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

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Abstract

A 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 assess 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 on 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 larger producer of cotton second to China. Cotton is very sensitive to management practices. For this reason, farmers are very careful with the application of the 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 the field variability. This can be achieved with the division of the fields into small sections called management zones (MZs). Using MZs, farmers can use different treatments to meet the real needs of the plants.

Environmental concerns about over-application of fertilizers in combination with the high price of fertilizers 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 the ideal 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.

Nitrogen (N) is very important macronutrient for crops. For cotton, the timing of N application is very critical to achieve high yield potential. 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 on N on American cotton. After using different rates they concluded that there is an increase of the seed cotton yield for N rates higher 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 the last 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) and Porter et al. (2010) and others 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 high rates of N. Moreover Dalezios et al. (2001) suggested that cotton yield can be estimated by using the NDVI values of the plants.

Over the past few 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.

**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 however Field 2 was clearly much more sandy than Field 1.

**Soil electrical conductivity**

Prior to planting, the apparent soil electrical conductivity (ECa) was measured with the Veris 3100. This sensor is pulled 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).](image-url)
NDVI
At each field, reflectance data were collected from mid-June until just prior to side-dress N application at weekly intervals using the Greenscreek 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 consists of 6 Greenscreek 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 average 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 Greenscreek 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
At 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 the VRA treatments and 3 replicates of the control. 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 we wished to avoid excessively complicating the comparisons with distance-induced variability. 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 highest N rates being applied to the medium-vigor NDVI class. VRA2 used three 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 highest rate was applied to the high-vigor NDVI class. The control treatment received a uniform side-dress rate same as the rate typically used by the farmer.

Table 1 summarizes the rates used for VRA1, VRA2, and Control in each of the study fields. The rates are presented both in terms of kg/ha of N as well as the corresponding 28% liquid N rates (L/ha) used to apply the side-dress N. Liquid N 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 of 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 of 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.
The statistical analysis of the data was focused on the comparison of the average yield with the amount of N used in each 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 the Excel software (Microsoft, USA).

Results and Discussion

NDVI
The NDVI values of the plants showed high spatial variability as well as a very large range. For example, just before side-dress N application, NDVI in Field 2 ranged from 0.12 to 0.86. The variability in NDVI truly represented the variability of plant vigor and biomass at that time, plant size ranged from less than 0.5 m to over 1 m.

Prescription maps
The prescription maps for the two fields are presented in Figures 3. Although each prescription map could potentially contain up to eight 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.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>NDVI Class</th>
<th>Application Rate (kg/ha)</th>
<th>Application Rate (L/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>VRA 1</td>
<td>45</td>
<td>90</td>
<td>67</td>
</tr>
<tr>
<td>Control</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VRA 2</td>
<td>56</td>
<td>79</td>
<td>124</td>
</tr>
</tbody>
</table>

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

Figure 2. NDVI maps of the project’s study fields created just before VRA of side-dress N. Please note that the Field 2 is considerably larger than Field 1.
Yield

Figure 4 presents the yield maps of from the two fields. The spatial variability of the yield was high in both fields. 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.

Treatment comparisons

The yields and crop growth parameters of the strips adjacent to each other 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 a large amount of variability between replicates. Economic return of the treatments was calculated by calculating the revenue from yield and subtracting from that 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 outperformed 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 significantly more profitable than the other two treatments.

The two VRA treatments used in this study differed primarily in the amount of N applied to the areas of the field with the highest vigor (high NDVI). VRA1 applied the highest N rates (208.2 L/ha) on the medium vigor areas while VRA2 increased N rates with plant vigor. The highest N rate (294.6 L/ha) was used on the highest vigor areas. 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 that 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 is positively correlated to soil ECa and therefore ECa was as important factor as 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. Because Field 2 was so sandy, it appears that ECa was the driving force behind yield results. 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 at Field 1.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (kg/ha)</th>
<th>Soil ECa (mS/m)</th>
<th>NDVI</th>
<th>As Applied N (L/ha)</th>
<th>Return ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VRA 1</td>
<td>3620</td>
<td>8.21</td>
<td>20.63</td>
<td>0.676</td>
<td>181.7</td>
</tr>
<tr>
<td>Control</td>
<td>3157</td>
<td>8.88</td>
<td>13.08</td>
<td>0.729</td>
<td>206.4</td>
</tr>
<tr>
<td>VRA 2</td>
<td>3513</td>
<td>15.84</td>
<td>23.08</td>
<td>0.751</td>
<td>246.3</td>
</tr>
<tr>
<td>VRA 1</td>
<td>3310</td>
<td>10.39</td>
<td>21.68</td>
<td>0.768</td>
<td>169.2</td>
</tr>
<tr>
<td>Control</td>
<td>3438</td>
<td>7.97</td>
<td>14.10</td>
<td>0.791</td>
<td>207.7</td>
</tr>
<tr>
<td>VRA 2</td>
<td>3448</td>
<td>9.27</td>
<td>16.20</td>
<td>0.774</td>
<td>248.3</td>
</tr>
<tr>
<td>VRA 1</td>
<td>3437</td>
<td>9.60</td>
<td>21.87</td>
<td>0.770</td>
<td>191.5</td>
</tr>
<tr>
<td>Control</td>
<td>3307</td>
<td>8.25</td>
<td>15.65</td>
<td>0.747</td>
<td>208.7</td>
</tr>
<tr>
<td>VRA 2</td>
<td>3564</td>
<td>7.52</td>
<td>15.28</td>
<td>0.760</td>
<td>219.4</td>
</tr>
<tr>
<td>Avg VRA1</td>
<td>3456</td>
<td>9.40</td>
<td>21.39</td>
<td>0.738</td>
<td>180.8</td>
</tr>
<tr>
<td>Avg Control</td>
<td>3301</td>
<td>8.37</td>
<td>14.28</td>
<td>0.756</td>
<td>207.6</td>
</tr>
<tr>
<td>Avg VRA2</td>
<td>3509</td>
<td>10.88</td>
<td>18.19</td>
<td>0.762</td>
<td>238.0</td>
</tr>
</tbody>
</table>
Next steps
Future the data analysis will be concentrated on the small management zones that were created within the strips according to the NDVI values of the plants. Specifically, the yield of the small management zones will be compared with the yield of the respective area of the control strip. These analyses will provide us with a better understanding of the factors that influence the yield.

Conclusions
This project’s results led to some useful conclusions for cotton farmers. They are:

- Decisions on appropriate N rates should be based not only on plant vigor but also on soil electrical conductivity because soil EC 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 ECa data to make the VRF application successful.
- Profitability is not always associated with the highest yield and farmers should focus on this factor more than on yield.
- Yield monitors must be improved to account for acceleration and deceleration errors which can greatly affect accuracy of yield data.

References
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