In-Season Precision Applications of Fluid Fertilizer to Optimize Cotton Productivity and Nitrogen Use Efficiency

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Abstract

Current nitrogen (N) fertility recommendations for cotton may need to be modified because of the significant yield increases resultant from new cotton cultivars and improved management practices. On the other hand, it is essential to develop innovative approaches that can manage N fertilizer more efficiently. The objective of this study in 2012 along with some work done in 2011 were to develop and evaluate algorithms for variable-rate N applications within a field based on the relationship of cotton lint yield with canopy Normalized Difference Vegetation Index (NDVI). A field trial was conducted at the University of Tennessee Research and Education Center at Milan in 2011 and 2012 to evaluate algorithms for variable-rate N applications based on the relationship of lint yield with NDVI in large strip plots (25-ft wide running the length of the field) in a randomized complete block design with three replicates. Each strip plot was divided into eight 50-ft long sub plots. The following six in-season fluid N treatments were evaluated: 1) zero N, 2) uniform N application rate of 50 lb/a of N over each strip plot, 3) uniform N application rate of 70 lb/a of N over each strip plot, 4) ordinary variable-rate N algorithm in the range of 30 to 90 lb N/a for each sub plot based on the average NDVI value in that sub plot, 5) reversed variable-rate N algorithm in the range of 30 to 90 lb N/a for each sub plot based on the average NDVI value in that sub plot , and 6) N application rate based on the average NDVI value in each strip plot. In treatment 4, when the NDVI reading was lower, more N fertilizer was applied. However, in treatment 5, when the NDVI reading was lower, less N fertilizer was applied. In treatment 6, the N application rate was the same for all sub plots within a strip plot, but it might be different among the three strip plots of the three replicates. Nitrogen fertilizer UAN (32-0-0) was injected with a KBH 8-row pull-type coulter injector for all in-season applied N treatments. In addition to the above in-season N treatments, all the plots received 23 lb N/acre as DAP prior to cotton planting each year. Leaf N concentrations were generally higher under in-season N applications than those under zero N at the early, mid, and late bloom stages. However, no significant differences in canopy NDVI or plant height were observed at mid or late bloom stages. Lint yield was not significantly affected by in-season N applications on this field that had already received the application of 23 lb N/a before cotton planting. The three variable-rate N algorithms consumed 7 to 11 lb/a more N than the uniform rate of 50 lb N/a, but 9 to 13 lb/a less of N than the uniform rate at 70 lb N/a. Our results suggest that it might be difficult to compare in-season variable-rate N applications with the traditional uniform-rate N applications in terms of their effects on cotton yields on those fields that have received pre-planting N applications.

INTRODUCTION

Presently, nitrogen (N) fertilizer is recommended to be applied at 30-60 lb N/acre on bottom fields and 60-80 lb N/acre on upland fields before or at cotton planting in Tennessee. These recommendations have been used for decades without any major modifications. Because of the significant yield increases resultant from new cotton cultivars and improvements in management practices, there is a need to re-evaluate the current N recommendations to see whether the N application rates are adequate for new cultivars to reach their optimal yield potentials.

On the other hand, there is an urgent need to develop innovative approaches that can manage N fertilizer more efficiently to increase grower profitability due to substantially increased N prices during the last several years. Overall, there are two major factors limiting N use efficiency in the current cotton production systems. Firstly, the current N management systems were developed based on a state or regional scale, and they have no capability to cope with spatial variability within individual fields. Under the current systems, cotton producers use a uniform N fertilizer rate for the entire field or even the entire farm, which often results in under- and over-applications of N. Secondly, large doses of N are usually applied early in the season (pre-planting or at planting) before cotton plants can effectively uptake and utilize it; this puts the applied N at high risk to environmental losses. In order to solve these two problems, there is a need to develop new N management systems that can generate variable-rate N recommendations for different areas within a field and emphasize the application of N in the mid-season.

Measuring crop N nutrition status during the growing season by optically sensing crop canopy seems to be a viable precision N management tool for variable-rate N applications within the field, emphasizing N application in the mid-season, and minimizing the cost of N application. Researchers have utilized on-vehicle, real-time optical sensing of crop canopy to generate Normalized Difference Vegetation Index (NDVI) to assess crop N nutrition status. This approach enables on-the-go diagnoses of crop N deficiency, real-time applying N fertilizer at variable rates, and precisely treating each area sensed without processing data or determining location within a field beforehand. Research on wheat and corn has shown an approximately 15% increase in N use efficiency and some significant yield increases with this approach. So far, precision N research has been focused on wheat and corn. Little investigation has been documented on cotton.

