COTTON RESPONSE TO ABRUPT CHANGE IN WATER APPLICATION

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Abstract

Water application to crops is a primary limiting factor to production and thus water status of the crop is essential information required in production management decisions. Cotton was grown under two constant levels of soil moisture and then the water levels were reversed while the change in water status was monitored at Lubbock, TX in 1998. The purpose of the experiment was to compare the sensitivity of leaf water potential, temperature of the crop canopy, and spectral reflectance to the change in water status of cotton. The low water level (WL) was dryland and the high water level (WH) was 1.0 *PET. The transient soil water treatments began on a day of scheduled irrigation which was 21 July (DOY 202). The transient water treatment that relieved water stress was TLH which changed from WL to WH and the treatment which induced water stress was THL which changed from WH to WL. When the transient water treatments were initiated in the WL and WH treatments the growth stage was first bloom plus two weeks. A change in leaf water potential occurred after three days. A change in canopy temperature between the TLH and THL treatments, expressed as the amount of daily time that the temperature was above 28 °C (DST), was detected after four days when the DST of THL became greater than for TLH. Spectral reflectance of the TLH and THL treatments was different between these treatments prior to switching water application input. Then spectral reflectance in the near infrared (NIR) band and the normalized difference vegetative index (NDVI) remained consistently higher in the THL than the TLH treatment for 8 days after water application rates were reversed. This was due to the large leaf area in THL which received water input at the WH level until the transient soil water treatments were imposed. Yields of the THL and TLH treatments of cotton were lower than those from the WH treatment and higher than for the WL treatment. Canopy temperature was sensitive to change in crop water status and can rapidly determine conditions in an entire field compared to leaf water potential which accurately measures water status but can not provide automated spatial measurements with current technology.

Introduction

Water status of cotton fluctuates daily due to variations in evaporative demand driven by energy input and factors which regulate rate of water vapor loss. Declining soil water also influences water status by affecting the rate of water uptake by the plant. These water status fluctuations lead to variations in plant cell turgor which affect vegetative and reproductive organ growth. Cause and effect relationships have been demonstrated between plant water status commonly measured as leaf water potential and yield. Ackerson, et al. (1977) reported a linear decline in cotton photosynthesis rate per unit of vegetative leaf area as LWP declined below -12 bars. Cotton fruit abscission increased dramatically as soil drying and evaporative demand lowered LWP below a threshold of about -18 bars (Guinn and Mauney, 1984; Grimes and Yamada, 1982).

To maximize crop productivity in high level management scenarios that are targeted in precision agriculture, crop water status and other inputs like plant population, fertility, diseases, weeds, and insects must be expertly managed. A critical aspect in managing an input factor is the capability to measure its temporal and spatial attributes. In the case of water status, leaf water potential (LWP) is one method for defining plant water status. LWP is a precise method of measuring plant leaf water status but it is labor and time intensive which are detriments where many measurements are frequently required. Other remote types of measurements have demonstrated sensitivity to water status by measuring plant characters that vary in response to changing water status.

Plant temperature is another attribute which is affected by water status. Well-watered plants have lower canopy temperatures than water-stressed plants and this response can monitor plant water status as a tool in crop management. The use of canopy temperature measured by infrared thermometers has been used to schedule irrigation, Wanjura, et al. (1995). The amount of daily time that canopy temperature remained above 28 °C was used as the irrigation criterion.

Another technology for remotely monitoring plants is spectral reflectance which responds to canopy size, canopy architecture, leaf shape and orientation, and some pigment concentrations. Hyperspectral canopy reflectance was acquired from irrigated corn having various nitrogen treatments by Bausch, et al. (1998). Their analysis suggests that red edge derivative ratios can be used to estimate the plant nitrogen status of irrigated corn. Spectral reflectance like plant temperature does not directly measure plant water status, but it can be affected by leaf parameters that are directly associated with water status.

In consideration of the above possibilities a study was conducted to compare several techniques for monitoring plant water status. The objective was to measure and compare the sensitivity of plant water potential, canopy temperature, and spectral reflectance of cotton growing in transient soil moisture regimes that were created by abruptly changing water application. In one transient soil moisture treatment water status progressed from stressed to

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:380-384 (1999)
National Cotton Council, Memphis TN

nonstressed (stress relief) and from nonstressed to stressed (stress induction) in another treatment.

