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 should possibly 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 to increase grower profitability due to substantially increased N prices. The objectives of this study for 2010 were to determine the optimal N fertilizer application rates for high-yielding cotton production systems in Tennessee and investigate the relationships among lint yield, canopy Normalized Differential Vegetation Index (NDVI), and leaf N. A field strip-plot experiment was conducted on five private farms in Fayette, Gibson, Haywood, Lake, and Lauderdale Counties in west Tennessee in 2010. Five N application rate treatments of 0, 40, 80, 120, and 160 lb N/acre were evaluated as side dress N in large field strip plots (38-ft wide running the length of the field) in a randomized complete block design with three replicates. Soil nitrate and ammonium prior to cotton planting and after harvest, leaf N at early bloom, and lint yields and quality at harvest were determined on an individual plot basis for all locations. The location in Gibson County was also used for precision N management research. Each strip plot at this location was divided into eight 100-ft long sub plots. Soil nitrate and ammonium prior to cotton planting and after harvest, canopy NDVI and leaf N at the early square and early, mid, and late bloom stages, and lint yields at harvest were measured on a sub plot basis. Results from the large strip-plot experiment showed applying 40 to 80 lb/a N via side dressing seemed to be adequate to meet plant N requirement during the mid season. Lint yield responses to N applications were statistically significant at Fayette, Haywood, and Lauderdale locations, and were nearly significant at Lake. Application of about 70 to 100 lb/a N (including pre-plant and side dress N) per season should be adequate for optimal cotton yields at these locations. The precision N experiment at Gibson showed weak correlations of lint yield with canopy NDVI and leaf N in 2010. Canopy NDVI was not a strong indicator of plant N nutrition during early square to late bloom. There was significant global spatial autocorrelation of residual lint yields (N treatment effects on yields excluded) within the test field based on Moran's I statistic. The LISA cluster map showed that there were some significant local clusters of residual lint yields within this test field. Overall, there was significant global and some significant local spatial dependence of lint yields relating to the characteristics of this test field.

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Introduction

Presently, nitrogen (N) fertilizers are recommended to be applied at 30-60 lb N/acre on bottom soils and 60-80 lb N/acre on upland soils 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 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 N management 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 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 Differential 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 about 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) investigate the relationship between lint yield and NDVI, and between NDVI and crop N nutrition status; and 3) if there is a significant relationship among cotton yield, NDVI, and crop N nutrition, then algorithms will 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 will be compared with the uniform-rate N application system in terms of N fertilizer use and lint yield. In 2010, our work focused on the Objectives 1 and 2.

Overall, if this project has been carried out successfully, it will provide accurate N fertilizer recommendations for high-yielding cotton production systems. It will also generate appropriate algorithms for in-season variable-rate N applications within a field on cotton. All these can significantly reduce N fertilizer consumption and improve cotton productivity, and thus increase grower profitability.

Materials and Methods

A field strip-plot experiment was conducted on five private farms in western Tennessee in 2010. The five cooperative farmers were Bill Walker (Fayette County), Jeff Dodd (Gibson County), Bradley Booth (Haywood County), John Lindamood (Lake County), and Eugene Pugh (Lauderdale County). The experiment in 2010 was conducted on the same field with the same plot layout as in 2009 at each location. The producer in Gibson County applied 40 lb/a N across the test field as pre-plant N in the form of calcium nitrate (27% N) before cotton planting. Nitrogen fertilizer at 20, 50, 30 lb/a N was applied to the test field as pre-plant N at Fayette, Haywood, and Lauderdale, respectively. A composite soil sample (10 cores) was taken at a depth of 2 ft. from each strip plot using a Concord hydraulic soil probe for estimating nitrate and ammonium in the soil profile from all locations in Fall 2009 or Spring 2010 prior to the pre-plant N application if any and initiation of side dress N treatments .

