REMOTE SENSING OF COTTON GROWN UNDER MULTIPLE WATER AND NITROGEN LEVELS

Donald F. Wanjura and Dan R. Upchurch
USDA-ARS, Cropping Systems Research Laboratory
Lubbock, TX

Abstract

Spectral measurements were made over cotton which had received five different preplant nitrogen fertilization rates for the third consecutive year in 2000. Half of the plots received only rain (WL) and the other half were fully irrigated to replace potential evapotranspiration (WH).Multispectral reflectance measurements were made to determine when seedling emergence could first be detected, and later in the season to detect plant size differences due to water and nitrogen treatments, and to estimate other crop agronomic factors. Spectral reflectance values were calculated for the blue(0.45 -0.52 μ), green (0.52 -0.60 μ), red (0.63 -0.69 μ), and near infrared (0.76 -0.90 μ) wavelengths and related to various plant characteristics. The presence of emerged seedlings was detected seven days after planting (one day after initial emergence) on DOY 143 by spectral reflectance in the red wavelength and by the normalized difference vegetation index (NDVI). At this time leaf area in the target areas averaged 12.1 cm^2, the leaf area index (LAI) was 0.02, and the ground cover was 1.3%. By 15 days after planting on DOY 151, seedling leaf area was linearly related to the NDVI values. The red wave band was the most sensitive individual band during stand establishment for detecting the presence of cotton seedlings. The NDVI was equally sensitive, but its sensitivity was due to the red band since the NIR wave band did not detect the presence of cotton seedlings between DOY 143 and DOY 158.

Between first square and peak bloom, NDVI was not sensitive to nitrogen fertilization level. Leaf area index differences between water levels was positively related to NDVI. Plant height was also positively related to NDVI across sampling dates, but within sample dates only at peak bloom. Similarly NDVI was negatively related to leaf nitrogen content in the WH treatment across dates. NDVI values separated plots into two progressively distinct groups as sampling proceeded from first square to peak bloom and these groups coincided with the WL and WH treatments. NDVI at peak bloom was significantly correlated with lint yield of the WH treatment, but not the WL treatment yields which were low and showed little variation.

Introduction

The potential application of remote sensing in precision farming is being studied as an information source technology. Since its introduction in the early 1970s the capability of this technology has greatly improved due to advancements in the electronic hardware and from spectral research that has revealed its capacity to detect various types of information about crops.

Uniform solar radiation and clear atmospheric conditions are the best environments for acquiring remote sensing measurements. The optimum scene is one which only contains the target of interest; ie, a field crop that completely covers the ground. However, these conditions occur infrequently and limit the use of spectral reflectance for timely crop production decision-making.

Previous research has provided information about the interaction of spectral radiation with plants which forms the basis for inferring crop conditions from spectral values in specific wave lengths. It is known that reflectance in the red wavelength (630-690 nm) region is sensitive to chlorophyll content in plant leaves and the near infrared (760 to 900 nm) wavelength is sensitive to the amount of leaf area. The emergence of green vegetation over a soil causes composite red radiance to decrease because of chlorophyll absorption and the overall infrared response to increase as a result of leaf mesophyll structure (Huete, et al, 1984). This knowledge is the foundation of the normalized vegetation index (NDVI) which is sensitive to canopy leaf area. A study by Maas (1998) demonstrated that crop ground cover could be estimated from canopy and soil reflectance. The effect of shadows on the estimated ground cover could also be compensated for by averaging reflectance in the red and near-infrared wave bands.

Currently there is great interest in using this technology to provide information about crop physical characteristics and plant nitrogen status for use in production management. Previous research has demonstrated the usefulness of multispectral reflectance measurements to detect when plants are under water stress. Bausch, et al. (1998) acquired hyperspectral canopy reflectance measurements over irrigated corn. Their analysis indicated that the red edge derivative ratios can be used to estimate plant nitrogen of irrigated corn.

The purpose of this study was to use multispectral reflectance to (1) determine when seedling emergence could first be detected, (2) detect plant size differences due to water and nitrogen fertilization levels, and (3) estimate other crop agronomic factors.

Procedure

Spectral measurements were made over field plots which were fertilized with different levels of nitrogen for the third consecutive year in 2000. Preplant furrow irrigation was applied on 2 to 5 May. Plots were differentially fertilized using five rates of N on 11-12 May. Nitrogen treatments and amounts (kg/ha) were N1- 0, N2- 56, N3- 112, N4- 168, and N5- 224. A preemergence herbicide application of 2.4 pt/ac of Caparol and 0.6 pt/ac of Staple was sprayed broadcast on the beds. The cotton variety Paymaster HS 2326 was planted on 15 May (DOY 136) with a John Deere 7300 MaxEmerge 2 Vacuum Planter on beds oriented north to south and spaced at 1 m. The insecticide Temik was applied in the seed furrow along with the cotton seed during planting. Initial cotton emergence occurred on 21 May (DOY 142).