The objectives of this study were to: 1) determine the optimal N fertilizer application rates for high-yielding cotton production systems in Tennessee; 2) estimate the spatial variations in lint yield, NDVI, leaf N concentration, and soil nitrate within a field; 3) investigate the relationships between lint yield and NDVI, and between NDVI and crop N nutrition status; and 4) if there is a significant relationship between cotton yield and canopy NDVI, then algorithms would be developed for variable-rate N applications within a field, based on the relationship between lint yield and NDVI. The algorithms for variable-rate N applications would be compared with the uniform-rate N application systems in terms of seasonal N fertilizer consumption and lint yield. The work that was done in 2009, 2010, and 2011 were mainly used to fulfill the tasks of Objectives 1, 2, and 3. The work laid out in Objective 4 was accomplished in 2011 and 2012. Since the results from Objectives 1, 2, and 3 have been reported to the Fluid Fertilizer Foundation in 2010 and 2011, this report will focus on the results related to Objective 4.

MATERIALS AND METHODS

A field trial was conducted at the University of Tennessee Research and Education Center at Milan in 2011 and 2012 to compare variable-rate N applications with the uniform-rate N application systems in terms of seasonal N fertilizer consumption and lint yield. The following six in-season fluid N treatments were evaluated in strip plots. Each strip plot was divided into 8 sub plots (25 ft. wide x 50 ft. long).

1. Zero N
2. Uniform N application rate of 50 lb/a of N over each strip plot
3. Uniform N application rate of 70 lb/a of N over each strip plot
4. Ordinary variable-rate N algorithm in the range of 30 to 90 lb N/a for each sub plot based on the average NDVI value in that sub plot
5. Reversed variable-rate N algorithm in the range of 30 to 90 lb N/a for each sub plot based on the average NDVI value in that sub plot
6. N application rate based on the average NDVI value in each strip plot

No N fertilizer was applied in any strip or sub plot in treatment 1 during the season. Nitrogen fertilizer of 50 lb/a N was applied to all sub plots in each strip plot in treatment 2. Nitrogen fertilizer at 70 lb/a N was applied to all sub plots in each strip plot in treatment 3. Nitrogen applications in treatments 4 to 6 were based on NDVI readings. In treatment 4, when the NDVI reading was lower, more N fertilizer was applied. However, in treatment 5, when the NDVI reading was lower, less N fertilizer was applied. In-season fluid N application rate ranged from 30 to 90 lb N/a for both treatments 4 and 5. In treatment 6, the N application rate was the same for all sub plots within a strip plot, but it might be different among the three strip plots of the three replicates. Nitrogen fertilizer UAN (32-0-0) was injected 1.5 inches deep into the soil and 10 inches to one side of the row with a KBH 8-row pull-type coulter injector for all the in-season applied N treatments. In addition to the above in-season N treatments, all the plots received 23 lb N/acre and 60 lb P_2O_5/a as diammonium phosphate and 60 lb K_2O/a as muriate of potash in this test in fall 2010. In March 2012, 23 lb N/a, 60 lb P_2O_5/a, and 90 lb K_2O/a were applied to all the treatments. The P and K fertilizers were broadcast applied based on the soil testing results each year.

The test field had four different soil types: Calloway, Falaya, Grenada, and Lexington. The initial soil nitrate-N and ammonium-N content within the top 2 ft. of soil varied substantially ranging from 3 to 57 ppm. All these suggest that the test field is spatially variable.

The dates of cotton planting, N treatment implementation, and other field operations for this test are presented in Table 1. A composite soil sample was collected at a depth of 2-ft. for nitrate and ammonium in the soil profile on a sub plot basis prior to treatment initiation. The following sampling and measurements were taken from each sub plot each year: Canopy NDVI data were recorded at the early square and early, mid, and late bloom stages using the GreenSeeker® (NTech Industries, Inc., CA) RT 200 Data Collection and Mapping System. A composite leaf sample (10 blades + petioles) was collected four times at about the same dates when NDVI data were taken. All leaf samples were analyzed for N concentrations using a LECO Tru-Spec Analyzer. Cotton harvest was completed timely for lint yield and gin turnout by harvesting the center 4 rows. A post-harvest soil sample was taken for soil nitrate and ammonium at a 2-ft depth. In addition, fiber quality attributes were determined on a strip plot basis each year.

