# COTTON RESPONSE TO AUTOMATED IRRIGATION CONTROL

**Donald F. Wanjura**
**USDA-ARS, Cropping Systems Research Laboratory**
**Lubbock, TX**

## Abstract

A cotton irrigation study was conducted at Lubbock, Texas in 1995 using continuously measured canopy temperature to automatically apply water. The objective of the experiment was to determine the number of irrigations applied by different time thresholds and measure the response of cotton to periods of either water deficit or excess applied at different times during the season. Three irrigation levels were created by using different stress times, accumulations of either 4, 6, or 8 hours above a canopy temperature threshold of 28°C, to produce irrigation signals. The irrigation signals scheduled irrigation in a system that used a base irrigation interval of 3 days. In addition to three normal water levels established by time thresholds of 4 h, 6 h, and 8 h, periods of water deficit and water excess were superimposed on each water level. Total irrigations of 39, 35, and 33 cm were applied by the 4 h, 6 h, and 8 h time thresholds, respectively, between DOY 180 and DOY 243. The number of irrigations applied by the time threshold treatments were similar except, during the late irrigation season between DOY 218 and DOY 243, when the 4 h and 6 h time threshold treatments applied 7 irrigations compared to 6 irrigations for the 8 h threshold treatment. The number of irrigations applied in 1995 varied from 18 to 15 with no radiation level limitations on the accumulation of stress time. Restricting stress time accumulation to the daylight period when radiation was above 200 $wm^{-2}$ improved the uniformity of irrigation control between 1995 and previous tests conducted in 1991 and 1992. Daily stress time and leaf water potential were linearly related among time threshold irrigation treatments. Daily stress time values were correlated with single, daytime leaf water potential measurements taken when the canopy was under maximum daily heat stress. There was no difference between the lint yields of 1404 and 1435 lbs/acre for the 4 h and 6 h time threshold treatments which were greater than the 1271 lbs/acre yield of the 8 h time threshold treatment.

## Introduction

There has been a major shift from furrow to center pivot irrigation delivery systems used in cotton production on the Texas High Plains. The number of center pivot irrigation systems has doubled from 1990 to 1995 within the 15-county High Plains Underground Water Conservation District No. 1 (Moseley, C., 1996). The rapid adoption of center pivot irrigation technology is being driven by the capability to apply irrigation at shorter intervals, in variable quantities, uniformly distributed across the field with less labor. Properly managed center pivot irrigation can increase cotton yields and reduce the yield variability among years that is caused by rainfall.

The capability for greater control of water application provides the opportunity to use irrigation more efficiently. One factor in efficient use of water is timely application in the proper quantity to control crop water status. Many procedures have been developed for scheduling irrigation that are based on soil moisture measurement, evapotranspiration, and plant water potential. Recently an irrigation scheduling procedure has been developed that uses continuous measurement of plant canopy temperature to indicate the need for irrigation, Wanjura, et al. 1992. This method is based on the premise that the summation of remotely measured canopy temperature above a crop specific threshold canopy temperature during the day is the single best externally measurable factor for indicating crop water status. In addition to the author, the use of accumulating time above a threshold temperature to schedule irrigation has been reported by Evett, et al. 1996. The use of this irrigation scheduling method to automatically control irrigation with superimposed periods of water deficit and water excess are reported here.

The objectives of the experiment were: (1) determine the number of irrigations applied by automated irrigation scheduling controlled by different time thresholds above a threshold temperature of 28°C, and (2) measure the response of cotton to imposed water stresses applied at different times during the season by withholding irrigation.

## Materials and Methods

The experiment was initiated on May 19, 1995 with the planting of the cotton cultivar Paymaster HS26 in beds spaced 40-inches apart and oriented in an East to West direction on the Texas Agricultural Experiment Station. The study area received a 4.0 inch preplant irrigation on April 10. Emergence began on May 24 and 50% of the final plant population of 53,000 plants/acre was achieved on May 28.

Three irrigation levels were created by using time accumulations of 4, 6, and 8 hours above a canopy temperature threshold of 28°C (82°F) to produce irrigation signals. The irrigation signals were used to schedule irrigation where the minimum irrigation interval was 3 days. The existence of an irrigation signal was checked beginning on the second day after an irrigation and were monitored for each succeeding day until an irrigation signal occurred. In this way the interval between irrigations could only be increased by the irrigation signals that depended on the time thresholds. Irrigation was started on June 28 when the number of main stem nodes averaged 7.8 and plants were at the first square stage of growth.

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Irrigation was applied through drip irrigation tubing which was placed on the surface of each bed by the row of plants. A separate header line supplied each plot and a Bermaad water meter was set to apply a 2.1 cm irrigation (1725 gallons).

