVI value ranges were entered into the FMX along with the corresponding gallons per acre rate (Figure 7).

Figure 6. Taking Greenseeker NDVI calibration readings in corn in 2012.
The FMX Field computer controls the variable rate spray system allowing an on-the-go application to be made (Figure 8). The spray system was comprised of a hydraulically driven centrifugal pump, a flowmeter, a flow control valve, a boom control valve, and variable rate spray nozzles. The field computer received a NDVI reading from the Greenseekers (Figure 9) and matched that reading to a preset application rate. It sent a signal to the flow control valve to open or close depending on the target application rate. The flowmeter monitored the flow rate and sent that reading back to the field computer which adjusted the target application rate as it traveled through the field (Figure 10).
Figure 8. The high clearance sprayer applying an early bloom application at the Northeast Research Station in St. Joseph, L.A.

Figure 9. The high clearance sprayer and the mounted Greenseeker crop sensors used to apply an early bloom application of N to cotton.
Figure 10. FMX run screen showing NDVI and target rate for N application to cotton.

A key component in the application was the variable rate spray nozzles that actually delivered the solution (Figure 11). The nozzles used were Vari-Target by Spray Target (Figure 12). They are a variable rate nozzle with an application rate range of 0.57 to 5.68 L/minute (0.15 to 1.50 gallons/minute). At a travel speed of 8 km/h (5 miles/h), this gives the nozzle a range of 43.9 to 438.5 L/ha (4.69 to 46.9 gallons/acre) with a 96.5 cm (38 inch) nozzle spacing. This converts to a N rate range of 17.1 to 171.2 kg/ha (15.3 to 152.9 pounds/acre). Only one tip per row was used and the nozzle spacing was adjusted in the FMX to match the row spacing of the field equipment. Balmoral’s equipment had eighteen 96.5 cm (38 inch) rows, Crigler’s equipment had twelve 91.4 cm (38 inch) rows, and Hardwick’s had twelve 91.4 cm (36 inch) rows. Based on the 2012 and 2013 experience, further refinements will be done to enhance the application procedure for 2014 (Figure 13).
Figure 11. Drop tube and variable rate spray nozzle used in the N application.

Figure 12. Vari-Target (by Spray Target) variable rate nozzle assembly used in the N application.
Soil texture zones in the trial fields were defined through Veris Ec data taken after harvest. The Veris machine is a towable rig that sends an electrical current down into the soil through a pair of coulters; the electrical current is received by two other pair of coulters (Figure 14). The Veris Ec machine measures the electrical conductivity (Ec) of the soil. As a general rule the lower the Ec readings, the lighter (sandier) the soil; the higher the numbers, the heavier (more clay) the soil. The Ec readings are separated into two texture zones. The shallow Ec zone is the soil layer that is 0.0 to 30.5 cm (0 to 12 inches) deep. The deep Ec zone is the soil layer that is 0.0 to 91.4 cm (0 to 36 inches) deep (Figure 15). The soil zones are one way of developing management zones for crop production. The shallow Ec zone is generally used for standard soil sampling down to 6 inches. In Tensas Parish, the deep Ec zones are used for yield analysis because they can have a larger influence on crop growth than the shallow.
Figure 14. The Veris Ec machine used by the LSU AgCenter.

Figure 15. Veris Ec machine showing how readings are taken. Coulter 2 and 5 transmit the electrical charge into the soil. Coulters 3 and 4 receive it as the shallow Ec zone readings. Coulters 1 and 6 receive it as the deep Ec zone readings.
All cotton trials were harvested with John Deere 7760 Round Cotton Module Pickers equipped with yield monitors and data recording systems. All data including NDVI readings, N rate applications, soil, ec and yield maps were analyzed in ArcGis 10.1.

The data were analyzed by two different methods. One method used the Statistical Analysis System (SAS) to analyze the lint yield and N rate for each treatment. The locations were used as blocks within a randomized complete block design.

The other method used was to compare the lint yield means for each treatment at each location. Each location was considered independent of the others. The lint yield and the N rate from the CS (treatment 2) were subtracted from the FS (treatment 1) and the differences converted into dollar amounts per hectare. These results showed a different perspective than the comparison of actual lint yields and N. The average price in 2013 for N was $1.27 per kg ($0.58 per lb) and for cotton lint was $1.69 per kg ($0.77 per lb).
Chapter 4. Results

Weather 2013

In 2013, the weather in Tensas Parish was ideal for growing cotton (Table 1). The normal growing season for cotton runs from April 1st to September 30th, the time from planting to crop termination. The growing season started off with moderate temperatures and ample rainfall during the early growth period. During the blooming and boll setting period, temperatures remained stable with adequate rainfall. The month of August was hot and dry, perfect conditions for low disease pressure, boll maturation and boll opening. Consequently there were very little losses to boll rot or weathering.

