Using GreenSeeker® to drive variable rate application of plant growth regulators and defoliants on cotton

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Abstract

The paper reports on a project designed to evaluate the feasibility of using the GreenSeeker® RT200 mapping system to drive variable rate application (VRA) of plant growth regulators (PGRs) and defoliants on cotton in Georgia, USA. The first year's results indicate that NDVI appears to be very good tool for differentiating management zones early and late in the growing season. At mid-season, when the entire field is covered by a solid green canopy, NDVI values become saturated and are not useful for creating PGR management zones. Several confounding factors prevented us from assessing the effectiveness of using NDVI to manage PGR application. Our results indicate that NDVI seems to be an excellent tool for managing defoliant applications. In the three fields we studied, VRA resulted in 8.4% less, 2.8% less, and 1% more defoliant used. In all 3 cases, defoliation effectiveness was at least as good as or better than a producer-selected constant rate.

Keywords: biomass, vegetation index, NDVI

Introduction

In the United States, cotton is grown in 17 states and is a major crop in 14 of those states. The Cotton Belt spans the southern half of the United States, stretching from Virginia to California. Over the last three years, the area planted to cotton ranged from 5.1 to 6.3 million hectares. Cotton is an intensively managed crop which requires careful nitrogen applications to prevent rank growth, plant growth regulators (PGRs) to maintain a balance between vegetative and reproductive growth, and defoliants at the end of the season to allow for mechanized harvesting. Additional inputs are needed for pest management.

Recent research (Vellidis et al., 2004) has documented the uneven distribution of plant biomass in cotton fields. This uneven distribution is a result of variability in soil parameters such as nutrients, moisture, pH, texture and variability in microclimate and disease and pest pressures. Yet most American cotton producers still apply agrochemicals at uniform rates across the entire field. Common sense as well as recent research suggests that variable rate application (VRA) of nitrogen, PGRs, and defoliants compensates for the uneven distribution of plant biomass and is a good management practice. For example, applying more PGR or defoliant to a section of the field with high biomass and less to a section with low biomass will result in more uniform plant growth or defoliation. In contrast, constant rate applications frequently result in over-application or under-application and subsequently uneven growth or defoliation. Uniform growth and defoliation results in higher harvesting efficiency, higher fiber quality, and an earlier harvest with an increased recoverable yield. Uneven growth or defoliation sometimes induces cotton producers to apply additional agrochemicals.

PGRs and defoliants are a major expense for cotton producers and inefficient use can significantly drive up production costs. VRA has the potential for improving the efficiency of application and the efficiency of production. VRA also has environmental benefits as chemicals are applied where needed at the rates needed and the threat of nonpoint source

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pollution is reduced. These issues have raised American cotton producers' interest in precision farming as a means of reducing production costs and improving profitability.

VRA on cotton can be implemented using various techniques. The use in this study entails using vehicle-based sensors to create biomass maps, delineating the map into management zones with similar biomass, ground-truthing the maps, creating appropriate agrochemical prescriptions for the zones, and then using a variable rate controller to apply the prescriptions.

Biomass maps are typically created from multispectral images captured by cameras on airborne or satellite platforms or by vehicle-based sensors. The technique relies on using vegetation indices (Vis) to quantify biomass.

VIs are mathematical ratios of light reflectance at specific wavelengths. Although dozens of vegetation indices have been developed, the one most commonly used for quantifying biomass is the NDVI or Normalized Difference Vegetation Index. NDVI is calculated as shown below. In the equation, NIR and RED are reflectance in the near infrared and in the red range, respectively.

$$\mathbf{NDVI} = \frac{\mathbf{NIR}_{\mathbf{reflectance}} - \mathbf{Red}_{\mathbf{reflectance}}}{\mathbf{NIR}_{\mathbf{reflectance}} + \mathbf{Red}_{\mathbf{reflectance}}} \quad (1)$$