The experimental design was a randomized complete block design with the irrigation levels randomly assigned within each block. Each time threshold irrigation treatment was replicated three times in plots which were 10 rows wide by 100 feet long.

Different water levels were established within each irrigation treatment by subdividing each plot into three parts. The north five rows of each plot were irrigated for the entire season according to the occurrence of irrigation signals generated by its time threshold level (Normal), the five south rows were divided in half, with irrigation withheld from the west half beginning on a designated date and continuing for the remainder of the season (Drought); and irrigation withheld from the east half on the same designated date but was later irrigated at twice the normal rate (2.1 cm X 2) (Drought/Excess). A time sequence of the irrigation treatments for one replication showing the beginning dates for imposing the Drought and Drought/Excess water levels is presented in Fig. 1.

Plant height and number of main stem nodes were measured in each irrigation treatment on July 20, August 3, and August 23. Leaf water potential was measured between 1330 h and 1500 h with a pressure bomb on one day in July, six days in August, and one day in September. Dry bulb and wet bulb air temperatures, solar radiation, and wind speed were measured at a 2 m height. A single infrared thermometer located directly above a row in a nadir position in one plot of each time threshold irrigation treatment measured canopy temperature continuously and controlled irrigation in all replications. Data from all sensors was logged by a Campbell Scientific 21X Data Logger as 15-min averages. Yield was determined by stripper harvesting the middle two rows in each water application treatment on November 20 after plants had been killed by freezing temperatures on November 5.

## Results and Discussion

Early season air temperatures were favorable for germination, emergence, and stand establishment. Irrigation in each water level began by activating the automated irrigation scheduling system at first square on June 28. First bloom was observed on July 17 in all plots.

The dates when the D and D/E water levels in each irrigation treatment were started are shown in Fig. 1. The beginning dates for the D water level was July 11, July 27, and August 11 in the 4 h, 6 h, and 8 h time thresholds, respectively. The D/E water levels began on August 11 in all time threshold treatments. The D/E water level in the 4 h time threshold only did not have a drought period since it began on the same date as the D treatment. The imposition of drought and excess irrigation periods on the three time threshold irrigation scheduling treatments was implemented to create plants that differed in vegetative growth and were not intended as irrigation water management strategies.

### Irrigation

The number of irrigations applied in each irrigation level declined linearly as the time threshold level increased from 4 to 8 hours, Fig. 2, from the first irrigation on June 28 to the last irrigation on August 31. Cumulative irrigation was 39, 35, and 33 cm for the 4 h, 6 h, and 8 h time thresholds, respectively, Fig. 3. The increase in cumulative irrigation was relatively constant for each time threshold because summer air temperatures remained warm and total rainfall for the time interval June 28 to August 31 was only 8.3 cm. Cumulative irrigation among the 3 threshold treatments for the D/E water levels differed more than the normal water level because the drought period began at different times in the 6 h and 8 h time thresholds and was omitted in the 4 h time threshold. Cumulative irrigations for the D/E treatments were 50 cm, 41 cm, and 27 cm for the 4 h, 6 h, and 8 h time thresholds, respectively. The D water levels had cumulative irrigations of 28 cm, 17 cm, and 9 cm, respectively, in the 4 h, 6 h, and 8 h time thresholds.

### Irrigation Signals

The number of irrigation signals that resulted from the three time thresholds in 1995 were calculated from the daily total accumulation of time above 28°C and for the daily period when solar radiation was greater than 200 $wm^{-2}$, Fig. 4. The 6 h time threshold had one additional irrigation signal and the 8 hour time threshold had four additional irrigation signals, respectively, outside the period when radiation exceeded 200 $wm^{-2}$. For comparison, irrigation scheduling controlled by time thresholds in 1991 and 1992 had the same number of irrigation schedules for both daily time intervals. These results suggest that an 8 h time threshold can accumulate time above 28°C when radiation level is too low to allow full opening of stomates; however, at higher water levels (2 h and 6 h time thresholds) accumulation of time above 28°C under low light conditions does not affect the generation of irrigation signals. The comparison of environmental factors in Table 1 indicate that the only significant difference among the years was a higher air temperature in 1995 compared to 1991 and 1992.

The number of irrigations applied varied from 17 to 15 between time thresholds of 4 h and 8 h in 1995, or an average decrease of 0.5 irrigations for a one hour increase in time threshold value. This compares with an average decrease of 1.3 irrigations for each one hour increase in time threshold value in 1991 and 1992. If time above 28°C is only accumulated while radiation is above 200 $wm^{-2}$, in 1995 there is a decrease of 1.75 irrigations for each hour of increase in time threshold and there would be no change in 1991 or 1992. This suggests that restricting the accumulation of time above 28°C to the daytime when radiation exceeds 200 $wm^{-2}$ will improve the uniformity of irrigation control among years.

