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 maybe need to be modified because of the significant yield increases resultant from new cotton cultivars and improved management practices. On the other hand, however, 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 2009 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 six private farms in Crockett, Fayette, Gibson, Haywood, Lake, and Lauderdale Counties in west Tennessee in 2009. 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 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 show applying 40 to 80 lb/a N via side dressing seems to be adequate to meet plant N requirement during the mid season. Lint yield responses to N applications were statistically significant at Fayette, Gibson, Haywood, Lake, and Lauderdale locations, and were nearly significant at Crockett. Application of about 80 lb/a N (including preplant and side dress N) per season should be adequate for optimal cotton yields at these locations. The precision N experiment at Gibson shows significant correlations of lint yield with canopy NDVI and leaf N at early, mid, and late bloom stages. Canopy NDVI is not a strong indicator of plant N nutrition during early to late bloom. There was no 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 shows that there were some significant local clusters of residual lint yields (N treatment effects on yields excluded) within this test field. Specifically, there were six sub plots with high residual yields surrounded by high residual yield neighbors, four high residual yield sub plots were surrounded by low residual yield neighbors, and two sub plots with low residual yields were surrounded by low residual yield neighbors. Overall, there was no significant global but 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, however, 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 (preplanting 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 2009, 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 six private farms (only five farms were proposed in the original proposal; we used six locations in case one of those locations may not work out well) in west Tennessee in 2009. The six cooperative farmers were Ryan Gorley (Crockett County), Bill Walker (Fayette County), Jeff Dodd (Gibson County), Bradley Booth (Haywood County), John Lindamood (Lake County), and Eugene Pugh (Lauderdale County). Cotton was the previous crop for all the locations. The producer in Gibson County applied 40 lb/a N across the test field as preplant N in the form of chicken litter before cotton planting. At Haywood, 50 lb/a N was applied to the test field as preplant N. No preplant N was applied at the other locations. 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 except Fayette (we did not have enough time to sample this location) prior to the initiation of side dress N treatments but after the preplant N application if any. In order to save the time on soil sampling, we also used these soil samples for the analyses of other nutrients/properties (such as pH, organic matter, P, K, etc.), although we know a 6 to 8 in. soil sample is usually used for testing these nutrients/properties.

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 six 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 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 November at each location. A composite seedcotton sample was collected from each strip plot for determining cotton fiber quality attributes. A post-harvest soil sample was collected at a 2-ft depth from Gibson and Haywood Counties. However, post-harvest soil sampling has not been finished at the other locations due to wet 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 and other nutrients/properties 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, 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 three times exactly at the same dates when NDVI data were taken. All these leaf samples were analyzed for N concentrations using our own LECO Tru-Spec Analyzer. The GPS positions for the field corners were measured on August 12 using a GPS hand held unit. Cotton harvest was completed on a sub plot basis in November 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. The pre-plant and post-harvest soil samples were analyzed for relevant soil nutrients/properties.

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, preplant soil 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

Initial Soil Fertility

The major fertility properties in the top 2 ft. of soil prior to treatment initiation at each location are presented in Table 3. These fields had soil pH ranging from 5.6 to 6.1, and organic matter of 0.8 to 1.3%. Gibson location had the highest available N (NO_3-N + NH_4-N) content of 15.4 ppm in the top 2 ft. of soil, while Crockett site having the lowest available soil N of 7.1 ppm. Estimated N release (ENR) from the soil varied with locations; it was 45.1 lb/a N at Crockett and 31.5 lb/a N at Lauderdale, representing the highest and lowest levels, respectively, out of all locations.

Mid-Season Leaf N Responses to Side Dress N Applications

Significant increases of early-bloom leaf N concentrations, ranging from 17 to 78%, with N applications were observed in 2009 compared with the 0 lb/a N control across all locations except Lauderdale (Table 4). Leaf N differences among the 40, 80, 120, and 160 lb/a treatments were statistically significant at Fayette and Gibson, but insignificant at other locations. Generally, the 2009 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 40 to 50 lb/a N was applied before planting at Haywood and Gibson locations, the preplant applied N did not seem to affect leaf N responses to side dress N applications relative to those at other locations without receiving any preplant N.

