USING REMOTE SENSING IN INSECT PEST MANAGEMENT?

Scott D. Stewart, Dorgelis Villarroel and Alex Thomasson
Mississippi Agricultural and Forestry Experiment Station
Mississippi State University
Mississippi State, MS

Abstract

Spectral reflectance values from multispectral images of cotton fields across two locations were compared with growth parameters, arthropod populations, and each other. Remotely sensed imagery was predictive of certain plant growth parameters such as height, total nodes, and numbers of bolls. Insect pest populations were generally too low for meaningful comparisons of reflectance values and density. There was a weak, but significant, relationship between the reflectance of values of some wavebands (e.g., 550 nm) and aphid density. Reflectance of 675 and 695 nm wavebands were highly correlated with each other. The strength of the relationships between other wavebands varied, depending upon whether comparisons were done within or across locations. Individual reflectance values of wavebands generally correlated with themselves for imagery collected on different dates; however, the strength of these relationships was variable.

Introduction

Aerial (airplane-based) or satellite imagery of cotton fields can provide information about the crop with potential for use by pest managers. For example, research has indicated that multispectral imagery, measuring the reflectance intensity of only 3-4 color wavelengths, can be used to classify the vigor of cotton growth. In turn, tarnished plant bug populations tend to be greater in vigorously growing cotton (Willers and Akins 2000). This relationship is currently being used to help monitor plant bug population in cotton. The same information can be used to build insecticide treatment prescriptions to cotton, based on geocorrected imagery, in a spatially variable manner (Willers et al. 2000). The possibility that remotely sensed imagery of crops can be used to predict the distributions of at least some arthropod populations has been demonstrated. However, the combined use of global positioning system (GPS) technology and remote sensing is primarily in its exploratory stage. Baseline data is still needed that relates color reflectance values observed in imagery to crop phenology and arthropod populations.

The "color" of a cotton field as measured by remotely sensed imagery includes the crop itself and background components such as soil and non-crop vegetation. A typical spectral profile of cotton (with little background interference) and bare soil is shown in Figure 1. Cotton vegetation typically has relatively low reflectance at wavelengths less than 700 nm, with a small peak of reflectance in the green wavebands and high near infrared (NIR) reflectance. Bare soil has a relatively linear reflectance profile, often with higher reflectance than cotton at wavelengths below 700 and lower above 700 nm. Early in the growing season when plants are small, the spectral signature of a cotton field is dominated by the background (soil) reflectance. As the crop grows, plants become a more dominant feature of the crop's spectral signature.

With multispectral imagery, only small parts of the spectral profile are measured (e.g., 550 nm = green, 675 nm = red, 840 nm = near infrared). NDVI (or normalized difference vegetation index) is often used to quantify the relative amount of foliage within a crop. It is calculated using the relative reflectance values of a red and a near infrared (NIR) wavelength as follows: NDVI = (NIR - red)/(NIR + red). Thus, if NIR reflectance increases (or decreases less) relative to red reflectance, so does the NDVI. Because vegetation typically has high NIR reflectance, and because plants have low red reflectance relative to NIR and soil, higher NDVI values result as vegetation increases. We expect low vigor areas of a cotton field to have relatively low NDVI values.

In this paper, we have related some crop growth parameters to color reflectance intensities measured with multispectral, remotely sensed imagery. Insect population were light in the study areas, so only limited data is presented about how imagery correlated with the densities of pest populations. Information is also presented about how the reflectance of individual color bands correlated with each other and across dates.

Material and Methods

Multispectral imagery was collected from two study areas in 2001. The first study area was of a farm located in Noxubee County, near Macon, MS and consisted of approximately 1,200 acres of cotton, corn, and soybean. At this location, our study was confined to three cotton fields comprising about 500 acres. All fields were Bt cotton planted in the first week of May and were maintained according to normal grower practices. The second study area was a 20-acre field of cotton located on the Plant Science Research Farm, Oktibbeha County, Mississippi State, MS. This field consisted of non-Bt cotton (BXN47, Stoneville Pedigree Seed Company) planted on three different dates (April 25, May 11, and June 27). This field was also maintained according to normal agronomic practices.

