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COTTON RESPONSE TO MULTIPLE IRRIGATION RATES CONTROLLED BY A CONSTANT TIME THRESHOLD

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Abstract

A cotton irrigation study was managed using the BIOTIC protocol with a time threshold of 5.5 h and applying irrigation rates of 2, 4, 6, or 8 mm in response to an irrigation signal. The objective of the study was to measure the irrigation frequency and amount that results from using a fixed time-threshold to generate irrigation signals and applying variable quantities of water in response to irrigation signals. Irrigation was initiated during the squaring growth stage and was terminated in each treatment when boll maturity reached 40%. The average time between irrigations was 1.4, 1.6, 2.2, and 2.2 d for irrigation rates of 2 mm, 4 mm, 6 mm, and 8 mm, respectively. Cumulative irrigation was positively related to irrigation rate. Daily stress time (DST) was calculated as the amount of time each day when the canopy temperature > 28°C. Average DST declined linearly as irrigation rate increased. Leaf water potential was statistically different among all irrigation rate treatments with higher values occurring in the higher irrigation rate treatments. Leaf area index at first bloom was ~ 1.5 in the 2 mm treatment and 1.9, 2.0, and 2.2 in the 4 mm, 6 mm, and 8 mm treatments, respectively. Lint yield increased linearly up to a cumulative irrigation of 9.0 in, which was applied by the 6-mm irrigation rate, the highest rate that remained in the deficit irrigation region. Irrigation water use efficiency (IWUE) declined in a curvilinear manner with increasing irrigation amounts from 4.0 to 12.0 inches.

Introduction

In semi-arid areas water availability is usually the dominant factor in determining cotton lint yields. Limited water increases plant water stress levels that reduce plant size. Periodic applications of water from either limited irrigation or rain alleviates plant water stress for a finite period followed by increasing water stress as the inadequate water amount is depleted. These water stress fluctuations in the plant lower fruit production and boll retention and subsequently may result in lower cotton lint yields.

Center pivot and surface drip irrigation systems have made it possible to reduce the range of water stress cycles by applying small irrigation amounts at frequent intervals. While the total quantities of water supplied may not be sufficient to produce high lint yields, reducing the magnitude of the water stress cycles increases the water use efficiency. One method for managing the application of limited irrigation is the Biological Identified Optimal Thermal Interactive Console (BIOTIC) irrigation protocol (Upchurch, et al., 1996).

Previous BIOTIC studies have used variable time thresholds, which are accumulations of time based on canopy temperature, to establish different irrigation levels. Different time thresholds change the number and frequency of irrigation signals that result in different amounts of irrigation being applied (Wanjura and Upchurch, 2005). Irrigation signals can occur daily and a 5 mm irrigation is applied in response to each signal regardless of the elapsed time since the last signal. In this two year study there was a linear lint yield response in each year to the amount of irrigation for time thresholds ranging from 5.5 to 8.5 h. This linear response indicates that all water levels remained in the deficit irrigation region and the excess level of irrigation was not reached, where the yield stays stationary or declines while water input continues to increase.

Varying time-thresholds to establish different water levels by applying fixed irrigation quantities results in different ranges of water stress fluctuations due to a change in the time interval between irrigations. Thus higher time-thresholds produce fewer irrigation signals and higher variations in water stress.

Different water levels can also be established with the BIOTIC protocol by using a fixed time-threshold and applying different quantities of water in response to irrigation signals. This approach should be more applicable where ground water is used for irrigation and wells have different water supply capacities. The objectives of this study were (a) measure cotton lint yield response to varying irrigation application rates in response to irrigation signals generated by a constant time threshold value, and (b) estimate the upper limit of deficit irrigation where the relationship between irrigation and lint yield is not linear.

Procedure

A 51 mm preplant irrigation was applied through a subsurface drip system from day of year (DOY) 130 – 134 in 2005. The cotton variety Paymaster HS 2326 was planted on DOY 133. Replanting occurred on DOY 158 after several hail events reduced the plant population to 20,000 plants/acre. The date of 50% of final stand establishment was DOY 162 followed by a final population of 52,000 plants/acre. Irrigation was started on DOY 193 and continued until each treatment reached the level of 40 % mature bolls. Nitrogen was injected at the rate of 10 lbs N/acre-in of irrigation beginning at squaring on DOY 194 until the end of boll setting on DOY 236.

Irrigation was managed using the BIOTIC protocol with a time threshold of 5.5 h and applying irrigation rates of 2, 4, 6, or 8 mm in response to an irrigation signal. An irrigation signal occurred when the stress time (ST) > the time threshold, calculated as the daily time when the average canopy temperature as measured by infrared thermometers in replications 2 and 3 > 28° C (82°F). The treatments (irrigation rates) were replicated 3 times in a randomized complete block arrangement. Plot size was eight rows spaced 40 inches apart by 550 feet long. Irrigation to each plot was controlled by solenoid valves and flow meters measured irrigation quantity. The entire irrigation study was automated and each treatment was controlled by the same time-threshold value and with the appropriate quantity of irrigation applied to each treatment.