Five N application rate treatments of 0, 40, 80, 120, and 160 lb N/acre were evaluated as side dress N in large field strip plots (38-ft wide strips running the length of the field) at all five locations in a randomized complete block design with three replicates. The dates of cotton planting and N treatment implementation for all locations are presented in Tables 1 and 2. Cotton was planted in 38" rows at all locations. All locations were managed using the recommended best management practices except the N treatments (Tables 1 and 2). A composite leaf sample (10 blades + petioles) was collected from the most newly fully developed leaves at the early bloom stage on a strip plot basis from all locations (Tables 1 and 2); all of these leaf samples were analyzed for N concentrations using our own LECO Tru-Spec Analyzer. Cotton was harvested using the farmer's cotton picker in September or October at these locations. A composite seedcotton sample was collected from each strip plot for determining cotton fiber quality attributes. One replicate of cotton seed samples (5 samples per location) was collected from each location, and the five locations were treated as five replicates for seed N analyses. A post-harvest soil sample was collected at a 2-ft depth from Fayette, Gibson and Lake Counties. However, post-harvest soil sampling has not been completed at the other locations due to dry weather conditions. Analysis of variance (ANOVA) for each measurement was conducted with a randomized complete block model using SAS statistical software (SAS Institute, Cary, North Carolina). Treatment means were separated using the protected LSD method. Probability levels less than 0.05 were designated as significant. The N fertilizer rate for achieving maximum lint yields was estimated for each location using a quadratic partial regression model.

The location in Gibson County was also used for precision N management research. Each strip plot at this location was divided into eight 100-ft long sub plots. A composite soil sample was taken at a depth of 2-ft. for nitrate and ammonium in the soil profile on a sub plot basis prior to treatment initiation. Canopy NDVI data were collected from each sub plot 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 (Tables 1 and 2). A composite leaf sample (10 blades + petioles) was collected on a sub plot basis for four times at about the same dates when NDVI data were taken (Tables 1 and 2). All leaf samples were analyzed for N concentrations using our own LECO Tru-Spec Analyzer. Cotton harvest was completed on a sub plot basis in September for each sub plot by harvesting the central six rows of cotton. A post-harvest soil sample was collected for soil nitrate and ammonium at a 2-ft depth from each sub plot.

Correlations of lint yield with canopy NDVI and leaf N concentrations and the coefficient of variation (CV) for each strip plot were estimated using SAS Statistical Software v.9.1. Spatial variations of lint yield, canopy NDVI, leaf N, and post-harvest soil N within the experiment were visualized in GIS maps using ArcView v.9.3. A quadratic regression of lint yield was conducted using the classic and spatial error models in GeoDa 0.9.5-i (Beta) with a weight matrix created using a 2nd order queen's contiguity model that includes all lower contiguity orders. In order to evaluate the spatial dependence of lint yield relating to the characteristics of the test field (not to N treatments), we removed the effects of side dress N treatments on lint yields from the lint yields data using the spatial error model, and we used the residual lint yields (which were obtained in the spatial error model in GeoDa and in which N treatment effects on lint yields have been excluded) to make Moran’s I statistic and scatter plot and the Localized Indicators of Spatial Autocorrelation (LISA) cluster map. Moran’s I statistics and scatter plot and the LISA cluster map of residual lint yields were created in GeoDa using the 2nd order queen's contiguity model that includes all lower contiguity orders.

Results and Discussion

Large Strip-Plot Experiment

Mid-Season Leaf N Responses to Side Dress N Applications

Significant increases of early-bloom leaf N concentrations, ranging from 6 to 73%, with N applications were observed in 2010 compared with the 0 lb/a N control across all locations except Gibson (Table 3). Leaf N differences among the 40, 80, 120, and 160 lb/a treatments were statistically significant at Fayette and Haywood, but insignificant at other locations. Generally, the 2010 results suggest that applying 40 to 80 lb/a N via side dressing is adequate to meet plant N requirement during the mid season. It was out of our expectation that although 20 to 50 lb/a N was applied before planting at Fayette, Haywood, and Lauderdale locations, the pre-plant applied N did not seem to affect leaf N responses to side dress N applications relative to those at Lake without receiving any preplant N.

Lint Yield Responses to Side Dress N Applications

Lint yield responses to N applications were statistically significant at Fayette, Haywood, and Lauderdale locations, and were close to significant at Lake in 2010 (Table 4). The general patterns of lint yield responses to N application rates were similar across those locations. At Fayette, lint yields increased as N application rate went up from 0 to 80 lb/a; however, there was no further yield increases with the application of 120 or 160 lb/a. At Haywood and Lauderdale, applying 40 lb/a or above had significant yield increases over 0 lb/a; 40 lb/a produced statistically similar or even higher lint yield compared with 80, 120, and 160 lb/a, suggesting that 40 lb/a of side dress N is adequate for cotton production at these two locations. Because 50 and 30 lb/a N were applied before cotton planting at Haywood and Lauderdale, respectively, our results suggest 70 to 90 lb/a are needed for the maximum yields at these two locations. Overall, the application of about 70 to 100 lb/a N (including pre-plant and side dress N) per season should be adequate for optimal cotton yields at these locations in 2010, which indicates that the current N fertilizer recommendations (60 to 80 lb/a N for upland soils, and 30 to 60 lb/a N for bottom soils) by University of Tennessee may be a bit too low for cotton production in Tennessee.