Following seedling establishment drip irrigation laterals were placed on the soil surface in each cotton plot. Cotton was grown under two water levels; the low water level (WL) was dryland and the high water level (WH) was 1.0 *PET (potential evapotranspiration). These water level treatments represent the extreme levels for commercial production in this semi-arid region.

The five N levels in each water level were replicated along the rows. Each plot was 12 m wide (12 rows spaced 1 m apart) by 12 m long. Plots were replicated four times across rows which provided a randomized complete block experiment with two water levels.

The BIOTIC irrigation protocol was used to time irrigation events in the WH treatment using a minimum irrigation interval of three days which increased in one day increments if an irrigation signal was not obtained beginning on the third day, Upchurch, et al. (1996). An irrigation signal was generated whenever the daily time accumulation of canopy temperature above 28 °C exceeded 5.5 hours. The WH received a 21 mm irrigation following each irrigation signal. In each water level there were five levels of N application replicated four times.

An infrared thermocouple (Model IRt/c .2 K 80F/27C, equipped with germanium lens, EXERGEN Corporation, Watertown, MA) was mounted on a pipe pole in one plot of each N level of the two water levels to continuous measure temperature of the upper surface of the canopy. Canopy temperature averaged during 15-min periods was stored by a CR7 Campbell Scientific data logger. An automated weather data collection system,

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:311-317 (2001)
National Cotton Council, Memphis TN

installed in the study area, measured dry and wet bulb temperatures, total radiation, net radiation, wind speed and direction, and rainfall, which were recorded as 15-min averages in a CR21X Campbell Scientific data logger.

In the alternate weeks between biomass harvests, crop phenological development was tracked biweekly by measuring plant height in both crops, number of leaves in corn, and number of main stem nodes in cotton from five randomly selected plants per plot. Crop development was monitored on three dates that coincided with spectral reflectance readings during the growing season by making biomass harvests of five plants per plot.

Protocol for Early Season Reflectance Readings

Spectral reflectance measurements were made during the stand establishment period in the inter-plot areas of the WH treatment. A multispectral radiometer (Analog Systems Devices, Model No. FSFR, Boulder, CO) and video camera were mounted on a horizontal bar which was supported by a monopod. Measurements started on the third row from the west side of a plot and progressed eastward in increments of one row on each day that spectral readings were taken.

The radiometer and video camera were positioned approximately 5.9 ft above the surface of the bed with the monopod fully extended and a circular target area of approximately 11.5 inches was viewed. When an area of the row was selected, a meter stick was placed on the bed surface and moved into the target area of the radiometer which was identified by a circle superimposed on the target area displayed in the video camera image. The boundary of the circle was marked on the soil surface of the furrow adjacent to the bed to define its limits and that of two additional areas along the row to provide a total of three target areas for the reflectance measurements. A series of five readings were made automatically in each target area containing the emerged cotton seedlings. Next the seedlings were carefully harvested to minimize disturbance of the soil surface in each of the three target areas and placed in separate plastic bags. Then radiation reflected from the same target areas, which now contained only bare soil, was measured again with the radiometer. The total time required to measure the three target areas and harvest the cotton seedlings of one plot was eight min.

After completing the reflectance measurements with the radiometer, the number of seedlings in each bag was counted, the leaves were removed and weighed, and passed through a leaf area meter, dried at 60°C, and then reweighed.

Protocol for In-Season Reflectance Readings

Following stand establishment, reflected radiation measurements were made on 5 July (DOY 187), 19 July (DOY 201), and 9 August (DOY 222) at the first square, first bloom, and peak bloom (four weeks after first bloom).

Spectral measurements were made between 0930 h and approximately 1200 h or until the shadow of the radiometer was visible on the spectralon reference panel. On DOY 187 measurements were made in the afternoon due to cloudy sky conditions in the morning. The spectral radiometer was mounted on a self-propelled telescoping boom which facilitated making measurements from a height of 35 ft above the canopy. After optimizing the radiometer across its entire wavelength range, replications 2 and 3 of each water level treatment were read. Within each replication there were five plots in each water level. Within each plot reflectance was measured over a three meter square area (three meters on three adjacent rows) located approximately at the center of each plot.

Reflectance measurements in a plot began by positioning the radiometer over the end of the three square meter area. Reflectance of the spectralon reference panel was made by taking five readings. The spectralon panel was removed from the radiometer's field of view and then a canopy reading was taken by making five individual readings. The radiometer was moved approximately two feet and a second set of canopy and spectralon reflectance measurements were taken. The boom was again moved and a third set of reflectance were made. After this third set of readings, the boom was moved to the next plot and situated at the beginning of a three square meter area and the measurement process was repeated.

Between each set of canopy readings, while the radiometer was over the spectralon panel, the radiance curve on the monitor of the radiometer was examined for saturation. If saturation was observed, the radiometer was re-optimized. Readings always began at the north end of replication 2 and the boom travelled south to the end of the tenth plot. The boom was then moved to the alley of replication 3 and readings would begin at the south end and progress northward. A 35 mm camera was mounted at the end of the pole containing the radiometer and a color picture was taken along with the spectral readings. A digital image of the target area was also taken with a video camera mounted by the radiometer. After readings were completed, the PC was brought to the laboratory and the radiance data was transferred to a computer and converted to reflectance values.