Procedure

Plots were furrow irrigated on 6 May and 9 May, respectively, to provide soil moisture for planting and stand establishment. Cotton was planted on beds oriented north to south and spaced 40-inches apart on May 14, 1998. The planting rate for the cultivar Paymaster HS 26 was 15.0 lbs/ac. The insecticide Temik was applied in the seed furrow at the rate of 2.3 lbs/ac. Prior to emergence 1.5 pt/ac of Dual and 2.4 pt/ac of Caparol was sprayed across the beds.

Cotton was grown using two constant water input regimes until the date that the transient soil water treatments were imposed. The WL treatment was dryland and WH was 1.0*PET. The transient soil water treatments began on a day of a scheduled irrigation which was 21 July (DOY 202). The transient water treatment that relieved water stress was TLH which changed from WL to WH and the treatment which induced water stress was THL which changed from WH to WL.

Final plant populations in the WL and WH water regimes were 34,200 and 49,700 plants/acre, respectively. Following stand establishment drip irrigation tubing was placed on the soil surface with the first irrigation applied on 1 June. The BIOTIC irrigation procedure has timed irrigation events using a minimum irrigation interval of three days which was increased in increments of one day when an irrigation signal was not obtained beginning on the third day, Upchurch, et al. (1996). An irrigation signal was obtained whenever the daily time accumulation of canopy temperature exceeded 5.5 hours above 28 °C. The WH treatment received 21 mm following each irrigation signal and the WL treatment received only rainfall.

Leaf water potential (LWP) measurements were made with a portable pressure chamber, Grimes and Yamada (1982). Cotton LWP measurements used the fourth fully expanded leaf below the main stem terminal and were made by inserting the leaf petiole through the pressure chamber grommet. LWP for each plot was calculated as the average of three samples. Observed chamber pressure when sap first bubbled from the end of the leaf blade was read as the LWP value. On the first day of the transient water status period measurements were made at predawn to determine the maximum water status condition. Thereafter midday readings were taken between 1400 and 1600 hours.

Infrared thermocouples were installed on poles in each plot to continuously measure temperature of the upper surface of the canopy. Average canopy temperature during 15-min periods was calculated and stored by a CR21X Campbell Scientific Data Logger. An automated weather data collection system was installed in the study area which measured dry and wet bulb temperatures, total radiation, net radiation, wind speed and direction, and rainfall.

Spectral reflectance were measured with a hyperspectral radiometer in the interval from 400 nm to 2500 nm from a nadir view. The radiometer was positioned over the middle of each plot and three measurements were made in adjacent rows with the radiometer positioned directly over the planted row. Readings were made on clear days during the period from 0930 to 1230 h or beginning at 1430 h to minimize the bi-directional reflectance effects of solar zenith angle. Reflectance for the blue, green, red, and near-infrared wavelengths were calculated by averaging the hyperspectral data over the intervals of 450-520 nm, 520-600 nm, 630-680 nm, and 775-900 nm, respectively.

Crop development was monitored during the growing season by making biweekly biomass harvests of five plants per plot. In the alternate weeks between biomass harvests phenological development was tracked by measuring plant height and number of main stem nodes from five randomly selected plants in each plot. Final yield was estimated by harvesting nine 1-m row lengths in the center of each plot which included three consecutive 1-m segments in three adjacent rows. The WH treatment was harvested on 27 October, WL on 30 October, and THL and TLH plots on 5 November.

Plot size was 40 feet wide (12 rows spaced 40 inches apart) by 40 feet long.

In each crop the WH and WL water levels were contiguous areas of four plots arranged across rows by five plots in the row direction separated by four plots each of THL and TLH treatments arranged in a single tier across rows. In each water level there were five levels of N replicated 4 times which were fertilized on 4 May. Nitrogen treatments and amounts in lbs./acre were N1- 0, N2- 50, N3- 100, N4- 150, and N5- 200. All plots fertilized with nitrogen also received 40 lbs./acre of P. The THL and TLH plots received the N4 fertilizer treatment.

Results

Automated control of irrigation used a 3-day irrigation frequency which also depended on the daily accumulation of at least 5.5 hours above 28 °C was started on 1 June. Irrigation plus rainfall amounts applied to each water level are given in Fig.1 with potential evapotranspiration (PET) shown as a reference level. The WH treatment received an average of 7 cm of irrigation per day which equalled 86 % of cumulative PET when irrigation was stopped on 23 September (DOY 266).

When the transient soil water treatments began on 21 July (DOY 202) plant height was 28 and 66 cm, respectively, in TLH and THL treatments. The number of main stem nodes was 13 and 16, respectively. The first bloom date had occurred on July 6 in both treatments. Plant height and leaf number or number of main stem nodes are compared for the transient water treatments along with WL and WH for each crop in Fig. 2.

