Optimizing Cotton Productivity and Nitrogen Use Efficiency

Current fluid nitrogen recommendations should possibly be modified.

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Summary: *Current fluid 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. Our field results showed statistically significant but weak correlations of lint yield with canopy NDVI readings no matter when NDVI values were collected. 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 yield (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 were significant global and some significant local spatial dependence of lint yields relating to the characteristics of this test field.*

Presently, N fluid fertilizers are recommended to be applied at 30 to 60 lbs/A on bottom soils and 60 to 80 lbs/A 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 improvement in management practices, there is a need to reevaluate 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 (NUE) 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 use 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 at 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 used on-vehicle, real-time optical sensing of crop canopy to generate Normalized Difference Vegetation Index (NDVI) to assess crop N nutritional 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 with this approach on wheat and corn has shown about a 15 percent increase in NUE, as well as some significant yield increases. So far, precision N research has been focused on wheat and corn. Little investigation has been documented on cotton.

Objectives

The objectives of this study were to:

- Determine the optimal N fertilizer application rates for high-yielding cotton production systems in Tennessee
- Estimate the spatial variations in lint yield, NDVI, leaf N concentration, and soil nitrate within a field
- Investigate the relationships between

lint yield and NDVI, and between NDVI and crop N nutrition status

- If there is a significant relationship between cotton yield and canopy NDVI, 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 compared with the uniform-rate N application system in terms of consumption and lint yield.

In 2011, our work focused on objectives 2 and 3.

Methodology

Location. Experiment was conducted on a private farm in Gibson County in western Tennessee.

Treatments. Five N application rates of 0, 40, 80, 120, and 160 lbs/A were evaluated as sidedress N.

Plots were 38-foot wide strips running the length of the field in a randomized complete block design with three replicates. Each strip plot in this test was divided into eight 100-foot-long sub plots.

Planting. Dates of cotton planting and N treatment implementation are presented in Table 1. Cotton was planted in 38-inch rows.

Summing up

Correlations. The correlations of lint yield with canopy NDVI were statistically significant at early square and early, mid, and late bloom stages (Table 2). The correlations of lint yield with leaf N were significant at mid and late bloom stages (Table 2). There was significant correlation of leaf N with canopy NDVI at mid and late bloom stages (Table 2). Overall the determination coefficient (R2) values for the above correlations in 2011 were similar to those in 2010, but lower than those in 2009, which suggests that the correlations of lint yields with canopy NDVI and leaf N vary with years.

GIS maps. Arc View GIS maps of canopy NDVI, leaf N, lint yields, and post-harvest soil N at Gibson are presented in Maps 1 through 10. The lint yield maps show that spatial variations in lint yield did exist within most strip plots. Visually, it seemed lint yield had a better correlation with canopy NDVI at late bloom (August 17) than the other growth stages. The post-harvest soil N map (Map 10) indicates that the sidedress N treatments implemented early in the season did not show evident impacts on soil nitrate