Seed N Responses to Side Dress N Applications

Unlike leaf N, seed N responses to side dress N applications were statistically insignificant across the five locations in 2010 (Fig. 1). There were some numerical small increases in seed N concentration as N application rate went up from 0 to 120 lb/a; however, there was no further increase with the application of 160 lb/a.

Post-Harvest Soil N Responses to Side Dress N Applications

So far, post-harvest soil sampling has been completed at Fayette, Gibson and Lake locations, and has not been finished at other locations due to dry soil conditions. Post-harvest N responses to N applications were statistically significant at Lake, but were not significant at Fayette or Gibson (Table 5). At Lake, post-harvest soil N increased as N application rate went up from 0 to 160 lb/a. Applying 160 lb/a had significantly higher soil N content at harvest than application of 0, 40, or 80 lb/a.

Precision N Management Experiment

Correlations of Lint Yields with Canopy NDVI and Leaf N

The correlations of lint yield with canopy NDVI were statistically significant at early, mid, and late bloom stages (Table 6). The correlations of lint yield with leaf N were significant at early square and mid and late bloom stages (Table 6). There was no significant correlation of leaf N with canopy NDVI regardless of growth stage (Table 6). Overall, the determination coefficient (R^2) values were lower for the above correlations in 2010 compared with those in 2009; which suggests that the correlations of lint yields with canopy NDVI and leaf N vary with years.

Spatial Analyses

GIS Maps of lint yields, canopy NDVI, leaf N, and post-harvest soil N at Gibson are presented in Fig. 2 to 11, respectively. The lint yield map shows that spatial variations in lint yield did exist within most strip plots. It seemed lint yield had a better correlation with canopy NDVI at the early bloom stage (July 20) than other growth stages, which is in agreement with the relevant R^2 values in Table 6. The post harvest soil N map indicates that the side dress N treatments implemented early in the season did not show evident impacts on soil available N after cotton harvest, which suggests that residual N from the N treatments was ignorable in the soil after harvest.

In order to examine the spatial dependence of lint yields within the test field at Gibson location, we conducted a quadratic regression of lint yields with side dress N application rates using the classic model in the GeoDa software, and we observed significant spatial dependence of lint yields within the test field (data not presented). Then, the spatial error model in GeoDa was used to conduct the quadratic regression of lint yields with side dress N rates; the output was presented in Table 7. It shows that the quadratic relationship of lint yields with side dress N application rates was significant on a sub plot basis.

In order to visualize the spatial dependence of lint yield relating to the characteristics of the test field (not to N treatments), we used the residual lint yields (which were obtained in the spatial error model in GoeDa and in which N treatment effects on lint yields have been excluded) to make Moran's I statistic and scatter plot and LISA cluster map. Moran's I statistic and scatter plot and LISA cluster map are presented in Fig. 12, and 13, respectively.

Moran's I and scatter plot evaluates global spatial autocorrelation. Moran scatter plot provides a visual exploration of global spatial autocorrelation. The four quadrants in the Moran scatter plot provide a classification of four types of spatial autocorrelation: high-high and low-low for positive autocorrelation; low-high and high-low for negative spatial autocorrelation. The value listed at the top of the graph is the Moran's I statistic. Fig. 12 shows that there was significant ($p = 0.003$) spatial autocorrelation of residual lint yields (N treatment effects on yields excluded) within the tested field.

The LISA cluster map estimates local spatial autocorrelation. It contains information on only those locations that have significant spatial autocorrelation. Four types of spatial autocorrelations are colored in four different colors: dark red for high-high, dark blue for low-low, pink for high-low, and light blue for low-high. These four categories correspond to the four quadrants in the Moran scatter plot. The LISA cluster map in Fig. 13 shows that there were some significant local clusters of residual lint yields (N treatment effects on yields excluded) within this tested field. Specifically, there were six sub plots with high residual yields surrounded by high residual yield neighbors, two low residual yield sub plots were surrounded by low residual yield neighbors, seven sub plots with low residual yields were surrounded by low residual yield neighbors, and two high residual yield sub plots were surrounded by low residual yield neighbors.