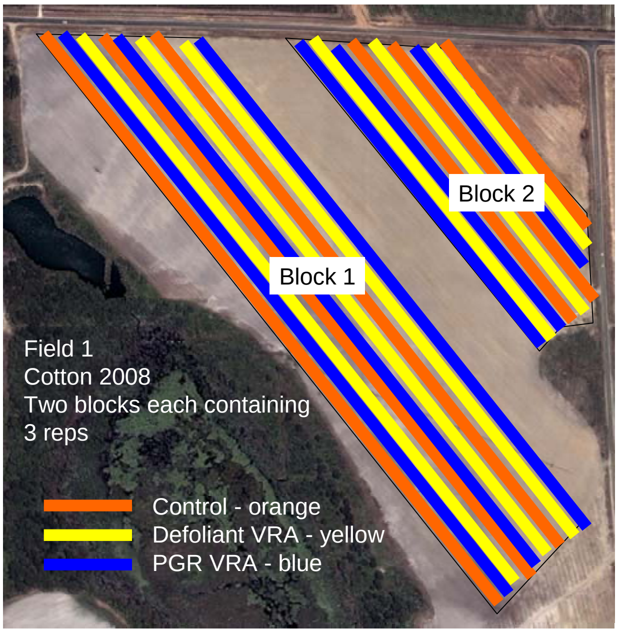
Several studies have shown very good correlations between NDVI and plant biomass and practitioners frequently refer to NDVI as an index which measures biomass.

The biggest users of NDVI for cotton management are cotton producers in the Midsouth region of the USA. There, NDVI maps are developed from multispectral aerial images by InTime (Greenville, Mississippi, USA), a company which offers precision farming services. The prescriptions are developed after NDVI maps are ground-truthed by a consultant or the producer. The prescriptions are then loaded into a variable rate controller and the chemicals applied with a ground-based sprayer or an aerial applicator. In many cotton producing areas, however, there are no service providers similar to InTime so cotton producers are evaluating alternative solutions. For example, in Louisiana and Alabama, cotton producers have been experimenting with variable rate application of PGRs and defoliants using vehicle-based sensors such as the GreenSeeker® (NTech Industries, Ukiah, California, USA) to develop NDVI maps. This paper presents the results from the first year of a project designed to evaluate the feasibility of using GreenSeeker® to drive variable rate application of PGRs and defoliants in Georgia, USA.

Materials and methods

To achieve our objectives, we designed a replicated experiment which compared three treatments: control, VRA of PGRs only, and VRA of defoliants only. Under the Control treatment, both PGR and defoliant was applied at a producer-selected constant rate. In the other 2 treatments, either the PGR or defoliant was applied variably while the other input was applied at the constant rate. The experimental design contained 3 experimental blocks within 2 producers' fields. Each block contained 3 replicates of each treatment. Each treatment replicate consisted of 18 rows of cotton that ran the entire length of the field. Thus there were 9 strips in each block (Figure 1). The replicates were randomly distributed within the block. Both fields were planted during the first week of May 2008 with Roundup-Ready® DP 555 seed. Block 1 was 11.6 ha (29 ac), Block 2 6.8 ha (17 ac), and Block 3 14.2 ha (35 ac).

We selected the GreenSeeker RT200 on-the-go variable rate application and mapping system with which to create NDVI maps and installed the system on a John Deere 6700 high clearance sprayer. The system consists of 6 GreenSeeker sensors, ruggedized PDA interface