Crop growth was monitored weekly from DOY 164 to 264 in all plots with a spectral-radiometer (Model MSR16, Cropscan Inc.). Normalized Difference Vegetative Index (NDVI) values were computed using the 880 and 660 nm reflectance. Biomass samples of ten plants in each plot at first square, first bloom, completion of boll setting, and mid- boll maturity (DOY's 187, 206, 234, 269) was used to track vegetative growth and fruiting development. Periodic measurements of leaf water potential with a pressure bomb of the first fully expanded leaf below the main stem terminal were used to estimate plant water status. Crop boll maturity was counted weekly in replications 2 and 3 beginning at first boll opening. Lint yield was measured from hand harvest samples in all plots on DOY 314 and stripper harvesting four rows in all plots on DOY 320.

Results and Discussion

A total of 72 mm of rain occurred after the first planting on DOY 133 and replanting on DOY 158. Additional rain of 36 mm fell between replanting and the first irrigation on DOY 193. Rain from first irrigation until irrigation was terminated in the 2mm irrigation rate treatment on DOY 265 was 88 mm.

Irrigation

The distribution and total number of irrigation events for all treatments contains periods of both high and low application frequency, Fig. 1. The average time interval of irrigation applications was 1.4, 1.6, 2.2, and 2.2 d for irrigation rates of 2 mm, 4 mm, 6 mm, and 8 mm, respectively. The average frequency of irrigation decreased as irrigation rate increased, which resulted in the total number of irrigations being inversely related to the irrigation rate, Fig. 2. Thus, cumulative irrigation across treatments was positively related to irrigation rate. However, cumulative irrigation was not directly correlated (1:1) with irrigation rate since there was a reduction in number of irrigation events as irrigation rate increased. As irrigation rate increased > 2 mm the change in plant size and water use did not increase at a constant rate. This suggests that changes in water use efficiency were occurring among the irrigation rate treatments. The same water stress level, as measured by the time-threshold, was used to control irrigation events in all treatments. The change in number of irrigation events across irrigation rates implies that the occurrence of the stress level of 5.5 h and perhaps the daily stress time (DST) on all days was also changing. The behavior of DST among the irrigation rate treatments is examined in the following section.

Daily Stress Time

Daily stress time calculated as the amount of time each day when the canopy temperature > 28°C, was measured by infrared thermometers. The DST in each irrigation rate treatment and a dryland plot are compared in Fig. 3. Daily weather conditions influenced the DST values of all treatments. The typical daily pattern among irrigation rate treatments was for DST to be lower for the higher irrigation rate treatments. Average DST for the irrigation period from DOY 193 - 265 displayed a linear decrease as the irrigation rate increased, Fig. 4. Higher irrigation rates

