USING GREENSEEKER® TO DRIVE VARIABLE RATE APPLICATION OF PLANT GROWTH REGULATORS AND DEFOLIANTS ON COTTON

George Vellidis
Heather Savelle
Glen Ritchie
Rodney Hill
Herman Henry
University of Georgia
Tifton, GA
Sergio Villagran
University of Concepcion
Chile

Abstract

This project was 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 study was conducted in three producer fields using replicated strips to evaluate treatments. We observed a large amount of soil and yield variability in each of the fields that was not related to treatments. The 2010 results indicate that NDVI appears to be very good tool for differentiating management zones early and late in the growing season. For the second year, we observed that 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. In other words, NDVI is no longer able to discriminate a large plant from a smaller plant if both plants have enough canopy to completely fill the GreenSeeker's optical field. To address this problem, we developed an ultra sonic sensing array which we used to collect plant height data. The ultrasonic sensors were mounted on the spray boom adjacent to the GreenSeeker sensors. We then developed decision rules for combining plant height and NDVI data to create biomass maps in late July and early August. The biomass maps were used to develop PGR management zones and subsequently, PGR prescription maps. Our results indicate that NDVI seems to be an excellent tool for managing defoliant applications. In the three fields we studied, VRA resulted in 22.7% less, 18.2% less and 15.6% less defoliant used. In all 3 cases, defoliation effectiveness was at least as good as a producer-selected constant rate. The total net gain of applying PGR and defoliants using VRA on our three study fields was +$1.71/ac. If these savings are projected over 2000 ac, the savings for 2009 would have been $3420. Based on 2 years of experience with this technology, the underlying variability of fields in the southeastern coastal plain will reliably result in financial savings from using VRA application of defoliants and perhaps even of PGRs. The effect of VRA application of PGRs on yield will be determined from ongoing geostatistical analyses.

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 12 to 16 million acres. 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; 2009) 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 many 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 higher recoverable yields. 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 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 VRA used in this study entails using remote sensing or other tools 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 created from multispectral images captured by cameras on airborne or satellite platforms or by ground-based sensors. The technique relies on using vegetation indices, or 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 is near infrared reflection.

$$NDVI = \frac{NIR_{reflectance} - Red_{reflectance}}{NIR_{reflectance} + Red_{reflectance}}$$

NDVI and similar VIs respond directly to chlorophyll concentrations. But because several studies have shown very good correlations between NDVI and plant biomass, 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 ground-based sensors such as the GreenSeeker® (NTech Industries, Ukiah, California, USA) to develop NDVI maps. This report presents the results from the second 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 constant rate. In the other two treatments, either the PGR or defoliant was applied variably while the other input was applied at a constant rate. The experimental design contained 3 experimental blocks within 3 producers' fields. Each block contained 3 replicates of each treatment. Each treatment replicate consisted of 18 rows of cotton planted on a 36 inch row spacing 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 2009 with Roundup-Ready® DP 555 seed. Field 1 was 12.3 ac, Field 2 11 ac, and Field 3 15 ac. All fields were irrigated and the producer managed every aspect of the crop except PGR and defoliant application and harvest.

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 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.

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

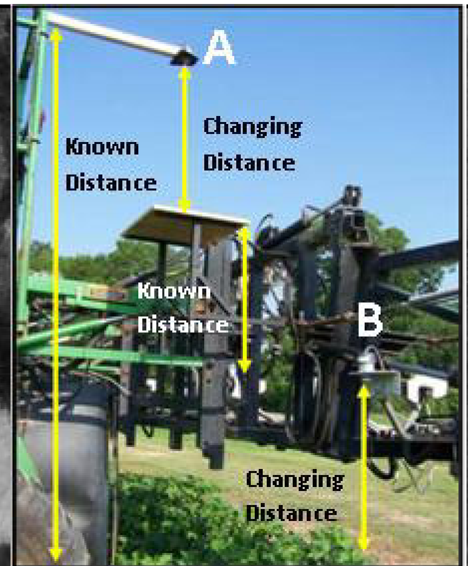

Figure 3. Ultrasonic height sensor A measures height of the boom and height sensor B measures the distance from the sensor to the plant. Using a set distance from sensor A to the ground and sensor B to the top of the boom, plant height can be calculated.

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 54 ft.

