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SUBSURFACE DRIP IRRIGATION OF COTTON USING TIME THRESHOLDS

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Abstract

Subsurface drip irrigation systems have high initial cost, which must be recovered through some combination of higher water use efficiency and yield to increase net return. Canopy temperature (TC) was used in a field study to measure stress time (ST) in cotton, which was the daily accumulation of time when TC > 28 °C. Three levels of ST, 2.5 hr, 5.5 hr, and 7.5 hr, were used as irrigation signal criteria and referred to as time thresholds (TT) that were use to time irrigations. The purpose of the study was to measure the effect of different time thresholds values on the quantity of irrigation applied and their effect on lint yield and efficiency of water use. Daily irrigation decisions were made and 5 mm quantities were applied in response to each irrigation signal. During the entire irrigation period, the 2.5 hr TT treatment received 78 (82% of days) irrigation signals, the 5.5 hr TT generated 60 (63%) irrigation signals, and the 7.5 hr TT had 35 (37%) irrigation signals. For days when an irrigation signal occurred, average daily ST was 353 (5.9 hr), 418 (7.0 hr), and 485 (8.1 hr) min. for 2.5 hr, 5.5 hr, and 7.5 hr TT, respectively. Total irrigation applied during the growing season was 398, 313, and 201 mm, respectively to 2.5, 5.5, and 7.5 hr TT treatments. Total water applied to the treatments was 577, 492, and 380 mm through the completion of crop. Highest lint yields of 1588 kg ha^{-1} and 1555 kg ha^{-1} produced by the 2.5 hr and 5.5 hr treatments, were not statistically different, and both were higher than the 1018 kg ha^{-1} yield from the 7.5 hr TT. Dryland yield was 307 kg lint ha^{-1}. Irrigation water use efficiency was 50 and 51 kg lint ha^{-1} cm^{-1}, respectively, for 5.5 hr TT and 7.5 hr TT, and both were higher than the 40 kg lint ha^{-1} cm^{-1} measured from 2.5 hr TT. Total water use efficiency was highest for the 5.5 hr TT (32 kg lint ha^{-1} cm^{-1}) and slightly less for the 2.5 hr TT (28 kg lint ha^{-1} cm^{-1}) and 7.5 hr TT (27 kg lint ha^{-1} cm^{-1}). The 5.5 hr TT produced the most favorable results when measured by the combined standards of yield and efficient use of water.

Introduction

The use of subsurface drip irrigation for cotton production is increasing because of greater awareness of the need to use water more efficiently. The emphasis on efficient water use is driven both by increasing demands on water where the supply is plentiful and where water is limited there is the need to use the available water more efficiently. Subsurface drip irrigation offers the potential of greatly reducing soil water evaporation loss and the capability to apply water in small quantities and at high frequencies to reduce fluctuations in the water status of crops.

The initial cost of subsurface drip irrigation systems is greater than center pivot irrigation systems and it can only be economically justified for crop production if it increases net profit. Since only water is being considered, subsurface drip irrigation must result in some combination of higher water use efficiency and yield to contribute to higher profit. In order to achieve the potential benefits of reduced water evaporation and greater control of crop water status fluctuations, a high level of irrigation management is required. In-season water management is commonly referred to as irrigation scheduling, which includes both the timing of irrigation applications and the amount of water applied. Previous research (Bordovsky and Lyle, 1999; Wanjura, et al, 1995) has shown that shorter time periods between irrigations increases cotton yield by reducing the fluctuation in the magnitude of water stress experienced by the crop.

The BIOTIC method of timing irrigation, Upchurch, et al. (1996) controls irrigation by monitoring the crop canopy temperature. The irrigation signal in BIOTIC is determined by the time-threshold (TT), which is the amount of time each day that crop temperature exceeds a crop specific temperature threshold, which is the optimum temperature for the crop based on it's physiological response to temperature. The magnitude of the time threshold also reflects local climatic conditions that determine potential evapotranspiration. We have previously studied the effect of different time thresholds on cotton lint yield using drip irrigation tubing placed on the soil surface. The research reported here was conducted to measure the effect of different time thresholds values on the quantity of irrigation applied and their effect on lint yield and efficiency of water use with subsurface drip irrigation.