Spatial Variations within Strip Plot

Coefficients of variation (CV) were generally low for canopy NDVI and leaf N within the strip plots at the early square and early, mid, and late bloom stages (Table 8). The CV values were greater with lint yields and postharvest soil N fertility (Table 8). Since all the sub plots within a strip plot received the identical N treatment, the CV value for each strip plot in Table 8 reflects the spatial variations within that strip plot. The CV results of 2010 showed the same trends as those of 2009.

Acknowledgments

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Table 1. Major operations performed for Crockett, Fayette, Haywood, Lake, and Lauderdale locations.

	Fayette	Haywood	Lake	Lauderdale
List of operations performed	**Date performed**	**Date performed**	**Date performed**	**Date performed**
Planting	5/15/10	5/8/10	4/29/10	5/27/10
Side-dressed liquid nitrogen treatments	6/15/10	6/14/10	6/16/10	6/18/10
Collected early-bloom leaf samples	7/16/10	7/14/10	7/16/10	7/27/10
Dried and ground all leaf samples	8/5/10	8/5/10	8/6/10	8/6/10
Harvested all strip plots for yield	9/29/10	10/8/10	9/17/10	10/19/10
Seed cotton samples pulled for lint quality analysis	9/29/10	10/8/10	9/17/10	10/19/10
Collected 2-ft. post-harvest soil samples	10/14/10		10/13/10	
Dried and ground soil samples	10/19/10		10/19/10	
Shipped soil samples for analysis	10/25/10		10/25/10	
Analyzed all leaf samples for N in lab.	11/3/10	11/3/10	11/3/10	11/3/10

Table 2. Major operations performed for Gibson Location.

List of operations performed	Date performed
Planted	5/5&14/10
Side dressed liquid nitrogen treatments	6/25/10
Collected early-square leaf samples	6/23/10
Recorded canopy NDVI @ early square	6/23/10
Collected early-bloom leaf samples	7/15/10
Recorded canopy NDVI @ early bloom	7/20/10
Collected mid-bloom leaf samples	8/2/10
Recorded canopy NDVI @ mid-bloom	8/3/10
Collected late-bloom leaf samples	8/16/10
Recorded canopy NDVI @ late-bloom	8/16/10
Dried and ground all sub-plot leaf samples	8/23-25-10
Shipped all leaf samples for analysis	9/17/10
Harvested center 6 rows of each 12 row sub-plot for yield	9/30/10
Collected Seed cotton samples for lint quality	9/30/10
Collected 2 ft. post-harvest soil samples	10/6/10
Dried and ground all soil samples	10/15/10
Shipped all soil samples for analysis	10/25/10

Table 3. Responses of early bloom leaf N concentrations to side dress N application rates. *

N rate	Fayette		Gibson		Haywood		Lake		Lauderdale	
(lb/a)	Conc. (%)	Increase (%)	Conc. (%)	Increase (%)	Conc. (%)	Increase (%)	Conc. (%)	Increase (%)	Conc. (%)	Increase (%)
0	2.58c		3.98		2.49c		3.94b		3.96b	
40	3.27b	26.7	4.15	4.3	3.75b	50.6	4.30a	9.1	4.39a	10.9
80	3.82a	48.1	4.05	1.8	3.98ab	59.8	4.44a	12.7	4.20ab	6.1
120	3.76a	45.7	4.14	4.0	4.22a	69.5	4.43a	12.4	4.43a	11.9
160	4.01a	55.4	4.05	1.8	4.30a	72.7	4.50a	14.2	4.34a	9.6
Sig.	<0.0001		0.3297		<0.0001		0.0110		0.0394	

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

Table 4. Lint yield responses to side dress N application rates.

N rate	Fayette		Gibson		Haywood		Lake		Lauderdale	
(lb/a)	lb/a	%	lb/a	%	lb/a	%	lb/a	%	lb/a	%
0	795.6d		807.7		920.6b		1072.6		950.2c	
40	845.0cd	6.2	862.1	6.7	1148.4a	24.7	1075.4	0.3	1101.1a	15.9
80	1022.2a	28.5	890.2	10.2	1250.1a	35.8	1201.5	12.0	1037.9b	9.2
120	915.6bc	15.1	928.0	14.9	1273.6a	38.3	1129.8	5.3	1058.2ab	11.4
160	991.7ab	24.6	932.0	15.4	1263.0a	37.2	1243.9	16.0	1023.2b	7.7
Sig.	0.0016		0.4929		0.0022		0.0682		0.0022	

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

Table 5. Post-harvest soil N (NH_4^+-N + NO_3^--N) responses to side dress N application rates.