Table 1. Weather data taken at the LSU AgCenter Northeast Research Station for a 5 month period in 2013.

<table>
<thead>
<tr>
<th>Month</th>
<th>Temperature</th>
<th>Total Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td>April</td>
<td>25 14</td>
<td>14.6</td>
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<tr>
<td>May</td>
<td>27 20</td>
<td>16.1</td>
</tr>
<tr>
<td>June</td>
<td>38 26</td>
<td>7.0</td>
</tr>
<tr>
<td>July</td>
<td>38 26</td>
<td>7.6</td>
</tr>
<tr>
<td>August</td>
<td>40 27</td>
<td>2.0</td>
</tr>
<tr>
<td>September</td>
<td>38 26</td>
<td>15.6</td>
</tr>
</tbody>
</table>
Balmoral 2013

The Balmoral location had one soil type, a heavy clay, with two deep Ec zones (Figure 16). The treatments were blocked in the field due to equipment requirements (Figure 17). There was a difference in the applied N rate of 6 kg/ha with FS having the overall highest N rate (Figures 18 and 19). The NDVI readings taken at early bloom (Figure 20) showed very little difference between the treatments (Table 2). Lint yield (Figure 21) analysis of the whole plot showed a difference between the two treatments of only 19 kg lint/ha with FS having the higher yield (Table 3). CS (Figure 21) had a net loss of $24.49 per hectare compared to FS (Table 4).

The analysis by deep ec zone showed that FS lint yield was 30 kg/ha in zone 1. In zone 2, CS had an increase of 100 kg/ha (Table 5). The N rate was 13 kg/ha less for CS in zone 1 but was the same for both treatments in zone 2 (Table 6). There were almost no differences between the NDVI readings in each zone (Table 7).

Figure 16. Deep Ec zones at Balmoral.  
Figure 17. Treatments at Balmoral.
Figure 18. Total N rate applied at Balmoral.

Figure 19. N applied by crop sensors at Balmoral at early bloom.

Figure 20. NDVI readings at early bloom at Balmoral.

Figure 21. Cotton lint yield at Balmoral.
Table 2. Whole plot treatment differences between N rate and lint yield.

<table>
<thead>
<tr>
<th>Location</th>
<th>Treatment</th>
<th>N rate</th>
<th>Lint yield</th>
<th>Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>kg/ha</td>
<td>kg/ha</td>
<td>N_rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>kg/ha</td>
</tr>
<tr>
<td>Balmoral</td>
<td>FS(^1)</td>
<td>146</td>
<td>1851</td>
<td>---</td>
</tr>
<tr>
<td>Balmoral</td>
<td>CS(^2)</td>
<td>140</td>
<td>1832</td>
<td>(6)</td>
</tr>
<tr>
<td>Crigler</td>
<td>FS</td>
<td>112</td>
<td>1985</td>
<td>---</td>
</tr>
<tr>
<td>Crigler</td>
<td>CS</td>
<td>99</td>
<td>2018</td>
<td>(13)</td>
</tr>
<tr>
<td>Hardwick</td>
<td>FS</td>
<td>84</td>
<td>1251</td>
<td>---</td>
</tr>
<tr>
<td>Hardwick</td>
<td>CS</td>
<td>165</td>
<td>1391</td>
<td>81</td>
</tr>
</tbody>
</table>

\(^1\)FS = Farmer Standard  
\(^2\)CS = Crop Sensor

Table 3. Whole plot treatments differences expressed as net returns per hectare.