Materials and Methods

The study was conducted in the field of the Plant Stress and Water Conservation Laboratory at Lubbock, TX. The cotton variety Paymaster 2326 BGRR was planted on 13 May 2002 in north-south rows having a spacing of 1 m. Two 13 mm irrigations were applied through a subsurface drip irrigation system on 14 May and 16 May to ensure adequate moisture for germination. Final seedling population averaged 50,500 plants/acre.

A subsurface drip irrigation system was installed in the field of the Plant Stress and Water Conservation Laboratory at Lubbock, TX. The spacing of irrigation laterals was 1 m and located under each bed. Lateral diameter was 0.875 in. ID with 0.23 gph emitters having a 24 in spacing. Each irrigation zone was comprised of 8 rows 542 feet long and was individually metered. An Elgal-Agro Controller Ver. 109 (Eldar-Shany, Yad Mordechai, 79145, Israel) was activated by a 5 mv signal from a Campbell Scientific CR 7 data logger that calculated stress time values and generated irrigation signals based on the average canopy temperature measured by infrared thermocouples located in plots of replications 2 and 3.

The time-threshold is an integral part of the BIOTIC protocol for timing irrigation applications. By selecting different values the time threshold results in different amounts of irrigation causing different crop water status conditions. Three irrigation treatments were controlled by TT of 2.5, 5.5, and 7.5 hr, which were selected to created conditions of excessive water application, optimum irrigation, and water stress condition. Air temperature > 28 °C, canopy temperature > 28 °C, and net radiation > 200 Wm^{-2} were required for a time interval to be added to the stress time accumulation for determining the occurrence of an irrigation signal. The protocol for determining irrigation signals is outlined in Fig. 1. Irrigation signals were dependent on the amount of time above a canopy temperature of 28 °C (referred to as stress time (ST)) exceeding the TT for each irrigation treatment. Irrigation decisions were made daily and a 5 mm application occurred in response to an irrigation signal, which could be over-ridden by recent sufficient amounts of rain. The target amount of water application was 5 mm by either rain or irrigation. Rain events > 5 mm were accumulated and prevented irrigation until its accumulation was reduced to zero at the rate of 5 mm day^{-1}. When the daily accumulation of ST for an irrigation treatment did not exceed the required TT, only 5 mm was applied in response to the next irrigation signal regardless, of the number of days between irrigation signals.

The field study was a randomized complete block design with four replications. Each plot included 16 rows comprised of two adjacent irrigation zones. Plant heights were measured weekly beginning on DOY 164 and bi-weekly biomass sampling started on DOY 171. Leaf water potential measurements were made weekly beginning on DOY 179 between 1400 and 1600 h using the pressure chamber method. The field was sprayed with Ginstar on DOY 270 (27 September) to drop the leaves. The center 8 rows of each plot was stripper harvested on DOY 316 to provide an estimate of lint yield.

In addition to monitoring canopy temperatures, air temperature, relative humidity, net radiation, and windspeed were measured at a 2 m height in 6 s intervals and all data was saved as 15-minute averages.

Results and Discussion

Irrigation

Prior to the first post-planting irrigation on DOY 170, 98 mm of rain provided sufficient moisture for plant growth. Then an additional 50 mm of rain was received between DOY 170 and DOY 192. Cumulative rain from planting through DOY 192 was 148 mm, which exceeded the amount of irrigation applied to any treatment since planting, Fig. 2.

The first post emergence irrigation after crop emergence was applied on DOY 170 at the beginning of the first square growth stage. Leaf area index was ~ 0.3 in all treatments and the canopy development was minimally sufficient to cover the soil when viewed by the infrared thermocouple from a nadir viewing position directly over the row. Total irrigation applied during the growing season to the three treatments was 398, 313, and 201 mm, respectively to 2.5, 5.5, and 7.5 hr TT treatments. Total water application to the treatments was 577, 492, and 380 mm through the completion of crop maturity, Fig. 3.

During the entire irrigation period from DOY 170-264, the 2.5 hr TT treatment received 78 irrigation signals, the 5.5 hr TT generated 60 irrigation signals, and the 7.5 hr TT generated 35 irrigation signals, Fig. 4. The 2.5 hr, 5.5 hr, and 7.5 hr TT treatments had 6, 5, and 0 irrigation signals, respectively, that occurred on days when the residual accumulation of rain was sufficient to substitute for a 5 mm irrigation. The trend of fewer irrigation signals being satisfied by rain substitution is consistent with increasing TT level and fewer total irrigation signals among the treatments.