N rate	Fayette		Gibson		Lake	
(lb/a)	ppm	%	ppm	%	ppm	%
0	1.70		5.30		5.30b	
40	1.73	1.8	5.93	11.9	5.30b	0.0
80	2.27	33.5	6.67	25.8	8.01b	51.1
120	2.60	52.9	12.07	127.7	9.77ab	84.3
160	2.30	35.3	10.43	96.8	13.23a	149.6
Sig.	0.1621		0.1436		0.0359	

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

Table 6. Correlations among lint yield, canopy NDVI, and leaf N at Gibson.

Dependent variable (Y)	Independent variable (X)	R^2	R	P
Lint yield	NDVI_6-23-10	0.022	0.148	0.1120
Lint yield	NDVI_7-20-10	0.246	0.496	<0.0001
Lint yield	NDVI_8-03-10	0.137	0.370	<0.0001
Lint yield	NDVI_8-16-10	0.162	0.402	<0.0001
Lint yield	Leaf N_6-23-10	0.064	0.253	0.0059
Lint yield	Leaf N_7-15-10	0.000	0.000	0.9841
Lint yield	Leaf N_8-02-10	0.199	0.446	<0.0001
Lint yield	Leaf N_8-16-10	0.037	0.192	0.0391
Leaf N_6-23-10	NDVI_6-23-10	0.015	0.122	0.1844
Leaf N_7-15-10	NDVI_7-20-10	0.012	0.110	0.2280
Leaf N_8-02-10	NDVI_8-03-10	0.012	0.110	0.2356
Leaf N_8-16-10	NDVI_8-16-10	0.017	0.130	0.1538

Table 7. Regression summary of output using spatial error model.

Variable	Coefficient	Std. Error	z-value	Probability
CONSTANT	77.02386	5.173978	14.88678	0.0000000
N	0.3346311	0.1363396	2.454393	0.0141123
N*N	-0.001784412	0.0007971619	-2.238456	0.0251913
LAMBDA	0.343574	0.1352886	2.539564	0.0110991

Table 8. Coefficient of variation (%) of canopy NDVI, leaf N, lint yield, and post-harvest soil N within strip plot at Gibson.

Strip plot	N rate	NDVI 6-23-10	NDVI 7-20-10	NDVI 8-3-10	NDVI 8-16-10	Leaf N 6-23-10	Leaf N 7-15-10	Leaf N 8-3-10	Leaf N 8-16-10	Yield	Post-harvest soil N
1	0	18.4	7	8.2	9.1	14	7.3	8.2	6.7	31.6	18
2	40	17.7	4.7	5.2	8.6	12.7	4.9	5.2	6	47.2	32.3
3	80	9.5	5.7	7	7.9	8.5	8.4	4.9	2.6	44.4	18
4	120	14.3	4	4.3	7.6	7.9	4.2	4.9	4.9	24.7	54.1
5	160	7.3	4.2	4.3	6.5	9.5	3.6	3.8	4	17.3	10.9
6	40	7.6	3.8	4.3	3.8	8.3	4.3	7	4.4	11.5	11.4
7	120	10	4.7	5.4	6.4	6.6	4.6	3.1	5.5	16.2	45.8
8	0	4.4	3.6	2.1	3.4	11.5	2.9	4.2	5.3	14.4	24
9	160	7.3	2.7	1.3	2.1	5.9	2.3	5.7	2.2	20.8	58.2
10	80	8.7	3.7	3.6	3.6	7.7	3.9	4.8	4.5	17.4	9.9
11	120	6.5	4.4	4.2	4.5	6.9	2.1	4.4	3	15	33.9
12	40	5.2	5.4	4.2	6.2	7.4	2.2	6.3	4.8	23.9	20.1
13	160	6.6	2.2	2	4.1	5.3	5.3	3.8	4.1	18.7	67
14	80	4.7	2.1	1.2	1.4	4.9	4	2.2	3.2	42.7	27.5
15	0	2.2	1.3	1.4	2.7	10.9	4.9	6.3	6.8	10.5	17.3

Fig. 1. Seed N responses to side dress N application rates.