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 2.5 and 4 ft above the plant/crop canopy. When in this optimal range, each sensor has an optical field of approximately 2 ft. So, when the crops are small, depending on the tillage system, bare soil or plant residue is also sensed. As the plants mature and the canopy closes, the optical field is filled with plant material. During 2009, we recorded raw reflectance in the red and NIR range in addition to GreenSeeker-calculated NDVI. Data were stored at 5 Hz

In addition to the GreenSeeker sensors, an ultrasonic height sensing system developed by our research team was mounted on the sprayer (Figure 3). Three sensors were mounted directly onto the spray boom adjacent to GreenSeeker sensors. A fourth sensor was mounted at a fixed point above the boom to measure the distance from the fixed point to the spray boom. This distance fluctuated as the sprayer operator attempted to maintain the spray boom at a relatively constant height above the plant canopy. Data from the ultrasonic sensors were collected at 5 Hz (same rate as the GreenSeeker), tagged with coordinates from the same GPS used by the GreenSeeker system, and stored in an onboard PDA. Boom height above plant canopy and plant height were calculated in real-time and displayed on the PDA's screen. This greatly assisted the sprayer operator in maintaining the spray boom at a relatively constant height above the canopy.

We used a Mid-Tech Legacy 6000 variable rate controller (VRC) on a 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 2009, NDVI maps were created at weekly intervals for all three blocks. The Farm Works software Desktop Mapper was used to delineate NDVI data into like classes or potential management

zones. After the first few NDVI maps were created, the experimental blocks were delineated into zones of low, medium, and high biomass. Three sampling areas were established within each treatment strip for a total of 27 sampling areas within each field (Figure 1). Within the constraints of ensuring that an adequate number of sampling areas were located within each of the treatments and centered on the middle 6 rows of each strip, the sampling areas were selected randomly within the zones. Each sampling area was 36 ft long × 6 rows wide area. The center of each sampling area was georeferenced with a DGPS receiver. Samples were only taken from the outside two rows of the sampling area in order to insure an accurate yield data set. The fields were harvested with a yield monitor-equipped 4-row cotton picker at season's end. Figure 4 summarizes the mapping, sampling, and application activities for each field.
Following each PGR application, prior to defoliant application, and approximately two weeks following the defoliant application, biomass samples were taken within each of the sampling areas. All plants within a two foot section were measured for plant height 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 72-96 hours. Cumulative leaf area index (LAI) of all sampled plants in each plot was measured prior to drying. The dry plant material was then weighed and the data recorded.

The day prior to defoliation, a 2-ft section of plants was randomly selected and flagged within each of the 81 sampling areas. The number of immature bolls, mature closed bolls, and open bolls on all the plants within the 2-ft section were counted and recorded. The procedure was repeated on the same plants approximately 2 weeks after defoliation.

<u>Creating prescription maps</u>
Prescription maps for the PGR and defoliant applications were created using the most recent NDVI map (Figure 5). As described above, Farm Works Desktop Mapper was used to delineate 3 classes or potential management zones from the NDVI data. Each class contained approximately 1/3 of the data points. Under this approach, approximately 1/3 of the data points with the lowest NDVI values were grouped into the "low" zone and approximately 1/3 of the data points with the highest NDVI values were grouped into the "high" zone. The remaining 1/3 were grouped into the "medium" zone.

For the second year, we observed that at mid-season (middle to late July), when the medium and high biomass zones are covered by a solid green canopy, NDVI values become saturated. Large swaths of a field or in some cases the entire field returned NDVI values greater than 0.85. In other words, NDVI is no longer able to discriminate a large plant from a smaller plant if both plants have enough canopy to completely fill the GreenSeeker's optical field. To address this problem, we used the ultra sonic sensing array described earlier to collect plant height data. We then developed a series of decision rules for combining plant height and NDVI data to create "biomass maps" in late July and August. Like the NDVI maps, plant height data were grouped into 3 classes.

