Variable rate application of side-dress nitrogen on cotton in Georgia, USA

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Abstract

Uniform application of fertilizers is inefficient as it does not consider field variability. During the last decade, variable rate application (VRA) has become increasingly popular. The goal of this study was to asses VRA strategies for applying side-dress nitrogen on cotton. The experiment was done in two cotton fields in southern Georgia, USA. The experimental design consisted of two variable rate application strategies and a control. Before cotton planting, the apparent electrical conductivity (ECa) was measured. Plant vigor was estimated by measuring NDVI with an optical sensor. The results showed that the high yield is correlated with high nitrogen rates and the ECa of the soil and that profitability increases by using VRA.

Keywords: NDVI, vegetation index, GreenSeeker, soil electrical conductivity, profitability

Introduction

Cotton production is very important in United States and all over the world. USA is the second largest producer of cotton, after China. Cotton is very sensitive to management practices. For this reason, farmers should be careful with the application of inputs as they have to apply them at the correct time and at the correct rates.

Gemtos et al. (2005) found that the within-field variability is high even in small fields while an uneven distribution of plant biomass in fields was found by Vellidis et al. (2004; 2009). The aim of precision agriculture (PA) practices is to manage field variability. This can be achieved with the division of the fields into management zones (MZs) where different treatments can be applied to meet plant requirements.

Environmental concerns about over-application of fertilizers as well as their high price contributed to the development of variable rate application techniques with the most commonly used being variable rate fertilization (VRF). The concept of VRF is that farmers apply an optimum amount of fertilizers according to the condition of the plants, without reducing the final yield. The availability of Global Positioning Systems (GPS) technology and Geographic Information Systems (GIS) made it relatively easy to use VRF. VRF can increase fertilizer use efficiency and gives farmers the opportunity to increase their profit.

For cotton, the timing of N application is critical to achieve high yield. Nitrogen helps the growth of the cotton plants, increases the yield and optimizes the quality of the cotton fiber (Bondada et al, 1996). Ansari and Mahey (2003) studied the effects of N on American cotton. After using different rates, they concluded that there is an increase of the seed cotton yield for N rates larger than 80 kg/ha. Saleem et al. (2010) and Bell et al. (2003) also reported that the seed cotton yield increases with N rate.

The trend of recent years is the application of VRF by using tractor-mounted sensors to apply VRF on-the-go according to the vigor of the plants. Khalilian et al. (2008)

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and Porter et al. (2010) showed that VRF application can reduce the Nitrogen usage by 30% without reducing the yield.

The response of plant vigor to different N rates was studied by Vellidis et al. (2011). The results showed that high NDVI values were measured from plants which received large rates of N. Moreover Dalezios et al. (2001) suggested that cotton yield can be estimated by using the NDVI values of the plants.

Over recent years, researchers have developed algorithms for VRA of N in cotton fields based on optical sensors (Arnal *et al.*, 2008; Khalilian *et al.*, 2008; Scharf *et al.*, 2009). An algorithm which uses NDVI and was used in the study reported here was developed by Oklahoma State University and modified at Clemson University for conditions of the southeastern USA (Figure 1). The algorithm estimates the amount of N that should be applied according to the NDVI values of the plants.

Identifying the optimal rates to be used for VRF of cotton is a real problem for cotton farmers. The objectives of this study were to show different methods for deciding the application rates of side-dress nitrogen on cotton and to demonstrate the advantages and disadvantages of each. This paper presents the initial analyses.

Material and methods

The experiment was conducted in two commercial cotton fields located near Tifton in southern Georgia, USA. The sizes and locations of the fields were: Field 1 – 0.5 ha (31.5134612°N, 83.5526628°W) and Field 2 – 2.5 ha (31.5074184°N, 83.5510209°W. The soil in the fields is classified as Tifton loamy sand.

<u>Soil electrical conductivity</u>

Prior to planting, the apparent soil electrical conductivity (ECa) was measured with a Veris 3100 (Veris technologies, Kansas, USA). This sensor was towed by a tractor. It measures the ECa in mS/m in depths between 0-30cm and 0-90cm. ECa is correlated with soil properties that affect the final yield of the crops such as soil texture, salinity, organic matter, and soil moisture. The recorded data were imported into the Farm Works™ v.2010.2.438 (Trimble Navigation Limited, USA) software to create ECa maps.