Analysis of variance for each measurement was conducted with a randomized complete block model using SAS statistical software (SAS Institute, Cary, North Carolina). Treatment means were separated with the protected LSD method if needed. Probability levels lower than 0.05 were designated as significant.

RESULTS AND DISCUSSION

Initial Soil N Fertility

Initial inorganic N (NO_3^--N + NH_4^+-N) content in the top 2 ft. of soil varied substantially among the 144 sub plots in the range of the minimum less than 3 ppm to the maximum 57 ppm prior to treatment initiation in spring 2011 in this study (data not presented).

Effects of N Algorithms on Leaf N Concentrations

Leaf N concentrations were similar among the 18 strip plots at early square before the N treatments were applied when the results of 2011 and 2012 were combined (Table 2). However, significant differences in leaf N were observed among the six N treatments at the early, mid, and late bloom stages (Table 2). Leaf N concentrations were mostly significantly higher in the five N applied treatments than those under treatment 1 (zero N) at the early, mid, and late bloom stages. It was unexpected that leaf N level was pretty high regardless of growth stage under the zero N treatment. Treatments 3, 4, and 5 had significantly or numerically higher leaf N concentrations than treatments 2 and 6 at the early, mid, and late bloom stages.

Effects of N Algorithms on Canopy NDVI Readings

Canopy NDVI is a good vegetation index to be used to estimate plant biomass on the ground. Canopy NDVI readings were statistically similar among the six in-season side dress N treatments at early square before these N treatments were implemented averaged over 2011 and 2012 (Table 3). Similarly no significant differences in NDVI were observed among the six N treatments at early, mid, or late bloom stage (Table 3).

Effects of N Algorithms on Plant Height

Similar to canopy NDVI, plant height did not differ significantly among the six in-season side dress N treatments at early square prior to N treatment implementation averaged 2011 and 2012 (Table 4). However, plant height was significantly different among the six N treatments at the early bloom stage (Table 4). Plants were significantly taller under treatment 3 than those with the other treatments at early bloom.

Effects of N Algorithms on Lint Yield, Gin Turnout, and Fiber Quality

Lint yield responses to in-season side dress N treatments were statistically not significant on the averages of 2011 and 2012 (Fig. 1). Numerically, lint yields were higher under treatments 3, 4, and 6 than those with the other treatments. Gin turnout was not significantly affected by the N treatments either (data not presented). No significant difference was observed in any fiber quality attribute among the six N treatments (Table 5).

Effects of N Algorithms on In-season Nitrogen Fertilizer Consumption

The in-season side dress N fertilizer consumption was 0, 50, 70, 61.3, 56.7, and 60 lb N/acre for treatments 1 to 6, respectively, in this study averaged over 2011 and 2012 (Fig. 2). The three variable-rate N algorithms (treatments 4, 5, and 6) consumed 7 to 11 lb/a more N than the uniform application rate of 50 lb N/a, but 9 to 13 lb/a less of N than the uniform rate at 70 lb N/a.

Effects of N Algorithms on Post-Harvest Soil N Contents

No significant differences were observed in post-harvest inorganic soil N (NO_3^--N + NH_4^+-N) among the six in-season side dress N treatments on the averages of 2011 and 2012 (Fig. 3). Numerically, soil inorganic N level was higher under treatments 3, 4, and 5 than those with the other treatments after cotton harvest.

SUMMARY

Leaf N concentrations were generally higher under in-season N applications than those under zero N at the early, mid, and late bloom stages. However, no significant differences in canopy NDVI or plant height were observed at mid or late bloom stage. Lint yield was not significantly affected by in-season N applications on this field that had already received the application of 23 lb N/a before cotton planting. The three variable-rate N algorithms consumed 7 to 11 lb/a more N than the uniform application rate of 50 lb N/a, but 9 to 13 lb/a less of N than the uniform rate at 70 lb N/a. Our results suggest that it might be difficult to compare in-season variable-rate N applications with the traditional uniform-rate N applications in terms of their effects on cotton yields on those fields that have received pre-planting N applications.

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Table 1. Major field operations performed on this test in 2011 and 2012.