Lint Yield Responses to Side Dress N Applications

Lint yield responses to N applications were statistically significant at Fayette, Gibson, Haywood, Lake, and Lauderdale locations, and were close to significant at Crockett in 2009 (Table 5). The general patterns of lint yield responses to N application rates were similar across all locations. At Fayette, lint yields increased as N application rate went up from 0 to 80 lb/a; however, there was no further significant yield increases with the applications of 120 and 160 lb/a. At Crockett and Gibson, 80 lb/a N or above generally resulted in significantly higher yields over the 0 lb/a control. At Haywood, Lake, and Lauderdale, applying 40 lb/a or above had significant yield increases over 0 lb/a; 40 lb/a produced statistically similar lint yield as 80, 120, and 160 lb/a suggesting that 40 lb/a of side dress N is adequate for cotton production at these three locations. Because 40 and 50 lb/a N were applied before cotton planting at Gibson and Haywood, respectively, our results suggest 80 to 90 lb/a are needed for the maximum yields at these two locations. Overall, the application of about 80 lb/a N (including preplant and side dress N) per season should be adequate for optimal cotton yields at these locations in 2009, 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 still be appropriate for cotton production with yields below 1400 lb/a in Tennessee.

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, and became stronger as the season moved forward from early to late bloom (Table 6). The correlations of lint yield with leaf N were significant at early, mid, and late bloom stages, and became weaker as the season moved forward from early and mid bloom to late bloom (Table 6). Although correlations of leaf N with canopy NDVI were significant at early, mid, and late bloom stages, but the determination coefficient (R^2) was low; which suggests that canopy NDVI is not a strong indicator of plant N nutrition during early to late bloom (Table 6).

Spatial Analyses

GIS Maps of lint yields, canopy NDVI, leaf N, preplant soil N, and post-harvest soil N at Gibson are presented in Fig. 1 to 9, respectively. The lint yield map shows that although N application rate had impacts on lint yields, NDVI, and leaf N, spatial variations in lint yield did exist within most strip plots. It seemed lint yield had a better correlation with canopy NDVI at the late bloom stage (August 24) than early and mid bloom stages, which is in agreement with the relevant R^2 values in Table 6. The preplant soil N map shows that the variations of soil available N (NO_3-N + NH_4-N) was high within the test field prior to treatment initiation. 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 8. 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. 10, and 11, 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. 10 shows that there was no significant ($p= 0.623$) spatial autocorrelation of residual lint yields (N treatment effects on yields excluded) within the test 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. 11 shows that there were some significant local clusters of residual lint yields (N treatment effects on yields excluded) within this test field. Specifically, there were six sub plots with high residual yields surrounded by high residual yield neighbors, four high residual yield sub plots were surrounded by low residual yield neighbors, and two sub plots with low residual yields 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 early, mid, and late bloom stages (Table 7). The CV values were greater with preplant soil

N, postharvest soil N fertility, and lint yields, particularly with preplant soil N (Table 7). Since all the sub plots within a strip plot received the identical N treatment, the CV value for each strip plot in Table 7 reflects the spatial variations within that strip plot.

Acknowledgments

This project was supported in part by Cotton Incorporated Cooperative Agreement No. 09-497TN, managed by Dr. Bob Nichols. We appreciate the cooperative farmers: Ryan Gorley (Crockett County), Bill Walker **(**Fayette County), Jeff Dodd (Gibson County), Bradley Booth (Haywood County), John Lindamood (Lake County), and Eugene Pugh (Lauderdale County) for allowing us to conduct tests on their farms. We also appreciate the technical cooperation of the Textile Service Laboratory of Cotton Inc. Technical assistance was provided by Bob Sharp, James Warren, Tracy Bush, Matt Ross, Dereck Eison, and others.

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

	Crockett	Fayette	Haywood	Lake	Lauderdale
List of operations performed	**Date performed**	**Date performed**	**Date performed**	**Date performed**	**Date performed**
Planting	5/19/09		5/17/09	5/19/09	5/17/09
Collected 2-ft. pre-plant soil samples	6/2/09	N/A	6/19/09	6/3/09	6/18/09
Side address liquid nitrogen treatments	6/19/09		6/25/09	6/22/09	6/23/09
Collected early-bloom leaf samples	7/21/09	7/24/09	7/21/09	7/24/09	7/24/09
Dried and ground all leaf samples					
Harvested all strip plots for yield	11/3/09	11/20/09	11/5/09	10/26/09	11/14/09
Seed cotton samples pulled for lint quality analysis	11/3/09	11/20/09	11/5/09	10/26/09	11/14/09
Collected 2-ft. post-harvest soil samples			11/9/09		
Dried and ground all soil samples					
Shipped soil samples for analysis	12/14/09		12/14/09	12/14/09	12/14/09
Analyzed all leaf samples for % N in our lab.	12/15/09	12/15/09	12/15/09	12/15/09	12/15/09

Table 2. Major operations performed for Gibson Location.