Results

Rain which began soon after emergence, totalled 18.8 cm from 16 events before the first irrigation was applied to the WH treatment, Fig. 1. Only 3.1 cm of rain was received after irrigation began during the remainder of the production period, Fig. 2. Total water applied to the WH treatment was 62.5 cm for the complete production period (DOY 146- DOY 195), which included 40.6 cm from rain compared with estimated total PET of 77.4 cm for the same period.

Reflectance During Stand Establishment

Reflectance for bare soil and soil with seedlings are summarized in Table 1 for five measurement dates during stand establishment. Bare soil reflectance values in the four wavebands were generally constant for the same target for dates DOY 143, DOY 144, and DOY 145, then increased on DOY 151 and again on DOY 158. These reflectance values are related to the rain events. Two rain events totalling 1.9 cm occurred between DOY 145 and DOY 151, and three additional rain events of 8.2 cm occurred between DOY 151 and DOY 158, Fig. 1. The soil surface shown in color photos and video images appeared smoother on DOY 151 and DOY 158 than the earlier dates due to the washing and sealing action of the rain on the soil surface.

The blue and green wave bands did not detect the presence of seedlings until DOY 158 and the NIR wave band did not detect differences on any date. The red wave band had the highest sensitivity by indicating differences between the two targets on all dates except DOY 145. The NDVI values were more sensitive than the single wavebands to the presence of seedlings since differences in the two targets were indicated on all measurement dates. Red wave band reflectance decreases as plant size increases while the NIR wave band reflectance increases. The combination of these contrasting responses is the basis of the sensitivity of NDVI to the presence of plants.

The sensitivity of reflectance in each wave band to amount of leaf area within each target was examined for DOY 143 and DOY 151 when leaf areas were measured from harvested seedlings. Seedling leaf areas ranged from about 7 to 24 cm^2 among targets on DOY 143 and from 19 to 60 cm^2 on DOY 151, Figs. 3a and 3b. The size of the circular target area viewed by the radiometer was 670 cm^2. Leaf area index within the target areas ranged from 0.01 to 0.03 with a mean of 0.02 on DOY 143 and from 0.02 to 0.09 with a mean of 0.05 on DOY 151. The corresponding ground cover values ranged from 0.5% to 2.4% with a mean of 1.3% on DOY 143 and 1.0% to 7.0% with a mean of 3.6% on DOY 151. The ground cover percentages were estimated from video images of each target using the Adobe

Photoshop software to outline seedling leaves. Seedling leaf areas averaged 12.1 cm^2 from 3.13 plants on DOY 143 and 34.7 cm^2 from 3.9 plants on DOY 151.

Wave band reflectance were not significantly related to leaf area on DOY 143 in Fig. 3 a or on DOY 151 in Fig. 3 b. The association between NDVI and target leaf areas was significant on DOY 151 (R^2= 0.88) but not on DOY 143 (R^2= 0.13), Fig. 4. Bare soil NDVI values for the same targets after removing seedlings had nonsignificant correlations on both dates.

In-Season Reflectance

Plant height and leaf area index were different between the two water levels, Table 2. Plant heights in both water levels were similar through DOY 201, but afterwards the plants in the WH level continued to grow and WL plants grew at a greatly reduced rate. Leaf area index in the WL treatment declined between DOY 201 and DOY 222 which reflected the high water stress conditions due to the lack of rain following the ample early season rains which stopped on DOY 205.

Reflectance were measured at first square, first bloom, and four weeks after first bloom. Reflectance values in the first three wave bands were higher in the WL water level than for the WH level on each date, Table 3. However, the NIR wave band reflectance was higher in the WH treatment than the WL treatment on DOY 222. Reflectance in the red waveband (0.63 - 0.69) decreased with date of measurement in WH plants, but was higher in the WL plants which also had a slight decrease between DOY 201 and DOY 222. Reflectance among nitrogen levels lacked consistent trends in any wave band on DOY 187 and on DOY 201 all reflectance were similar among nitrogen levels. On DOY 222, reflectance in the blue, green, and red wave bands for nitrogen level N5 were significantly lower than for N1, N2, and N3. Reflectance of all nitrogen level were similar in the NIR wave band on DOY 201 and DOY 222. Since the NIR wave band is sensitive to amount of leaf area, this suggests that all nitrogen levels had comparable values when averaged for the two water levels, as shown in Table 2.

The crop water condition of the WH treatment was more favorable for growth and yield and more likely than the WL treatment to show effects of the different nitrogen treatments. Therefore the spectral response among nitrogen levels was analyzed in the WH treatment, Table 4.