Crop Stress

Leaf water potential was measured during the irrigation period to provide an independent characterization of crop water status to that of the ST measurements that were used to time irrigation applications, Table 1. During the 57 day period between DOY 179 and 235, 45 mm of rain was received, with 36 mm falling between DOY 186-189. During the 57 days, 42, 32, and 20 irrigation signals were generated in the 2.5 hr, 5.5 hr, and 7.5 hr TT treatments, respectively. The primary trends were for leaf water potential to decrease with time in all TT treatments. Across treatments leaf water potential values were significantly different between all treatments, decreasing in value as the TT value increased. A predawn measurement of leaf water potential on DOY 221 indicated that the 2.5 hr irrigation treatment was the only treatment where plants recovered to24 full turgor during the night. The steady decline of leaf water potential in the 2.5 hr TT treatment suggests that the 5 mm irrigation applications were insufficient to fully replace daily water use. Previous studies in 1998 and 1999 used drip irrigation laterals placed on the surface of beds and the basic irrigation frequency was 3 days with 21 mm irrigations (7 mm/ day) applied after each irrigation signal based on a 5.5 hr TT. Leaf water potentials in the 5.5 hr TT did not fall below –2.5 MPa, Wanjura and Upchurch, 2002.

Daily ST for the three TT irrigation treatments are shown in Fig. 5 for the period from DOY 187 to DOY 183. The period is selected for making comparisons because plant size is sufficient for allowing TC measurements without viewing soil. The average daily ST during this period, based on all days regardless of whether an irrigation signal was generated, was 319, 359, and 402 min. for 2.5 hr, 5.5 hr, and 7.5 hr TT, respectively. The number of days with irrigation signals was 50, 40, and 21 for the same sequence of treatments. For only days when an irrigation signal occurred average daily ST was 353, 418, and 485 min. for 2.5 hr, 5.5 hr, and 7.5 hr, respectively.

The ST values enclosed in the two " dotted – line boxes" for DOY 220 and DOY 224 are relatively cool and hot days, respectively. There were no irrigation signals on DOY 222 in contrast to DOY 244 when all treatments received irrigation signals. The diurnal plots are presented in Fig. 6 to provide a comparison of the canopy temperatures for the three TT treatments. DOY 222 was partly cloudy and maximum TC of the 2.5 hr and 5.5 hr TT treatments was 30 °C and predominately remained below TA, Fig. 6a. TC during the afternoon of DOY 224 displayed maximum temperatures that were inversely related to the amount of irrigation. TC of the 5.5 hr and 7.5 hr TT were warmer than TA during the middle of the day light period when TA increased above 24 °C, but the 2.5 hr TT remained below TA, Fig. 6b. During the day TC of well-watered cotton remained below TA provided the vapor pressure deficit was relatively high.

Crop Development

Plant height and fruiting measurements were made weekly, except when biomass samples were taken on six dates. The first difference in plant height occurred on DOY198 when treatments 2.5 hr TT and 5.5 hr TT were significantly taller than plants in the 7.5 hr TT treatment, Fig. 7a. Plant height increased rapidly in all treatments until DOY 198, but afterwards height increase was 200 mm, 100 mm, and 20 mm, respectively in 2.5 hr, 5.5 hr, and 7.5 hr TT treatments. Leaf area index change paralleled the height increase showing maximum values of 5.1, 3.9, and 3.3 for the 2.5 hr TT, 5.5 hr TT, and 7.5 hr TT treatments, respectively, in Fig. 7 b. The slow-down in plant growth was in the early phase of high frequency irrigation applications when no rain occurred.

The cessation of height and leaf growth coincided with the period of rapid increase in green boll formation, Fig. 8 a, which occurred between DOY 198 and DOY 210. The dramatic slowing of vegetative growth was correlated with the equally dramatic increase in boll formation. Boll maturity is shown in Fig. 8 b where beginning on DOY 233, the rate of boll maturity was similar among the three irrigated treatments until all bolls have matured on DOY 260. Differences in water stress among the irrigated treatments did not appear to significantly affect the rate of boll maturation.