List of operations performed	Date performed
Planting	5/8/09
Collected 2-ft. pre-plant soil samples	6/25/09
Side dress liquid nitrogen treatments	6/25/09
Collected early-bloom leaf samples	7/20/09
Collected mid-bloom leaf samples	8/4/09
Collected late-bloom leaf samples	8/24/09
Recorded canopy NDVI @ early-bloom	7/20/09
Recorded canopy NDVI @ mid-bloom	8/4/09
Recorded canopy NDVI @ late-bloom	8/24/09
Dried and ground all leaf samples	
Harvested center 6 rows of sub-plots for yield	11/6/09
Collected 2-ft. post-harvest soil samples	11/25/09
Dried and ground all soil samples	
Shipped soil samples for analysis	12/14/09
Analyzed all leaf samples for % N in our lab.	1/13/10

Table 3. Basic soil properties for test fields prior to the initiation of this study.

County	TEC (me/100g)	pH (H_2O)	OM (%)	NO_3-N (ppm)	NH_4-N (ppm)	ENR (lb/a)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	S (ppm)	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
Crockett	10.7	5.6	1.3	2.8	4.3	45.1	46.1	120.1	1114.9	109.0	24.4	0.5	187.9	145.5	1.2	1.2
Gibson	14.1	5.9	1.1	8.1	7.3	41.6	16.1	107.3	1483.6	250.5	29.0	0.4	145.5	135.7	1.1	1.7
Haywood	12.4	5.7	1.1	7.9	3.8	41.7	21.5	132.3	1132.9	222.9	38.8	0.5	174.7	138.3	1.2	0.9
Lake	16.5	6.1	1.1	8.0	3.9	41.7	45.0	174.3	2147.0	241.6	13.4	0.5	246.2	45.7	2.3	1.9
Lauderdale	11.8	5.5	0.8	7.0	3.9	31.5	35.7	88.6	1092.9	183.9	16.1	0.7	250.1	103.5	1.8	1.8

Table 4. Responses of early bloom leaf N concentrations to side dress N application rates. *

N rate	Crockett		Fayette		Gibson		Haywood		Lake		Lauderdale	
	Conc.	Increase	Conc.	Increase	Conc.	Increase	Conc.	Increase	Conc.	Increase	Conc.	Increase
(lb/a)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
0	2.24b		2.07c		2.78d		3.05b		3.5b		3.58	
40	3.34a	49.1	3.14b	51.7	3.54c	27.3	3.82a	25.2	4.35a	24.3	3.94	10.1
80	3.79a	69.2	3.25ab	57.0	3.56bc	28.1	4.18a	37.0	4.09a	16.9	3.93	9.8
120	3.83a	71.0	3.31ab	59.9	3.76a	35.3	4.1a	34.4	4.45a	27.1	3.86	7.8
160	3.74a	67.0	3.69a	78.3	3.69ab	32.7	4.36a	43.0	4.47a	27.7	3.97	10.9
Sig.	0.0008		0.0003		<0.0001		0.0097		0.0062		0.4753	

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

Table 5. Lint yield responses to side dress N application rates.

N rate	Crockett		Fayette		Gibson		Haywood		Lake		Lauderdale	
(lb/a)	lb/a	%	lb/a	%	lb/a	%	lb/a	%	lb/a	%	lb/a	%
0	951		877.7d		1045b		727b		1108.3c		1092.3c	
40	1152	21.1	993.7c	13.2	1242.7ab	18.9	1029a	41.5	1279.7a	15.5	1203.7ab	10.2
80	1278.7	34.5	1114ab	26.9	1442a	38.0	1069.7a	47.1	1284.3a	15.9	1209.7a	10.7
120	1143.7	20.3	1031bc	17.5	1352.3a	29.4	1158a	59.3	1165.3b	5.1	1152.3b	5.5
160	1222	28.5	1173a	33.6	1433a	37.1	1161.7a	59.8	1275a	15.0	1179.3ab	8.0
Sig.	0.0932		0.0009		0.0322		0.0086		<0.0001		0.0053	