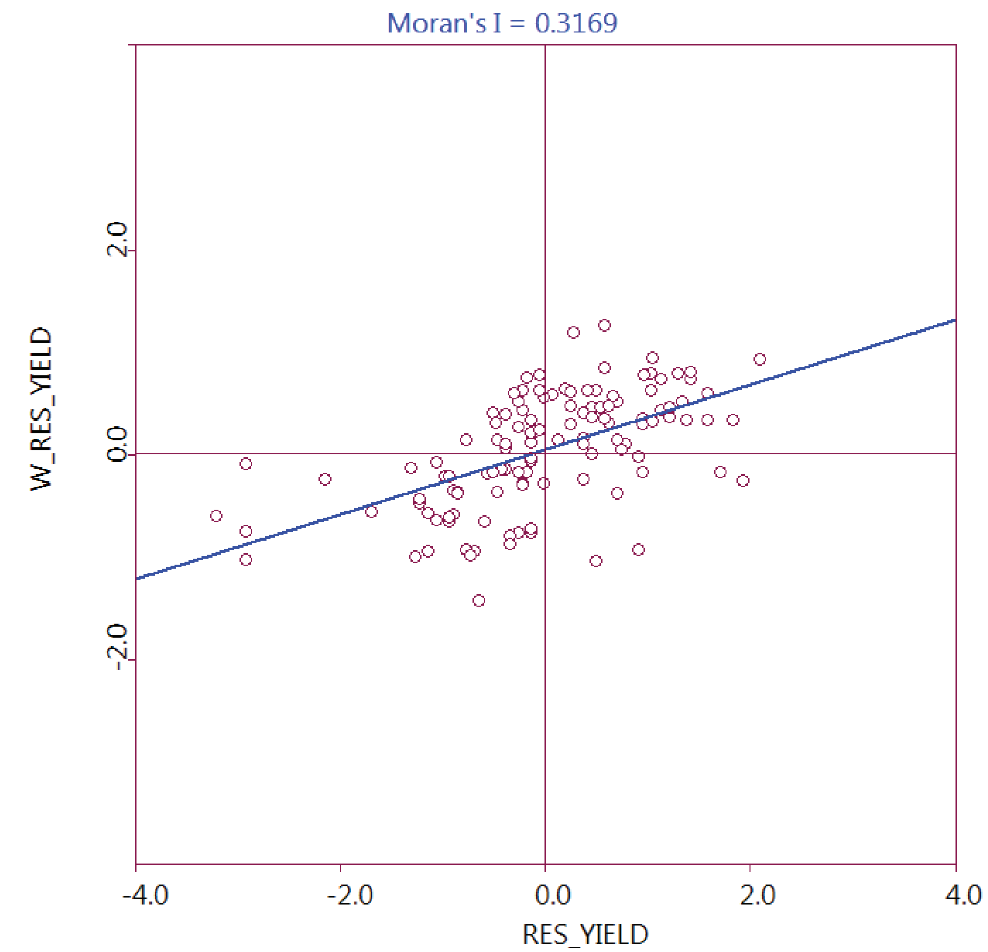


Figure 1: *Moran's I and scatter plot of residual lint yield (N treatment effects on yields excluded) at Gibson in 2011.*

Table 1. Major operations performed at Gibson in 2011.

List of operations performed	Date performed
Cotton planting	5/21/2011
Side dress liquid nitrogen treatments	6/15/2011
Collected early square leaf samples	7/5/2011
Collected early bloom leaf samples	7/27/2011
Collected mid-bloom leaf samples	8/4/2011
Collected late bloom leaf samples	8/17/2011
Recorded canopy NDVI at early square	7/5/2011
Recorded canopy NDVI at early bloom	7/27/2011
Recorded canopy NDVI at mid-bloom	8/4/2011
Recorded canopy NDVI at late bloom	8/17/2011
Dried and ground all leaf samples & shipped them for analyses	10/14/2011
Harvested center 6 rows of each 12-row plot	10/1/2011
Collected seed cotton samples for lint quality	10/1/2011
Collected 2 ft. post-harvest soil samples	11/10/2011
Dried and ground all soil samples & shipped them for analysis	12/6/2011

and ammonium after cotton harvest, which suggests that residual nitrate and ammonium from the N treatments were ignorable in the soil after harvest.

Spatial dependence. In order to examine the spatial dependence of lint yield within the test field, we conducted a quadratic regression of lint yields with sidedress 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 sidedress N rates; the output is presented in Table 3.

In order to visualize the spatial dependence of lint yield relating to the characteristics of the test field (not to N treatments), we used residual lint yields (which were obtained in the spatial error model in GeoDa and in which N treatment effects on lint yield had 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 shown in Figures 1 and 2.

Autocorrelation. Moran's I and scatter plot evaluate global spatial autocorrelation. Moran's I scatter plot provides a visual exploration of global spatial autocorrelation. The four quadrants of Moran's I 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 Moran's I statistic. Figure 1 shows that there was significant (p = 0.001) spatial autocorrelation of residual lint yields (N treatment effects on yields excluded) within the tested field.