Lint Yield

The field was sprayed to defoliate leaves on DOY 270 and most leaves dropped after two weeks.

The treatments were stripped on DOY 316 (12 November) following an extended period of rainy and cloudy weather that began in the middle of October. The lint yields in Table 2 indicate that the highest yield of 1588 kg ha^{-1} was measured from the 2.5 hr TT, but it was not statistically different from the 1555 kg ha^{-1} yield for the 5.5 hr TT. The 1018 kg lint ha^{-1} from the 7.5 hr TT was lower than from the other treatments. As a comparison the dry land yield was 307 kg lint ha^{-1}.

Water use efficiency based total irrigation was highest and similar for the 5.5 hr TT and 7.5 hr TT and lowest for the 2.5 hr TT. Efficiency of total water use was highest for the 5.5 hr TT and slightly less for the 2.5 hr TT and 7.5 hr TT. The 5.5 hr TT produced the most beneficial results when measured by the combined standards of high yield and efficient use of water.

References

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Upchurch, D. R., D. F. Wanjura, J. J. Burke, and J. R. Mahan. 1996. Biologically-Identified Optimal Temperature Interactive Console (BIOTIC) for managing irrigation. United States Patent No. 5,539,637. July 23, 1996.

Wanjura, D. F., D. R. Upchurch, and J. R. Mahan 1995. Control of irrigation scheduling using temperature-time thresholds. Trans. ASAE 38:403-409.

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Table 1. Leaf water potential values for three time threshold irrigation treatments, 2002.

Day of Year	Time Threshold Treatments 2.5 hr	5.5 hr	7.5 hr.	Dryland
	Leaf water potential, MPa			
179	-1.59 b _1/	-1.44 ab	-1.39 a	-----
182	-1.59 a	-1.62 a	-1.63 a	-----
196	-1.85 a	-2.02 b	-2.41 c	-----
205	-2.06 a	-2.33 b	-2.81 c	-3.45 d
213	-2.20 a	-2.73 b	-2.94 c	-3.76 d
217	-2.41 a	-2.78 b	-3.00 c	-3.88 d
221 Predawn	-0.90 a	-1.17 b	-1.46 c	-2.79 d
227	-2.64 a	-2.79 b	-3.31 c	-3.84 d
235	-2.76 a	-2.90 b	-3.04 c	-3.66 d

_1/ Leaf water potentials for the same day of year followed by a common letter are statistically similar at the 0.01 probability level according to Duncan's Multiple Range Test.

Table 2. Yield and water use efficiency for time-threshold irrigation treatments, 2002

Time Threshold Treatments	Lint yield, kg ha^{-1}	Total Irrigation cm	Total Water cm	Water Use Efficiency Irrigation	Total Water
				kg lint ha^{-1} cm^{-1}	
2.5 hr	1588 a _1/	39.8	57.7	39.9	27.5
5.5 hr	1555 a	31.3	49.2	49.7	31.6
7.5 hr	1018 b	20.1	38.0	50.6	26.8

_1/ Lint yields followed by a common letter are statistically similar at the 0.01 probability level according to Duncan's Multiple Range Test.

