USE OF ACTIVE RADIOMETERS TO ESTIMATE BIOMASS, LEAF AREA INDEX, AND PLANT HEIGHT IN COTTON

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ABSTRACT

Active radiometers have been tested extensively as tools to assess in-season nitrogen (N) status of crops like wheat (*Triticum aestivum*), corn (Zea mays), and cotton (*Gossypium hirsutum)*. Fewer studies target in-season plant growth parameters such as biomass, plant height or leaf area index (LAI). Uses of this plant data include simulation modeling, total N uptake measurements, evapotranspiration (ET) estimates and irrigation recommendations. Our objective in this study was to examine relations between canopy reflectance and biomass, LAI and plant height in irrigated cotton. Canopy reflectance was measured at 1 m height above the tallest plants in field using two, three-band Crop Circle ACS-470 radiometers in a 2.5-ha irrigated nitrogen (N) fertilizer management study in cotton in central Arizona. Cotton was planted in May in 1 m rows. There were 18 plots that were 170 m long. Interference filters were centered on 800, 780, 730, 670, 590, and 530 nm. Wavelength widths were 20 nm for 800 and 780 nm and 10 nm for the rest. Plant height was estimated with a Honeywell 943 ultrasonic distance sensor. Canopy reflectance and plant height were sensed every 7 to 14 days during the season with one pass per plot at 0.5 m/sec, and data were acquired at 5 Hz. Leaf area index was measured five times per season at 24 to 72 DGPS-referenced points using a Li-Cor LAI-2000 Plant Canopy Analyzer. Manual plant heights were taken at the 72 points as well. Biomass (1 m^2) samples were cut at ground level two times during the season. Variation in plant parameters were due to N fertilizer treatments and to sandy areas of the field with reduced water holding capacity. Several vegetative indices (VIs) were calculated and correlated with biomass, LAI, and plant height. Correlations were strongest with VIs and LAI or plant height and weakest with biomass. The normalized vegetative index (NDVI) using red as the visible band correlated with LAI, biomass, and lint yield better than using green or amber. NDVI amber correlated with N rate slightly better than NDVI-red. Correlations were weaker from using VIs that used reflectance in the red edge such as normalized difference red edge (NDRE) or the DATT index. In summary, NDVI calculated with and active sensor and plant height from an ultrasonic sensor appear to have potential to guide N fertilizer management, plant growth regulators and or harvest aid applications in irrigated cotton in the southwest USA.

INTRODUCTION

Multi-spectral spectroradiometers have potential to estimate in-season growth parameters of cotton such biomass, leaf area index, plant height and plant N content. Most research to date has used “sensors” active or passive to estimate biomass and plant N (Chua et al. 2003; Bronson et al. 2011; Buscaglia, H.J., and Varco, J.J. (2002.). Maas (1998) and Ritchie et al. (2010) estimated cotton ground cover with satellite remote sensing data.

The objectives of this study were to estimate in-season cotton biomass, LAI, and plant height using an active multi-spectral sensor. A secondary objective was to evaluate an ultra-sonic sensor for estimating cotton plant height.

MATERIALS AND METHODS

This study was conducted in 2013 in Maricopa, AZ on a Casa Grande sandy clay loam-Trix sandy clay complex. The field was located at 33.067^{o}N, 111.971^{o}W at an elevation of 368 m. The experimental design was a randomized complete block experimental with three replications. Plots were 170 m long, and eight m wide. Cotton cultivar Delta Pine 1044 was planted in 1 m rows on beds on 1 May 2013 (121 day of year (DOY).

Nitrogen fertilizer was applied as urea ammonium nitrate solution, 320 g N kg^{-1} concentration. Nitrogen fertilizer was either knifed-in the side of the bed or injected with irrigation water. Rates of N were 0, 74, and 148 kg N ha^{-1} applied in two splits, 29 May, 2013, 21 June (149 and 172 DOY). Four DGPS-referenced sampling points were placed in each of the 18 plots (Six N treatments x three replicates) for a total of 72 sampling points for biomass, and LAI.

Surface irrigation was applied about every 10 days after first square. Total seasonal irrigation totaled 90 cm.

Leaf area index was measured five times (170, 182, 190, 212, 219, 227) during the season with a Li-Cor LAI-2000 Plant Canopy Analyzer (Li-Cor, Lincoln, Nebraska). Aboveground biomass samples were harvested from two 0.5 m lengths of row at ground level at early bloom and at first open boll (170 and 217 DOY).

Canopy reflectance was measured 11 times in the season, DOY 143, 148, 156, 165, 170, 177, 190, 200, 206, 217, and 231, with a Crop Circle^{TM} ACS-470 active sensor (Holland Scientific Inc., Lincoln, NE). The Crop Circle sensor has a field of view of 30^{o} x 14^{o} and was positioned 1 m above the canopy of the tallest plants. The sensor was mounted a four-wheel cart (White and Conley, 2013). The rate of data acquisition was 5 Hz and one pass per 170 m plot was made. Reflectance was measured with one Crop Circle ACS-470 sensor in 2010-2011 at three wavebands: 760 nm (40 nm width), 590 nm (20 nm width), and at 650 nm (20 nm width). In 2011-2012, two Crop Circle ACS-470s were deployed. The first sensor had interference filters at 800 nm (20 nm width), 590 nm (10 nm width), and 670 nm (10 nm width). The second sensor had filters at 800 nm (20 nm width), 780 nm (20 nm width), and 730 nm (10 nm width).