<table>
<thead>
<tr>
<th>Location</th>
<th>Treatment</th>
<th>N rate</th>
<th>Lint yield</th>
<th>Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>kg/ha</td>
<td>kg/ha</td>
<td>N*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$/ha</td>
</tr>
<tr>
<td>Balmoral</td>
<td>FS(^2)</td>
<td>146</td>
<td>1851</td>
<td>---</td>
</tr>
<tr>
<td>Balmoral</td>
<td>CS(^3)</td>
<td>140</td>
<td>1832</td>
<td>7.62</td>
</tr>
<tr>
<td>Crigler</td>
<td>FS</td>
<td>112</td>
<td>1985</td>
<td>---</td>
</tr>
<tr>
<td>Crigler</td>
<td>CS</td>
<td>99</td>
<td>2018</td>
<td>16.51</td>
</tr>
<tr>
<td>Hardwick</td>
<td>FS</td>
<td>84</td>
<td>1251</td>
<td>---</td>
</tr>
<tr>
<td>Hardwick</td>
<td>CS</td>
<td>165</td>
<td>1391</td>
<td>(102.87)</td>
</tr>
</tbody>
</table>

\(^1\)N priced at $1.27/kg and cotton lint priced at $1.69/kg.  
\(^2\)FS = Farmer Standard  
\(^3\)CS = Crop Sensor

Table 4. Whole plot NDVI readings by treatment.

<table>
<thead>
<tr>
<th>Location</th>
<th>Treatment</th>
<th>N rate</th>
<th>Lint yield</th>
<th>NDVI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>kg/ha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balmoral</td>
<td>FS(^1)</td>
<td>146</td>
<td>1851</td>
<td>0.77</td>
</tr>
<tr>
<td>Balmoral</td>
<td>CS(^2)</td>
<td>140</td>
<td>1832</td>
<td>0.74</td>
</tr>
<tr>
<td>Crigler</td>
<td>FS</td>
<td>112</td>
<td>1985</td>
<td>0.74</td>
</tr>
<tr>
<td>Crigler</td>
<td>CS</td>
<td>99</td>
<td>2018</td>
<td>0.73</td>
</tr>
<tr>
<td>Hardwick</td>
<td>FS</td>
<td>84</td>
<td>1251</td>
<td>0.76</td>
</tr>
<tr>
<td>Hardwick</td>
<td>CS</td>
<td>165</td>
<td>1391</td>
<td>0.76</td>
</tr>
</tbody>
</table>

\(^1\)FS = Farmer Standard  
\(^2\)CS = Crop Sensor
Table 5. Lint yields by treatment and deep Ec zones.

<table>
<thead>
<tr>
<th>Deep Ec Zones</th>
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<th>2</th>
<th>3</th>
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<tbody>
<tr>
<td>Balmoral</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>FS(^1)</td>
<td>1968</td>
<td>1662</td>
<td>---</td>
</tr>
<tr>
<td>Balmoral</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS(^2)</td>
<td>1938</td>
<td>1762</td>
<td>---</td>
</tr>
<tr>
<td>Crigler</td>
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</tr>
<tr>
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<td>2112</td>
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<td>Crigler</td>
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<td></td>
<td></td>
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<tr>
<td>CS</td>
<td>1790</td>
<td>2188</td>
<td>2157</td>
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<tr>
<td>Hardwick</td>
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<tr>
<td>FS</td>
<td>1166</td>
<td>1226</td>
<td>1369</td>
</tr>
<tr>
<td>Hardwick</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>1385</td>
<td>1365</td>
<td>1440</td>
</tr>
</tbody>
</table>

\(^1\)FS = Farmer Standard  
\(^2\)CS = Crop Sensor

Table 6. Nitrogen rates by treatment and deep Ec zones.

<table>
<thead>
<tr>
<th>Deep Ec Zones</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balmoral</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS(^1)</td>
<td>146</td>
<td>146</td>
<td>---</td>
</tr>
<tr>
<td>Balmoral</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS(^2)</td>
<td>133</td>
<td>146</td>
<td>---</td>
</tr>
<tr>
<td>Crigler</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>112</td>
<td>112</td>
<td>112</td>
</tr>
<tr>
<td>Crigler</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>93</td>
<td>107</td>
<td>102</td>
</tr>
<tr>
<td>Hardwick</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>84</td>
<td>84</td>
<td>84</td>
</tr>
<tr>
<td>Hardwick</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>161</td>
<td>165</td>
<td>168</td>
</tr>
</tbody>
</table>

\(^1\)FS = Farmer Standard  
\(^2\)CS = Crop Sensor

Table 7. NDVI readings by deep Ec zones.