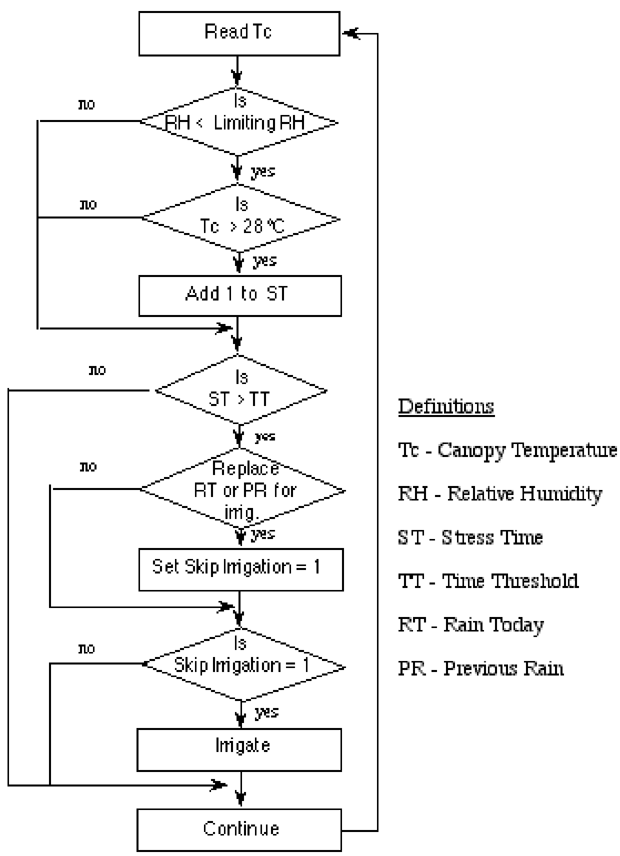

Figure 1. Flow chart of irrigation protocol showing that irrigation signals depend on canopy temperature, relative humidity, time threshold value and use of rain to substitute for irrigation applications, 2002.

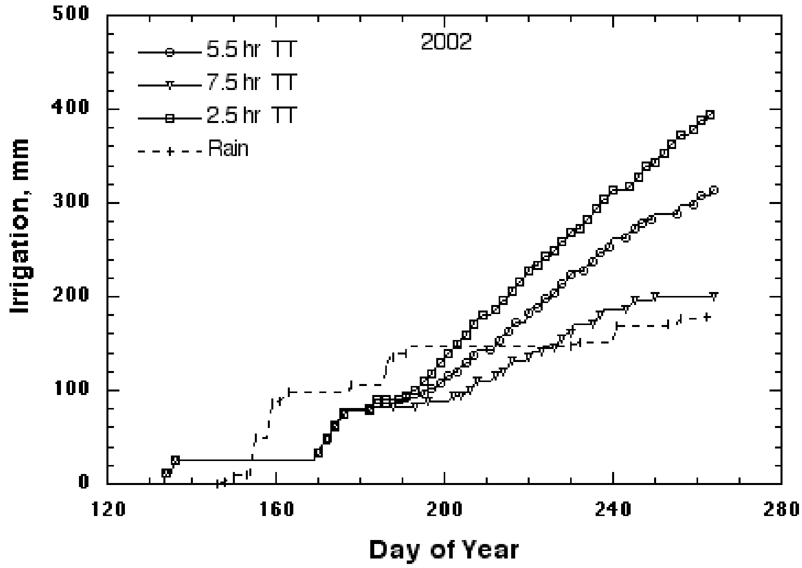

Figure 2. Cumulative irrigation and rain applied between planting and the completion of boll maturity in each treatment, 2002.

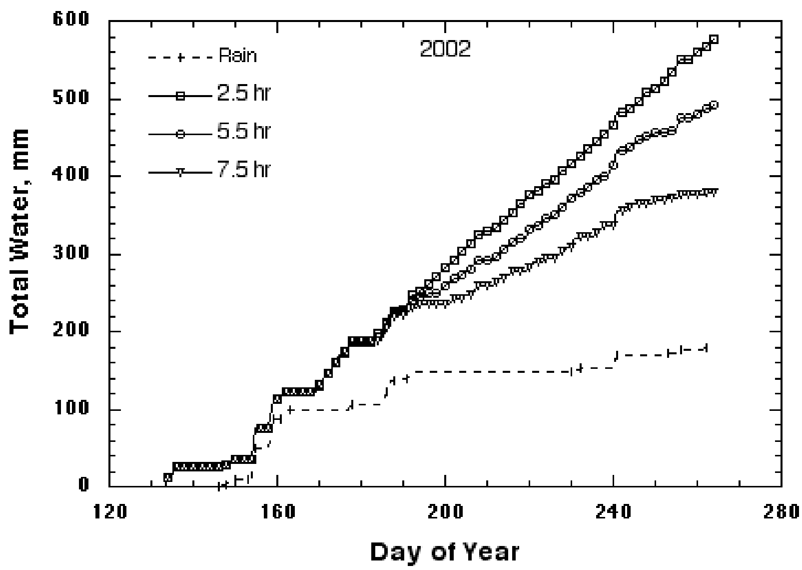

Figure 3. Total seasonal rain and water application from planting through the completion of crop maturity in each treatment, 2002.