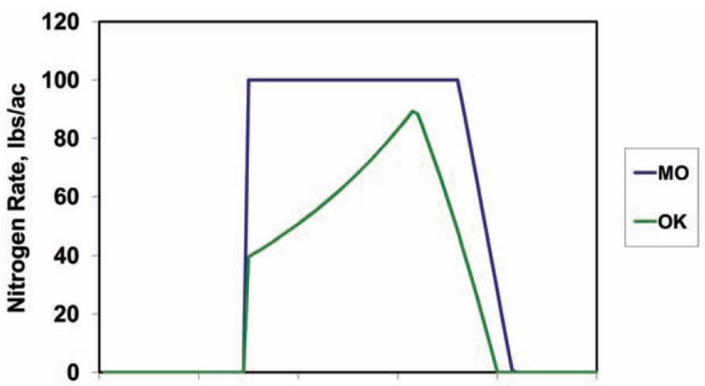

Figure 1. Nitrogen rate derived from two nitrogen prescriptions based on: Missouri (MO) and Oklahoma (OK) methods (from Taylor and Fulton, 2010).

NDVI

In each field, reflectance data were collected at weekly intervals from mid-June until just prior to side-dress N application using the Greenseeker RT200 on-the-go variable rate application and mapping system (Trimble, Ukiah, CA, USA) installed on a John Deere 6700 high clearance sprayer. The system consisted of 6 Greenseeker sensors, ruggedized PDA interface with color display, and desktop and PDA software. The sensors were mounted on the spray boom. The RT200 allows for optical reflectance data (red and NIR wavelengths) to be stored individually. In this study, only the data from sensors measuring reflectance from the inner 4 rows of cotton were used. The individual sensor responses were averaged to produce red and NIR reflectance for the 4 rows. Reflectance data were used to calculate NDVI and several other Vis. However, only NDVI response will be discussed in this paper. The Greenseeker system was linked to a DGPS receiver and all data were georeferenced in real time. Data were imported into the Farm Works software and were classified according to the quantile method by which each class has the same number of data points. The data were then used to create NDVI maps with three classes (low, medium, and high) representing plant vigour or biomass (Figure 2).

Experimental design and VRA treatments

In both study fields, the experimental design consisted of two variable rate application strategies (VRA1 and VRA2) and a control. The fields were divided into nine 6-row strips allowing 3 replicates of each treatment. The design was not randomized. Rather the strips were assigned to a repeating pattern (VRA1, Control, VRA2) to allow for direct comparison of adjacent VRA and Control treatments. This was done primarily because the fields were terraced and not all the strips were immediately adjacent to each other and secondary we wanted to avoid excessive comparisons.

The N side-dress rates for the VRA1 treatment were based on the N algorithm for cotton developed at Oklahoma State University and modified at Clemson University (Figure 1). Generally, VRA1 resulted in the largest N rates being applied to the medium-vigor NDVI class. VRA2 used different rates of side-dress N for low, medium, and high vigor areas, determined by the researchers based on prior experiments. In this treatment, the largest rate was applied to the high-vigor NDVI class. The control treatment received a uniform side-dress application at the rate typically used by the farmer.

Table 1 summarizes the rates used for VRA1, VRA2, and Control in each of the study field. The rates are presented as l/ha of 28% liquid N (the material used for the side dressing). Side-dress application rates were varied using an Ag Leader Insight™ variable rate controller and a Capstan™ variable rate system.

The Farm Works software was used to create prescription maps for the fields. The prescription rates shown in Table 1 were assigned to MZs based on the low, medium, and high vigor zones created from the NDVI data collected just prior to application of side-dress N.

Harvest

The fields were harvested in late October 2012 with a 4-row John Deere cotton harvester equipped with an Ag Leader yield monitor and DGPS receiver. The yield data were imported into the Farm Works software to generate the yield maps.

Table 1. Variable rate side-dress N application rates for Fields 1 and 2.

	Application Rate (l/ha)		
	NDVI Class		
Treatment	Low	Medium	High
VRA 1	114.4	156.3	208.2
Control	208.2		
VRA 2	135.8	183.5	294.6

The statistical analysis of the data focused on comparisons of the average yield of a strip with the amount of N used in that strip. Additionally, the results of the VRA1 and VRA2 treatments compared to the results of the adjacent Control treatments. All the data analysis was done using Excel software (Microsoft, USA).