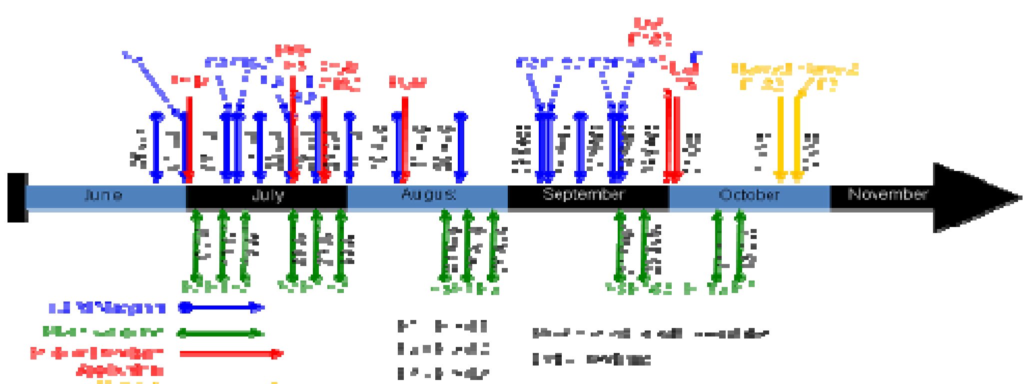

Figure 4. Timeline showing project activities in all three fields. Arrows <u>without</u> the F1 (Field 1), F2 (Field 2), or F3 (Field 3) designation indicate that the event took place in all fields on the same date.

Table 1. PGR Product Rates per field (oz/ac).

	PGR App 1 (oz/ac)			PGR App 2 (oz/ac)			PGR App 3 (oz/ac)		
	Uniform Rate	*Fields 1&2*	*Field 3*	*Uniform Rate*	*Fields 1&2*	*Field 3*	*Uniform Rate*	*Fields 1&2*	*Field 3*
High		10	9.3		16	14		16.3	16.3
Medium	8	8	8	12	10	12	14	14	14
Low		0	6.7		0	10		11.7	11.7

In summary, the decision rules which were purposely conservative, assigned areas with either a high or medium NDVI class value and a high plant height class value into the high biomass zone. Likewise, areas with a high NDVI class and a medium plant height class were assigned to the high biomass zone. Combinations of classes resulting in a medium biomass zone followed a similar pattern. Only combinations with low NDVI and low plant height classes were assigned to the low biomass zone. The biomass maps were then used to develop PGR management zones.

The management zones were ground-truthed by walking through the plots and comparing our visual observations to the management zone assignments. PGR and defoliant VRA prescriptions were developed by a University of Georgia cotton extension specialist during ground-truthing. The extension specialist also recommended the constant PGR rate while the producer recommended the constant defoliant rate. Figure 5 presents the NDVI map and the resulting prescription map used to apply defoliants on Field 3.

PGR applications

From early in the season, Fields 1 and 2 where characterized by extreme variability in plant size and canopy cover. Even by the end of July, some areas of the fields still contained small plants. NDVI values in these areas were generally very low and they were placed in the low management zone. Consequently during the first and second PGR applications in Fields 1 and 2 (July 1 and 24), the low zone received a zero PGR rate. The medium and high zones received medium and high PGR rates, respectively. During the final PGR application in August the low zone received a low PGR rate. In Field 3, high, medium and low rates were applied during each of the three PGR applications. The PGR rates applied on each date are given in Table 1.

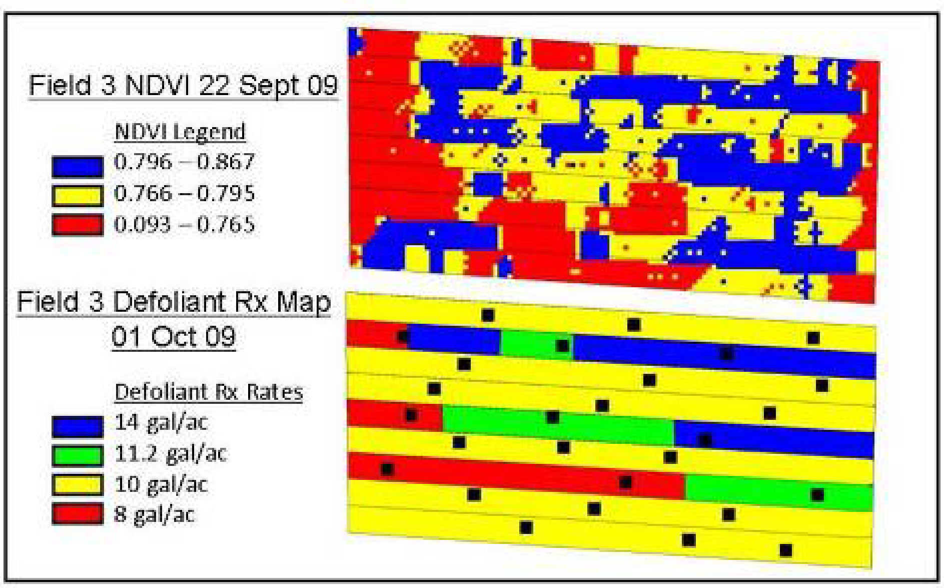

Figure 5. NDVI map (top) and the resulting prescription map (bottom) used to apply defoliant on Field 3. VRA of defoliant was done only in the 3 VRA strips (see Figure 1). The remainder of the field received a constant rate of 10 gal/ac. The black squares indicate the 27 sampling areas in Field 3.