Multispectral images were collected by airplane using a RDACS camera operated by ITD-Spectral Visions. The aircraft was flown at an altitude of 6,000 feet, rendering a spatial resolution of about 2.0 m per pixel. Spectral reflectance was measured for four wavebands (550 ± 5, 675 ± 5, 695 ± 5, and 840 ± 5 nm). We received band-to-band registered images, and geocorrection and image analyses were done using Imagine software (ERDAS, Atlanta, GA).

Within each field (3 in the first study area, 1 in the second study area), 12-21 waypoints were selected (Figs. 2 and 3). Each waypoint represented about 9 pixels (i.e., 6 m X 6 m). Based on differences that were apparent in the imagery, we chose waypoints in the fields that represented a range of reflectance values. Ground-truthing data such as plant growth parameters and insect populations were then collected from these points during the growing season at irregular intervals from June until harvest. Imagery was collected on three dates including 6/18 (Noxubee Co. only), 7/05, and 7/17. After the season, digital reflectance values for the pixels surrounding each waypoint were determined for each wavelength. These uncorrected numbers were used in analyses. Two different NDVI's were calculated using reflectance values from the two red wavebands (i.e., 675 nm for NDVI 1, and 695 nm for NDVI 2) and the NIR waveband.

Plant growth data included plant height, total numbers of nodes, and counts of total bolls. On each sampling date, counts were made of five randomly selected plants within a 10 m perimeter of each waypoint. Total bolls per meter were counted for 1 or 2 meters of row within the same area. Yield and soil nutrient data were also collected but will not be discussed in this paper.

Insect data were also collected around each waypoint. This included numbers of heliothine eggs and larvae (tobacco budworm and bollworm) on 10-20 plants, tarnished plant bugs and big-eyed bugs per 25 sweeps or per two drop cloths, and numbers of aphids per leaf on 5-10 leaves per waypoint. Other data on arthropod populations were also recorded, but populations were too low to justify analyses.

For analyses, we used linear regression procedures (Proc Reg, SAS Institute 1998) to correlate the above data (from selected sample dates) with the reflectance values for individual wavebands and for the NDVI values. For some data, we also used stepwise regression to identify which of the four wavebands statistically contributed to the fit of the various models. In most cases, we only did regressions for data collected within a location, rather than across location (i.e., Oktibbeha and Noxubee Co.). This prevented identifying a relationship between reflectance values and other data that were only the result of location effects. Within a date, we also correlated various wavebands with each other. This provides information about the usefulness of various waveband sensors used to collect the imagery. We also regressed each individual waveband on itself, across dates, to determine if reflectance values collected on one date were predictive of values on other dates.

Results and Discussion

Across all dates and locations, the range of reflectance values were 29.2-152.0 (550 nm), 17.4-136.2 (675 nm), 20.4-140.0 (695 nm), 152.0-62.4 (840 nm). NDVI values ranged from -0.13-0.70 (NDVI 1) and -0.06-0.66 (NDVI 2). One must be careful when comparing uncorrected reflectance values across dates because atmospheric conditions can affect these values. However, as expected, we observed that NDVI values increased significantly from mid June (6/18) to July (7/05 and 7/17 imagery dates, Table 1). The reflectance values of all individual wavebands decreased after 6/18. However, the percentage reduction of the 840 nm waveband was less than that of the red wavebands; thus explaining why NDVI values increased.

Remotely sensed imagery was predictive of plant height at the various waypoints (Tables 2 and 3). This was especially true at the Oktibbeha County location where there were three distinct planting dates. Thus, imagery data was useful in distinguishing among the three planting dates in this field. At the second location, where all fields were planted at about the same time, there was less correlation between reflectance values and plant height. This is not surprising given that plants at the location were relatively similar in phenology,. Generally, taller plants had higher NDVI values, higher reflectance at 840 nm, and lower reflectance in the other wavebands (although correlation with the green waveband was relatively poor). Imagery also correlated with total node counts in a manner similar to plant height (data not shown). This is to be expected since weanticipated, and observed, that plant height and total nodes were positively correlated, especially at the location with multiple planting dates.