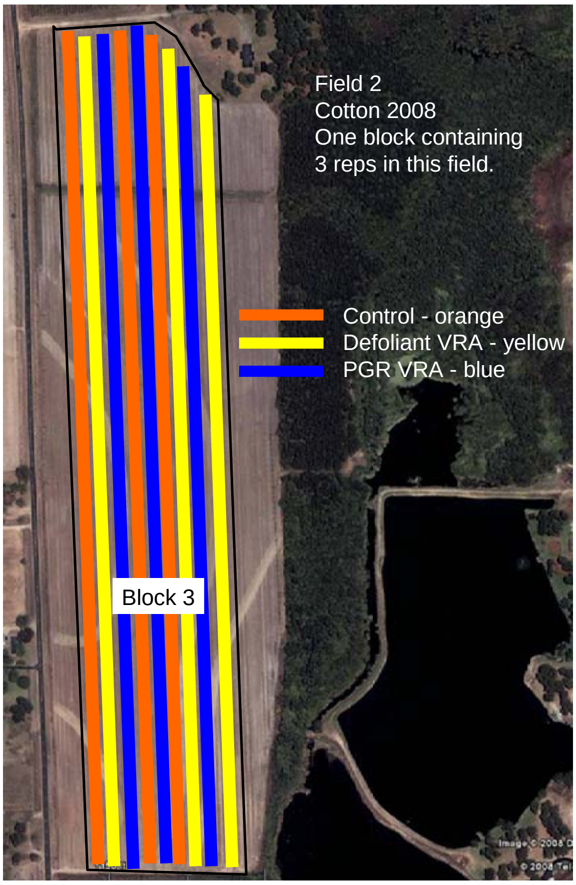


Figure 1. Aerial photographs of the fields used in the study. Superimposed on the photographs is the experimental design showing the replicated strips. Each strip is 18 rows wide or approximately 16.2 m (54 ft).

with color display, and desktop and PDA software. The sensors were mounted on the spray boom (Figure 2) to sense 3 rows of cotton on either side of the sprayer centerline. Thus the middle 6 rows of the 18 rows in each strip were directly sensed. Although the NDVI response of each individual sensor was recorded, only the average response was used for creating NDVI maps of the experimental blocks. The GreenSeeker system was linked to a DGPS receiver and all data were georeferenced in real time.

A GreenSeeker sensor generates light at two specific wavelengths (red and NIR), then measures the light reflected from the target – typically plant material and soil. Because the sensors create their own illumination, through light modulation they are able to mostly eliminate the interference of ambient light. For optimal performance, the sensors must be located between 0.8 and 1.2 m above the plant/crop canopy. When in this optimal range, each sensor has an optical field of approximately 0.6 m. So, when the crops are small, depending on the tillage system, bare soil or plant residue is also sensed. As the

Figure 2. Two of the 6 GreenSeeker® sensors mounted on the spray boom of the JD6700 high clearance sprayer used in the study.

plants mature and the canopy closes, the optical field is filled with plant material.

We installed a Mid-Tech Legacy 6000 variable rate controller (VRC) on the John Deere 6700 high clearance sprayer to variably apply PGRs and defoliants in response to prescription maps created from the NDVI maps produced by the GreenSeeker system.

Collecting biomass data

Beginning with the last week in June 2008, NDVI maps were created at weekly intervals for all three blocks. Management Zone Analyst (MZA) software was used to delineate NDVI data into like classes or potential management zones. MZA uses a fuzzy c-means unsupervised clustering algorithm to assign field information into like classes (Fridgen et al., 2004). MZA is free software developed by the United States Department of Agriculture.

The results from the first few NDVI maps were overlaid and used to delineate the experimental blocks into zones of low, medium, and high biomass. Two to 3 sampling areas were established within each strip (replicate). Each sampling area consisted of two 10 m long × 3 rows wide areas bracketing the middle 6 rows of each strip. The center of each sampling area was georeferenced with a DGPS receiver.

Biomass data were collected 4 times during the growing season on the dates shown in Figure 3. At each sampling event, three adjacent plants were selected within each of the sampling areas. Plant height was measured and then the plants were clipped at the soil surface, bagged, and returned to the laboratory for further processing. At the laboratory, the plant material was separated into leaves, stems, and fruit and oven-dried at 70°C for 48 hours. The dry plant material was then weighed and the data recorded.

Creating and applying prescription maps

Prescription maps for the PGR and defoliant applications were created using the most recent NDVI map (Figure 3). As described above, MZA was used to delineate 3 like classes or potential management zones from the NDVI data. The PGR VRA prescriptions and constant rates were recommended by the producers based on the maps we presented to them and on their personal observations of the crop. The defoliant prescriptions used on the VRA defoliant strips were developed by a University of Georgia cotton extension specialist who walked through the field and compared his visual observations to our maps. Producer recommendations were used for the constant rates.