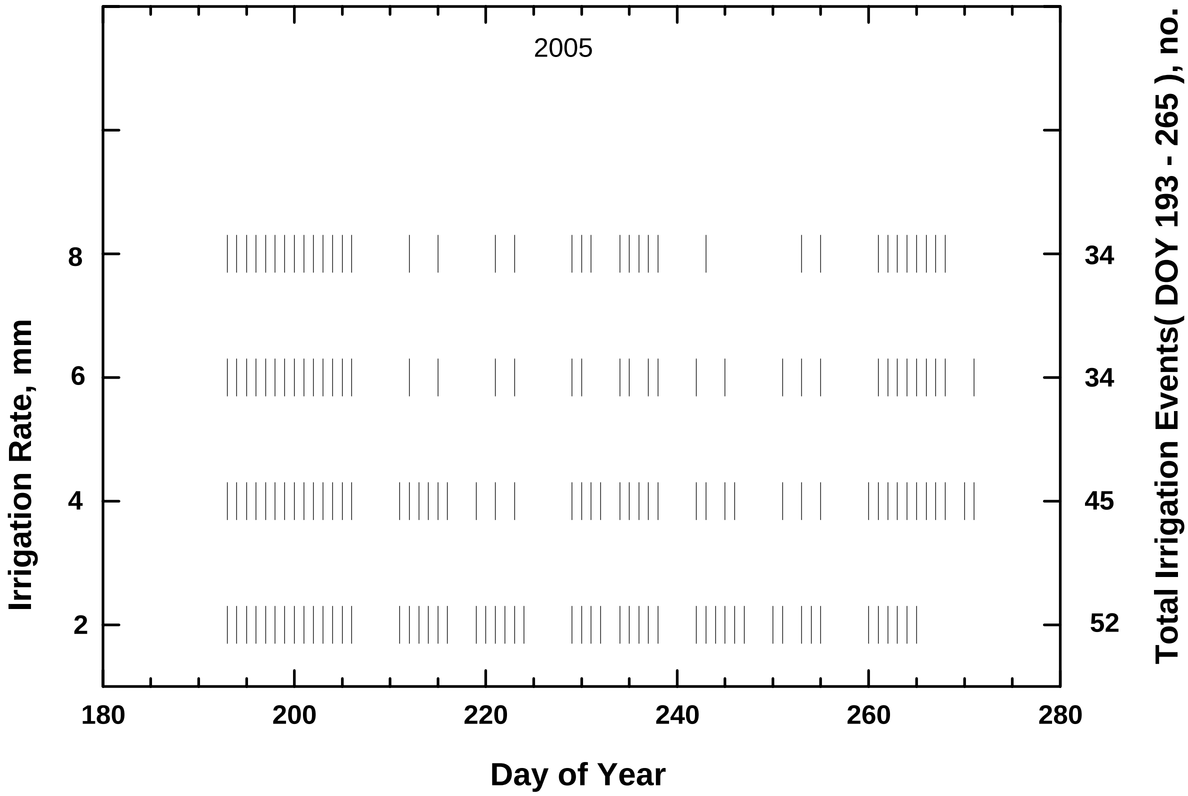

Fig. 1 Distribution of irrigation events for four irrigation rate treatments during the irrigation period from DOY 193 – 265, 2005.

produced sufficient levels of soil water, which grew plants rapidly and resulted in complete ground cover with adequate soil water for transpiration and cooling.

Leaf Water Potential

The leaf water potential values in Table 1 support the trend of lower DST in the high irrigation rate treatments shown in Fig. 4. Leaf water potential values were statistically different ($p < 0.01$) among all irrigation rate treatments on each of the four sampling dates. In general the range of leaf water potential values among treatments increased as time progressed through the growing season. The range was -0.43 and -1.31 MPa on DOY 201 and DOY 238, respectively. Apparently, the soil water in the root zone was being depleted to a greater extent in the lower irrigation rate treatments as the season progressed.

Table 1 Leaf water potential for four irrigation rate treatments and dryland for four dates in 2005.

Irrigation Rate, mm	Sampling Date: 20 July (201) [1]	2 August (214)	11 August (223)	26August (238)
	- - - Leaf Water Potential, MPa - - -			
2	-2.18 a [2]	-2.50 b	-2.78 b	-3.16 b
4	-1.97 b	-2.21 c	-2.44 c	-2.74 c
6	-1.86 c	-2.03 d	-2.38 c	-2.53 d
8	-1.75 d	-1.70 e	-2.14 d	-1.85 e

Dryland	----	-2.33 a	-3.07 a	-3.38 a

[1] Numbers in parentheses are DOY.
[2] Values for the same date followed by a common letters are statistically similar at the 0.01 level of probability.

Leaf Area Index

Biomass samples were taken on DOY 187, 206, 234, and 269. The DOY 187 sampling was during the squaring stage before in-season irrigation was started on DOY 193, and the DOY 269 was near the termination of irrigation. The leaf area index (LAI) values on DOY 206 for the 2 mm irrigation rate treatment was significantly lower ($p < 0.01$) than the other treatments, Fig. 5. The first bloom date was observed on DOY 202 when LAI values were approximately 1.5 in the 2 mm treatment and 1.9, 2.0, and 2.2 in the 4 mm, 6 mm, and 8 mm treatments, respectively. LAI values on DOY 234 were highest in the 8- mm irrigation rate treatment, followed by the 4-mm and 6-mm treatments, and lowest in the 2-mm treatment. All treatment LAI values showed decreases on DOY 269 when the 8- mm treatment was highest and followed in order by the 6-mm, 4-mm, and 2-mm treatments.