Results and Discussion

<u>NDVI</u>

The NDVI values of the plants showed high spatial variability. For example just before side-dress N application, NDVI in Field 2 ranged from 0.12 to 0.86 and plant height ranged from less than 0.5 m to over 1 m.

<u>Prescription maps</u>

The prescription maps for the two fields are presented in Figure 3. Although each prescription map could potentially contain up to seven different rates (three for VRA1, three for VRA2, and one for Control) the number of rates was only six because the medium VRA1 rate and the Control rate were the same. Actual rates ranged from 114.4 l/ha to 294.6 l/ha.

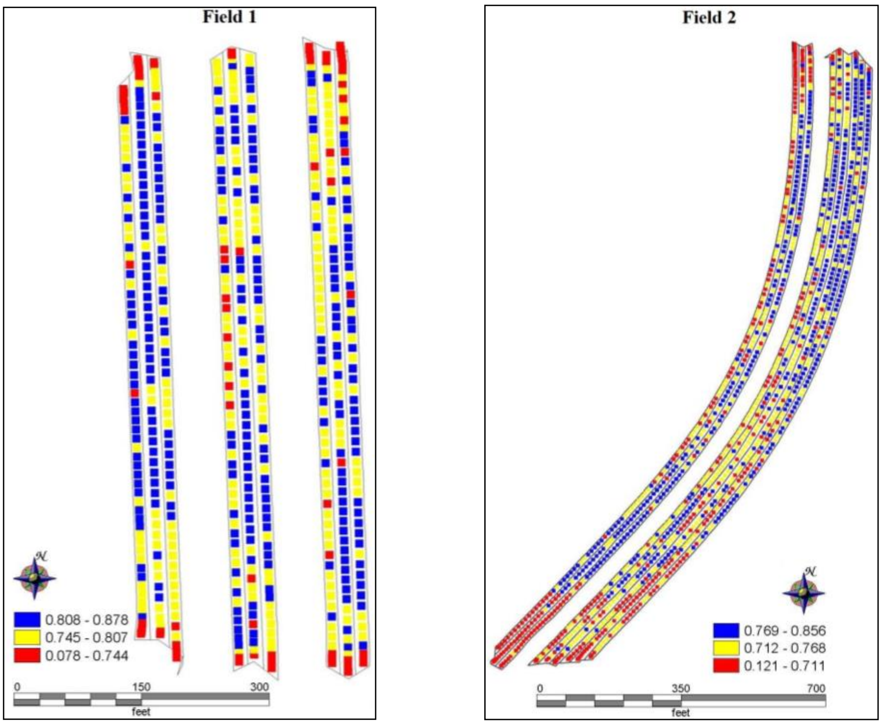

Figure 2. NDVI maps of the study fields created just before VRA of side-dress N. Field 2 is considerably larger than Field 1.

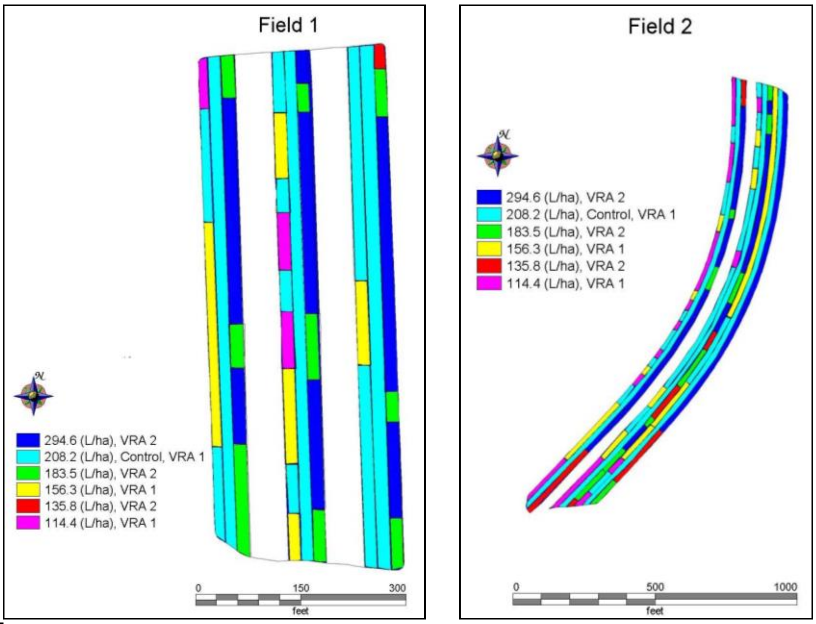

Figure 3. Prescription maps for VRA of side-dress N using 28% liquid N. The application rate for the medium VRA1 rate and the Control rate were the same.