On DOY 187 reflectance in the blue, green, and red wave bands were highest in nitrogen treatments N1 and N5 , followed by N3, N2, and N4. In the NIR wave band reflectance values of N1, N2, N3, and N5 were similar and higher than for N4. For the NDVI values the ranking of reflectance from highest to lowest was N4, N2, N3, N1, and N5, which was the reverse of the ranking in the blue, green, and red wave bands. The overall result is no effect of nitrogen level on spectral values.

Reflectance value rankings on DOY 201 in the blue, green, and red wave bands was N3, N1, and N5, followed by N2, and N4. In the NIR wave band N2 was highest and N4 was lowest. The NDVI values of N4 and N2 were greater than for N5, N1, and N3. The reflectance value differences within wave bands were not consistent on DOY 201.

On DOY 222 there were no reflectance differences among nitrogen treatments in the blue wave band. In the green wave band N1, N2, and N3 were higher than N5. The red wave band reflectance of N3 was higher than for N4 and N5 with wave bands N3, N2, and N1 being similar and having intermediate values. Reflectance of N5 in the NIR wave band was higher than all nitrogen levels except N3. The NDVI value for N5 was significantly higher than the other N levels. The effect of nitrogen application rate was minimal on reflectance on all measurement dates and wavebands.

Estimating Plant Characteristics

The NDVI values of the WH treatment were consistently higher than the WL treatment indicating that leaf areas were higher. The NDVI values of the WL treatment also declined between DOY 201 and DOY 222 indicting that its leaf area actually declined due to the severe water stress induced by the lack of rain, Fig. 5. While NDVI values were similar among nitrogen levels within water levels, the NDVI values for each nitrogen level was always highest in the WH treatment for each sampling date.

Average LAI values for each water level in Table 2 are linearly related to the corresponding NDVI values in Table 3, as shown in Fig. 6. Data points along the regression generally increase in value as the sampling dates progress through the season, except for the WL at PB which had a small value due to reduced plant size caused by water stress. The NDVI and NIR reflectance was higher over a cotton canopy that showed increasing levels of water stress, but had higher leaf area than a canopy experiencing decreasing levels of water stress, Wanjura and Upchurch (1999).

Plant height was positively related to NDVI values during the growing season, omitting the WL treatment on DOY 222, Fig. 7. This is in agreement with the relationship between NDVI and LAI shown in Fig. 6 and is probably reflecting this relationship rather than plant height because plant height and LAI are highly correlated.

The NDVI values of WL and WH treatments separated into distinct groups with time where WH had higher NDVI values than WL for each sample date, Fig. 8. Leaf nitrogen % and NDVI in the WH treatment were approximately linearly related across samples dates as LAI was increasing from 0.5 to 1.5. However, within a sampling date the NDVI was not sensitive to leaf nitrogen content.

Lint yield is generally related to plant leaf area and this is shown by the linear relationship between NDVI on DOY 222 and lint yield in the WH treatment (R^2= 0.59), Fig. 9. The spectral measurements for this relationship were made at peak bloom (four weeks after first bloom) which was 48 days before irrigation was terminated on DOY 270. Yields in the WL treatment were not sensitive to NDVI, probably due the low yield levels which were less than 100 lbs./acre.

Summary

The red wave band was the most sensitive spectral indicator during stand establishment for detecting the presence of cotton seedlings on DOY 143 when leaf area in the target areas averaged 12.1 cm^2, an LAI value of 0.018, and estimated ground cover of 1.3%. NDVI was equally sensitive, but its sensitivity was due to the red band since the NIR wave band did not detect the presence of cotton seedlings between DOY 143 and DOY 158.

Between first square and peak bloom, NDVI was not sensitive to nitrogen into two progressively distinct groups as sampling proceeded from first square to peak bloom and these groups coincided with the WL and WH treatments. NDVI on DOY 222 (peak bloom) was significantly correlated with lint yield of the WH treatment, but not the WL treatment yields which showed little variation and were low (< 100 lbs./ac).

References

Bausch, W. C, K. Diker, A. F. H. Goetz, and B. Curtis. 1998. Hysperspectral characteristics of nitrogen deficient corn. ASAE Paper 983061, American Society of Agricultural Engineers, 2950 Niles Rd., St. Joseph, MI 49085

Huete, A. R., D. F. Post, and R. D. Jackson. 1984. Soil spectral effects on 4-space vegetation discrimination. Remote Sens. of Envir. 15:155-165.

Maas, S. J. 1998. Estimating cotton canopy ground cover from remotely sensed scene reflectance. Agron. J. 90:384-388.

Upchurch, D. R., D. F. Wanjura, J. J. Burke, and J. R. Mahan. 1996. Biologically -identified optimal temperature interactive console (BIOTIC) for managing irrigation. U. S. Patent 5,539,637, July 23, 1996.

Wanjura, D. F. and D. R. Upchurch. 1999. Cotton response to abrupt change in water application. Proceed. Beltwide Cotton Conferences, pp 380-384.

Table 1. Reflectance of bare soil and soil with cotton seedling measured in four wavebands during stand establishment, 2000.