* 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_7-20-09	0.278	0.528	<0.0001
Lint yield	NDVI_8-4-09	0.427	0.653	0.0602
Lint yield	NDVI_8-24-09	0.505	0.711	<0.0001
Lint yield	Leaf N_7-20-09	0.396	0.629	<0.0001
Lint yield	Leaf N_8-4-09	0.367	0.606	<0.0001
Lint yield	Leaf N_8-24-09	0.260	0.509	<0.0001
Leaf N_7-20-09	NDVI_7-20-09	0.192	0.438	0.0039
Leaf N_8-4-09	NDVI_8-4-09	0.355	0.596	0.0047
Leaf N_8-24-09	NDVI_8-24-09	0.114	0.338	0.0011

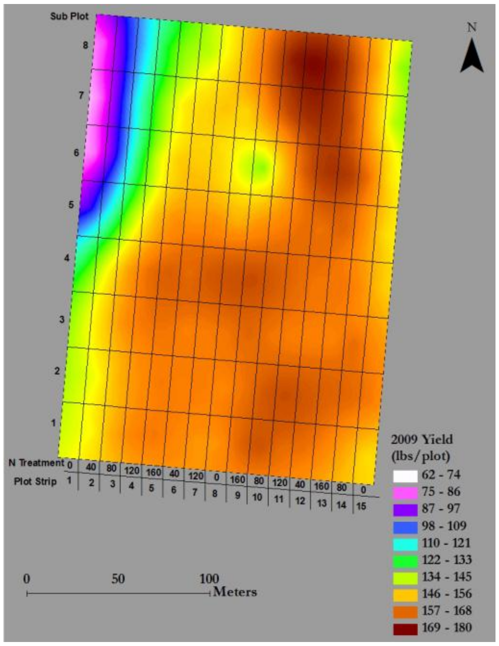
Table 7. Coefficient of variation (%) of preplant soil N, canopy NDVI, leaf N, lint yield, and post-harvest soil N within strip plot at Gibson.

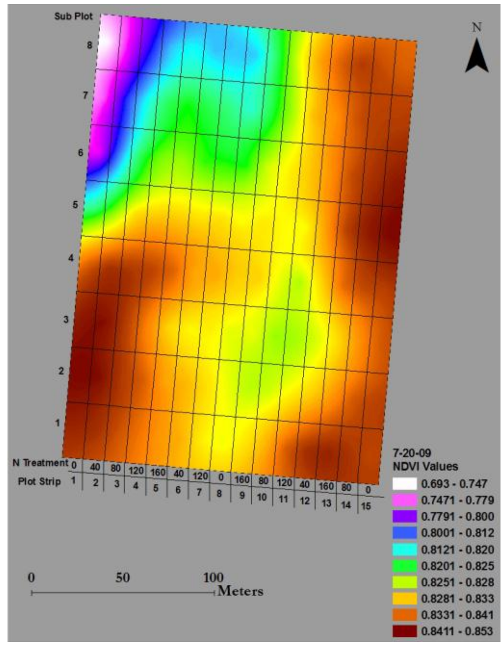
Strip plot	N rate	Preplant soil N	NDVI_7-20-09	NDVI_8-4-09	NDVI_8-24-09	Leaf N_7-20-09	Leaf N_8-4-09	Leaf N_8-24-09	Lint yield	Post harvest soil N
1	0	65.3	7.9	8.1	7.3	14.4	5.3	9.7	29.1	27.1
2	40	28.2	4.0	4.7	3.1	4.2	5.3	9.8	13.0	19.4
3	80	42.5	2.8	1.5	1.8	5.2	16.5	7.3	11.9	10.4
4	120	24.9	1.8	2.1	1.5	0.0	3.4	4.1	3.9	11.7
5	160	24	2.1	1.9	1.1	2.0	1.5	5.5	3.3	13.8
6	40	51.2	3.3	1.7	2.1	3.3	10.4	8.3	7.5	14.2
7	120	21.2	2.2	1.1	1.4	3.6	4.6	5.3	6.9	11.6
8	0	22.3	3.3	4.5	4.6	12.7	6.3	5.8	9.8	11.4
9	160	26.9	2.7	0.9	1.1	4.4	3.5	5.1	23.8	17.4
10	80	29.1	1.8	2.3	1.0	2.8	6.5	5.8	7.0	8.5
11	120	25.8	3.9	5.0	1.6	2.8	4.5	6.7	7.3	17.6
12	40	24	2.2	0.0	1.3	3.2	9.4	4.1	6.9	20.7
13	160	17.5	2.2	1.1	1.3	2.6	2.9	4.4	6.7	11.6
14	80	22.1	0.8	1.2	1.7	5.1	6.5	6.9	5.3	19.5
15	0	30.2	1.1	3.0	3.7	12.2	7.3	10.9	16.4	11.2