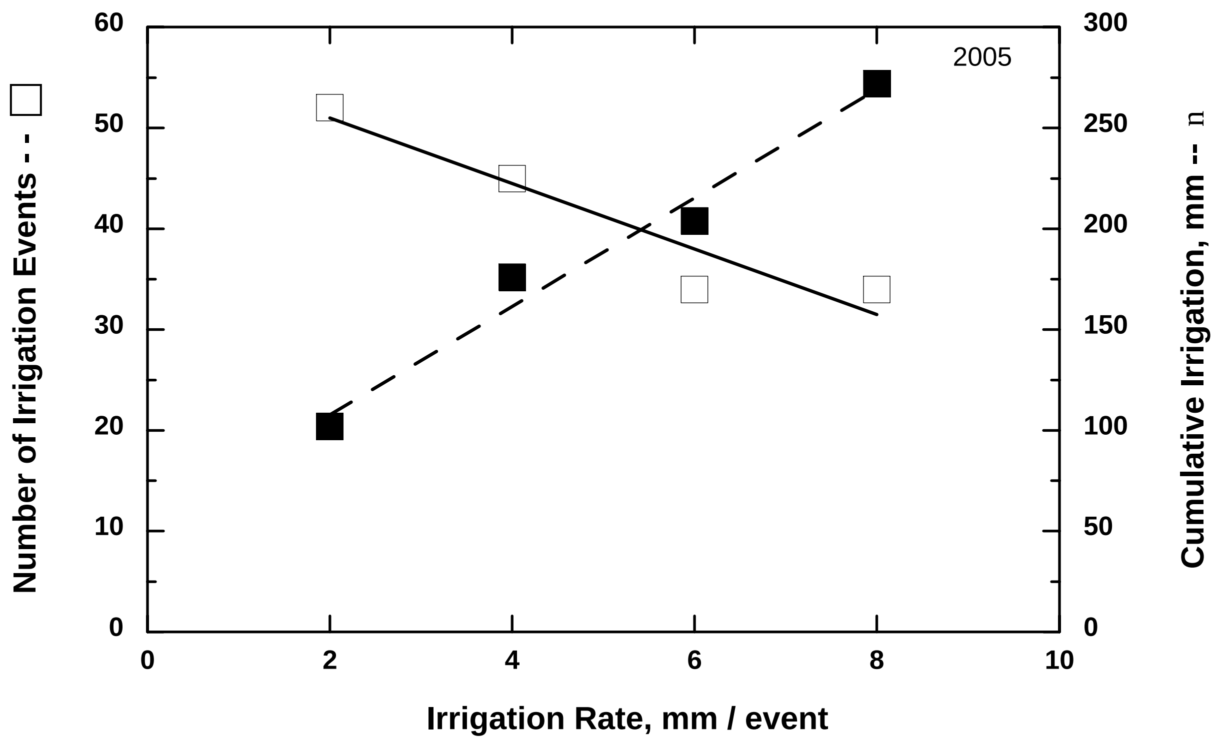

Fig. 2 Number of irrigation events and cumulative irrigation from DOY 193 to DOY 265 for irrigation rates of 2 mm, 4 mm, 6 mm, and 8 mm applications for each irrigation event, 2005.

Spectral Reflectance

The spectral reflectance measurements began on DOY 164 and continued weekly through DOY 264, Fig. 6. The NDVI value of the 2-mm irrigation rate treatment reached its maximum value on DOY 229 and then gradually declined for the remainder of the irrigation period. The NDVI values in the 4-mm, 6-mm, and 8-mm treatments increased rapidly through DOY 214 and then remained constant from DOY 220 - 235. After the first irrigation the NDVI values of the three highest irrigation rates were similar with a trend of small successive declines between 8-mm, 6-mm, and 4-mm, respectively. The NDVI values of the three highest irrigation rate treatments were significantly greater from those of the 2 mm treatment during the irrigation period.

The NDVI values were not different among the 4-mm, 6-mm, and 8-mm treatments on DOY 235, Fig. 6; however, the LAI values in Fig. 5 showed similar values for the 4-mm and 6-mm treatments with the LAI of the 8-mm treatment being higher. The NDVI values on DOY 264 and the sampled LAI values on DOY 269 had similar trends among all treatments.

Lint Yield

Lint yield was determined by hand harvesting 2-m row lengths from four rows at three row locations (75, 275, and 475 feet from the south end) and by stripping four rows in each plot, Table 2. Lint turnout was highest in the stripper-harvested cotton because the mechanical stripper was equipped with a bur extractor that removed burs from the seed cotton. For each method of harvest there was a pattern of decreasing turnout as the irrigation rate increased among treatments. Hand harvested lint yield of the 2-mm treatment was significantly lower than the other treatments. Stripper harvested lint yields were highest in the 4-mm and 6-mm treatment. Hand harvested yields averaged 151 lbs/acre higher than stripped yields. The lint yield difference between hand harvesting and stripping generally increased as irrigation rate increased. The rate of boll maturity was lowest in the 8 mm treatment and the bur extractor may have removed some seed cotton from immature bolls in this treatment. The yield data plotted in Fig. 7 shows that yield did not increase beyond cumulative irrigation of 9.0 inches that was applied by the 6-mm and 8-mm irrigation rate treatments.