At the Oktibbeha County location, there was a good relationship of boll counts with reflectance values, particularly the green and red wavebands (Tables 4 and 5). This is to be expected because there were distinct differences in boll counts among the three planting dates (data not shown), and as already mentioned, imagery could be used to distinguish between these planting dates. The 840 nm waveband was the best predictor of numbers of bolls per meter at the Noxubee county location, but the relationship was weak ($R^2 = 0.22$).

Heliothine and tarnished plant bug populations were low, and no meaningful relationships between waveband reflectance values and population densities could be found unless regressions were done across locations. However, it is felt that comparisons across locations are not valid; positive correlation between insect densities and reflectance values likely represent difference between atmospheric conditions, crop variety, soil types, and other coincidentally related factors. At the Noxubee County location, we were able to detect a weak relationship between numbers of aphids per leaf (third to fourth leaf from terminal) and reflectance values for 550 nm (on two dates) and 840 nm (on one date). Aphid populations were positively correlated with reflectance values at these wavelengths (Table 6). Only the green waveband was selected in stepwise regression of reflectance values on aphid populations. Because green reflectance decreased as plant grew taller, this data could suggest that aphids populations were higher in less vigorous cotton. However, we did not detect a significant relationship between plant height and aphid density (data not shown, $P > 0.04$). It is possible that aphids somehow affected the amount of green reflectance in plants.

Within a given date and across locations, there was a highly positive correlation between the two red wavebands ($R^2 = 0.90$ to 1.0, Table 7). This was true for regressions done within locations as well (Table 8). The two NDVI's also correlated well with each other, which is to be expected considering the close relationship between the two red wavebands used in their calculation. Thus, these data indicate that either redwave bands (or NDVI values) provided similar information about the crop.

The NIR waveband did not correlate well with the green or red wavebands, even though linear models were sometimes significant. The linear model clearly was not appropriate for relating NIR reflectance with the reflectance values of other wavebands when regressions were done across locations (e.g., Fig. 4, Table 7). However, a linear model did appear more appropriate when regressions were done within locations for 5 July, although R^2 values were still not particularly high (Table 8). On this date, the reflectance values of the 675 nm waveband was negatively correlated with NIR reflectance.

The relationship between the green (540 nm) and red wavebands was strongly positively and linear across locations and within the Oktibbeha Cty. Location (Fig. 5, Tables 7 and 8). The relationship between 500 and 675 nm was also fairly strong at the Noxubee Cty. location on 18 June, when plants were still relatively small, but there was poor correlation on 5 July.

Between-date correlation of wavebands varied considerably, and examples of these relationships are shown in Table 9. Generally, the relationship between reflectance values collected on one date compared with values from another date was best for the 840 nm waveband. However, when regressions were done across locations (Table 9) or within the Oktibbeha County location (data not shown), all wavebands correlated relatively well, especially the green and red wavebands.

Summary

Remotely sensed imagery was predictive of certain plant growth parameters such as height, total nodes, and numbers of bolls. The imagery could readily distinguish plant growth characteristics for cotton planted on several, disparate plating dates (e.g., Oktibbeha Co. location). The relationship of these parameters with spectral reflectance was less evident, as expected, at the Noxubee County location where all fields were planted within a few days of each other. The relationship between waveband reflectance values and insect pest populations were generally poor. However, with the exception of aphids, population densities were too low to draw meaningful conclusions from these data. The correlation of reflectance values with aphid density, although significant, was also low. Aphid populations on leaves within a plant are highly variable, so our sampling may not have been sufficient to accurately estimate density at each waypoint.