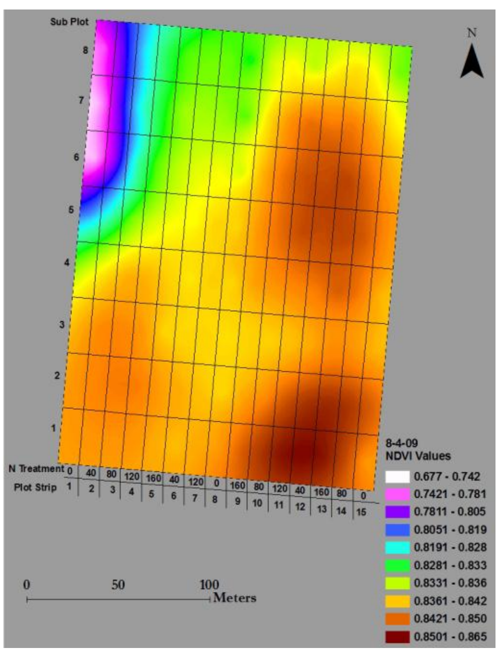
Table 8. Regression summary of output using spatial error model.

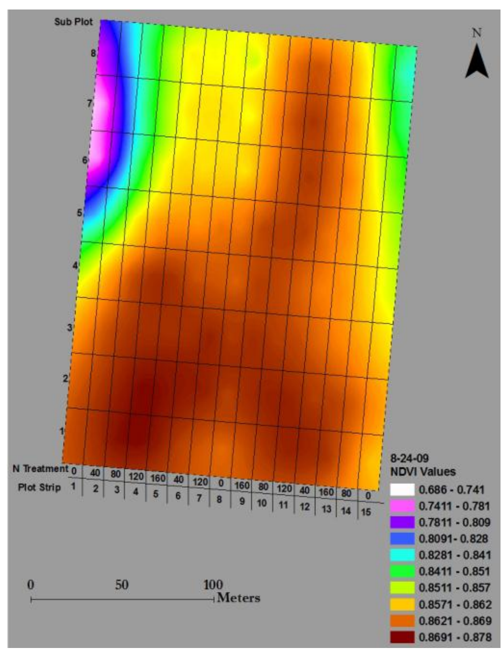
Variable	Coefficient	Std.Error	z-value	Probability
CONSTANT	111.945	8.384583	13.35129	0.0000000
N	0.6533547	0.1883389	3.469036	0.0005224
N*N	-0.002522847	0.001113112	-2.26648	0.0234219
LAMBDA	0.4996764	0.1757293	2.843444	0.0044630

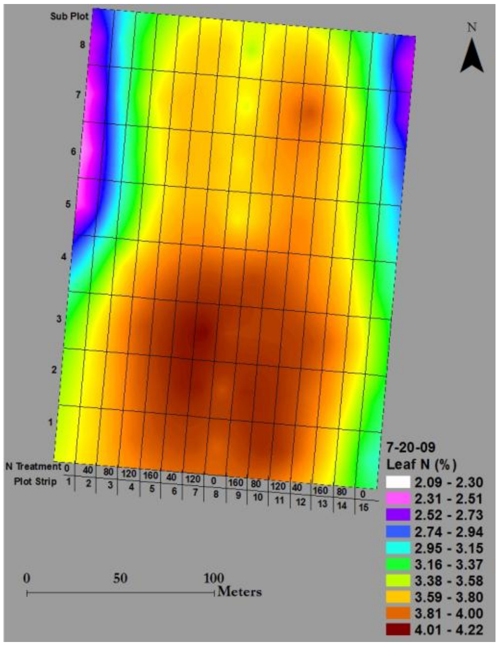
Fig. 1 to 9. Maps of lint yields, canopy NDVI, leaf N, preplant soil N, and post-harvest soil N at Gibson.