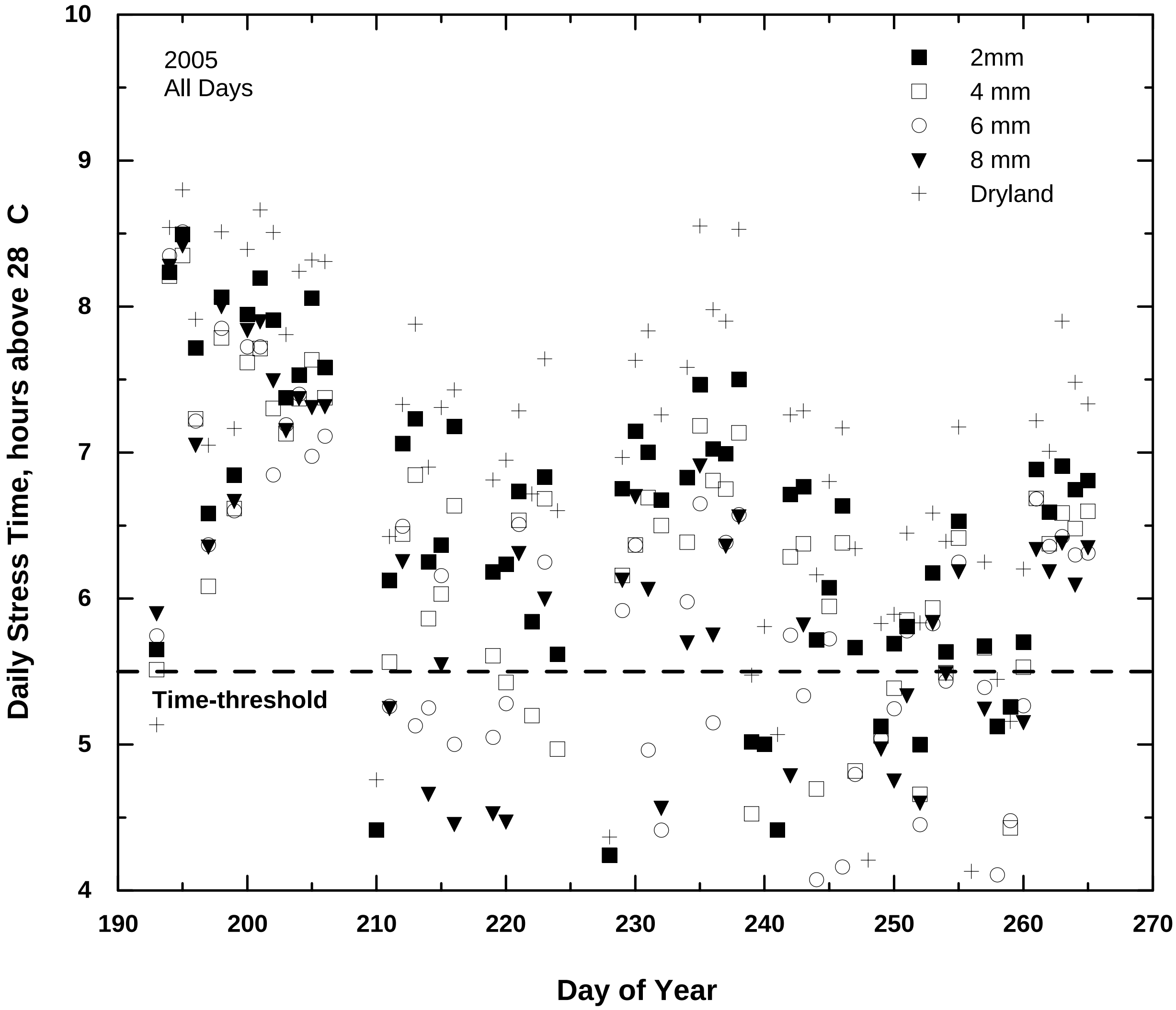

Fig. 3 Daily stress times during the irrigation period DOY 193 – 265 for four irrigation rate treatments and a dry land plot, 2005.

Irrigation water use efficiency (IWUE) declined in a curvilinear manner with increasing irrigation applications from 4.0 to 12.0 in across the four irrigation rate treatments, Fig. 8. Total water use efficiency (TWUE) (irrigation plus rain) decreased linearly for water applications ranging from 7.5 to 15.4 in, but the rate of decline was lower than for IWUE. The reduction between IWUE and TWUE was greater for the lower irrigation rate treatments because rain was a more significant component of total water applied.

Summary

A cotton irrigation study was managed using the BIOTIC protocol with a time-threshold of 5.5 h and applying irrigation rates of 2, 4, 6, or 8-mm in response to an irrigation signal. The average time between irrigation applications was 1.4, 1.6, 2.2, and 2.2 d for irrigation rates of 2-mm, 4-mm, 6-mm, and 8-mm, respectivel. Cumulative irrigation up to the level of 40 % mature bolls was positively related to irrigation rate. Average daily stress time (DST) during the irrigation period declined linearly as irrigation rate increased. Leaf water potential values were statistically different among all irrigation rate treatments with higher values occurring in the higher irrigation rate treatments. LAI values at first bloom were approximately 1.5 in the 2-mm treatment and 1.9, 2.0, and 2.2 in the 4-mm, 6-mm, and 8-mm treatments, respectively. Lint yield increased up to a cumulative irrigation of 9.0 in that was applied by the 6-mm irrigation rate treatment. Irrigation water use efficiency (IWUE) declined in a curvilinear manner with increasing irrigation amounts from 4.0 to 12.0 in. For the production environment of this study the 6-mm irrigation rate was the highest value that remained within the deficit irrigation region.