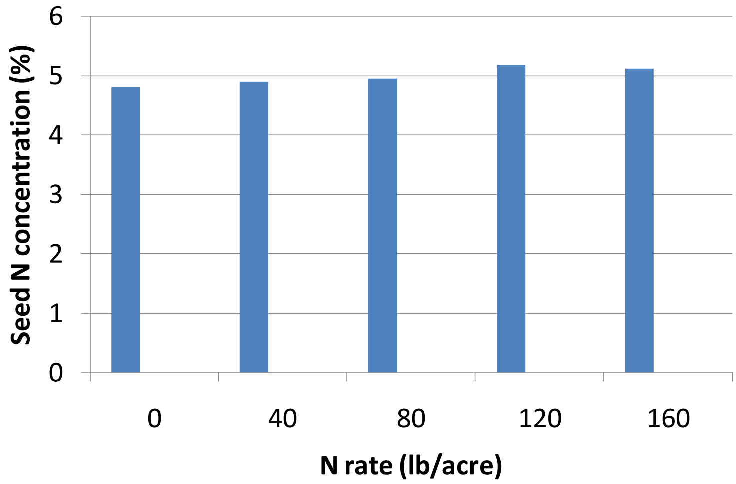
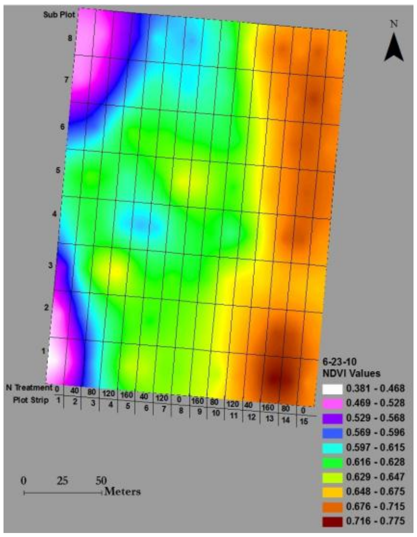
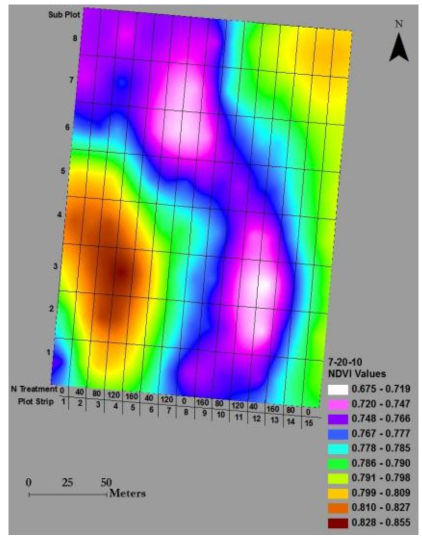
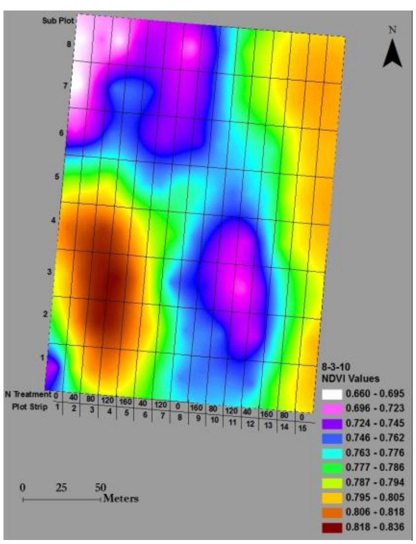
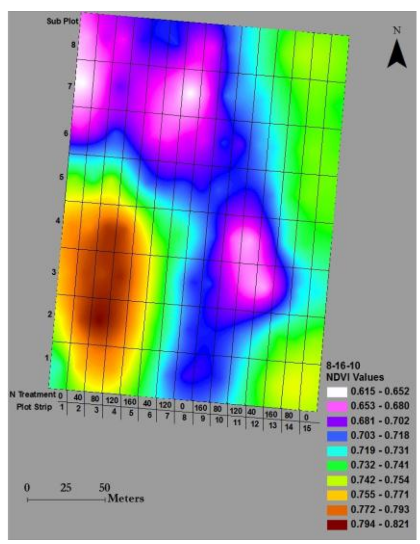


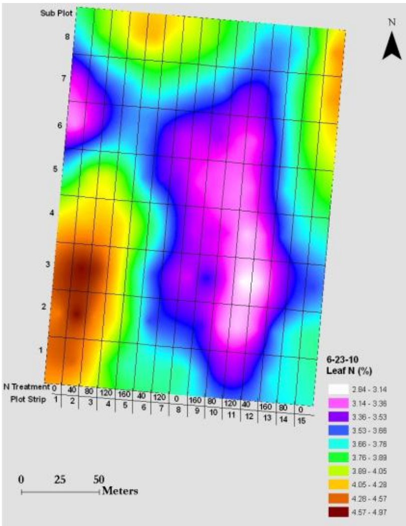
Fig. 2 to 11. ArcView GIS Maps of canopy NDVI, leaf N, lint yields, and post-harvest soil N at Gibson.