**Leaf Water Potential**

The average leaf water potential(LWP) values for the normal water levels increased from 17.4 bars to 22.4 bars as the time threshold value that controlled irrigation increased from 4 hours to 8 hours, Table 2. The average leaf water potential values for the D/E water level were approximately 15 bars in all time threshold irrigations because all D/E plots were irrigated in amounts equal to two times the quantity of the normal water level. All D water levels had average leaf water potentials in excess of 30 bars, an indication of severe water stress. The LWP value of 26.8 bars for the normal water level of the 6 h time threshold on August 29 and 25.8 bars for the 8 h time threshold on August 30 were both higher than for other days. Both dates were second decision days, which were 4 days since the last irrigation. The irrigation interval at this time was 4 days in these treatments rather than the minimum interval of 3 days. This observation suggests that canopy temperature, which produces the irrigation signal, was sensitive to time since last irrigation and probably reflects a slightly "drier" soil and lower plant water potential.

The five readings for August 28 through September 1 were made on five consecutive days for the purpose of following each time threshold through one irrigation cycle, even though each time threshold treatment was not at the same phase of the cycle. Leaf water potential values for the normal water level of each time threshold were regressed against the amount of daily stress time (amount of time that canopy temperature exceeded 28°C), Fig. 5. Daily stress time and the LWP values among time threshold irrigation treatments were linearly related. Represented in the data points are all days in the irrigation cycle,I.e.; day of irrigation(day 2), the day after irrigation(day 1), and the decision day day 0).

**Plant Size**

On each measurement date plant height of the normal 4 h time threshold treatment was significantly greater than the 6 h and 8 h time thresholds which were similar, Table 3. The differences in number of main stem nodes among time threshold treatments were similar to the effects noted for plant height. The excess irrigation which began on August 11 increased plant height in the 4 h time threshold, which did not have a period of drought, but in the 6 h and 8 h time thresholds, plant height of the D/E plants were 80% and 60% of those in the 8 hour normal water level treatment.

**Yield**

Lint yields of the 4 h and 6 h normal time threshold treatments were higher than for the 8 h, Table 4. Among the drought water level treatments there were no significant differences in yield even though the drought treatment in the 8 h time threshold began 30 days earlier than in the 4 h time threshold. Yields of the D/E water levels in the 4 h and 6 h time thresholds were the same with the 8 h time threshold being significantly lower. In the 4 h time threshold treatment the D/E treatment was not subjected to a period of drought, and yet the excess water beginning on August 11 did not increase yield.

## Summary

The imposition of drought and excess irrigation periods on the three time threshold irrigation scheduling treatments was implemented to create plants that differed in vegetative growth and were not intended as irrigation water management strategies. In addition to 8.3 cm of rainfall, the irrigation applied by the 4 h, 6 h, and 8 h time thresholds was 39, 35, and 33 cm between DOY 180 and DOY 243. The number of irrigations applied in 1995 varied from 18 to 15 with no radiation level limitations on the accumulation of stress time. Restricting stress time accumulation to the day light period when radiation was above 200 $wm^{-2}$ improved the uniformity of irrigation control between 1995 and previous results in 1991 and 1992, Figure 4. Daily stress time and the LWP values among time threshold irrigation treatments were linearly related. This relationship indicates that accumulating time above a threshold temperature during the daytime is sensitive to a single crop water status measurement that was made when the combination of solar radiation and air temperature produce the maximum heat stress on the canopy. The lint yields of 1404 and 1435 lbs./acre for the 4 h and 6 h time threshold treatments were greater than the 1271 lbs/acre for the 8 h time threshold treatment. During the late irrigation season, between DOY 218 and DOY 243, the 4 h and 6 h time threshold treatments applied 7 irrigations compared to 6 irrigations for the 8 h threshold treatment.

## References

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Table 1. Average values for four environmental factors during the period July 3 to August 31 in 1991, 1992, and 1995.

| Environmental factor* | 1991 | 1992 | 1995 |
|---|---|---|---|
| Air Temp at 2 m, °C | 26.2 | 26.2 | 28.5 |
| Solar Radiation, $wm^{-2}$ | 577 | 620 | 624 |
| Vapor Pressure Deficit, kPa | 1.56 | 1.79 | 1.68 |
| Relative Humidity, % | 59 | 54 | 62 |

*Daily period used in calculating each factor was 0800 h to 2000 h.

