1631 Canopy spectral reflectance can guide in-season nitrogen fertilization of irrigated cotton

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Nitrogen (N) fertilization of cotton in arid and semiarid areas is usually guided by soil nitrate tests and the yield goal. Canopy spectral reflectance between first square and mid bloom can be a powerful tool to assess leaf nitrogen (N) status and biomass in cotton. We present several site-years of date from center-pivot and subsurface drip irrigated cotton relating normalized difference vegetative index to leaf N, biomass, and lint yields. Correlations between spectral reflectance indices, e.g normalized difference vegetative index (NDVI) an leaf N and biomass are better from small plots, compared to landscape scale studies, and correlations improve from early to late season. Our research has also tested using reflectance-based N management for SDI cotton. Reflectance based N management has resulted in savings of N fertilizer, compared to soil nitrate test based management, without reducing lint yields.

Introduction

Spectral reflectance of crop canopies is a good estimator of crop biomass or canopy cover. Much of the early work in this area was done with satellite images (Lennington and Sorensen, 1984; Wiegand et al., 1990; Quarmby et al., 1992), which has the disadvantages of requiring cloud free conditions and turn around and processing time. Reflectance data is typically used to calcualte vegetative ratio indices of reflectance at red and near infrared (NIR) (or of green and NIR) wavebands are calculated. The normalized difference vegetative index or NDVI was proposed by Tucker (1979) as $(R_{NIR}-R_{red})/(R_{NIR}+R_{red})$, where R_{NIR} and R_{red} are reflectance in the near infrared and reflectance in the red regions, respectively. Proximal sensing at the canopy level to estimate crop N status has received recent strong interest. Bausch and Duke (1996) reported that R_{NIR}/R_{green} related to leaf N when reflectance of corn was measured under a center pivot at a 10 m height. Oklahoma researchers in have extensively tested a ground-based spectroradiometer with upward and downward facing NIR and red sensors directly over the row in wheat. They related N uptake, biomass (Stone et al, 1996; Solie et al., 1996) and yield (Raun et al., 2001) with NDVI. Osborne et al. (2002) correlated plant N and P concentration, biomass and grain yield of corn with hyperspectral reflectance at 3 m above the canopy.

Field reflectance studies that assess in-season biomass and plant N concentration in cotton have been relatively few. Maas (1998) estimated cotton ground cover with a portable spectroradiometer. Plant et al. (2001) used false infrared images from aircraft at 850 to 1500 m altitude above cotton plots that received various N fertilizer rates, and then related NDVI to N rate and to lint yield. In West Texas, Li et al. (2001) reported that NDVI calculated from measurements of spectral reflectance with a hand held spectroradiometer at 2 m above the canopy correlated well with cotton N uptake, biomass, and with lint yield.

In-season canopy level sensing of spectral reflectance has the potential to supplement pre-plant soil testing data, by providing information on the need for fertilization. In center-pivot- and subsurface drip-irrigated areas such as the High Plains, in-season fertigation with the irrigation water is commonly practiced, therefore, timely information on the need for fertilizer would be beneficial (Chua et al., 2003).

The objectives of these studies were to: i) determine if reflectance indices can assess cotton leaf N concentration, biomass, and lint yield, ii) determine the effect of N management on spectral reflectance, and iii) test spectral reflectance measurements as in-season N decision aids for irrigated cotton, and compare them to soil-test based N management,.

Keywords: Remote sensing, NDVI, leaf nitrogen, soil nitrate

Materials and Methods

Cotton was planted in May of 2000-2004 at three irrigated sites in the Southern High Plains of Texas: Lamesa, a center-pivot irrigated site on a sandy loam, Ropesville, a center-pivot irrigated site on a sandy clay loam, and Lubbock, a subsurface drip irrigated site on a sandy clay loam.