Because the 08 July NDVI values for the low and medium biomass zones were similar, these two zones within each block were grouped together and received the same rate (medium rate) during the 15 July PGR application. The high biomass zones received the highest rate. During the August PGR application in Block 3 (Figure 1) and the October defoliation in all blocks, 3 different rates were used (low, medium, and high).

A PGR marketed under the trade name PIX® was applied on all three blocks on 15 July, and on Block 3 only on 19 August. The second PIX® application scheduled for Blocks 1 and 2 was cancelled because of the deluge of rain brought to the area by Hurricane Fay between August 21 and 23 – approximately 230 mm of rainfall over the 3 day period.

The heavy rain and high winds associated with the storm caused the cotton plants to fall over effectively eliminating the alleyways on which our sprayer traveled through the fields. At that point, the two producers who managed the fields requested that we not pass through the fields with our sprayer until conditions improved. Consequently no additional NDVI maps were created until early October, 2008. Both fields were defoliated in mid-October, 2008. Again, the producers requested that we not use the sprayer in the fields following defoliation. To ensure that we were able to document the NDVI response of defoliation, we measured NDVI in each of the sampling areas with a hand-held GreenSeeker sensor. The handheld sensor is identical to the sensors used on the sprayer. Data were recorded continuously while

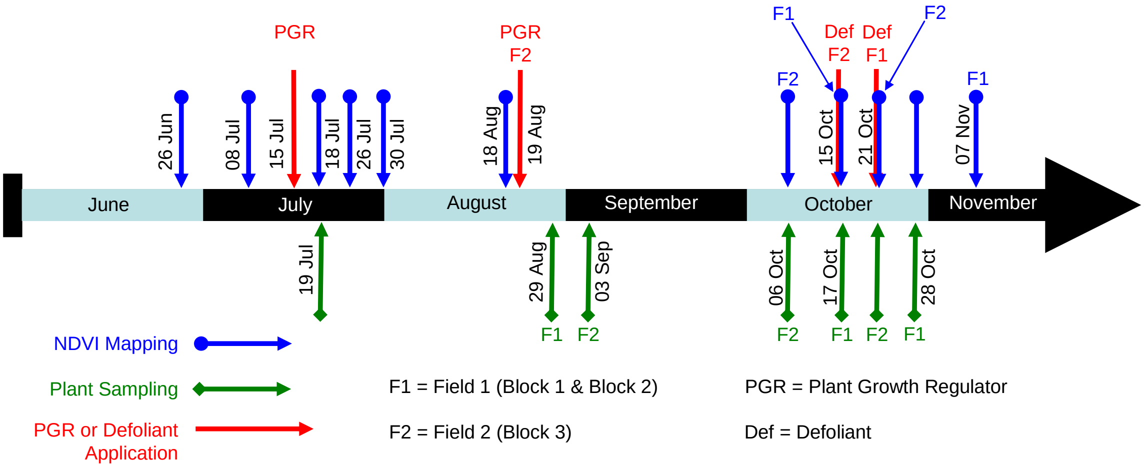


Figure 3. Project timeline showing the occurrence of NDVI mapping, plant sampling, and PGR and defoliant applications. Arrows without the F1 (Field 1) or F2 (Field 2) designation indicate that the event took place in both fields on the same date.

a student passed the sensor over a continuous section of plants within the sampling area. The data were averaged and a single NDVI value assigned to the sampling area. Figure 3 summarizes the mapping, sampling, and application activities for each field.

Two defoliants (Thidiazuron and Tribufos) as well as a boll opener (Ethephon) were applied simultaneously during defoliation. The high, medium, and low application rates of active ingredient applied were 367, 260, and 210 mL/ha (12.4, 8.8, 7.1 oz/ac), respectively. The constant or control rate selected by the producers was 355 mL/ha (12 oz/ac) for Blocks 1 and 2 and 296 mL/ha (10 oz/ac) for Block 3. Defoliation took place on 15 October in Block 3 and 21 October in Blocks 1 and 2. Defoliation effectiveness was assessed with plant sampling on 28 October in Block 3 and 07 November in Blocks 1 and 2.