The two red wavebands (675 and 695 nm) and the two NDVI values were always very closely correlated. Thus, the value of the second red waveband sensor used in imagery acquisition (and the associated NDVI value) is questionable. There was a weak relationship between reflectance at 550 nm (green) and 840 nm (NIR). Green and red reflectance correlated well, but less well within the location where fields had similar planting dates. Waveband reflectance values from one date generally correlated with reflectance values of the same waveband collected on another date. Indeed, across both location and for images collected on 7/05 and 7/17, reflectance of the 675 nm wave band was 94% correlated with itself. For the Noxubee County location where fields had essentially the same planting date, the relationship between reflectance values collected on different dates was not as strong, and the NIR waveband correlated better than other wavebands or NDVI values. Also, images collected over a short time interval were more related than were images collected over a longer interval (see Table 9, Noxubee Co.). Because reflectance values on different dates are related, it may not be necessary to acquire images on more than just a few dates. In the future, we also plan to evaluate how reflectance values collected in one year relate to subsequent imagery from different years.

Because remotely sensed imagery can be used to qualify growth parameters (i.e., vigor) of cotton, and because at least some arthropod populations may also distribute themselves in relation to plant development, the use of imagery as a pest management tool justifies further investigation.

Acknowledgement

We acknowledge the Remote Sensing Technology Center, Mississippi State University for providing remotely sensed imagery and funding support of this research.

Literature Cited

SAS Institute. 1998. SAS user's guide: statistics. SAS Institute, Cary, NC.

Willers, J. L., and D. C. Akins. 2000. Sampling for Tarnished Plant Bugs in Cotton, *In* Lygus Management (D. A. Nordlund and D. D. Hardee, eds.), Southwestern Entomologist, September, Supplement No. 23: 39-57.

Willers, J.L. J.K., Dupont, R. Campanella, M. R. Seal, K. B. Hood, J. Williams, and D. Woodard. 2000. Employment of spatially variable insecticide applications for tarnished plant bug control in cotton. Pp. 1133, *In* Proc. Beltwide Cotton Insect Control Conference, National Cotton Council America, Memphis, TN.

Table 1. Digital waveband reflectance values, and NDVI values, from remotely-sensed images across three dates. Data are averaged across locations.

Date	Waveband	Mean	SEM	% Changerelative to 6/18
6/18	550	81.58	1.85	N/a
	675	57.47	1.54	N/a
	695	66.13	1.72	N/a
	840	122.3	2.22	N/a
	NDVI 1	0.361	0.01	N/a
	NDVI 2	0.299	0.01	N/a
7/05	550	51.69	4.01	- 35.4
	675	35.99	3.77	- 37.4
	695	36.54	2.73	- 44.7
	840	90.74	1.40	- 25.8
	NDVI 1	0.491	0.03	+ 36.0
	NDVI 2	0.462	0.02	+ 54.5
7/17	550	56.18	3.54	- 31.1
	675	38.13	3.67	- 33.7
	695	40.24	3.74	- 39.2
	840	102.1	2.94	- 16.7
	NDVI 1	0.496	0.02	+ 37.4
	NDVI 2	0.473	0.02	+ 31.0

Table 2. Results of linear regressions of selected plant height data (inches) on waveband reflectance values within locations.

Dates and Local	Waveband	Intercept	Slope	R^2	P>F
Ht = 6/19	550	35.45	-0.23	0.158	0.1428
Image = 6/18	675	36.93	-0.34	0.528	0.0022
Local = Nox.	695	36.71	-0.29	0.437	0.0073
	840	-18.09	0.33	0.365	0.0171
	NDVI 1	5.50	38.21	0.661	0.0002
	NDVI 2	7.38	38.94	0.617	0.0005
Ht = 7/23	550	12.93	0.45	0.025	0.3154
Image = 7/17	675	73.96	-1.70	0.436	0.0001
Local = Nox.	695	79.84	-1.80	0.325	0.0001
	840	9.10	0.26	0.426	0.0001
	NDVI 1	8.82	41.99	0.434	0.0001
	NDVI 2	7.49	46.69	0.442	0.0001
Ht = 7/30	550	59.62	-0.38	0.895	0.0001
Image = 7/17	675	52.50	-0.37	0.906	0.0001
Local = Okt.	695	52.43	-0.35	0.898	0.0001
	840	-146.3	1.33	0.626	0.0001
	NDVI 1	7.37	56.29	0.909	0.0001
	NDVI 2	8.64	54.92	0.889	0.0001

Table 3. Model parameters from stepwise linear regression of selected plant height (inches) data on four waveband reflectance values (within locations).