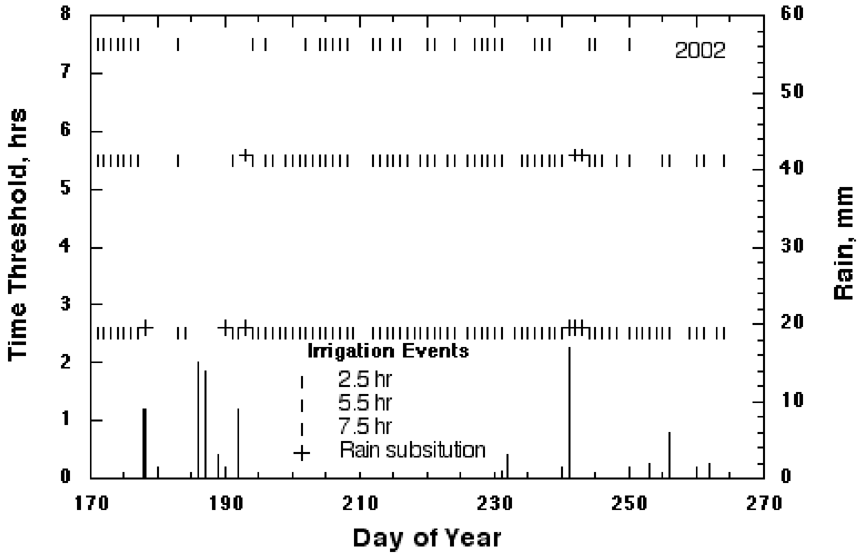

Figure 4. Irrigation events resulting from irrigation signals developed by time threshold treatments of 2.5 hr, 5.5 hr, and 7.5 hr, 2002.

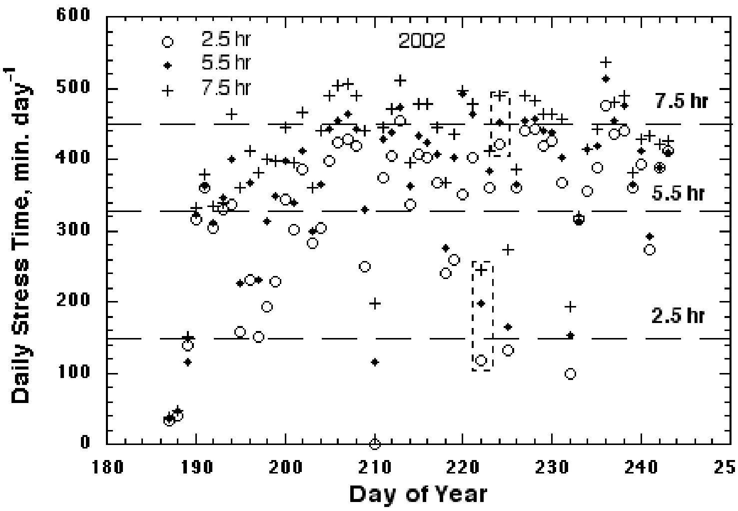

Figure 5. Daily stress times for three time threshold irrigation treatments between DOY 187 and DOY 243, 2002.