In the growing seasons of 2000-2004, we measured spectral reflectance at 50 or 80 cm above the canopy of cotton at early squaring and at mid bloom cotton the hand-held passive spectroradiometer (Model MSR16R, CropScan, Inc. Rochester, MN) consisted of upward and downward facing radiation transducers that have 16 interference filters (450, 470, 500, 530, 550, 570, 600, 630, 650, 670, 700, 780, 820, 870, 1600, 1700 nm). The bandwidth of the 16 filters ranged from 6.5 to 17.0 nm for 450 to 1700 nm wavelength centers. The radiometer was programmed to take 100 readings from each of the 16 upward and downward sensors, which took just 4 s.

In 2003 and 2004, spectral reflectance was also measured at 80 cm above the canopy of early squaring cotton with the GreenSeeker® hand-held active spectroradiometer (NTech Industries Inc., Ukiah, CA). The GreenSeeker measures spectral reflectance at two wavelengths, 670 and 780 nm and has a 60-cm wide field of view. The GreenSeeker sensor was held at 80 cm above the canopy and walked 4 m distance for two rows of cotton at each of the 135 DGPS points. About 150 reflectance readings were taken by the GreenSeeker in each 4 m pass.

At early squaring we harvested 8 cotton plants and analyzed the squares, leaves, and stems for N concentration, and recorded dry weights. At mid bloom, 4 plants were harvested and dry weights recorded, but only the leaves were analyzed for N. The sampling locations were 125 GPS-referenced points within 27 strip plots (8 m rows by 500-1000 m long) at Lamesa and in the center of 30 small plots (8 m rows X 15 m) at Ropesville and Lubbock.

Nitrogen fertilizer was added at the rate of 134 kg N ha^{-1} minus 0-60 cm soil NO_3-N ha^{-1} at Lamesa. This soil test recommendation was for a 1100 kg lint ha^{-1} yield goal (Zhang et al., 1998). The soil test based treatments at Lubbock received 168 kg N ha^{-1} minus 0-60 kg NO_3-N ha^{-1}, based on a 1400 kg ha^{-1} lint goal (Zhang et. al, 1998). N was split twice at Lamesa and four times at Lubbock. The reflectance based treatment received 30 kg N ha^{-1} at planting. Additional 30 kg N ha^{-1} applications of N were added at early squaring, early bloom and peak bloom if NDVI was < 95 % of NDVI of the well-fertilized plots (Chua et al., 2003). Hand picking of cotton was done in October of each year on 4 m of row at each GPS point in Lamesa and in each small plot at Lubbock.

Results and Discussion

Normalized difference vegetative index reflected N treatment means for leaf N and biomass between 2002 and 2004 at Lamesa (Table 1). In 2003, N management did not affect leaf N, biomass or the three calculated NDVIs. Correlations, however, between these variables at Lamesa were weak (data not shown, Bronson et al., 2005). At the Lubbock site, however, correlations between NDVI and leaf N, biomass and yield were moderate to high (Table 2). Chlorophyll meter readings correlated well with leaf N, but not with biomass. Good correlation between spectral indices eg. NDVI and both leaf N and biomass are an important feature of canopy reflectance. The reason for better relationships at Lubbock is that small plots were used there, compared to the long, landscape-scale plots at Lamesa. Fertilizer studies on small plots tend to have low standard errors, and more variance in yield and other dependent variables explained by the fertilizer treatment. At landscape scale, a larger number of soil and water relation factors influence crop growth and nutrient uptake besides the fertilizer treatments.

Treatment differences were small between the red and green NDVIs, and between the passive and active sensors. Larger NDVIs were calculated from the active sensor than the passive sensor, due to a larger field of view (Table 1). The green NDVI correlated with plant N status slightly better than red NDVI (Table 2), but both NDVIs distinguished N management effects (Table 3).

At Ropesville, TX in 2000, and at Lubbock in 2000-2001, we tested using spectral reflectance to manage in-season N application of irrigated cotton (Tables 3 and 4). Well-fertilized reference plots received 202 and 134 kg N ha^{-1} in 2000, and 2001, respectively (Table 4). At early squaring, N management did not affect leaf N, biomass or NDVIs (Table 3). Therefore no additional N was added to the reflectance based treatment at that stage. At early bloom and peak bloom, however, NDVI was significantly less with the reflectance treatment and so 30 kg N ha^{-1} N was added to both of these growth stages. Leaf N was affected by N management at early and peak bloom, and biomass was only affected at peak bloom.