References

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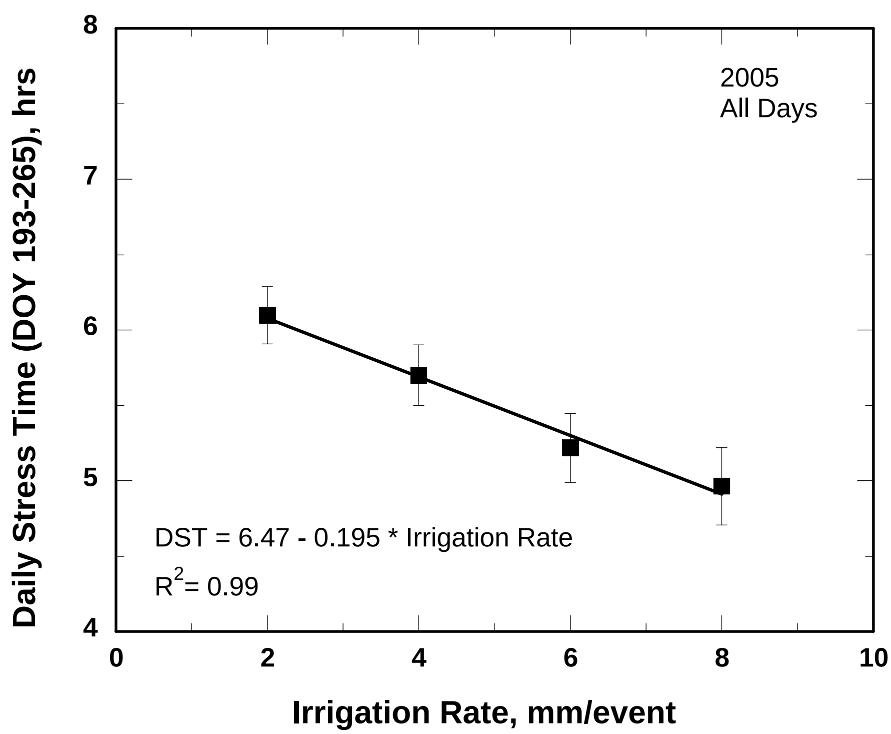

Fig. 4 Relationship of irrigation rate per application and daily stress time for all days during the irrigation period from DOY 193 – 265, 2005.