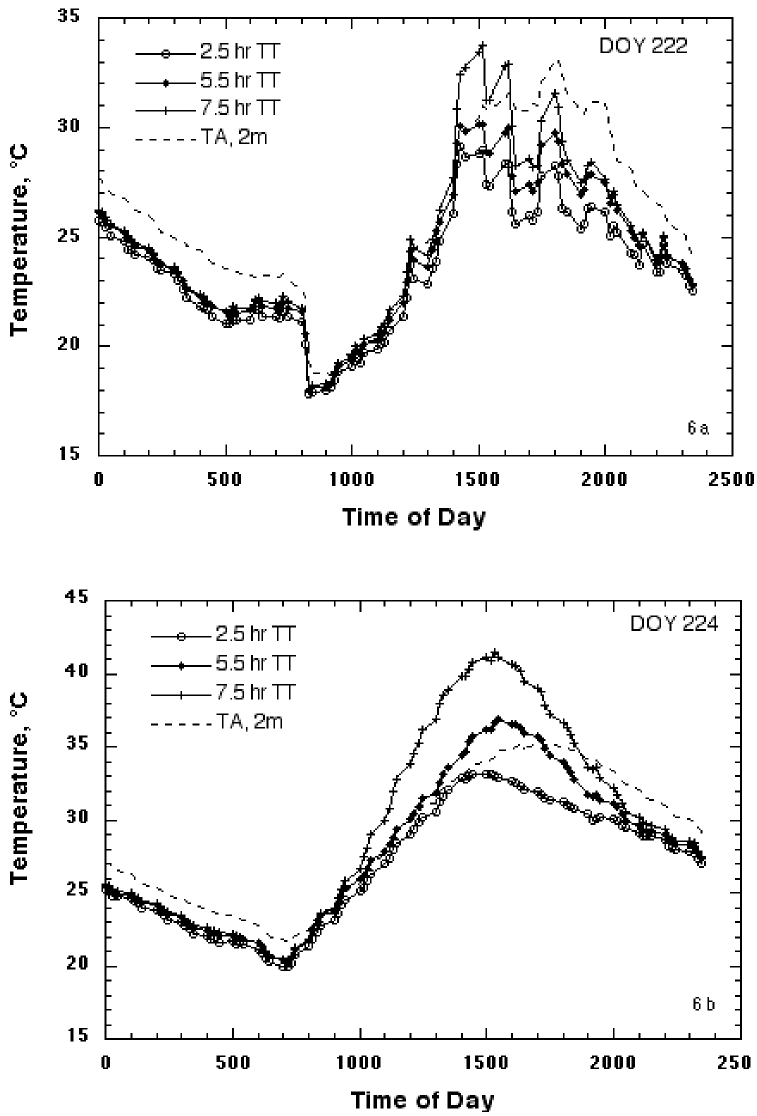

Figure 6. Canopy temperature of three time threshold treatments and air temperature. Figure 6a shows DOY 222 was cool and no treatments received irrigation signals. Figure 6b shows a warmer day on DOY 224 when all treatments received irrigation signals.