	Wave Band				
Target	**Blue (.45-.52)**	**Green (.52 -.60)**	**Red (.63-.69)**	**NIR (.76 -.90)**	**NDVI _1/**
		Reflectance, %			
		DOY 143			
Bare soil	15.8 a 2/	10.0 a	16.4 a	23.6 a	0.18 b
BS+Seedlings	5.6 a	9.8 a	15.9 b	23.3 a	0.19 a
		DOY 144			
Bare soil	5.9 a	10.0 a	16.2 a	23.5 a	0.19 b
BS+Seedlings	5.3 a	9.1 a	14.4 b	22.3 a	0.22 a
		DOY 145			
Bare soil	5.0 a	8.4 a	13.7 a	20.3 a	0.19 b
BS+Seedlings	5.1 a	8.7 a	13.9 a	20.9 a	0.21 a
		DOY 151			
Bare soil	6.9 a	11.8 a	19.3 a	27.5 a	0.18 b
BS+Seedlings	6.5 a	11.2 a	17.8 b	27.9 a	0.22 a
		DOY 158			
Bare soil	12.1 a	19.2 a	28.7 a	37.8 a	0.14 b
BS+Seedlings	10.5 b	17.7 b	23.8 b	38.3 a	0.23 a

_1/ NDVI = (NIR - Red)/ (NIR + Red)

_2/ Reflectance values for bare soil and bare soil with seedlings on the same date and waveband are statistically similar(P=0.05) if followed by a common letter as determined from the F-Test.

Table 2. Plant height and leaf area index for two water levels and five nitrogen fertilization levels at three stages of growth, 2000.

Water Level		Nitrogen Level				
WH	**WL**	**N1**	**N2**	**N3**	**N4**	**N5**
			Plant Height, cm			
			DOY 187			
29.3 a _1/	28.3 a	29.4 ab	29.6 a	28.5 ab	27.3 b	29.3 ab
			DOY 20			
39.3 b	40.9 a	40.2 a	41.3 a	39.6 a	40.2 a	39.4 a
			DOY 222			
52.3 a	44.3 b	47.2 b	49.1 a	48.3 ab	48.4 ab	48.5 ab
			Leaf Area Index			
			DOY 187			
0.49a_1/	0.40 b	0.50 a	0.41 a	0.49 a	0.40 a	0.43 a
			DOY 201			
1.0 a	0.84 a	0.96 a	0.89 a	0.95 a	0.90 a	0.89 a
			DOY 222			
1.5 a	0.47 b	1.04 a	1.05 a	1.01 a	0.95 a	0.93 a

_1/ Values for water level or nitrogen levels are statistically similar (P=0.05) if followed by a common letter as determined with the Duncan's New Multiple Range Test.

Table 3. Reflectance for two water levels and five nitrogen fertilization levels at three stages of growth, 2000.

Wave	Water Level		Nitrogen Level				
Length	**WH**	**WL**	**N1**	**N2**	**N3**	**N4**	**N5**
				Reflectance, percent 1/			
				DOY 187			
Blue	8.3 b	9.6 a	9.2 a	9.0 ab	8.7 b	8.1 c	9.2 a
Green	13.8 b	15.7 a	15.1 a	14.7 ab	14.4 b	13.4 c	15.0 a
Red	19.3 b	22.1 a	21.3 a	20.8 ab	20.2 b	18.5 c	21.2 a
Nir	36.8 b	37.6 a	37.1 b	36.8 b	38.1 a	37.2 b	36.5 b
NDVI	0.31 a	0.26 b	0.27 c	0.28 c	0.31 b	0.34 a	0.27 c
				DOY 201			
Blue	4.9 b	6.9 a	5.9 a	6.0 a	5.9 a	5.2 a	6.1 a
Green	8.7 b	11.5 a	10.1 a	10.2 a	10.0 a	8.9 a	10.4 a
Red	9.8 b	15.0 a	12.3 a	12.7 a	12.1 a	10.3 a	12.8 a
Nir	37.9 b	39.2 a	38.5 a	38.2 a	39.3 a	38.2 a	37.9 a
NDVI	0.60 a	0.45 b	0.52 a	0.51 a	0.54 a	0.58 a	0.51 a
				DOY 222			
Blue	3.7 b	6.9 a	5.2 a	5.5 a	4.9 b	4.6 ab	4.6 c
Green	6.3 b	11.6 a	9.0 a	9.1 a	8.3 b	7.9 bc	7.8 c
Red	6.0 b	16.6 a	11.2 a	11.6 a	9.9 b	9.4 bc	9.0 c
Nir	41.5 a	34.6 b	37.9 a	37.7 a	39.5 a	39.0 a	39.9 a
NDVI	0.75 a	0.35 b	0.55 c	0.54 c	0.61 b	0.62 ab	0.64 a

_1/ Reflectance values for the same wavelength between water levels or among nitrogen levels are statistically similar (P=0.05) if followed by a common letter as determined with the Duncan's New Multiple Range Test.

Table 4. Multispectral reflectances of cotton grown under five nitrogen fertilization levels in the WH treatment, 2000.