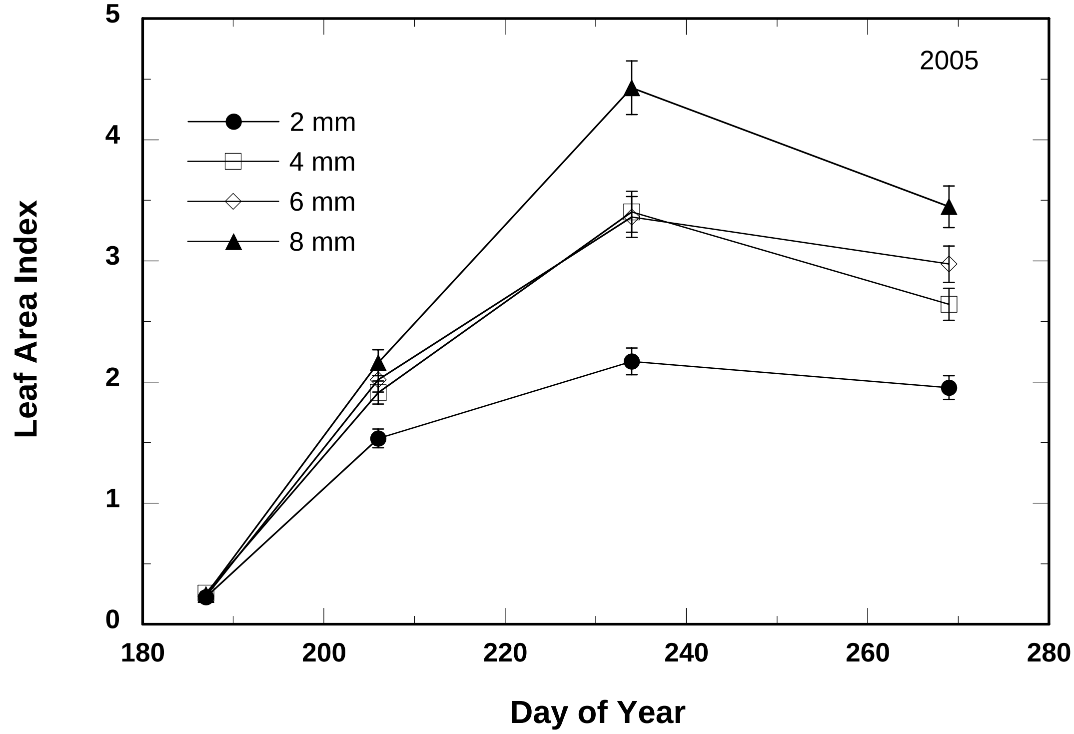

Fig. 5 Leaf area index values for four irrigation rate treatments measured on four dates beginning during the squaring growth stage, 2005.

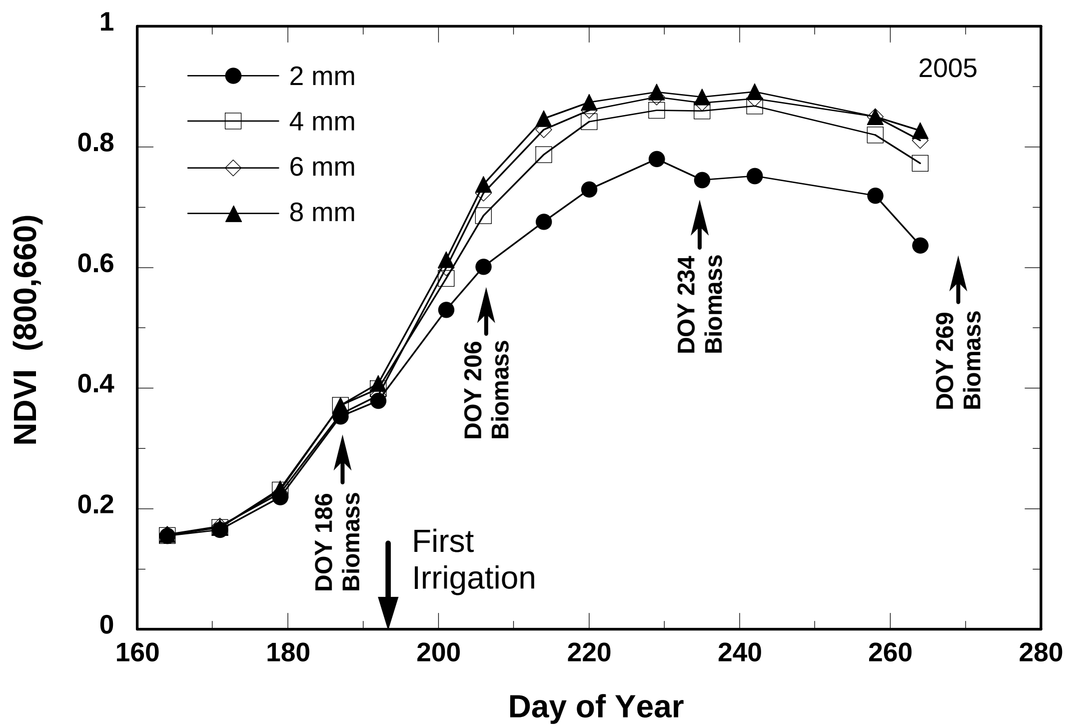

Fig. 6 Spectral NDVI values for four irrigation rate treatments measured at weekly intervals during the growing season, 2005.

Table 2 Lint yield for four irrigation rate treatments and Dryland using hand and stripper harvesting, 2005

Irrigation	Hand Harvest		Stripper Harvest	
Rate, mm	Lint, lbs/acre	Turnout,%	Lint, lbs/acre	Turnout,%
2	1182 b[1]	.275 a	1064 b	.333 a
4	1441 a	.270 ab	1265 a	.314 bc
6	1440 a	.262 bc	1312 a	.320 ab
8	1371 a	.254 c	1182 ab	.304 c
Dryland	788	.276	594	.311

[1] Values for the same date followed by a common letters are statistically similar at the 0.01 level of probability.