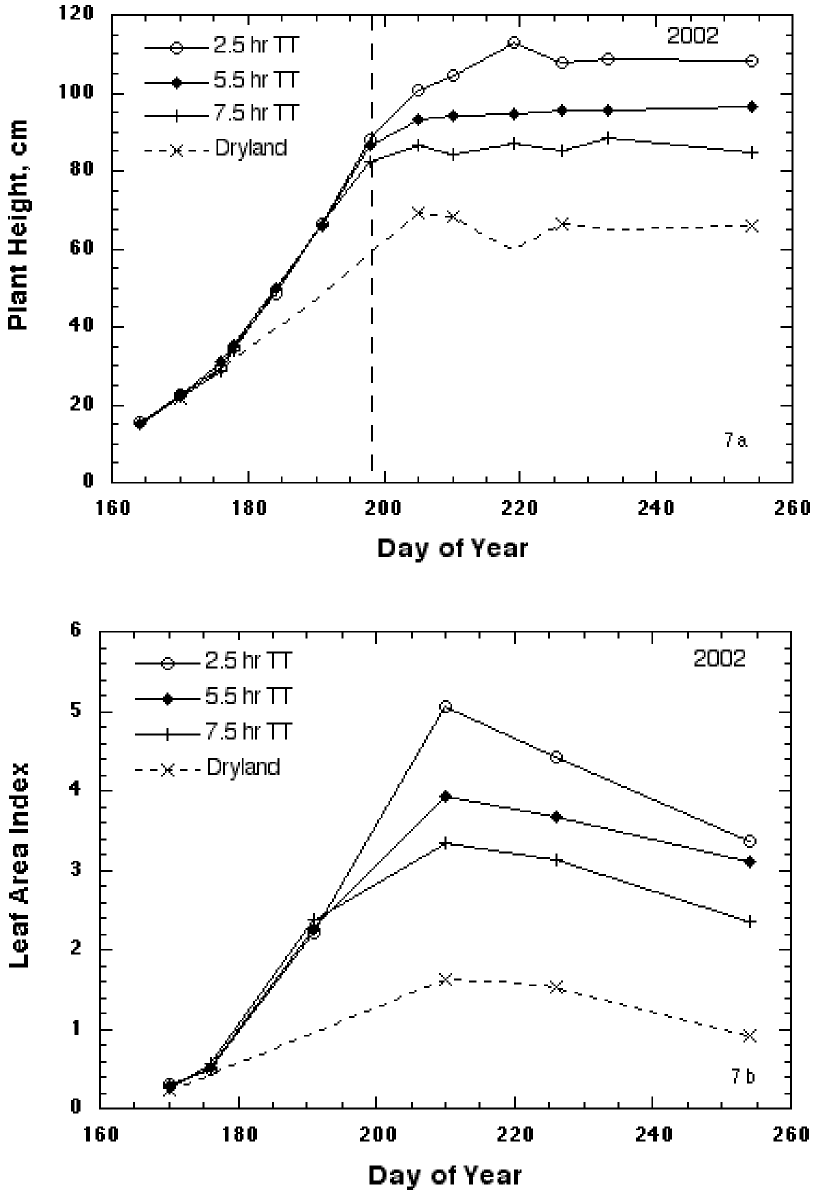

Figure 7. Plant height and leaf area index development for the three time threshold irrigation treatments and a dryland comparison, 2002.

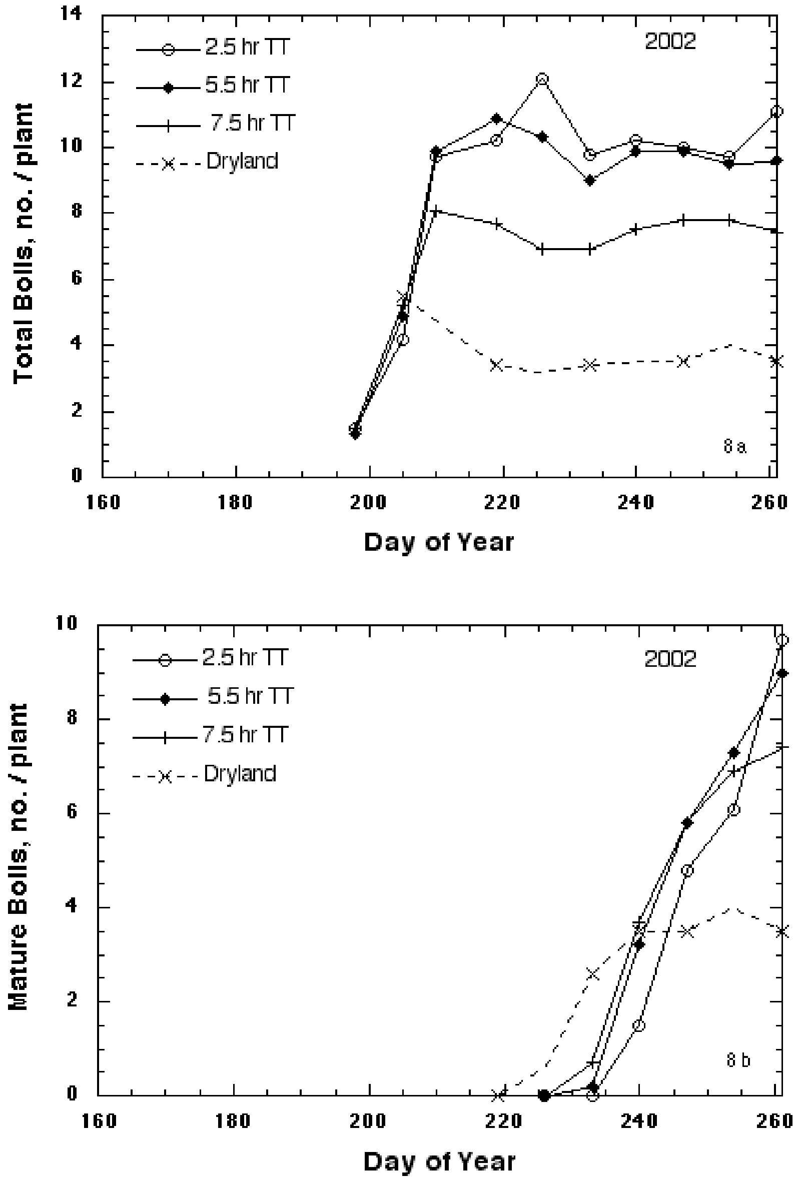

Figure 8. Total boll numbers and mature boll numbers for 2.5 hr, 5.5 hr, and 7.5 hr TT treatments in subsurface irrigated and dryland cotton, 2002.