In 2000 at both sites, 83 kg N ha^{-1} was saved using spectral reflectance based management (Table 4). In 2001 at Lubbock, no N was saved with reflectance management relative to soil test based management. Lint yields were similar with reflectance based or soil test based N management in all 3 site-years (Table 4).

Conclusion

Spectral reflectance indices, i.e. NDVI correlated well with leaf N and biomass of small plots in subsurface drip irrigated cotton, but not as well on large plots under a center pivot. Using canopy reflectance as an in-season indicator of need for N fertilizer looks promising. We observed modest saving of N fertilizer using NDVI, compared to soil test based N management, without a reduction in yields.

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Table 1. Early squaring leaf N, early squaring biomass, and normalized vegetative index-red, and normalized vegetative index- green as affected by N fertilization, Lamesa, TX, 2002 – 2004 (standard errors are in parenthesis) (adapted from Bronson et al., 2005)

	Leaf N	Biomass	NDVI-R-P	NDVI-G-P	NDVI-R-A	
	g kg^{-1}	kg ha^{-1}				
	<u>2002</u>					
Blanket N	45.9 (0.8) a†	ND	0.76 (0.01) a	0.65 (0.003) a	ND	
Variable-rate N	46.3 (0.8) a	ND	0.76 (0.01) a	0.65 (0.003) a	ND	
Zero N	42.6 (0.8) b	ND	0.74 (0.01) b	0.64 (0.003) b	ND	
	<u>2003</u>					
Blanket N	38.9 (0.2) a	756 (35) a	0.41 (0.01) a	0.51 (0.01) a	0.52 (0.02) a	
Variable-rate N	39.0 (0.2) a	767 (35) a	0.41 (0.01) a	0.51 (0.01) a	0.52 (0.02) a	
Zero N	38.2 (0.2) a	757 (35) a	0.40 (0.01) a	0.51 (0.01) a	0.52 (0.02) a	
			<u>2004</u>			
Blanket N	39.3 (0.5) a	2043 (69) a	0.73 (0.02) a	0.64 (0.01) a	0.86 (0.004) a	
Variable-rate N	39.0 (0.5) a	2099 (69) a	0.73 (0.02) a	0.63 (0.01) a	0.86 (0.004) a	
Zero N	32.3 (0.5) b	1869 (69) b	0.69 (0.02) b	0.61 (0.01) b	0.85 (0.004) b	

NDVI-R-P $=(R_{780} - R_{670})/(R_{780} + R_{670})$, where R_{780} is passive reflectance from 50 or 80 cm the canopy, centered on 780 nm, and R_{670} is passive (red) reflectance centered on 670 nm.

NDVI-G-P $= (R_{780} - R_{550})/(R_{780} + R_{550})$ where R_{780} is passive reflectance from 50 or 80 cm above the canopy, centered on 780 nm, and R_{550} is passive (green) reflectance centered on 550 nm.

NDVI-R-A $=(R_{780} - R_{670})/(R_{780} + R_{670})$, where R_{780} is active reflectance from 50 or 80 cm above the canopy, centered on 780 nm, and R_{670} is active (red) reflectance centered on 670 nm.

† Means in a column followed by the same letter are not significantly different at $P = 0.05$.