<table>
<thead>
<tr>
<th>Deep Ec Zones</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balmoral</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS(^1)</td>
<td>0.79</td>
<td>0.74</td>
<td>---</td>
</tr>
<tr>
<td>Balmoral</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS(^2)</td>
<td>0.78</td>
<td>0.71</td>
<td>---</td>
</tr>
<tr>
<td>Crigler</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>0.69</td>
<td>0.78</td>
<td>0.75</td>
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<tr>
<td>Crigler</td>
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<td></td>
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<tr>
<td>CS</td>
<td>0.71</td>
<td>0.78</td>
<td>0.74</td>
</tr>
<tr>
<td>Hardwick</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FS</td>
<td>0.77</td>
<td>0.77</td>
<td>0.74</td>
</tr>
<tr>
<td>Hardwick</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS</td>
<td>0.78</td>
<td>0.76</td>
<td>0.74</td>
</tr>
</tbody>
</table>

\(^1\)FS = Farmer Standard  
\(^2\)CS = Crop Sensor
Hardwick 2013

At the Hardwick site, the treatments were stripped through the field (Figure 22). Hardwick had the greatest differences in lint yield between FS and CS in both whole plot (Figure 23) and deep Ec zones (Figure 24). For the whole plot, 140 kg/ha more lint was produced in CS than in FS (Table 3). It also had the highest difference in N rates (Figure 25) with CS using 81 kg/ha more total N than FS (Figure 26). After assigning monetary values to both lint yield and N, CS showed a net profit of $133.73 per hectare greater than FS (Table 3). The NDVI readings taken at the early bloom (Figure 27) N application were the same for both treatments (Table 4).

The analysis by deep ec zone showed that CS lint yield was 219 kg/ha in zone 1. In zone 2, CS had an increase in lint yield of 139 kg/ha and an increase of 71 kg/ha in zone 3 (Table 5). The N rate ranged from 77 to 84 kg/ha higher in all zones for CS compared to FS (Table 6). There were almost no differences between the NDVI readings in each zone (Table 7).

Figure 22. Treatments at Hardwick.
Figure 23. Cotton lint yield at Hardwick.

Figure 24. Deep Ec zones at Hardwick.
Figure 25. N applied by crop sensor at Hardwick.

Figure 26. Total N rate applied at Hardwick.
Figure 27. NDVI readings at early bloom at Hardwick.

Crigler 2013

The Crigler location had the greatest variability in soil types/textures (Figure 28) and was the best example of how crop sensors can discern the differences in the field. The treatments were blocked in the field due to equipment requirements (Figure 29). NDVI readings at early bloom (Figure 30) for both treatments were almost equal (Table 4). The whole plot lint yield (Figure 31) showed CS produced 34 kg/ha more lint than FS and used 6 kg/ha less total N (Figure 31; Table 2). The CS N application (Figures 32 and 33) showed a net profit of $72.28 per hectare greater than FS (Table 3).

The analysis by deep Ec zone showed that CS lint yield was 12 kg/ha in zone 1. In zone 2, CS had an increase of 37 kg/ha over FS and 45 kg/ha increase over FS in zone 3 (Table 5).
Figure 28. Deep Ec zones at Crigler.

Figure 29. Treatments on Crigler.
Figure 30. NDVI readings at Crigler at early bloom.

Figure 31. Cotton lint yield at Crigler.
Figure 32. Total N applied at Crigler.

Figure 33. N rate applied by crop sensors at early bloom at Crigler.
The N rate was 19 kg/ha less for CS in zone 1 and N rates for CS in zones 2 and 3 were 5 and 10 kg/ha less than the FS, respectively (Table 6). There were almost no differences between the NDVI readings in each zone (Table 7).

Analysis of all the data proved that one definitive factor, soil variability, has a large influence on using crop sensors and NDVI to apply N at early bloom to cotton. The three locations in 2013 covered three different levels of soil variability. Crigler’s site was the most variable, Hardwick’s soils were also variable, but at the Balmoral location, the soil was all heavy clay. The greater the amount of variability in the soil, the better the crop sensors were able to discern the differences and adjust the N rate accordingly.

NDVI readings for the whole field treatments and deep ec zones varied little between treatments at each of the locations. This shows that the cotton plants that received the half rate of fertilizer had the same growth rate and plant health as the full rate plants. It also confirmed that the early bloom N application was made on time before any N deficiency was evident in the cotton plants.