Year	List of operations performed	Date performed
2011	Planted DPL 0912 with a 8-row planter	05/11/11
	Collected 2 ft. pre-treatment soil samples (2/plot)	05/26/11
	Recorded canopy NDVI prior to N treatment	06/24/11
	Side dressed fluid N treatments by plot	07/12/11
	Collected early square leaf samples (10/plot)	07/12/11
	Recorded early square plant height (10/plot)	07/12/11
	Recorded canopy NDVI at early bloom	07/21/11
	Collected early bloom leaf samples (10/plot)	07/22/11
	Recorded early bloom plant height (10/plot)	07/22/11
	Recorded canopy NDVI at mid bloom	08/01/11
	Collected mid bloom leaf samples (10/plot)	08/02/11
	Recorded mid bloom plant height (10/plot)	08/02/11
	Recorded canopy NDVI at late bloom	08/15/11
	Collected late bloom leaf samples (10/plot)	08/12/11
	Recorded late bloom plant height (10/plot)	08/12/11
	Harvested center 4 rows of each 8 row plot & collected seed cotton samples by strip plot	10/11/11
	Collected 2 ft. post-harvest soil samples (2/plot)	11/1, 2, & 7/11
2012	Planted DPL 0912 with a 8-row planter	05/10/12
	Recorded canopy NDVI prior to N treatment	07/11/12
	Collected early square leaf samples (10/plot)	07/11/12
	Recorded early square plant height (10/plot)	07/11/12
	Side dressed fluid N treatments by plot	07/18/12
	Recorded canopy NDVI at early bloom	07/19/12
	Collected early bloom leaf samples (10/plot)	07/19/12
	Recorded early bloom plant height (10/plot)	07/19/12
	Recorded canopy NDVI at mid bloom	07/26/12
	Collected mid bloom leaf samples (10/plot)	07/26/12
	Recorded mid bloom plant height (10/plot)	07/26/12
	Recorded canopy NDVI at late bloom	08/08/12
	Collected late bloom leaf samples (10/plot)	08/08/12

Recorded late bloom plant height (10/ plot)	08/08/12
Harvested center 4 rows of each 8 row plot & collected seed cotton samples by strip plot	10/25/12
Collected 2 ft. post-harvest soil samples (2/ plot)	11/09/12

Table 2. Effects of N treatments on leaf N concentration at different growth stages averaged over 2011 and 2012.

N Treatment	Early Square	Early Bloom	Mid Bloom	Late Bloom
1	4.05	3.83c*	3.58c	3.44b
2	4.04	4.08ab	3.68bc	3.69ab
3	4.07	4.17ab	3.84a	3.88a
4	4.13	4.14ab	3.76ab	3.73a
5	4.18	4.23a	3.77ab	3.84a
6	3.96	4.02bc	3.70bc	3.65ab
Significance	ns	**	**	*

* Values within a column followed by the same letter are not significantly different at the 0.05 probability level.

Table 3. Effects of N treatments on canopy NDVI at different growth stages averaged over 2011 and 2012.

N Treatment	Early Square	Early Bloom	Mid Bloom	Late Bloom
1	0.55	0.69	0.70	0.73
2	0.57	0.70	0.71	0.73
3	0.58	0.70	0.71	0.73
4	0.56	0.69	0.70	0.73
5	0.55	0.70	0.72	0.75
6	0.58	0.68	0.70	0.72
Significance	ns	ns	ns	ns

Table 4. Effects of N treatments on plant height at different growth stages averaged over 2011 and 2012.

N Treatment	Early Square	Early Bloom	Mid Bloom	Late Bloom
1	25.3	32.2b*	36.6	38.8
2	26.2	31.9b	36.8	39.6
3	26.5	33.8a	38.3	40.1
4	26.0	32.4b	36.9	39.2
5	25.8	32.0b	36.9	39.6
6	26.2	31.7b	36.5	39.3
Significance	ns	*	ns	ns

* Values within a column followed by the same letter are not significantly different at the 0.05 probability level.

Table 5. Effects of N treatments on fiber quality averaged over 2011 and 2012.

N Treatment	Micronaire	Strength	Length	Uniformity
1	4.95	32.9	1.12	83.2
2	4.90	33.3	1.11	83.3
3	4.95	32.2	1.09	82.3
4	4.95	33.0	1.11	82.9
5	4.85	33.1	1.11	83.7
6	5.00	32.2	1.09	82.7
Significance	ns	ns	ns	ns

Fig. 1. Effects of N treatments on lint yield averaged over 2011 and 2012.