Dates and Local	Selected wavebands	Intercept	Slopes	R^2	P>F
Ht = 6/19	550	19.17	0.48	0.714	0.0005
Image = 6/18	675		-0.66		
Local = Nox.					
Ht = 7/23	550	43.64	-0.97	0.503	0.0001
Image = 7/17	840		0.34		
Local = Nox.					
Ht = 7/23	675	-13.86	-0.29	0.949	0.0001
Image = 7/17	840		0.47		
Local = Okt.					

Table 4. Results of linear regressions of selected boll count data (no./m) on waveband reflectance values within locations.

Dates and Local	Waveband	Inter.	Slope	R^2	P>F
Bolls = 8/21-24	550	21.89	0.69	0.005	0.6555
Image = 7/17	675	151.2	-4.07	0.211	0.0025
Local = Noxub.	695	173.49	-4.60	0.1817	0.0054
	840	-6.22	0.66	0.223	0.0018
	NDVI 1	-5.34	102.0	0.216	0.0022
	NDVI 2	-10.01	116.1	0.231	0.0015
Bolls = 9/06	550	134.3	-0.90	0.700	0.0001
Image = 7/17	675	117.2	-0.88	0.706	0.0001
Local = Oktib.	695	118.03	-0.86	0.725	0.0001
	840	-205.1	2.01	0.1975	0.0436
	NDVI 1	10.84	131.0	0.675	0.0001
	NDVI 2	12.83	130.4	0.687	0.0001

Table 5. Model parameters from stepwise linear regression of boll counts (no./m) on four waveband reflectance values (within location).

Dates and Local	Selected wavebands	Intercept	Slopes	R^2	P>F
Bolls = 8/21-24	550	101.6	-3.04	0.288	0.0016
Image = 7/17	840		0.92		
Local = Noxub.					
Bolls = 9/06	550	267.1	5.81	0.850	0.0001
Image = 7/17	695		-6.56		
Local = Oktib.	840		-1.84		

Table 6. Results of linear regressions of aphid density (no./leaf) on waveband reflectance values (Noxubee Co.).

Dates	Waveband	Intercept	Slope	R^2	P>F
Aphids = 7/02	550	-87.98	3.12	0.144	0.0388
Image = 7/05	675	35.73	-1.16	0.029	0.3681
	695	30.26	-0.77	0.008	0.6471
	840	-25.06	0.46	0.102	0.0860
	NDVI 1	-19.08	52.41	0.067	0.1672
	NDVI 2	-18.01	54.65	0.060	0.1906
Aphids = 7/10	550	-328.8	11.68	0.214	0.0101
Image = 7/05	675	75.44	-1.34	0.004	0.7372
	695	49.30	0.00	0.000	0.9996
	840	-84.73	1.61	0.133	0.0473
	NDVI 1	-34.52	136.7	0.048	0.2428
	NDVI 2	-39.76	156.6	0.053	0.2225

Table 7. Results of linear regressions when waveband reflectance values (and NDVI values) were correlated with each other. Regressions were done across all locations.

Date	Y (nm)	X (nm)	Inter.	Slope	R^2	P>F
7/05	550	675	13.62	1.06	0.984	0.0001
	550	695	-0.42	1.43	0.943	0.0001
	550	840	-65.46	1.29	0.202	0.0002
	675	695	-11.74	1.31	0.900	0.0001
	675	840	-51.79	0.97	0.129	0.0039
	695	840	-47.42	0.92	0.223	0.0001
	NDVI 1	NDVI 2	-0.07	1.21	0.938	0.0001
7/17	550	675	19.45	0.96	0.992	0.0001
	550	695	18.17	0.94	0.995	0.0001
	550	840	-6.24	0.61	0.258	0.0001
	675	695	-1.20	0.98	0.996	0.0001
	675	840	-23.36	0.60	0.223	0.0001
	695	840	-21.83	0.61	0.229	0.0001
	NDVI 1	NDVI 2	0.02	1.01	0.992	0.0001

Table 8. Results of linear regressions when waveband reflectance values (and NDVI values) were correlated with each other. Regressions were done within locations for selected dates of 18 June (Noxubee Co.) and 5 July (both locations).