A PGR marketed under the trade name PIX® was used. The PGR was first applied on all three fields on 1 July 2009. In Field 3 the second PGR application was on 22 July 2009 while in Fields 1 and 2, the second PGR application was on 24 July 2009. The final PGR application was on 11 August 2009 in all three fields.

Defoliant application

Two defoliants (Dropp and Folex) as well as a boll opener (Prep) were applied simultaneously during defoliation. The rates of each product for both the uniform application and VRA are provided in Table 2. Defoliation in Fields 1 and 2 took place on 28 September 2009 and defoliation in Field 3 took place on 1 October 2009. Defoliation effectiveness was assessed with plant sampling the day before defoliation and again approximately 2 weeks after defoliation as described above. In Fields 1 and 2 this occurred on 12 October 2009 and in Field 3 on 13 October 2009. No NDVI sensing was done following defoliation by request of the producer who was concerned about decreasing yields if equipment was driven through the field.

Yield maps

All three fields were harvested with a university-owned 4-row John Deere 9965 cotton picker equipped with an Ag Leader® (Ag Leader, Ames, Iowa) cotton yield monitor. Sensors are installed on ducts 1 and 3 of the picker. Field 1 was harvested on 20 October 2009, Field 2 on 21 October 2009, and Field 3 22 October 2009. The middle 4 rows of each strip were harvested first and each strip was assigned an individual load number on the Ag Leader console. The remaining 14 rows in each strip were then harvested and assigned unique load numbers.

Analysis of results

The Farm Works Desktop Mapper software package was used to extract NDVI values corresponding to the 4 middle rows within the sampling areas from the NDVI maps. NDVI data from the mapping dates closest to the plant sampling dates were associated in a table. These values will be used in geostatistical analyses discussed below. The experiment was also evaluated qualitatively using the observations of project personnel.

Results and Discussion

Equipment performance

Overall, the GreenSeeker system performed well during the study. The Mid-Tech Legacy 6000 variable rate controller and the John Deere 6700 high clearance sprayer system had an application rate range of 8 to 14 gal/ac. The system was able to achieve 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.

Yield

Yield results were highly variable across all three fields and not obviously associated with the VRA treatments (Figure 6). From past experience, we can attribute this range of yield variability to at minimum variability in soil texture, soil water holding capacity and topography. Soil EC and topographic maps were created of all three fields and will be used in subsequent analyses. In all fields, but especially in Fields 1 and 2 there was a great deal of soil EC (Figure 7) variability and some topographical differences. Yield data reflect this variability. For example, the southwestern area of Field 2 is topographically low and had very low soil EC (Figure 7). The low soil EC indicates that this area is very sandy, even at depth. Cotton here exhibited poor growth throughout the season and had some of the lowest yields measured (Figure 6). In contrast, the eastern side of Field 1 produced some of the highest yields (Figure 6). The area was topographically the highest of Fields 1 and 2 and contained moderate soil EC values.

Geostatistical techniques

Table 2. Defoliant product rates per field (oz/ac).

Rate	Prep (oz/ac)			Dropp (oz/ac)			Folex (oz/ac)		
	Uniform Rate	*Fields 1&2*	*Field 3*	*Uniform Rate*	*Fields 1&2*	*Field 3*	*Uniform Rate*	*Fields 1&2*	*Field 3*
High		32	32		2.4	2		10	8
Medium	32	22.9	25.6	2	1.7	1.6	6	7.1	6.4
Low		18.3	18.3		1.4	1.1		5.7	4.6