The SAS statistical output showed that there were no significant differences in lint yield between the two treatments. The number of locations (blocks) was too few to separate out any treatment effects. The overall lint yield means were 1696 kg/ha (1514 lbs/acre) for FS and 1747 kg/ha (1560 lbs/acre) for the CS treatment.
Chapter 5. Discussion

The use of a crop sensors and NDVI to provide additional N at early bloom on cotton is a viable option for producers. The trial showed that the greater the soil variability, the better the crop sensors were able to pick out differences in the cotton crop. A split application of N allows producers the flexibility to manage the N needs of the cotton based on yield goals and the environment of the cropping season. Two of the three trials in 2013 were irrigated and all three locations produced good yields, with the non-irrigated location producing the highest yields. The NDVI readings taken at early bloom showed that there was very little difference in plant growth between treatments. The trial demonstrates a cotton plant’s N use is low until early bloom when it increases significantly (Figure 34). Applying the full amount of N needed to

Figure 34. Nitrogen use by cotton according to growth stage (National Cotton Council, nd)
produce a cotton crop at an early growth stage exposes the N to losses before it can be taken up by the plant. An application of half the N by sidedress injection during an early growth stage gives the cotton enough N to grow until early bloom and also allows the producer some leeway for applying the additional N in case of delays due to weather or other factors.

The use of drop nozzles from a commercial high-clearance sprayer combined with variable rate nozzles was demonstrated to be a very efficient way to make an early bloom application to cotton. Dribbling the liquid fertilizer on top of the ground close to the plants exposes the N to losses but with the addition of an urease inhibitor, the losses can be minimized until a rainfall or irrigation event moves the N into the soil profile.

In 2012, there was an additional treatment. It was a half rate of the FS followed by an early bloom application using crop sensors and NDVI followed by a rate of 33.6 kg per hectare (30 lbs per acre) of N applied as a prescription. The prescription would add N to areas of the field where the lint yield could be raised with additional N. These areas would be defined by previous yield maps, farmer history of the field, or soil zones by type or texture. This treatment was applied in 2012 but in all locations it was the lowest yielding. This treatment was only applied at the Crigler site in 2013 but the data was not included because of the method of application. The N was applied by the equipment operator based on the visual look of the cotton plants. There were no other criteria for selecting the areas to receive treatment. While there was a positive response at this site for 2013, the ability to repeat the treatment in another year or field is minimal at best.

One factor that has an influence on the adoption of a mid-season N application using crop sensors is the cost of the equipment and technology to make the application. The cost and revenue figures that were used in the analysis included only the direct cost of the N. Other direct costs that would need to be considered include fuel and labor for the second application. The
fixed cost of the equipment and technology could have also been prorated and included.

Inclusion of these additional costs would have given a better economic analysis of the returns for mid-season N applications using crop sensors.

This trial effectively demonstrated how agricultural research can be taken from small plots and moved into a commercial production setting. The crop sensors used were commercially available and the use of NDVI has been shown to have a good correlation at specific growth stages of cotton. The adaptation of the high clearance sprayer system of application, while smaller than production sprayers, showed that making a dribble application at early bloom can be done successfully and efficiently. Each of the producers we worked with already had a high clearance sprayer that could be easily set up for making an application at early bloom.
Chapter 6. Conclusion

Nitrogen is a major nutrient used in crop production and it has a significant effect on crop yields but can be easily over or under-applied. Much research has been conducted on the correct amount of N crops need during the growing season. Some research has included the use of crop sensors for data collection and for application timing.

This trial showed how much the influence of soil variability can have on the amount of N needed and actually used by a cotton crop during a production year. At the Panola location, which had the same soil type throughout the field, the FS N rate and the CS N rate were only 6 kg/ha apart and had a lint yield difference of only 19 kg/ha. At the Crigler location, the CS application used 13 kg/ha less N, but out-produced the FS by 33 kg/ha. The Hardwick location had the greatest yield increase, 140 kg/ha, by the CS treatment (Figure 35) but it also used the most N: 81 kg/ha more than the FS. The additional amount of N applied at Hardwick’s location also presented itself at harvest. The CS strips matured later than the FS strips (Figure 36). This is evident by the number of unopened bolls present after the cotton was defoliated.

Crop sensors and NDVI are used regularly on commercial farms to determine optimum timing for N applications in corn and wheat crops. In cotton, the transfer of research on using crop sensors for N applications from agricultural experiment stations to commercial production operations has lagged behind other crops. The equipment, techniques, procedures and results are known. Applying this knowledge through on-farm demonstrations and trials will complete the information transfer from researchers to producers.
Figure 35. Hardwick location showing strips with different N rates at late bloom. The light green strips are the Farmer Standard N rate and the dark green strips are the Crop Sensor treatments.

Figure 36. Hardwick location showing the effect of N rates on maturity at defoliation. Crop sensor treatment is on left and the Farmer Standard is on the right.
References