Local	Y (nm)	X (nm)	Inter.	Slope	R^2	P>F
Noxub.	550	675	24.26	0.99	0.685	0.0001
6/18	550	695	18.05	0.96	0.796	0.0001
	550	840	39.55	0.34	0.170	0.0067
	675	695	-0.19	0.87	0.953	0.0001
	675	840	57.74	-0.002	0.000	0.9839
	695	840	59.03	0.06	0.006	0.6372
	NDVI 1	NDVI 2	0.06	1.00	0.973	0.0001
Noxub.	550	675	31.54	0.047	0.003	0.7135
7/05	550	695	29.70	0.124	0.014	0.4503
	550	840	25.59	3.35	0.266	0.0005
	675	695	-7.98	1.22	0.916	0.0001
	675	840	30.87	-0.14	0.5173	0.0001
	695	840	30.54	-0.10	0.436	0.0001
	NDVI 1	NDVI 2	0.00	1.08	0.985	0.0001
Oktib.	550	675	26.09	0.92	0.995	0.0001
7/05	550	695	-67.7	2.41	0.971	0.0001
	550	840	548.6	-4.61	0.338	0.0057
	675	695	-102.6	2.63	0.980	0.0001
	675	840	574.9	-5.08	0.347	0.0050
	695	840	239.7	-1.75	0.292	0.0114
	NDVI 1	NDVI 2	-0.27	2.27	0.986	0.0001

Table 9. Results of linear regressions when waveband reflectance values (and NDVI's) were correlated with themselves between selected dates.

Dates (Y vs. X)	nm	Inter.	Slope	R^2	P>F
7/5 vs. 6/18	550	27.86	0.06	0.159	0.0088
(Noxub. only)	675	14.07	0.09	0.171	0.0065
	695	19.21	0.04	0.087	0.0575
	840	14.05	0.59	0.600	0.0001
	NDVI 1	0.45	0.51	0.438	0.0001
	NDVI 2	0.46	0.42	0.327	0.0001
7/17 vs. 7/05	550	13.13	0.83	0.890	0.0001
(Across locals)	675	4.21	0.94	0.937	0.0001
	695	-2.27	1.16	0.721	0.0001
	840	-52.86	1.71	0.655	0.0001
	NDVI 1	0.19	0.62	0.749	0.0001
	NDVI 2	0.17	0.64	0.521	0.0001
7/17 vs. 6/18	550	39.04	0.05	0.147	0.0122
(Noxub. only)	675	21.45	0.05	0.101	0.0407
	695	24.25	0.03	0.079	0.0712
	840	35.24	0.46	0.386	0.0001
	NDVI 1	0.42	0.38	0.274	0.0004
	NDVI 2	0.44	0.30	0.203	0.0028

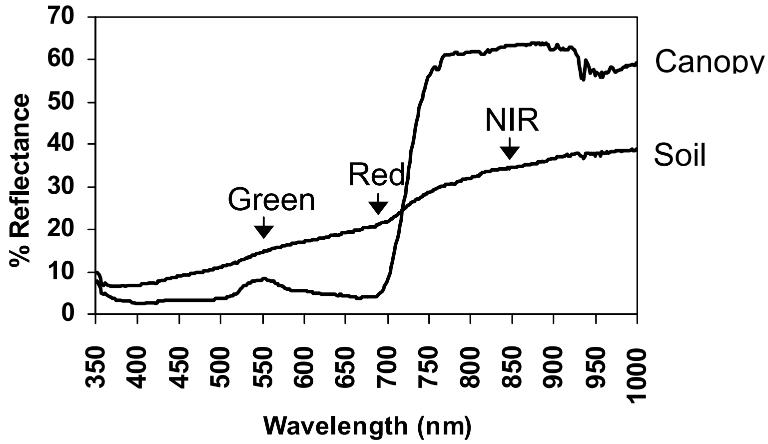

Figure 1. Example of the spectral signatures of cotton plants vs. bare soil. Data were taken with a hand-held hyperspectral photometer.