The LISA cluster map estimates local 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. The LISA cluster map in Figure 2 shows that there were some significant local clusters of residual lint yields (N treatment effects on yield excluded) within these significant local clusters of residual lint yields (N treatment effects on yields excluded) within this tested field. Specifically, there were eighteen sub plots with high residual yields surrounded by high

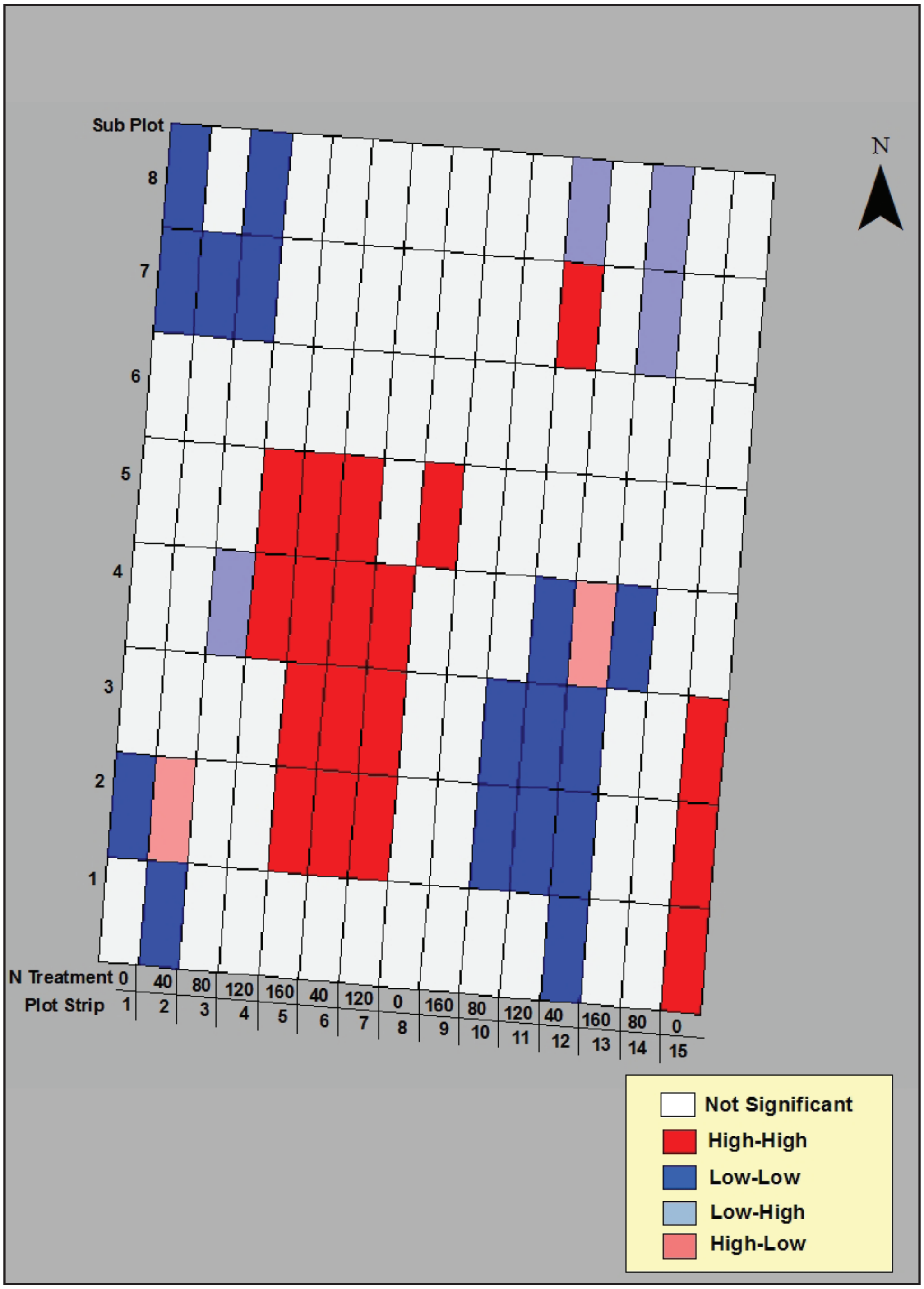
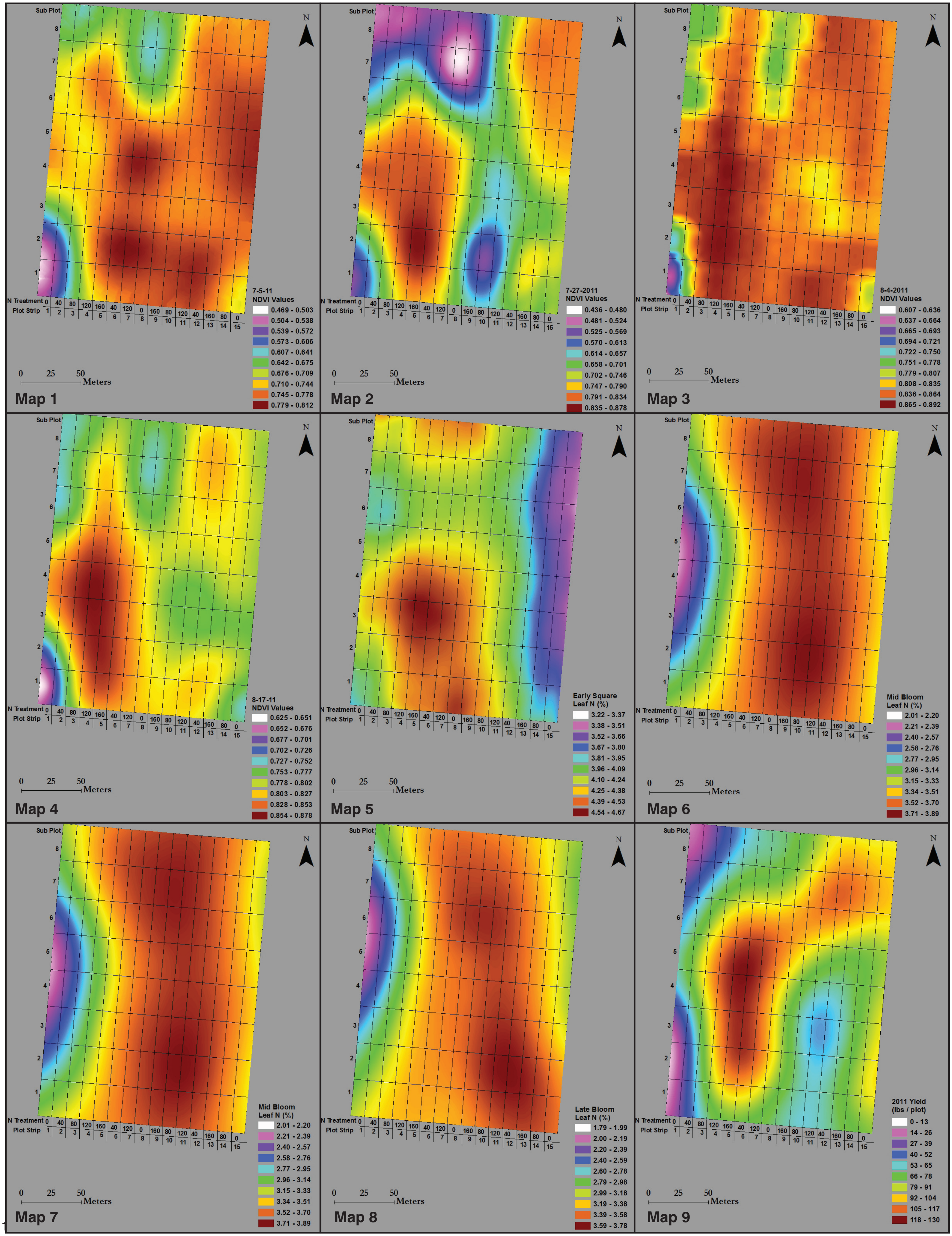
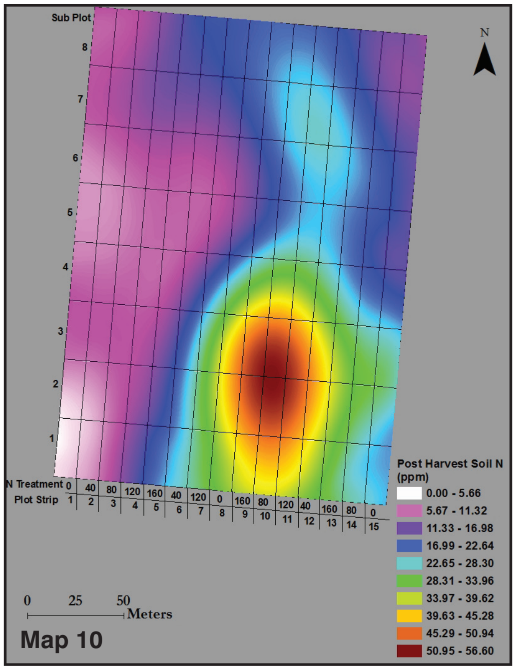