Analysis of results

ArcGIS® (ESRI, Redlands, California) was used to extract NDVI values corresponding to the 6 middle rows adjacent to sampling areas from the NDVI maps. NDVI data from the mapping dates closest to the plant sampling dates were associated in a table. Statistical analyses were performed to determine if there were significant differences between treatments. To overcome possible spatial dependence between NDVI observations, we incorporated spatial autocorrelation into the standard general linear models (spatial-GLM). In the spatial-GLM, three distance-related parameters (sill, range and nuggets) were estimated, along with those in the standard-GLM. The spatial-GLM was carried out by PROC MIXED in SAS. The experiment was also evaluated qualitatively using the observations of the producers, researchers, technicians, and students associated with the project.

Although yield data are available, they are not reported in this paper because of page limitations. Block 3 was harvested on 12 November 2008 while Blocks 1 and 2 were harvested on 08 January 2009. Both fields were harvested with producer-owned John Deere cotton harvesters equipped with Ag Leader® (Ag Leader, Ames, Iowa) cotton yield monitors.

Results and discussion

Equipment performance

Overall, the GreenSeeker system performed well during the study. Our only frustration with the GreenSeeker system was that on occasion, multiple PDA resets were required to establish the proper communication links between the PDA user interface in the sprayer cabin, the DGPS, and the sensors. Once these links were established, the system performed flawlessly.

Our experience with similar PDAs indicates that this is a frequent problem and may be a function of software or hardware compatibility with the PDA's operating system.
The Mid-Tech Legacy 6000 variable rate controller and the John Deere 6700 high clearance sprayer system was calibrated at 4 application rates: 74 L/ha (8 gal/ac), 92 L/ha (10 gal/ac), 111 L/ha (12 gal/ac), and 129 L/ha (14 gal/ac). The system was able to achieve the three higher rates consistently but had difficulty maintaining the lowest rate. Because the VRC recorded the actual application rates, we were able to create as-applied maps and compare them to the target prescription maps as illustrated in Figure 4.

NDVI
During late June and July and again in October, there was a wide range of NDVI values. In June and July, lower NDVI values may have been the result of nitrogen deficiency (which was not measured during plant sampling), lower biomass, or a combination of both. In October, lower values indicated loss of chlorophyll from crop senescence. In mid-season (August), more than 90% of NDVI values exceeded 0.8 and nearly half were above 0.9 (Table 1). These observations reflect that by mid-season there was a complete, dense, and very green canopy throughout the fields. This close clustering of NDVI values effectively eliminates this VI as a tool for discriminating biomass differences during mid-season cotton. Large biomass differences did exist during this period and were documented by the plant sampling. The biomass differences were driven primarily by plant size which NDVI was not able to discriminate effectively under full-canopy conditions. There was good correlation between NDVI and plant height, stem mass, and leaf mass during the early and late season periods but not during mid-season. Therefore NDVI appears to be an effective tool for delineating potential management zones during the early and late season.

PGRs
In both study fields, the inherent variability of soils and topography resulted in a very wide range of plant biomass data. For example, in Block 3, the southernmost end of the block (shown in yellow in the NDVI map of Figure 4) is very sandy. Here plants reached a maximum height of 0.3 m. In contrast, the central section of the block contained a swath of plants that exceeded 1.5 m in height (red areas in Figure 4). The area just north and south of a waterway on the northern end of the block (yellow in Figure 4) is topographically low and remained flooded for several days and water logged for at least two weeks after the heavy rains in August. This resulted in the early defoliation of all the plants in the area, loss of most of the plants, and some leaf re-growth on the remaining plants in September. Similar, but not as extreme, variability was observed in Blocks 1 and 2.
For the reasons discussed above, there were statistically significant differences in plant height, stem mass, leaf mass, and fruit mass across zones within a treatment. There were no statistical or visual differences across treatments within zones with the same NDVI class. PGRs are applied to maintain a balance between vegetative and reproductive growth. Plants which receive the optimal application rate should have higher yields than plants which receive suboptimal rates. Consequently, we expected to see some differences in our results as plants within the same zone but in different treatments received different rates. One possible explanation for these results is that the PGR response may have been overwhelmed by

Table 1. Distribution of NDVI values during the growing season in Block 3 (Field 2).