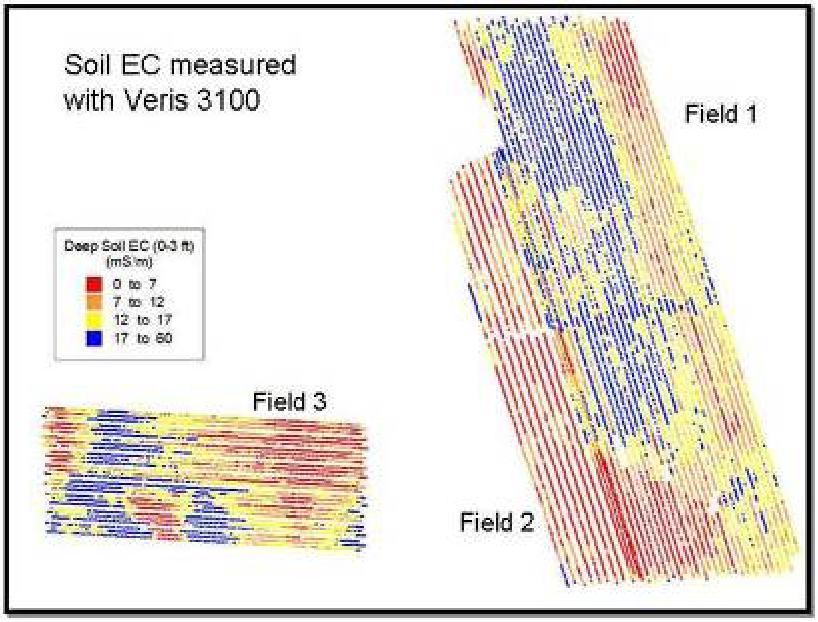

Figure 7. Deep soil EC (0-3ft) of Fields 1, 2, and 3 as measured with the Veris 3100. The range of variability measured in these fields as somewhat higher than typically measured near Tifton.

Because our treatment strips included this underlying variability, the data from our sampling areas are not only influenced by our treatments (VRA vs Uniform), but also greatly influenced by the underlying variability. Consequently it is not possible to evaluate the experimental results using traditional statistical techniques which assume that only treatments affect the results. Geostatistical techniques are currently being used to analyze the data but were not complete at the time this paper was written. Therefore, the remainder of the paper focuses on results whose interpretation is not directly dependent on underlying variability.

NDVI

As described earlier, NDVI maps alone were effective at delineating management zones for PGR applications early

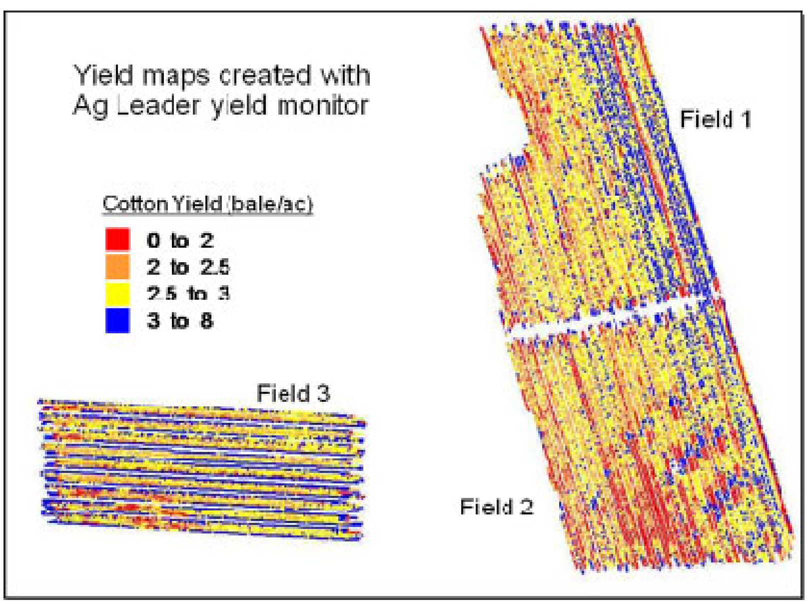

Figure 6. Cotton yield maps show bales/acre of lint in Fields 1, 2 and 3. Yield maps were created with an Ag Leader yield monitor mounted on a John Deere 9965 4-row cotton picker.

in the growing season (early July) and for the defoliant applications (late September). Biomass differences under closed canopy conditions during mid-season were driven primarily by plant size which NDVI was not able to discriminate effectively. During this period, plant height data from the ultrasonic sensor was used in addition to NDVI to create PGR prescription maps. A series of decision rules for combining plant height and NDVI data to create "biomass maps" were used. 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. Using the red and NIR reflectance data collected during the season, we are retroactively investigating other indices which use these two bandwidths. Our goal is to identify a vegetation index which can be used to delineate management zones mid-season.