Figure 2: *LISA cluster map of lint yield (N treatment effects on yields excluded) at Gibson in 2011.*

Table 2. Correlations among lint yield, canopy NDVI, and leaf N concentration at Gibson in 2011.

Dependent variable (Y)	Independent variable (X)	R2	R	P
Lint yield	NDVI_7-5-11	0.13	0.36	<0.0001
Lint yield	NDVI_7-27-11	0.18	0.42	<0.0001
Lint yield	NDVI_8-4-11	0.29	0.54	<0.0001
Lint yield	NDVI_8-17-11	0.26	0.51	<0.0001
Lint yield	Leaf N_7-5-11	0.02	0.14	0.114
Lint yield	Leaf N_7-27-11	0.01	0.1	0.193
Lint yield	Leaf N_8-4-11	0.05	0.22	0.024
Lint yield	Leaf N_8-17-11	0.04	0.2	0.021
Leaf N_7-5-11	NDVI_7-5-11	0.01	0.1	0.195
Leaf N_7-27-11	NDVI_7-27-11	0	0	0.994
Leaf N_8-4-11	NDVI_8-4-11	0.05	0.22	0.018
Leaf N_8-17-11	NDVI_8-17-11	0.08	0.28	0.002


Map 1
7-5-11
NDVI Values
0.469 - 0.503
0.504 - 0.538
0.539 - 0.572
0.573 - 0.606
0.607 - 0.641
0.642 - 0.675
0.676 - 0.709
0.710 - 0.744
0.745 - 0.778
0.779 - 0.812
Map 2
7-27-2011
NDVI Values
0.436 - 0.480
0.481 - 0.524
0.525 - 0.569
0.570 - 0.613
0.614 - 0.657
0.658 - 0.701
0.702 - 0.746
0.747 - 0.790
0.791 - 0.834
0.835 - 0.878
Map 3
8-4-2011
NDVI Values
0.607 - 0.636
0.637 - 0.664
0.665 - 0.693
0.694 - 0.721
0.722 - 0.750
0.751 - 0.778
0.779 - 0.807
0.808 - 0.835
0.836 - 0.864
0.865 - 0.892
Map 4
8-17-11
NDVI Values
0.625 - 0.651
0.652 - 0.676
0.677 - 0.701
0.702 - 0.726
0.727 - 0.752
0.753 - 0.777
0.778 - 0.802
0.803 - 0.827
0.828 - 0.853
0.854 - 0.878
Map 5
Early Square
Leaf N (%)
3.22 - 3.37
3.38 - 3.51
3.52 - 3.66
3.67 - 3.80
3.81 - 3.95
3.96 - 4.09
4.10 - 4.24
4.25 - 4.38
4.39 - 4.53
4.54 - 4.67
Map 6
Mid Bloom
Leaf N (%)
2.01 - 2.20
2.21 - 2.39
2.40 - 2.57
2.58 - 2.76
2.77 - 2.95
2.96 - 3.14
3.15 - 3.33
3.34 - 3.51
3.52 - 3.70
3.71 - 3.89
Map 7
Mid Bloom
Leaf N (%)
2.01 - 2.20
2.21 - 2.39
2.40 - 2.57
2.58 - 2.76
2.77 - 2.95
2.96 - 3.14
3.15 - 3.33
3.34 - 3.51
3.52 - 3.70
3.71 - 3.89
Map 8
Late Bloom
Leaf N (%)
1.79 - 1.99
2.00 - 2.19
2.20 - 2.39
2.40 - 2.59
2.60 - 2.78
2.79 - 2.98
2.99 - 3.18
3.19 - 3.38
3.39 - 3.58
3.59 - 3.78
Map 9
2011 Yield
(lbs / plot)
0 - 13
14 - 26
27 - 39
40 - 52
53 - 65
66 - 78
79 - 91
92 - 104
105 - 117
118 - 130
Sub Plot
N Treatment
Plot Strip
0 25 50 Meters
N