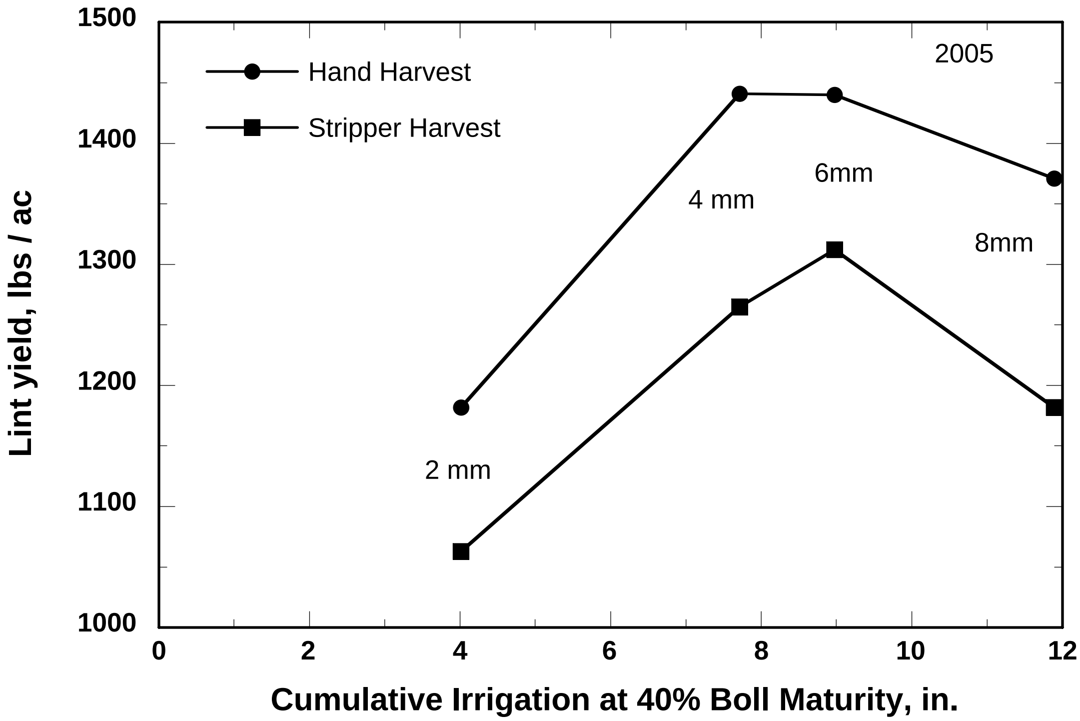

Fig. 7 Cumulative irrigation for four irrigation rates and lint yield for hand harvested and stripped cotton, 2005.

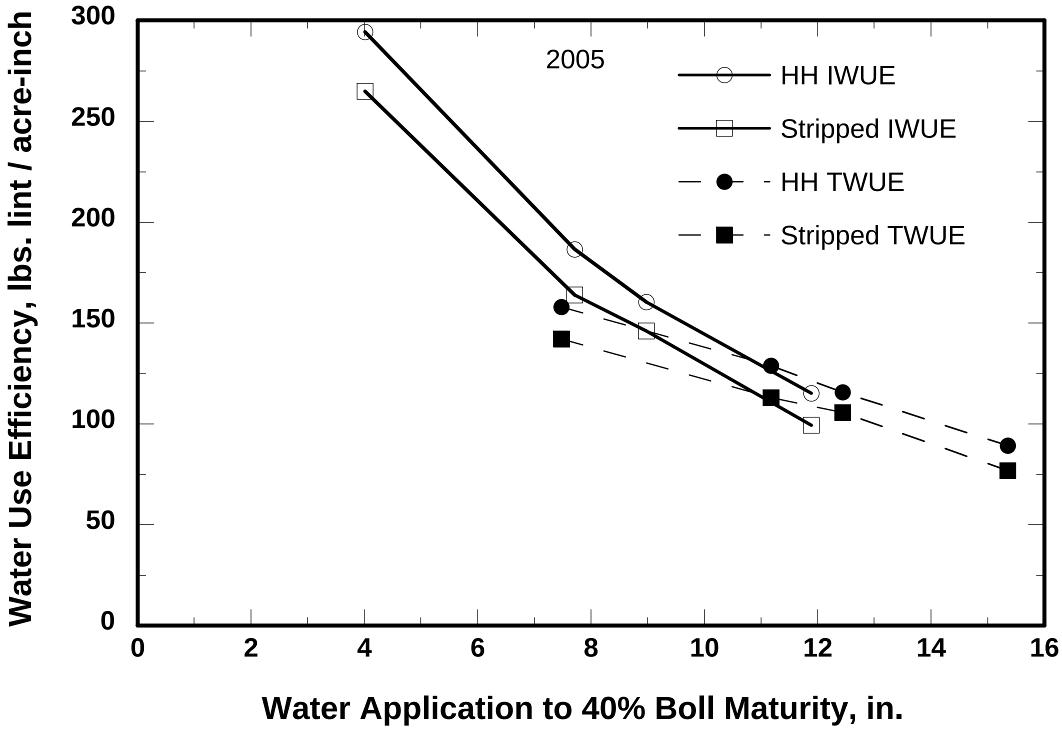

Fig. 8 Water application vs. irrigation (IWUE) and total (TWUE) water use efficiencies for hand harvested and stripped cotton, 2005.