Wave Length	Nitrogen Level N1	N2	N3	N4	N5
			Reflectance, percent /1		
			DOY 187		
Blue	8.8 a	8.0 d	8.5 b	7.6 d	8.9 a
Green	14.4 a	13.2 c	14.1 b	12.6 d	14.5 a
Red	20.3 a	18.3 c	19.8 b	17.4 d	20.5 a
Nir	37.0 a	37.0 a	37.0 a	36.2 b	36.7 a
NDVI	0.29 d	0.34 b	0.30 c	0.35 a	0.29 d
			DOY 201		
Blue	5.1 a	4.9 b	5.1 a	4.6 c	5.1 a
Green	9.0 a	8.5 b	9.0 a	8.1 c	8.9 a
Red	10.1 a	9.4 b	10.3 a	8.9 c	10.0 a
Nir	37.7 b	38.7 a	38.1 ab	37.0 c	37.8 b
NDVI	0.58 b	0.62 a	0.58 b	0.62 a	0.59 a
			DOY 222		
Blue	3.6 a	3.9 a	3.8 a	3.5 a	3.4 a
Green	6.4 a	6.5 a	6.6 a	6.1 ab	5.8 b
Red	6.2 ab	6.3 ab	6.5 a	5.9 b	5.1 c
Nir	40.9 cd	41.6 bc	41.9 ab	40.7 d	42.5 a
NDVI	0.74 b	0.74 b	0.74 b	0.75 b	0.79 a

_1/Reflectance values for the same wavelength and date are statistically similar (P=0.05) if followed by a common letter as determined with the Duncan's New Multiple Range Test.

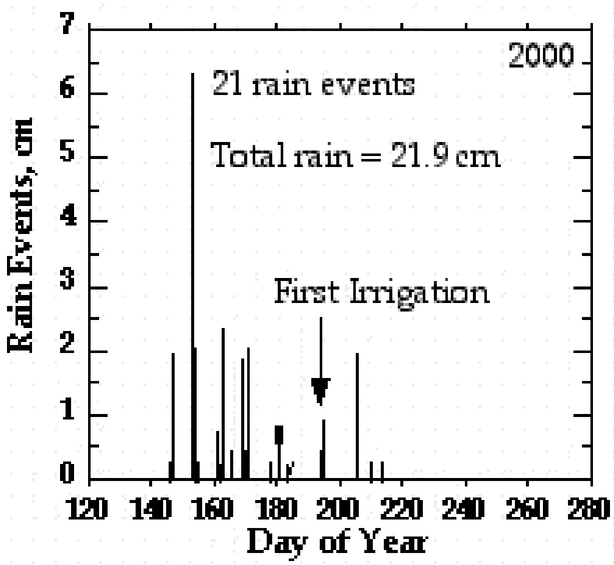

Figure 1. Rain events from planting through the end of irrigation, 2000.

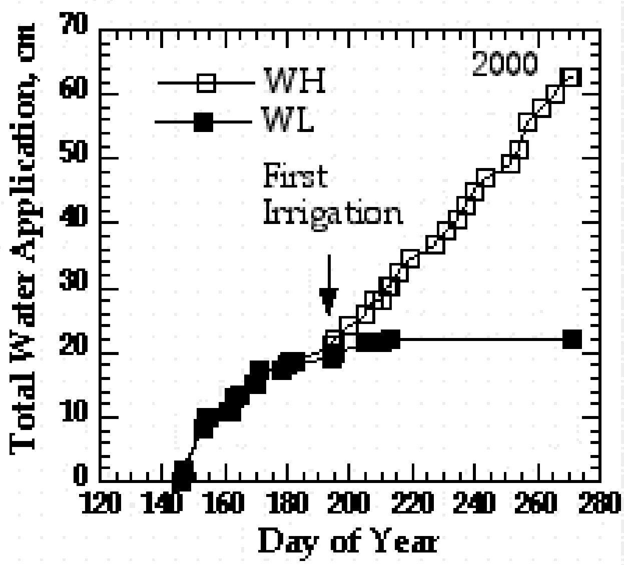

Figure 2. Comparison of total water applied to the WL and WH level treatments during the 2000 production season.