PGRs

At the end of the season, there were differences in the amount of product used per acre in the VRA strips versus the uniform rate strips which are summarized in Table 3. The first PGR application used 14% less product per acre, the second application used 6.5% less per acre, and the third application used 1% less per acre. At the end of the season we used a total of 7% less product per acre in the VRA strips than the uniform rate strips. The cost per acre in each field for both the uniform strips and the VRA strips is outlined in Table 3. The VRA strips resulted in an average savings of $0.12 per acre.

Although definitive comparisons of plant growth parameters measured via biomass sampling (leaf, fruit, stem biomass; LAI; plant height) to evaluate the effectiveness of VRA of PGR will be done with the geostatistical analyses, some preliminary comparisons are shown in Figure 8. The graph compares plant growth parameters in the VRA strips to those in the strips receiving uniform PGR applications. Early in the season, fruit biomass, total biomass, and LAI in the VRA strips were on average lower than those parameters in the uniform rate strips while the plant height was very similar. By the end of the season all of the parameters, including fruit biomass, were higher in the VRA strips than the uniform rate strips. Despite the underlying variability, this appears to be a positive response to the VRA treatment. 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.

Table 3. PGR cost difference per acre.

	Field 1&2	**Field 3**
Uniform Rate ($/ac)	$1.62	$1.62
VRA Rate ($/ac)	$1.48	$1.53
Net Gain or Loss ($/ac)	+ $0.14*	+ $0.12

* + indicates net gain as a result of using VRA

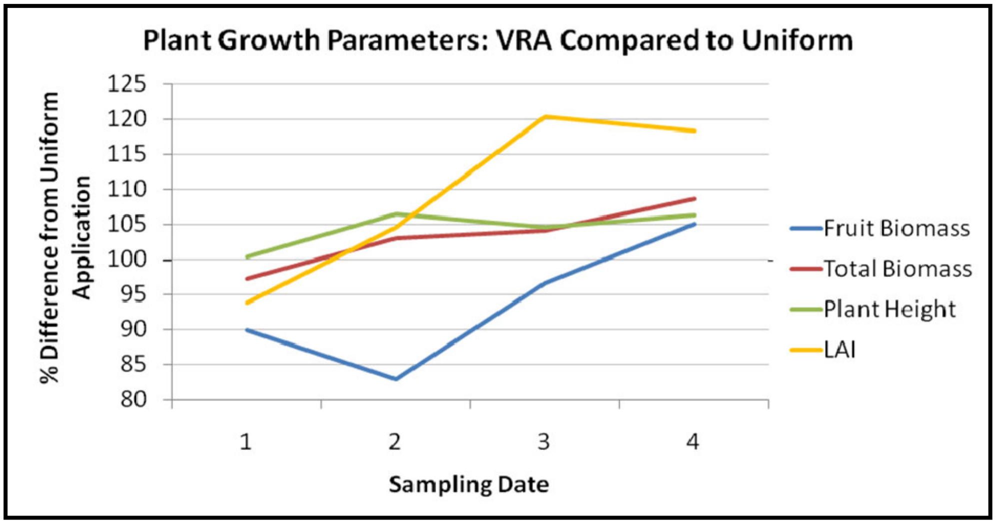

Figure 8. Percent difference between VRA treatment and uniform treatment biomass parameters. The 100% line defines the uniform treatment parameters.

Defoliants

Defoliation was very effective in all three fields regardless of treatment. Defoliation effectiveness was measured by comparing LAI and leaf biomass from the sampling areas before and after defoliation. Across the three fields, the uniform defoliant rate reduced LAI by 98% while the VRA rate reduced LAI by 96%. The uniform rate reduced leaf biomass by 97.8% and the VRA rate reduced leaf biomass by 95%.

VRA of defoliants resulted in using significantly less product than with the uniform rate. In the VRA strips we used 17% less Dropp/acre, 15% more Folex/acre, and 25% less Prep/acre. The differences in the percentages are a result of the differences in the mix of products recommended by the extension specialist and producer (see Table 2). So even though more Folex was used in the VRA strips because of the prescription difference, there was still a relatively large cost savings as a result of using VRA of defoliants (Table 4). The total difference in using VRA of defoliants is a net gain of $1.62/acre in Fields 1 and 2 and a net gain of $1.55/acre in Field 3. The net gain in all three fields as a result of using VRA of defoliant is $1.58/acre. Our preliminary conclusion is that VRA of defoliants is as effective as uniform application of defoliants in promoting leaf drop and significantly more cost effective.