Map 10

residual yield neighbors, sixteen low residual yield sub plots were surrounded by low residual yield neighbors, four sub plots with low residual yields were surrounded by high residual yield neighbors, and two high residual yield sub plots were surrounded by low residual yield neighbors.

Spatial variations. Coefficients of variation (CV) were generally low for canopy NDVI and leaf N within each strip plot at the early square and early, mid, and late bloom stages (Table 4).

The CV values were greater with lint yields and post-harvest soil nitrate and ammonium (Table 4). Since all the sub plots within a strip plot received identical N treatments, the CV value for each strip plot in Table 4 reflects the spatial variations within that strip plot. The CV results of 2011 showed the same trends as those of 2009 and 2010.

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Table 3. Regression summary of output using spatial error model at Gibson in 2011.

Variable	Coefficient	Std. Error	z-value	Probability
CONSTANT	66.803	6.406	10.428	0.000
N	0.281	0.120	2.344	0.019
N*N	-0.001	0.001	-1.201	0.230
LAMBDA	0.666	0.090	7.401	0.000

Table 4. Coefficient of variation (%) in canopy NDVI, leaf N, lint yield, and post-harvest soil N within each strip plot at Gibson in 2011.

		NDVI	NDVI	NDVI	NDVI	Leaf N	Leaf N	Leaf N	Leaf N		Post-harvest
Strip plot	N rate	7/5/2011	7/27/2011	8/4/2011	8/17/2011	7/5/2011	7/27/2011	8/4/2011	8/17/2011	Yield	soil N
1	0	19.2	10.1	11.3	9.3	8.3	13.1	14.8	18.1	5.6	79.7
2	40	10.3	7.5	5.6	3.6	5.4	8.2	16.3	11.3	23.2	37.5
3	80	4.3	4.2	3.2	2.7	5.3	7	7.5	5.1	17.5	34.9
4	120	6.1	7	1.5	1	7.5	4.7	6.7	6.4	13.7	58.7
5	160	2.8	2.2	1.7	1.4	2.4	5.8	4.3	3.3	9.6	60.3
6	40	5.8	8.6	2.9	2.1	4.3	3.8	3.7	6.6	29.3	51.1
7	120	18	13.8	6.8	5.3	6.3	3.1	3.1	5.7	27	49.9
8	0	6.1	5.1	2.4	1.2	5.6	6.1	7.7	8.7	19.5	59.8
9	160	5.1	4	3	1.9	3.9	5.5	3	4.5	20.1	103.2
10	80	4.4	19.7	2.2	1.9	3.2	9.2	2.2	4.7	20.3	53.9
11	120	1.6	3.4	3	1.9	3.2	8.6	3.9	3.9	13.4	79.3
12	40	3.8	3.9	2.8	2.3	4.4	10.5	2.6	8.3	36.3	59.2
13	160	2.1	1.8	1.5	1.3	4.5	4.8	3.6	4.9	24	40.8
14	80	3.4	4.9	1	1	2.9	3.5	4.2	5	19	72.8
15	0	7.6	5.4	2.9	3	4	7	3.9	9.4	9.1	22