<u>Yield</u>

Figure 4 shows the yield maps of the two fields: both fields were very variable. Both fields were irrigated with center pivot irrigation systems, and because of heavy rains during the summer, the pivot tracks became channels for runoff. As a result they became badly eroded in Field 1. This forced the cotton harvester to slow down to a virtual stop to cross the pivot tracks, causing edge-of-field effects at several positions within the field (Figure 4). Edge-of-field effects result in artificially high yields when the harvester is decelerating and artificially low yields when the harvester is accelerating. We created a 10 m buffer on either side of the pivot tracks and created similar buffers at the edges of the fields. All yield data points within the buffer areas were excluded from the analyses.

<u>Treatment comparisons</u>

The yields and crop growth parameters of the adjacent strips were compared to assess the performance of the VRA treatments and the Control. These results are presented in Tables 2 and 3. In Field 1, the average yield of the VRA1, VRA2, and Control treatments was 3456, 3509, and 3301 kg/ha, respectively. In this field, VRA2 had the best overall results although there was much variability between replicates. Economic return was calculated as the revenue from yield minus the cost of the side-dress N used. In Field 1, both VRA treatments were more profitable than the Control.

In Field 2, yields were generally lower and Control out-performed both VRA treatments. The average yield of the VRA1, VRA2, and Control treatments was 2911, 2806, and 3090 kg/ha, respectively (Table 3). Overall profitability was considerably lower than in Field 1 but VRA1 was more profitable than the other two treatments.

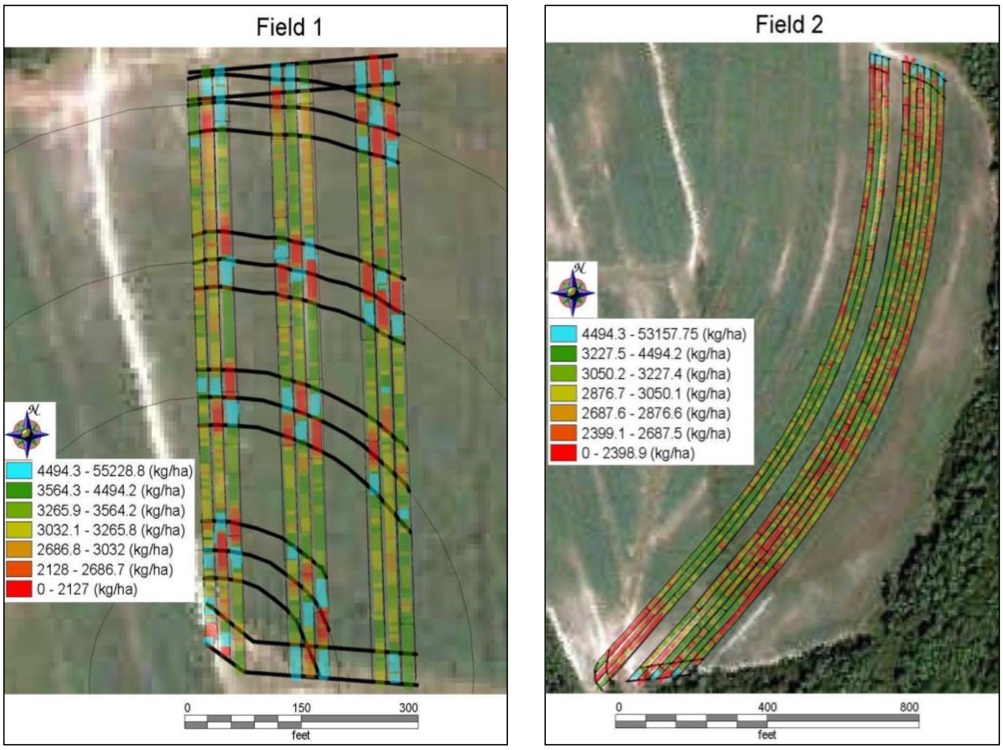

Figure 4. Yield maps of Fields 1 and 2 showing the buffer areas used to remove edge-of-field effects.