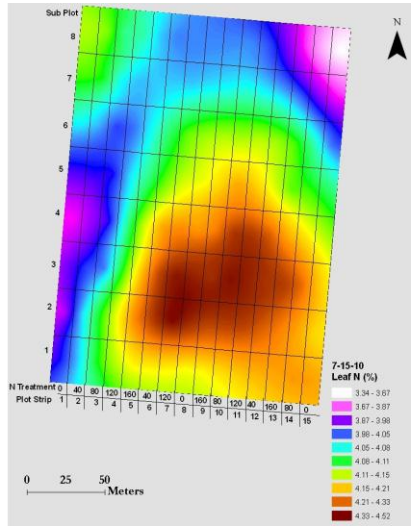


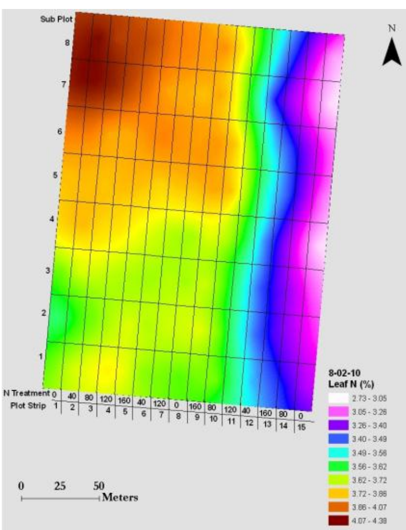


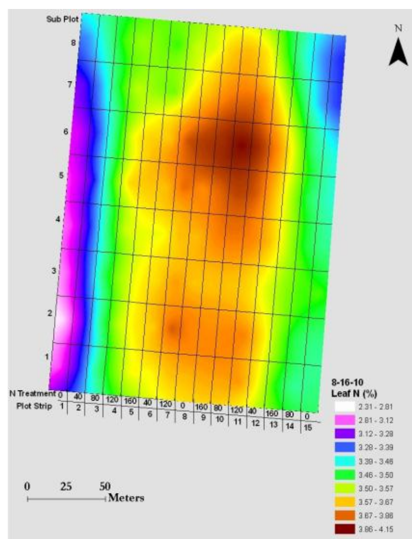


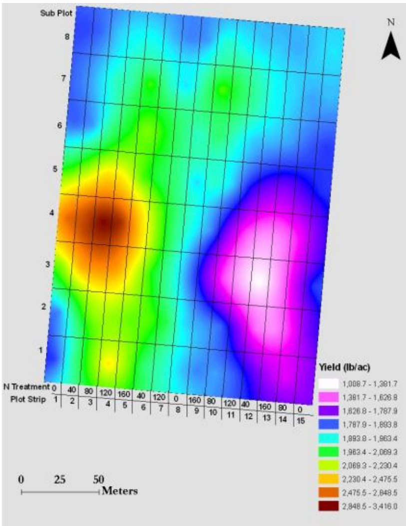



Sub Plot
8
7
6
5
4
3
2
1
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 25 50 Meters
6-23-10
Leaf N (%)
2.84 - 3.14
3.14 - 3.36
3.36 - 3.53
3.53 - 3.66
3.66 - 3.76
3.76 - 3.89
3.89 - 4.05
4.05 - 4.28
4.28 - 4.57
4.57 - 4.97