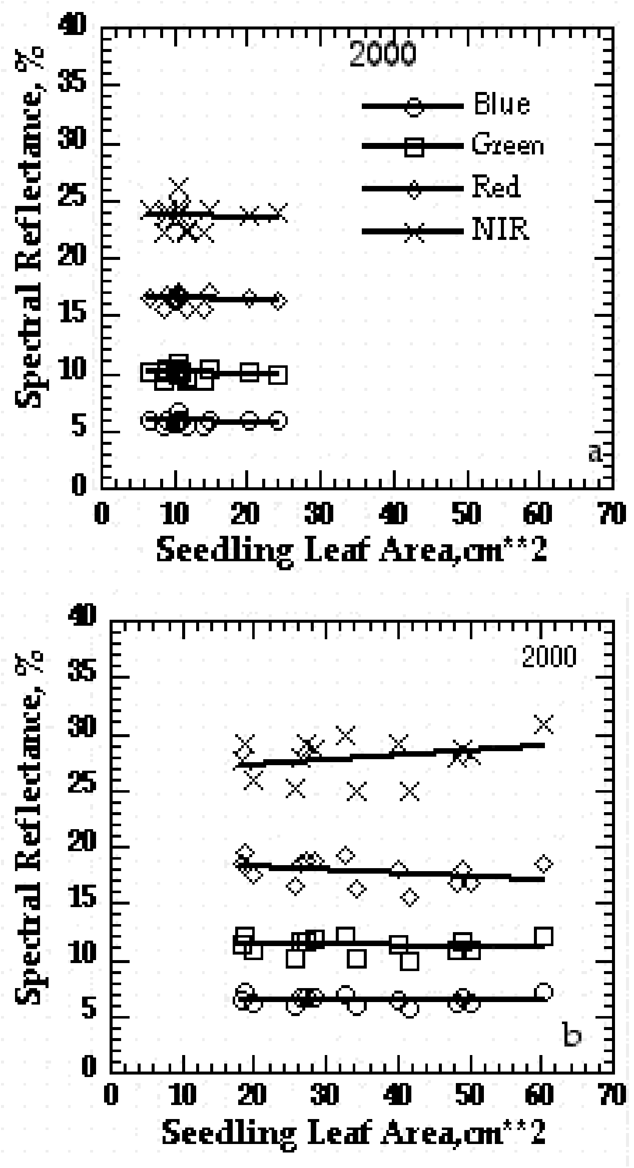

Figure 3. Seedling leaf area in the remotely sensed target areas versus spectral reflectance in four wave bands on (a) DOY 143 and (b) DOY 151 in 2000.

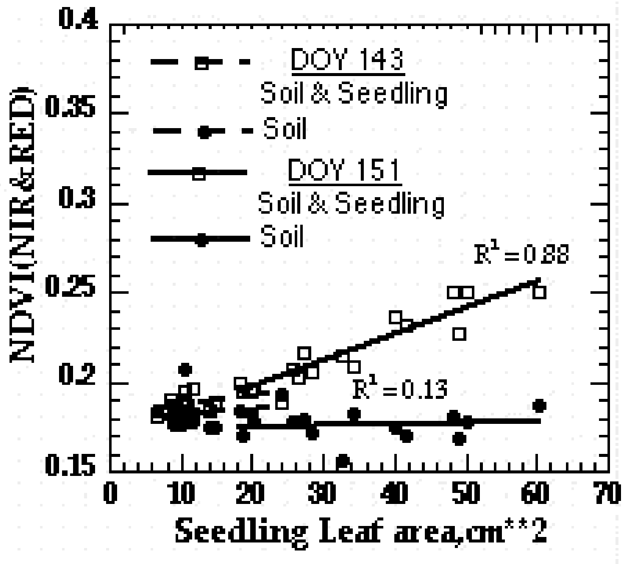

Figure 4. Relationship between NDVI values and seedling leaf area in the target areas on DOY 143 and DOY 151 for scenes with soil & seedlings and for only soil.

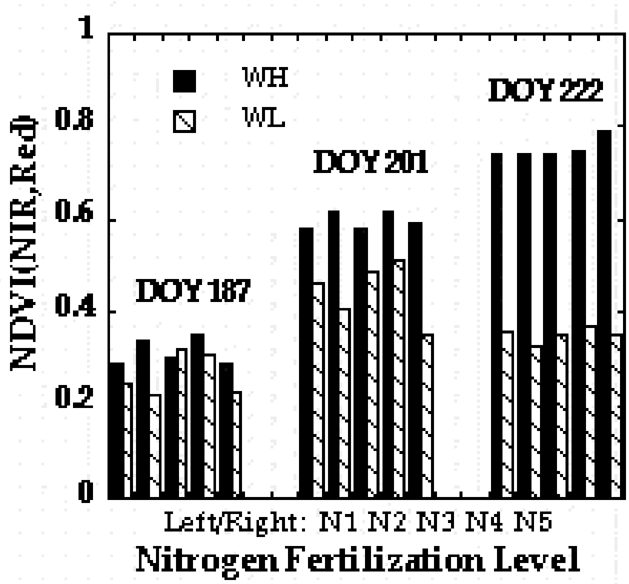

Figure 5. Comparison of NDVI values for cotton grown under five nitrogen fertilization rates and two water levels (WH and WL) at first square, first bloom, and peak bloom.