A side effect of varying the application of defoliants (Dropp and Folex) was the variable rate application of the product used to promote boll opening (Prep) after defoliation because all 3 products are typically applied simultaneously. As with the defoliants, Prep was applied at high, medium, and low rates but those rates were determined by NDVI response and not directly associated with the number of unopened bolls. As described earlier, we attempted to quantify the effects of VRA by counting the number of closed and open bolls before and approximately 14 days after defoliation. The results exhibited a great deal of variability (Table 5) and do not appear to be associated with the VRA rates. The variability is not a function of earlier VRA of PGR treatments because

Table 4. Cost per acre and cost difference per acre of each defoliant product in both uniform strips and VRA strips.

Product	Uniform Application ($/ac)	VRA Application ($/ac)		Difference (Uniform–VRA) ($/ac)	
		Field 1&2	Field 3	Field 1&2	Field 3
Dropp	$2.70	$2.28	$2.15	+ $0.42*	+$0.55
Folex	$2.87	$3.42	$3.08	- $0.55	-$0.21
Prep	$6.19	$4.44	$4.98	+$1.75	+$1.21
Net gain or loss by using VRA of defoliant				**+$1.62**	**+$1.55**

* + indicates net gain as a result of using VRA

Table 5. Percentage of unopened bolls opened following defoliation.

Field	**% Bolls Opened Between Defoliation and Harvest (14 day)**			
	VRA Prep Application Rate			Uniform Prep Rate
	High	*Medium*	*Low*	
Field 1	- *	71%	70%	82%
Field 2	55%	80%	44%	83%
Field 3	62%	42%	70%	66%

* No biomass sampling area within the High defoliant application zones in Field 1.

both the Control strips and the VRA of defoliants strips received uniform PGR applications.

Summary

Remote sensing tools like the GreenSeeker appear to be both useful and practical for managing PGR and defoliant application on cotton in Georgia. 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 alone useful for creating PGR management zones. However, NDVI can be used in conjunction with an ultrasonic height sensor array to create effective mid-season management zones. In the three fields we studied, we used 14% less, 6.5% less and 1% less product for each of three PGR applications. These differences were primarily a result of the low biomass zones which received a zero rate during the first and second applications. Over the entire growing season, we used 7% less product in our VRA of PGR strips which resulted in an average savings of $0.12/ac (Table 6).

NDVI appears to be an excellent tool for managing defoliant applications. Under typical growing conditions, cotton plants begin senescing as they approach maturity providing for a wide range of NDVI values and the opportunity to create management zones that benefit from VRA. In the three experimental fields which we studied, VRA resulted in 22.7% less, 18.2% less and 15.6% less defoliant used per acre. In all 3 cases, defoliation effectiveness was at least as good as the constant rate. VRA of defoliants resulted in a net gain of $1.58/ac (Table 6).

The total net gain of applying PGR and defoliants using VRA on our three study fields was +$1.71/ac. If these savings are projected over 2000 ac, the savings for 2009 would have been $3420. Based on 2 years of experience with this technology, the underlying variability of fields in the southeastern coastal plain will reliably result in financial savings from using VRA application of defoliants and perhaps even of PGRs. The effect of VRA application of PGRs on yield will be determined from ongoing geostatistical analyses.

Table 6. Cost difference totals for use of both PGR and Defoliants in each field.

Products	**Difference in Cost (VRA – Uniform) ($/ac)**		
	Fields 1&2	**Field 3**	**Season Average**
PGR	+$0.14	+$0.10	+$0.12
Defoliants	+$1.62	+$1.55	+$1.58
TOTAL	**+$1.76**	**+$1.65**	**+1.71**

* + indicates net gain as a result of using VRA

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References

Vellidis, G., B. Ortiz, G. Ritchie, A. Peristeropoulos, C. Perry and K. Rucker. 2009. Using GreenSeeker® to drive variable rate application of plant growth regulators and defoliants on cotton. In: van Henten, E.J., D. Goense, and C. Lokhorst (Eds.), Precision Agriculture '09 – Proceedings of the 7th European Conference on Precision Agriculture (7ECPA), Wageningen, the Netherlands, pp. 55-72.

Vellidis, G., M.A. Tucker, C.D. Perry, T. Wells, and C. Kvien. 2004. Predictive cotton lint yield maps from aerial photographs. Precision Agriculture 5(6):547–564.