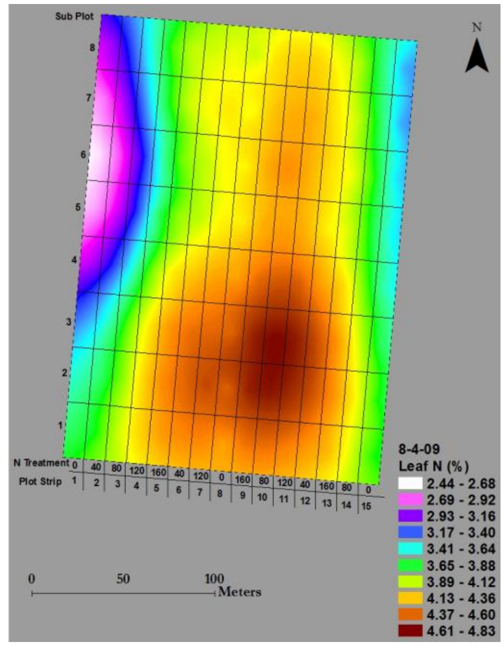




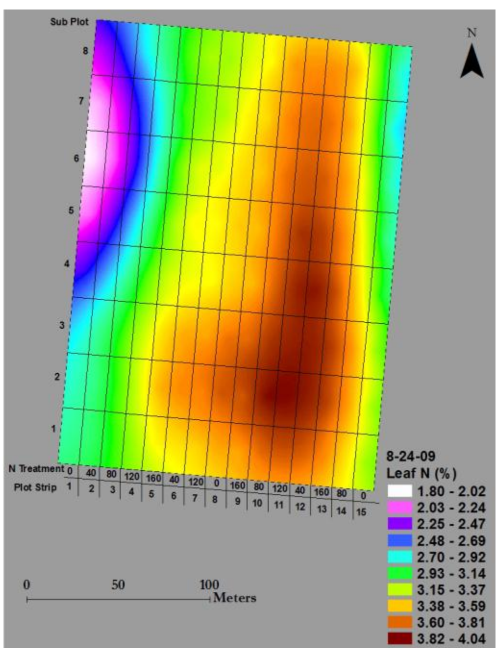




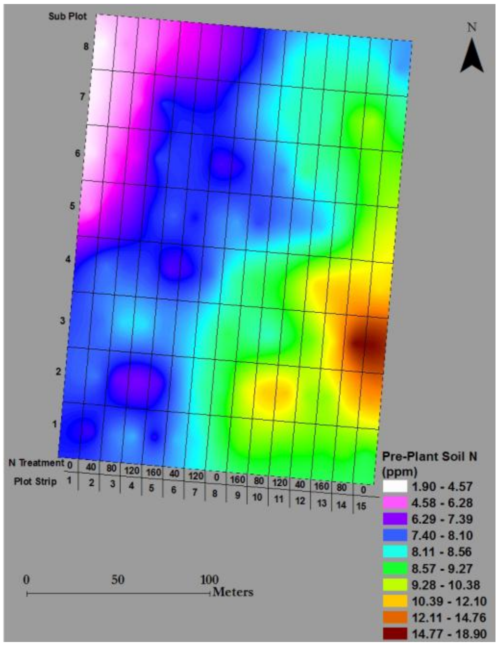
Sub Plot
N
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
0 50 100 Meters
7-20-09
Leaf N (%)
2.09 - 2.30
2.31 - 2.51
2.52 - 2.73
2.74 - 2.94
2.95 - 3.15
3.16 - 3.37
3.38 - 3.58
3.59 - 3.80
3.81 - 4.00
4.01 - 4.22



Sub Plot
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 50 100 Meters
8-4-09
Leaf N (%)
2.44 - 2.68
2.69 - 2.92
2.93 - 3.16
3.17 - 3.40
3.41 - 3.64
3.65 - 3.88
3.89 - 4.12
4.13 - 4.36
4.37 - 4.60
4.61 - 4.83



Sub Plot
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 50 100 Meters
8-24-09
Leaf N (%)
1.80 - 2.02
2.03 - 2.24
2.25 - 2.47
2.48 - 2.69
2.70 - 2.92
2.93 - 3.14
3.15 - 3.37
3.38 - 3.59
3.60 - 3.81
3.82 - 4.04