ND is not determined

Table 2. Correlation of N rate, leaf N, biomass, lint yield, chlorophyll meter readings (SPAD), and vegetative indices, Lubbock, 2001 (adapted from Bronson et al., 2003)

	Leaf N	Biomass	Lint yield	SPAD	GNDVI	RNDVI
	Early squaring					
N Rate				0.61**		
Leaf N						
Leaf N Acc.			0.98**		0.38*	0.39*
Biomass					0.39*	0.40*
Lint yield						
	Early bloom					
N Rate	0.82**		0.60**	0.76**	0.82**	0.69**
Leaf N			0.51*	0.76**	0.63**	0.43*
Leaf N Acc.		0.90**		0.45*	0.55**	0.52*
Biomass						0.42*
Lint yield					0.47**	0.46*
	Peak bloom					
N Rate	0.80**	0.39*	0.62**	0.64**	0.86**	0.75**
Leaf N			0.55**	0.56**	0.71**	0.70**
Leaf N Acc.			0.41*			
Biomass						
Lint yield					0.654**	0.74**

GNDVI = $(R_{820}-R_{550})/(R_{820}+R_{550})$; RNDVI = $(R_{820}-R_{670})/(R_{820}+R_{670})$ where R is percent reflectance at waveband indicated in subscript.

Table 3. Effects of nitrogen fertilizer management on biomass, leaf N, chlorophyll meter readings (SPAD) and spectral reflectance indices, Lubbock, 2001 (adapted from Bronson et al., 2003).

Treatment	N applied	Biomass	Leaf N	Leaf N Acc	SPAD	GNDVI	RNDVI
	-------kg ha^{-1}-------		g kg^{-1}	kg ha^{-1}			
	Early squaring						
Well-fertilized	67	260	45.5	7.9	44.4	0.47	0.44
Soil test	34	265	46.0	8.1	44.8	0.47	0.43
Reflectance	34	225	46.2	7.0	44.1	0.47	0.42
Chlorophyll meter	34	238	46.7	7.4	44.3	0.46	0.41
Zero	0	272	44.8	7.9	43.3	0.47	0.43
LSD (p=0.05)		NS	0.9	NS	NS	NS	NS
	Early bloom						
Well-fertilized	101	1195	42.3	25.8	44.0	0.63	0.74
Soil test	67	1175	41.8	25.0	43.6	0.63	0.74
Reflectance	34	1041	38.2	20.1	41.0	0.60	0.70
Chlorophyll meter	34	1078	39.3	21.1	41.4	0.60	0.71
Zero	0	1013	34.9	18.2	39.4	0.58	0.68
LSD (p=0.05)		NS	1.2	4.8	1.1	0.02	0.02
	Peak bloom						
Well-fertilized	134	3395	38.0	46.8	43.1	0.69	0.79
Soil test	101	2566	37.2	34.9	43.1	0.69	0.79
Reflectance	67	2760	35.8	36.4	41.0	0.67	0.77
Chlorophyll meter	34[†], 67[‡]	3226	35.1	41.9	39.9	0.66	0.77
Zero	0	2519	30.5	30.2	38.9	0.63	0.72
LSD (p=0.05)		591	1.9	9.5	2.3	0.01	0.02

[†] added to surface drip plots; [‡] added to subsurface drip plots

GNDVI = $(R_{820}-R_{550})/(R_{820}+R_{550})$; RNDVI = $(R_{820}-R_{670})/(R_{820}+R_{670})$; where R is percent reflectance at waveband indicated in subscript.

Table 4. Lint and seed yields, and biomass and N accumulation at first open boll, as affected by N management (adapted from Chua et al., 2003).

Treatment	Ropesville 2000	Lubbock 2000	Lubbock 2001
	---------------------- N fertilizer applied (kg ha^{-1}) --------------------		
Well-fertilized	202	202	134
Soil Test	134	134	101
Reflectance	51	51	101
Chlorophyll meter	34	84	84
Zero	0	0	0
	------------------ N Accumulation (kg ha^{-1}) -------------------		
Well-fertilized	78	104	122
Soil Test	69	94	123
Reflectance	70	76	102
Chlorophyll meter	59	87	102
Zero	50	68	71
LSD (*P*=0.05)	16	13	19
	------------------ Lint Yield (kg ha^{-1}) --------------------		
Well-fertilized	682	1060	1485
Soil Test	705	1068	1429
Reflectance	687	1026	1344
Chlorophyll meter	623	1033	1395
Zero	707	887	1163
LSD (*P*=0.05)	NS	90	138