Leaf Water Potential

The transient soil water study was initiated on 21 July when the early morning and afternoon LWP values of TLH were lower than THL, Table 1. By 23 July the LWP of the two transient water treatments had equalized and were different from constant water level treatments WL and WH. The LWP values of the transient treatments separated on 24 July (DOY 205) when THL was lower than TLH. The water status of the cotton separated three days after initiating the transient soil water treatments.

The pattern of adjustment in afternoon LWP by the two transient water treatments is shown in Fig. 3 with an arrow indicating the first date when values for the TLH and THL treatments were different. Interday LWP variations in the two constant water level treatments occurred in response to daily microclimate variations or to irrigation events. During the transition period LWP of the WH treatment ranged from -22 to -26 bars and treatment WL was more consistent remaining between -27 and -28 bars.

Canopy Temperature

Canopy temperature of water stressed crops are higher than for well-watered crops during most of the day time period. Daily stress time (DST) was calculated as the amount of time that canopy temperature remained above 28 °C. DST for the THL and TLH treatments was then compared as a relative measure of water status. On Doy 202, the day of initiating the transient soil water treatment, the DST of THL was greater than for TLH, Fig. 4. On DOY 203 the DST of THL increased above TLH, but than there were no treatment differences for the next two days. DST of THL was greater than TLH on DOY 206 and retained this difference for the following three days. DST reflected the effect of the transient soil water treatment after 4 days compared to 3 days for LWP.

Spectral Reflectance

Spectral reflectance in the blue, green and red wavelengths were greater in the TLH treatment than in the THL treatments for each of the four measurement dates, Table 2. The NIR band reflectance and the NDVI value were always higher in the THL treatment than the TLH treatment and the differences were large because of the large canopy size differences. Unlike the LWP and DST values the NDVI values did not switch between the TLH and THL treatments, even though the difference in NDVI values did decrease slightly between DOY 202 and DOY 210.

Yield

Cotton yields were 234 and 1286 lbs. lint/acre for the WL and WH irrigation levels. The WL treatment received only rainfall which totalled 15 cm and the WH treatment received a rainfall plus irrigation amount of 57 cm. The 1998 yields compared closely to the 1997 yields which were 326 and 1348 lbs. lint/acre for the WL and WH treatments, respectively. A high level of water stress is indicated for the WL treatment which had a yield CV of 33% compared to 13% for the WH treatment.

The yield response from the THL(stress induction) and TLH (stress relief) treatments were alike when compared to the WL and WH treatments. The THL treatment increased yield compared to the WL treatment and TLH decreased yield in relation to WH. These responses reflect the fact that a large portion of the yield potential was established prior to the time of initiating the transient soil water treatments. A larger plant with more bolls was established in the THL treatment than in the WL treatment before starting the treatment. The TLH treatment had a smaller plant with fewer bolls than the WH treatment when the transient treatment was begun. The water stress was relieved in the TLH treatment which began to grow vegetatively and then set additional bolls which matured late. At the season’s end, the TLH treatment had fully mature bolls at the bottom of the plant and immature bolls at the upper main stem node positions.

Summary

The change in cotton water status growing in two transient soil moisture treatments, THL and TLH, was detected by LWP after three days, in four days by DST, but not by spectral reflectance (NDVI) after eight days. Leaf water potential directly measured plant water status and quickly responded to changing moisture conditions but it is a slow and labor intensive procedure. Canopy temperature was an accurate indicator of plant water status that can rapidly provide a spatial indication of plant water status in the field from remotely measured temperatures. Plant height, number of main stem nodes, and leaf area index of the TLH treatment increased above the THL treatment after the transient soil moisture change occurred on 22 July. Lint yield of the TLH treatment was 734 lbs./acre compared to 406 lbs./acre for the THL treatment.

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Table 1. Cotton leaf water potential values for four soil water regimes during the early transient soil water period, 1998.

Date	Soil Water Regime			
	WL	WH	TLH	THL
	---------------Leaf water potential, bars---------------			
21 July AM	----	-8.52 a[1]	-6.16 b	----
21 July PM	-27.10 a	-25.05 b	-26.97 a	-24.77 b
22 July PM	-26.45 a	-23.05 c	-25.57 ab	-25.05 b
23 July PM	-26.95 a	-22.34 c	-24.20 b	-24.50 b
24 July PM	-27.33 a	-25.30 c	-24.60 c	-26.48 b
27 July PM	-27.95 a	-23.02 c	-21.70 d	-27.05 b

[1]Leaf water potential values on the same line followed by a common letter are significantly different at the 0.05 probability level according to Duncan's Multiple Range Test.