17 July 2008		18 August 2008		06 October 2008	
NDVI	% of Data	NDVI	% of Data	NDVI	% of Data
0.50 – 0.65	26%	0.00 – 0.80	6%	0.50 – 0.65	30%
0.65 – 0.75	38%	0.80 – 0.90	45%.	0.65 – 0.75	28%
0.75 – 0.90	33%	0.90 – 0.94	49%	0.75 – 0.90	33%

residual soil nitrogen from a legume crop in the spring of 2008 which preceded the cotton.

Defoliant

Defoliation was very effective in Block 3. With the exception of one sampling area from which we collected 15.4 g of leaves from 3 plants, all the plants collected, regardless of treatment, were completely defoliated. This indicates that the 3 defoliant rates used in the VRA treatment were as effective as the constant rate. A normalized value of 271 mL/ha (9.2 oz/ac) of active ingredient were used on the VRA treatment compared to 296 mL/ha (10 oz/ac) on the control treatment or 8.4% less product for the same level of defoliation.

The defoliation results from Blocks 1 and 2 were more complex. This field's producer

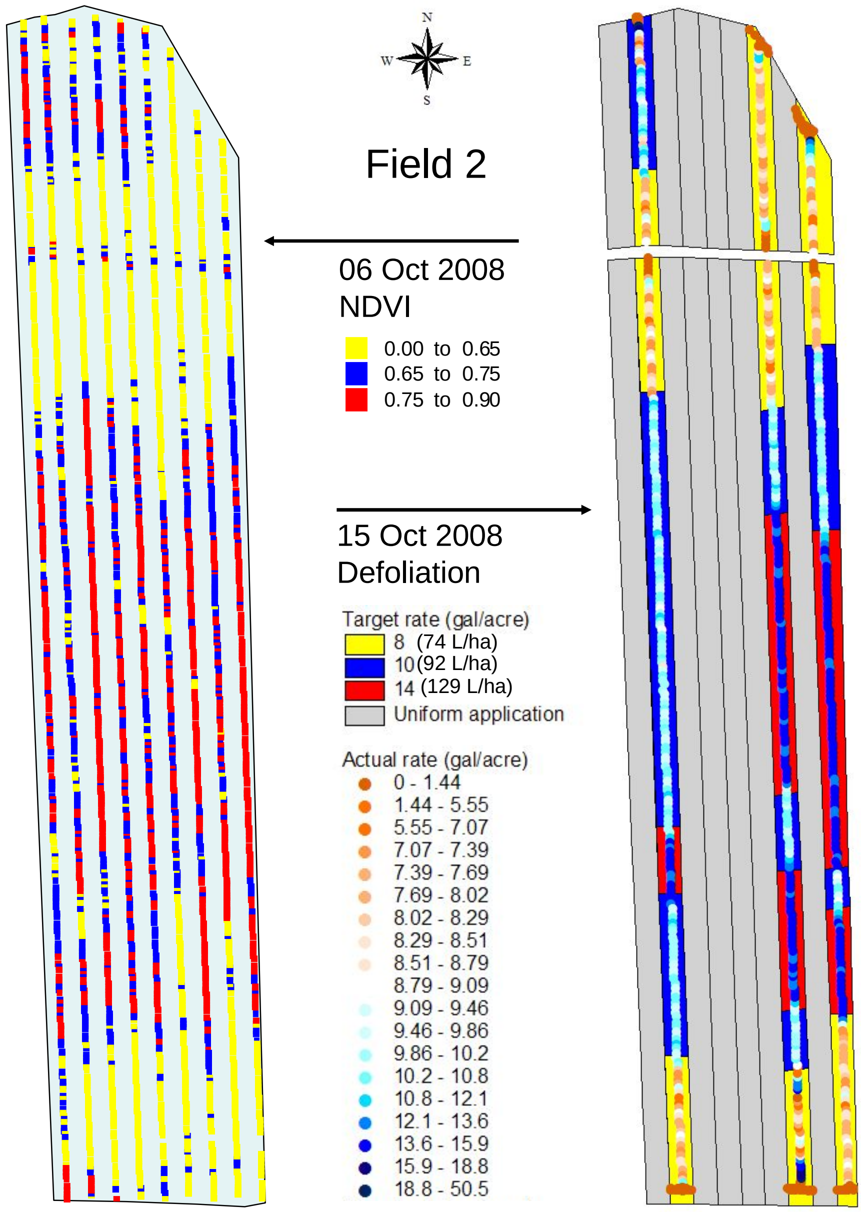


Figure 4. In the NDVI map to the left, each strip represents 1 of 9 treatment replicates. As the crop approaches maturity, the range of NDVI values increases allowing for better zone delineation. The map on the right displays the target defoliant application rates in the three defoliant VRA strips as solid blocks of color. The dots indicate the application rate achieved by the VRC and sprayer. The 2 higher rates were achieved consistently while the lowest rate was not. The field was fully defoliated within a week of application.

exhausted his irrigation water supply in mid-July. Little rainfall was received in the next month and the cotton began to mature. The heavy rains of late August reversed this trend and 0.2 to 0.3 m of new growth with many leaves and young fruit topped the cotton plants by mid-October when the field was defoliated. NDVI maps of Block 1 and Block 2 created on 15 October show that more than 86% and 87% of the data points were above 0.75 NDVI in Block 1 and Block 2, respectively. In contrast, only 33% of Block 3 was above 0.75 one week earlier (Figure 4). Using the Block 3 NDVI thresholds to create the defoliant application zones for Blocks 1 and 2 resulted in only medium and high application rates in Block 1 and just two small low application rate areas totaling 0.2 ha (0.5 ac) in Block 2.