The results show that in Field 1, applying more N to the high vigor areas resulted in higher overall yields for the VRA2 treatment. It also resulted in applying more N than either VRA1 or the control and a net gain in profitability (Table 2). The same pattern was observed during 2011 in a field immediately adjacent to Field 1 (the two fields are separated by a farm road) (Borghetti, 2012).

In contrast to Field 1 where results matched anticipated outcomes, the results from Field 2 were surprising (Table 3). Here Control significantly outperformed both VRA treatments. This result is difficult to explain by using NDVI and N rates alone. Statistical analyses showed however, that average yield was positively correlated to soil ECa and suggests that ECa was a more important factor than N in determining yield. In Field 2, soil ECa was considerably higher in the control strips than in the VRA strips (Table 3). Soils with higher ECa are likely to be more productive than soils with lower ECa. The driving force behind yield results is associated with the physical conditions of the soil, such as the soil moisture content, that is reflected by ECa. Soil ECa variability was particularly high in these fields and especially at the 0 – 90 cm depth making it clear that soil variability should also be considered when determining N application rates.

Table 2. Results of variable rate application of N on Field 1.

Treatment	Yield (kg/ha)	Soil ECa (mS/m)		NDVI	As Applied N (l/ha)	Return ($/ha)
		0-30 cm	0-90 cm			
VRA 1	3620	8.21	20.63	0.676	181.7	2267
Control	3157	8.88	13.08	0.729	206.4	1946
VRA 2	3513	15.84	23.08	0.751	246.3	2154
VRA 1	3310	10.39	21.68	0.768	169.2	2071
Control	3438	7.97	14.10	0.791	207.7	2130
VRA 2	3448	9.27	16.20	0.774	248.3	2110
VRA 1	3437	9.60	21.87	0.770	191.5	2140
Control	3307	8.25	15.65	0.747	208.7	2043
VRA 2	3564	7.52	15.28	0.760	219.4	2206
Avg VRA1	3456	9.40	21.39	0.738	180.8	2159
Avg Control	3301	8.37	14.28	0.756	207.6	2039
Avg VRA2	3509	10.88	18.19	0.762	238.0	2156

Table 3. Results of variable rate application of N on Field 2.

Treatment	Yield (kg/ha)	Soil ECa (mS/m)		NDVI	As Applied N (l/ha)	Return ($/ha)
		0-30 cm	0-90 cm			
VRA 1	2778	6.99	13.3	0.697	155.8	803
Control	3151	8.01	14.3	0.758	209.9	692
VRA 2	3036	8.09	17.7	0.715	243.5	394
VRA 1	2945			0.731	166.7	841
Control	3057	5.51	13.04	0.757	206.8	650
VRA 2	2783	3.61	7.84	0.723	209.1	454
VRA 1	3011	5.66	11.69	0.715	167.8	877
Control	3062	10.43	21.49	0.674	207.3	650
VRA 2	2597			0.691	203.7	367
Avg VRA1	2911	6.33	12.51	0.714	163.4	840
Avg Control	3090	7.98	16.28	0.729	208	664
Avg VRA2	2806	5.84	12.81	0.710	218.8	405

<u>Next steps</u>

Future data analysis will concentrate on the small management zones that were created within the strips according to the NDVI values of the plants. Specifically, the yield and the ECa of the small management zones will be compared with the yield and the ECa of the respective area of the control strip. These analyses may provide better understanding of the factors that influence yield.

Conclusions

This results led to the following conclusions:

- Decisions on appropriate N rates should be based not only on plant vigor but also on soil electrical conductivity because soil ECa can affect the yield independently of the amount of N used.
- The amount of N is important to achieve high yield but it should be combined with NDVI data to make the VRF application successful.

- The farmer's profit is not always associated with the highest yield. Farmers should focus on the methods which reduce the production cost without considerable yield decrease.

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