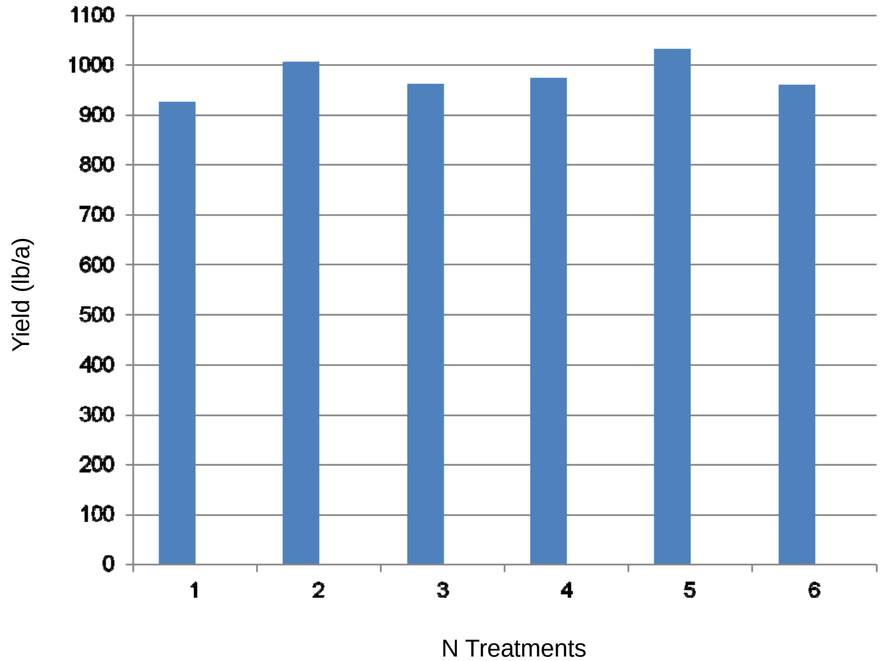

Fig. 2. Effects of N treatments on in-season fluid N fertilizer consumption averaged over 2011 and 2012.

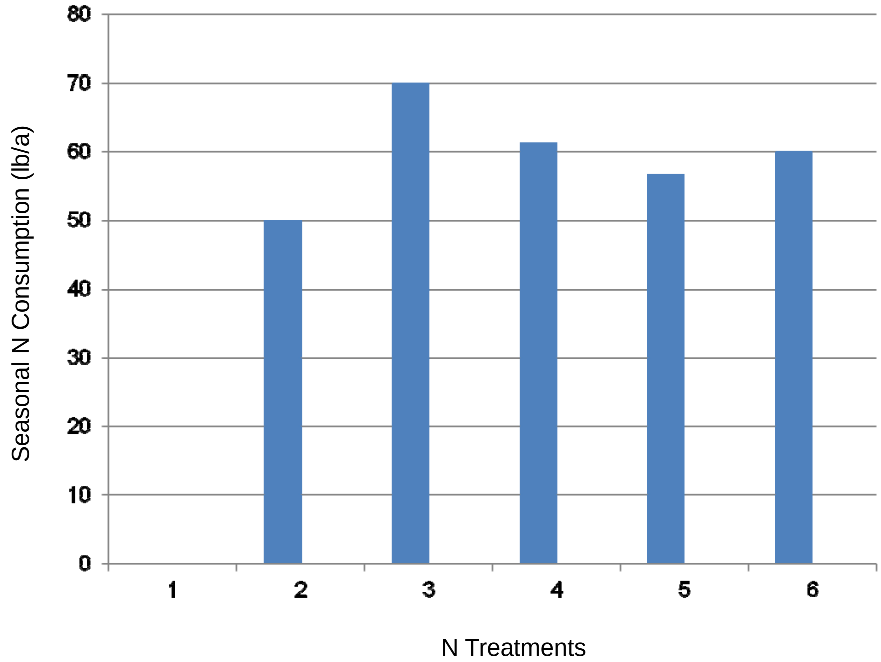

Fig. 3. Effects of N treatments on post-harvest soil inorganic N (total of NO_3^--N + NH_4^+-N) averaged over 2011 and 2012.