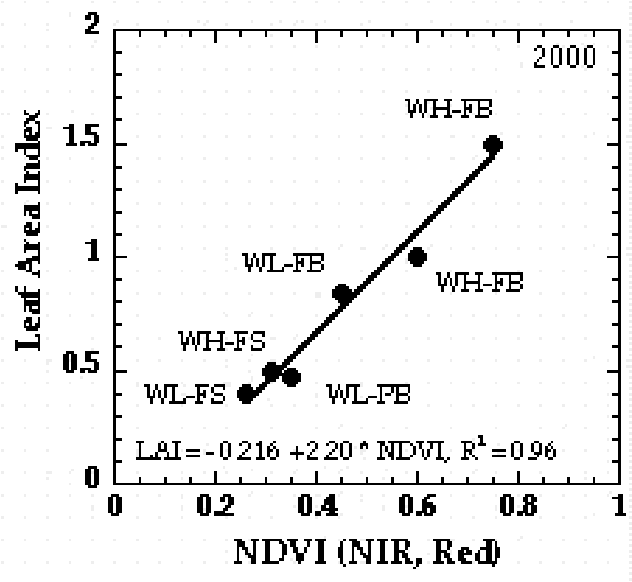

Figure 6. Linear relationship between NDVI values and leaf area index of cotton grown under two water levels (WL and WH) during the period from first square to peak bloom.

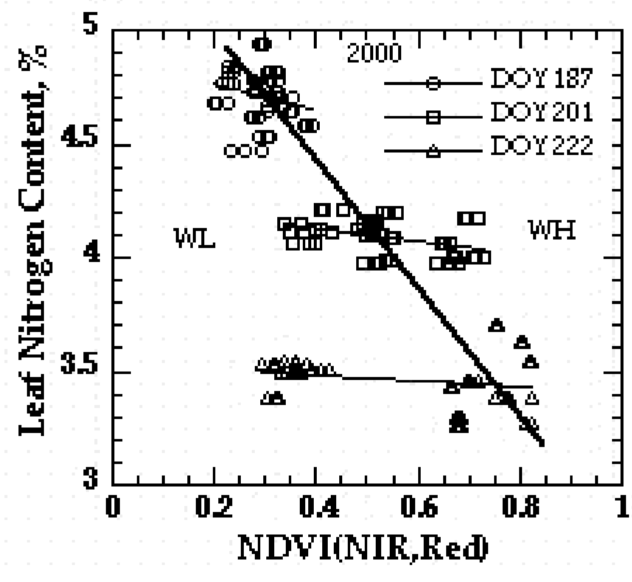

Figure 8. NDVI values are negatively related to leaf nitrogen content between first square and peak bloom. The values for the WL and WH treatments separate into distinct groups as the season progresses.

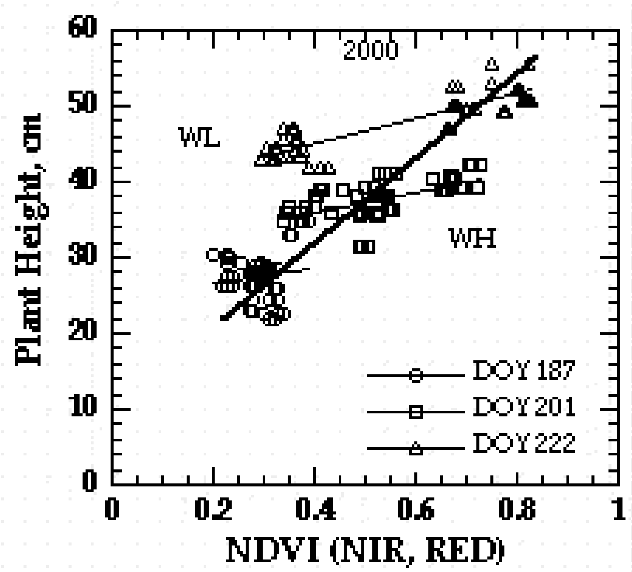

Figure 7. Positive relationship between NDVI values and plant height between first square and peak bloom. In general the data points below the trend line are from the WH treatment and those above are from the WL treatment.

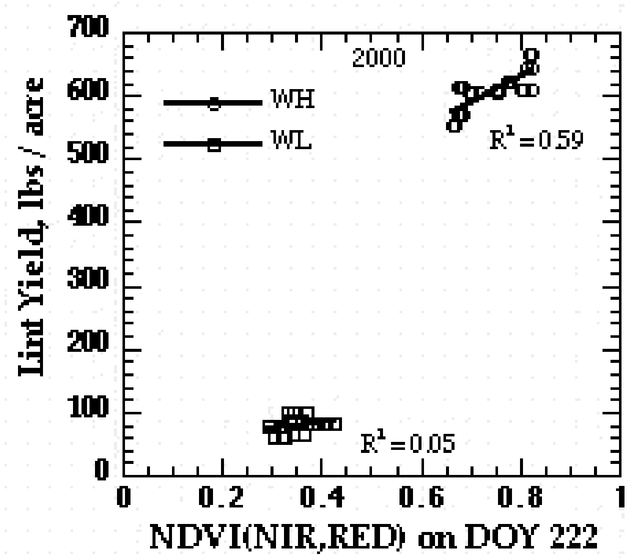

Figure 9. Relationship of NDVI values on DOY 222 (peak bloom) with lint yield in the WL and WH treatments, 2000.