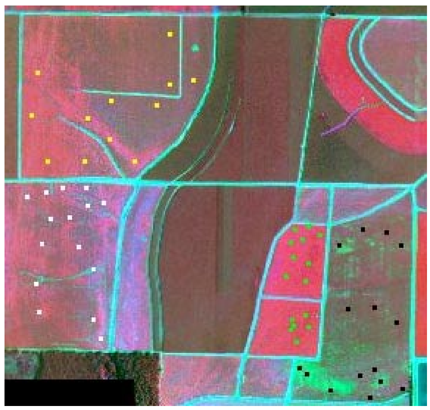

Figure 2. Sampling points for three cotton fields at the Noxubee Co. location. Green points are in soybean. The image was acquired 5 July.

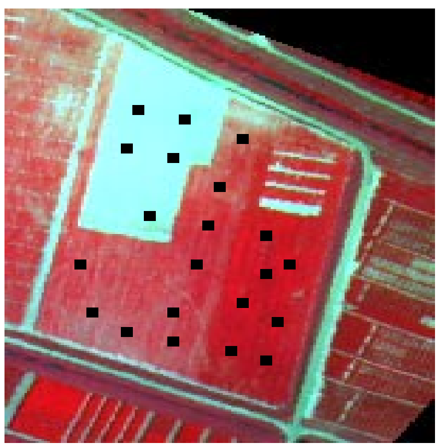

Figure 3. Sampling points of the cotton field at the Oktibbeha Co. location. The three planting dates are evident. The image was acquired 5 July.

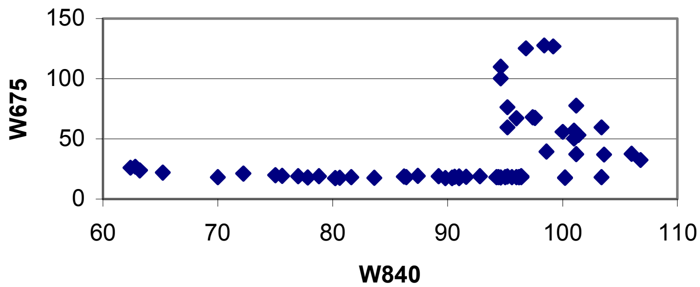

Figure 4. Relationship between the reflectance values of cotton measured at 550 nm and 840 nm nm (see Table 7 for parameter estimates of linear regression). Data is from imagery collected on 5 July across two locations. All values of W675 < 35 were from the Noxubee County location; higher values were from Oktibbeha County. Although the above response was not linear, within locations responses appeared linear when significant (see Table 8).

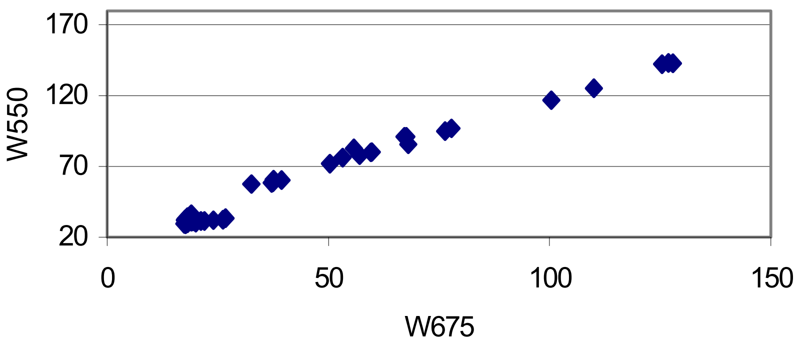

Figure 5. Relationship between the reflectance values of cotton measured at 550 nm and 675 nm (see Table 7 for parameter estimates of linear regression). Data is from imagery collected on 5 July across two locations. All values of W550 less than 50 were form Noxubee County. Although this overall response was highly linear, a linear response within the Noxubee County location was less evident (see Table 8).