Table 2. Spectral reflectance of cotton in four wave bands and normalized vegetative index, Lubbock, TX, 1998.

Date	Water Level	Blue	Green	Red	NIR	NDVI[1]
DOY	WL	0.072a[2]	0.129a	0.186a	0.337b	0.29b
202	TLH	0.069a	0.123a	0.179a	0.320b	0.28b
	THL	0.037b	0.062b	0.064b	0.385a	0.72a
	WH	0.041b	0.064b	0.066b	0.402a	0.72a
DOY	WL	0.066a	0.123a	0.175a	0.332c	0.31b
203	TLH	0.053b	0.104b	0.149b	0.292d	0.33b
	THL	0.030c	0.061c	0.062c	0.386b	0.73a
	WH	0.028c	0.058c	0.052c	0.406a	0.78a
DOY	WL	0.060a	0.114a	0.163a	0.315c	0.32c
205	TLH	0.058a	0.112a	0.158a	0.321c	0.34c
	THL	0.025b	0.050b	0.041b	0.387b	0.81b
	WH	0.023c	0.046b	0.033c	0.415a	0.85a
DOY	WL	0.063a	0.120a	0.172a	0.316c	0.30d
210	TLH	0.054b	0.104b	0.144b	0.316c	0.38c
	THL	0.033c	0.066c	0.066c	0.369b	0.70b
	WH	0.027d	0.055d	0.046d	0.423a	0.80a

[1]NVDI is the normalized vegetative index calculated as (NIR - Red) / (NIR + Red).
[2]Reflectance for the same date in the same column followed by a common letter are statistically the same at the 0.05 level of probability.

Table 3. Cotton yields for constant water level and transient water treatments, 1998.

Irrigation Treatment	Yield, lbs./acre	Coefficient of Variability, %
--------------------Constant Irrigation Level--------------------		
WL	234 b[1]	33 a
WH	1286 a	13 b
---------------------Transient Water Level---------------------		
THL	406 b	19 a
TLH	734 a[2]	26 a

[1]Values in the same column and factor followed by a common letter are significantly different at the 0.05 probability level according to Duncan's Multiple Range Test.
[2]Ten percent of the lint yield for TLH was harvested from bolls which were immature (unopened) at the time of harvest.

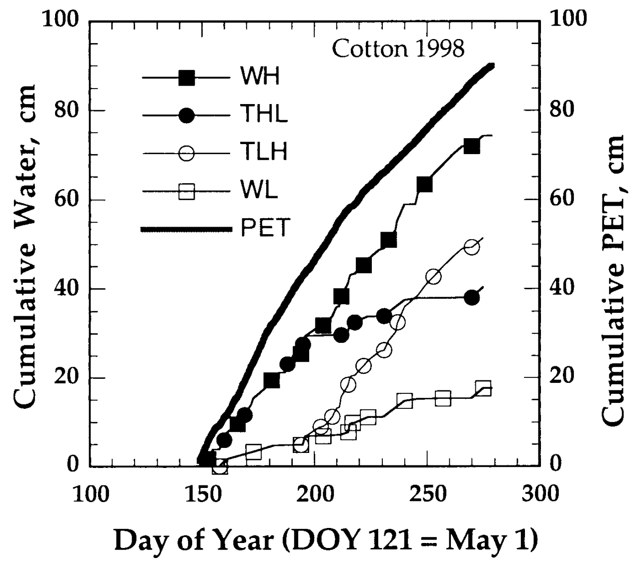

Figure. 1. Cumulative water received by constant water and transient level treatments, 1998.