Our cotton extension specialist recommended the same defoliant application rates for Blocks 1 and 2 as were used for Block 3. Consequently, the vast majority of Blocks 1 and 2 were sprayed with the highest defoliant rate. The producer's constant rate (355 mL/ha, 12 oz/ac) was slightly lower than our highest rate (367 mL/ha, 12.4 oz/ac).

In Block 1, a normalized value of 359 mL/ha (12.1 oz/ac) of active ingredient was used on the VRA treatment compared to 355 mL/ha (12 oz/ac) on the control treatment or 1% more product. Dried leaf mass remaining on the plants averaged 12.1 g in the VRA treatment and 26.2 g in the Control treatment (constant rate). In Block 2, a normalized value of 345 mL/ha (11.7 oz/ac) of active ingredient was used on the VRA treatment compared to 355 mL/ha (12 oz/ac) on the control treatment or 2.8% less product. Dried leaf mass remaining on the plants averaged 7.3 g in the VRA treatment and 29.2 g in the Control treatment (constant rate). The leaf mass differences are attributed to the slightly higher application rate used in the VRA treatment. Although the differences between VRA and Control leaf mass were statistically significantly different in both Block 1 and Block 2, it is unclear if these differences held any practical significance in terms of recoverable yield until the yield data are analyzed.

Conclusions

Tools like the GreenSeeker appear to be both useful and practical for managing PGR and defoliant application on cotton. These tools are very good at differentiating management zones based on NDVI early and late in the growing season. At mid-season, when the entire field is covered by a solid green canopy, NDVI values become saturated and are not useful for creating PGR management zones. Several factors prevented us from assessing the effectiveness of using NDVI to manage PGR application. However, NDVI seems to be an excellent tool for managing defoliant applications. Under typical growing conditions, cotton plants have begun senescing as they approach maturity providing for a wide range of NDVI values and the opportunity to create management zones. In the three experimental blocks which we studied, VRA resulted in 8.4% less, 2.8% less, and 1% more product. In all 3 cases, defoliation effectiveness was at least as good as or better than the constant rate.

Acknowledgements

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