NDVI Red (Tucker, 1979) values was calculated as:

$$(R_{800} - R_{670})/ (R_{800} + R_{670})$$

NDVI Amber (Solari *et al*. 2008) was calculated as:

$(R_{800} - R_{590})/ (R_{800} + R_{590})$ (Solari *et al.*, 2008).

NDVI Green was calculated as:

$(R_{800} - R_{530})/ (R_{800} + R_{530})$.

NDRE (Rouse e*t al.*, 1974) was calculated by as:

$(R_{800} - R_{730})/ (R_{800} + R_{730})$

The DATT (Datt, 1999) was calculated as:

$(R_{800} - R_{730})/ (R_{800} - R_{670})$

A Honeywell 943 ultrasonic distance sensor, powered by 24 V was deployed, also at 1 m above the tallest plants in the field on the four-wheel cart DOYs 143, 165, 170, 177, 190, 206, and 217. The ultrasonic detector was deployed adjacent to the active sensor. Two manual plant height measurements were made at each of the 72 DGPS points five times during the season (DOY 165, 177, 190, 206, and 217).

ArcView (9.4) was used to clip 4 m long lengths of active sensor and ultrasonic sensor data centered on each of the 72 DGPS points. Proc Corr (SAS 9.3) was used to correlate all point data collected.

RESULTS AND DISCUSSION

The Honeywell ultrasonic sensor was evaluated by comparisons with manual height measurements (Table 1). This regression was weak at 165 DOY, but improved to good fits from 177 DOY on.

Table 1. Pearson correlation of manual plant measurements and plant height estimated from an ultrasonic height sensor, Maricopa, AZ 2013

DOY	Regression equation	R^2
165	Y = 0.51*x + 8.1	0.37
177	Y = 0.95*x + 4.3	0.66
190	Y = 0.91*x -1.6	0.78
206	Y = 0.94*x -2.6	0.54
217	Y = 0.99*x-4.7	0.59

Correlations among the five VIs and biomass, LAI, plant height are presented for early bloom, mid bloom and first open bolls in Tables 2, 3, and 4. The three NDVIs estimated these plant parameters with high pearson correlation coefficients. The two VIs that utilized red edge, NDRE and DATT performed poorly in estimating the plant parameters. Plant height was the plant B

Correlation of the VIs with final lint yield improved between early bloom to mid bloom, and was highest with NDVIR (Table 3 and 4). This was also reported by Bronson et al. (2012) in Texas. The study was an N fertilizer study, so correlation of the VIs of N rate was evaluated. None of the VIs were correlated with N rate at early bloom (Table 2). By first open boll all VIs were correlated with N rate, with NDVIA having the highest correlation (r = 0.60). Also similar to our work in Texas, NDVIR correlated slightly better and NDVIA for biomass and lint yield. Similar, to Bronson et al. (2012) on farmers' fields, correlations of VIs with lint yield was less than that of N rate. This indicates that spatial variation in soil properties and soil N supply were more important than N fertilizer rate in controlling biomass and final lint yield. In conclusion, VIs, especially NDVIs calculated from canopy reflectance from an active sensor and estimates of crop height showed great potential in estimating biomass, LAI, and lint yield in irrigated cotton. The sensors therefore have potential to guide N fertilizer applications and variable rate applications of plant growth regulators and harvest aids in the southwest USA.

Table 2. Correlation of biomass, leaf area index, plant height, and vegetative indices at early bloom, (170 day of year) Maricopa, AZ, 2013

	NDVIA	NDVIR	NDVIG	NDRE	DATT
Biomass	0.58	0.60	0.51	NS	NS
LAI	0.45	0.47	0.43	0.30	NS
Plant height	0.94	0.96	0.85	0.47	-0.36
N rate	NS	NS	NS	NS	NS
Lint yield	0.56	0.55	0.56	0.40	NS

Table 3. Correlation of leaf area index, plant height, and vegetative indices at mid bloom (190 day of year), Maricopa, AZ, 2013

	NDVIA	NDVIR	NDVIG	NDRE	DATT
LAI	0.26	NS	NS	0.32	NS
Plant height	0.90	0.95	0.80	0.34	-0.44
N rate	0.27	NS	0.28	0.32	NS
Lint yield	0.71	0.73	0.73	0.26	-0.34

Table 4. Correlation of biomass, leaf area index, plant height, and vegetative indices at first open boll (217 day of year), Maricopa, AZ, 2013

	NDVIA	NDVIR	NDVIG	NDRE	DATT
Biomass	0.44	0.53	0.42	0.32	NS
LAI	0.73	0.70	0.67	0.48	NS
Plant height	0.86	0.91	0.80	0.69	0.44
N rate	0.60	0.47	0.52	0.49	0.41
Lint yield	0.67	0.75	0.63	0.48	NS

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