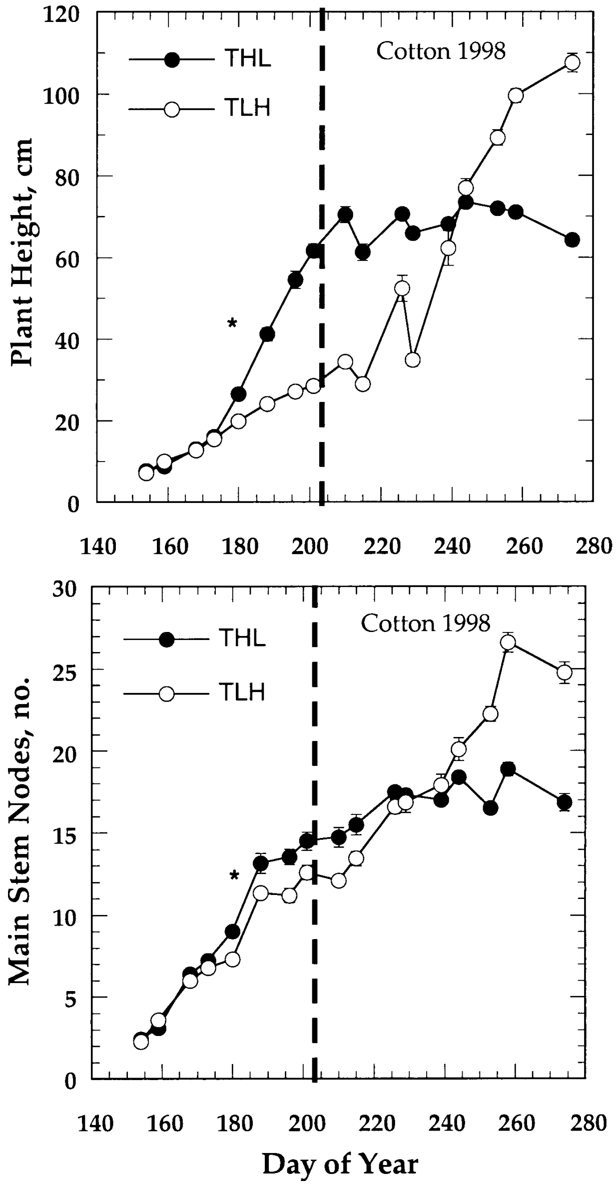

Figure 2. Plant height and main stem nodes in constant water and transient water treatments before and after the date of water application reversal.

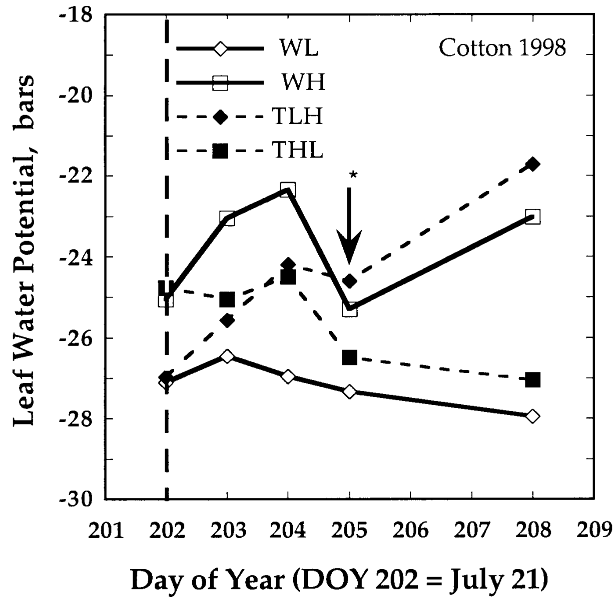

Figure 3. Leaf water potential adjustment by TLH and THL immediately after reversing water levels, 1998. The vertical dashed-line is the water reversal date and the arrow is the separation date.

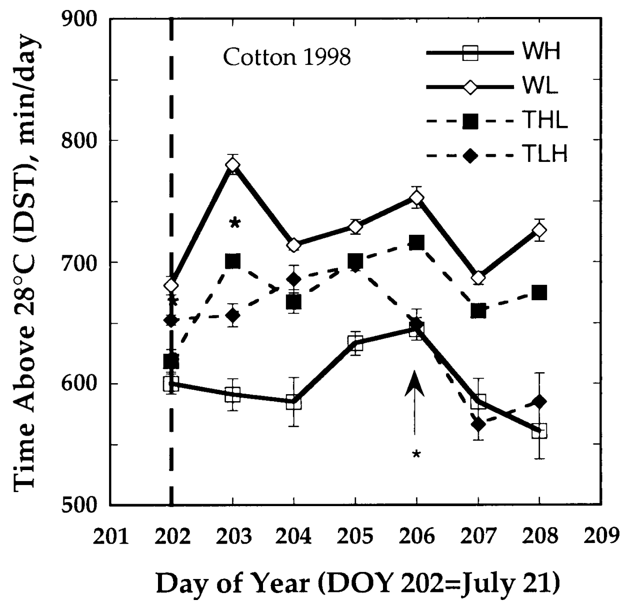

Figure 4. Canopy temperature adjustment (DST) by TLH and THL immediately after reversing water levels, 1998. The vertical dashed line is the water reversal date and the arrow is the separation date.