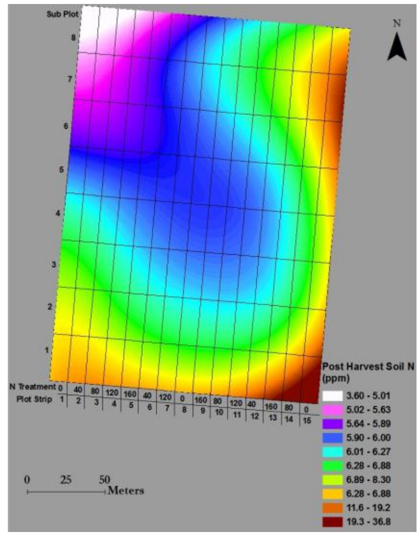

Sub Plot
8
7
6
5
4
3
2
1
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 25 50 Meters
7-15-10
Leaf N (%)
3.34 - 3.67
3.67 - 3.87
3.87 - 3.98
3.98 - 4.05
4.05 - 4.08
4.08 - 4.11
4.11 - 4.15
4.15 - 4.21
4.21 - 4.33
4.33 - 4.52


Sub Plot
8
7
6
5
4
3
2
1
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 25 50 Meters
8-02-10
Leaf N (%)
2.73 - 3.05
3.05 - 3.26
3.26 - 3.40
3.40 - 3.49
3.49 - 3.56
3.56 - 3.62
3.62 - 3.72
3.72 - 3.86
3.86 - 4.07
4.07 - 4.38


Sub Plot
8
7
6
5
4
3
2
1
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 25 50 Meters
8-16-10
Leaf N (%)
2.31 - 2.81
2.81 - 3.12
3.12 - 3.28
3.28 - 3.39
3.39 - 3.46
3.46 - 3.50
3.50 - 3.57
3.57 - 3.67
3.67 - 3.86
3.86 - 4.15



Sub Plot
8
7
6
5
4
3
2
1
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Yield (lb/ac)
1,008.7 - 1,381.7
1,381.7 - 1,626.8
1,626.8 - 1,787.9
1,787.9 - 1,893.8
1,893.8 - 1,963.4
1,963.4 - 2,069.3
2,069.3 - 2,230.4
2,230.4 - 2,475.5
2,475.5 - 2,848.5
2,848.5 - 3,416.0
0 25 50
Meters



Sub Plot
8
7
6
5
4
3
2
1
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Post Harvest Soil N (ppm)
3.60 - 5.01
5.02 - 5.63
5.64 - 5.89
5.90 - 6.00
6.01 - 6.27
6.28 - 6.88
6.89 - 8.30
6.28 - 6.88
11.6 - 19.2
19.3 - 36.8
0 25 50
Meters

Fig. 12. Moran's I and scatter plot of residual lint yield (N treatment effects on yields excluded) at Gibson.

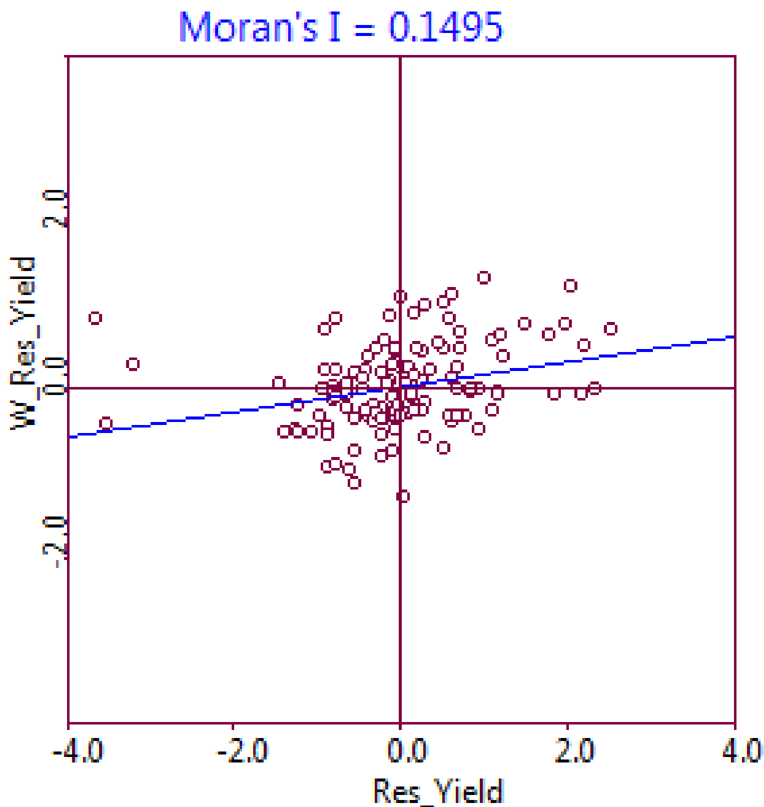


Fig. 13. LISA cluster map of lint yield (N treatment effects on yields excluded) at Gibson.