Sub Plot
8
7
6
5
4
3
2
1
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
N
0 50 100 Meters
Pre-Plant Soil N (ppm)
1.90 - 4.57
4.58 - 6.28
6.29 - 7.39
7.40 - 8.10
8.11 - 8.56
8.57 - 9.27
9.28 - 10.38
10.39 - 12.10
12.11 - 14.76
14.77 - 18.90

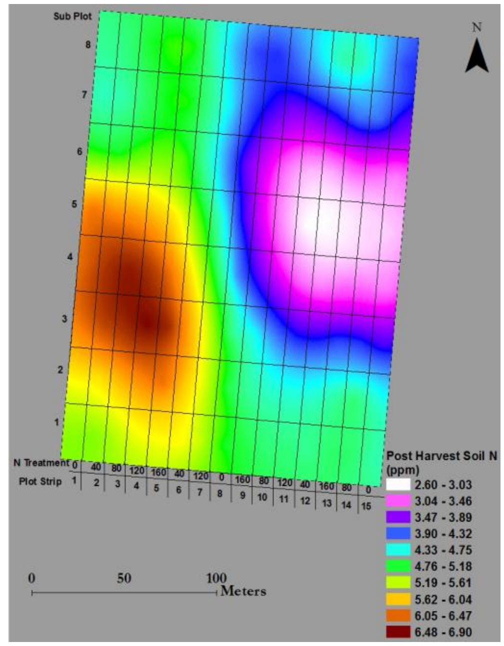

Sub Plot
8
7
6
5
4
3
2
1
N Treatment 0 40 80 120 160 40 120 0 160 80 120 40 160 80 0
Plot Strip 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
N
0 50 100 Meters
Post Harvest Soil N (ppm)
2.60 - 3.03
3.04 - 3.46
3.47 - 3.89
3.90 - 4.32
4.33 - 4.75
4.76 - 5.18
5.19 - 5.61
5.62 - 6.04
6.05 - 6.47
6.48 - 6.90

Fig. 10. Moran's I and scatter plot of residual lint yield (N treatment effects on yields excluded) at Gibson.

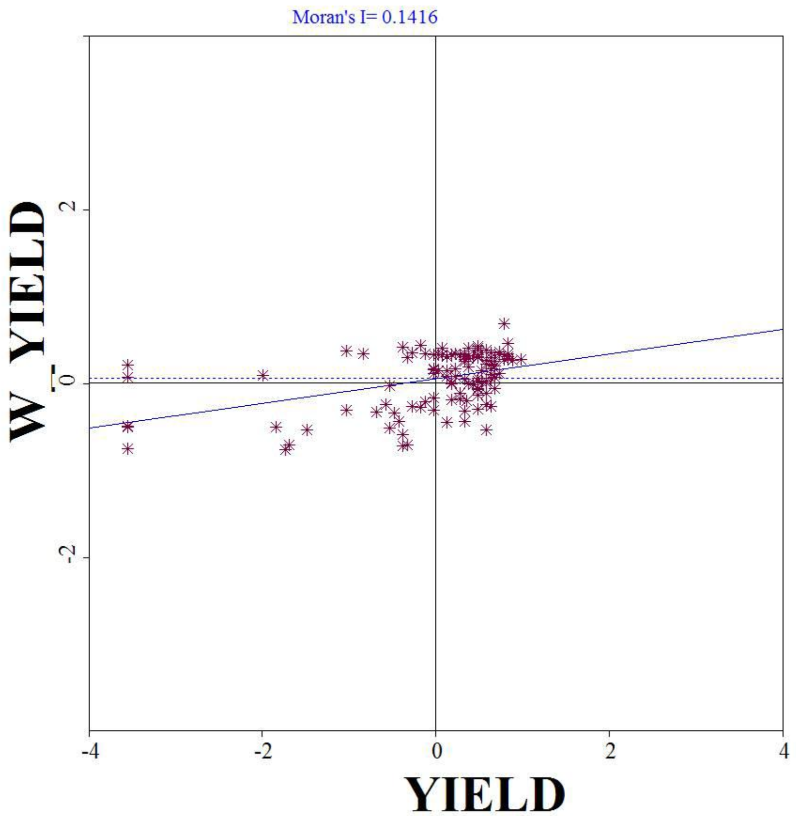


Fig. 11. LISA cluster map of lint yield (N treatment effects on yields excluded) at Gibson.