Table 2. Total leaf water potential in three time threshold irrigation scheduling treatments subdivided into three water levels, 1995.

| | --------Leaf Water Potential, bars-------- | | |
|---|---|---|---|
| Date | Drought | Excess | Normal |
| | ------------------4 Hour------------------- | | |
| 7-27 | ---* | --- | 19.8 |
| 8-25 | 29.5 | 14.7 | 15.1 |
| 8-28 | 33.2 | 14.6 | 18.5 |
| 8-29 | 35.3 | 14.5 | 19.2 |
| 8-30 | >37.0 | 14.4 | 17.1 |
| 8-31 | >37 | 14.0 | 17.0 |
| 9-01 | >37 | 15.3 | 15.1 |
| Avg | | 14.6 | 17.4 |
| | -------------------6 Hour------------------- | | |
| 7-27 | --- | --- | 19.3 |
| 8-25 | 32.8 | 14.5 | 15.1 |
| 8-28 | 33.3 | 14.9 | 16.2 |
| 8-29 | 36.3 | 17.3 | 26.8 |
| 8-30 | >37.0 | 15.2 | 17.4 |
| 8-31 | >37 | 14.6 | 15.4 |
| 9-01 | >37 | 16.0 | 17.5 |
| Avg | | 15.4 | 18.2 |
| | -------------------8 Hour------------------- | | |
| 7-27 | 23.8 | --- | 19.9 |
| 8-25 | 32.2 | 14.7 | 24.3 |
| 8-28 | 32.0 | 14.8 | 21.5 |
| 8-29 | 37.0 | 16.0 | 20.2 |
| 8-30 | >37.0 | 17.3 | 25.8 |
| 8-31 | .37 | 14.8 | 23.5 |
| 9-01 | >37 | 12.0 | 21.6 |
| Avg | | 14.9 | 22.4 |

*Leaf water potential was not measured because the treatment did not exist on this date.

Table 3. Plant height and number of main stem nodes in three time threshold irrigation scheduling treatments subdivided into three water levels, 1995.

| Date | Drought | Excess | Normal |
|---|---|---|---|
| | ---------------Plant Height, cm--------------- | | |
| | | 4 Hour | |
| 7-20 | ---* | --- | 57.5 a[1] |
| 8-03 | --- | --- | 80.5 a |
| 8-23 | 89.4 bc | 103.7a | 98.6 ab |
| | | 6 Hour | |
| 7-20 | --- | --- | 54.8 b |
| 8-03 | 65.1 c | --- | 72.6 b |
| 8-23 | 66.9 d | 80.3 c | 84.4 c |
| | | 8 Hour | |
| 7-20 | --- | --- | 54.2 b |
| 8-03 | 48.1 d | --- | 70.1 b |
| 8-23 | 46.3 e | 50.9 e | 80.4 c |
| | -------Number of Main Stem Nodes-------- | | |
| | | 4 Hour | |
| 7-20 | --- | --- | 13.8 a |
| 8-03 | --- | --- | 17.6 a |
| 8-23 | 18.1 bc | 19.7 a | 18.9 ab |
| | | 6 Hour | |
| 7-20 | --- | --- | 13.4 b |
| 8-03 | 16.3 c | --- | 16.9 b |
| 8-23 | 15.8 e | 17.9 c | 17.9 c |
| | | 8 Hour | |
| 7-20 | --- | --- | 13.6 b |
| 8-03 | 13.1 d | --- | 16.1 c |
| 8-23 | 13.3 g | 14.3 f | 16.8 d |

*Indicates no measurements were made because the treatment did not exist on this date.

[1]Numbers in the same row followed by a common letter are statistically the same at the 0.05 level of probability according to the Tukey-Kramer test..

Table 4. Cotton yields for three time threshold irrigation scheduling treatments and drought and drought/excess periods superimposed on each time threshold, Lubbock, TX, 1995.

| Treatment | Lint Yield, Lbs/Acre | Treatment Comparison: Water Levels | Time thresh-olds | Drought | Drought/ Excess |
|---|---|---|---|---|---|
| 4 Hour | | | | | |
| Normal | 1404 | ab * | a | | |
| Drought | 557 | d | | a | |
| Drought/ Excess | 1359 | ab | | | a |
| 6 Hour | | | | | |
| Normal | 1436 | a | a | | |
| Drought | 452 | d | | a | |
| Drought/ Excess | 1239 | b | | | a |
| 8 Hour | | | | | |
| Normal | 1271 | ab | b | | |
| Drought | 388 | d | | a | |
| Drought/ Excess | 828 | c | | | b |

*Yields followed by a common letter in the same column are statistically the same at the 0.05 level of probability according to the Tukey-Kramer test.

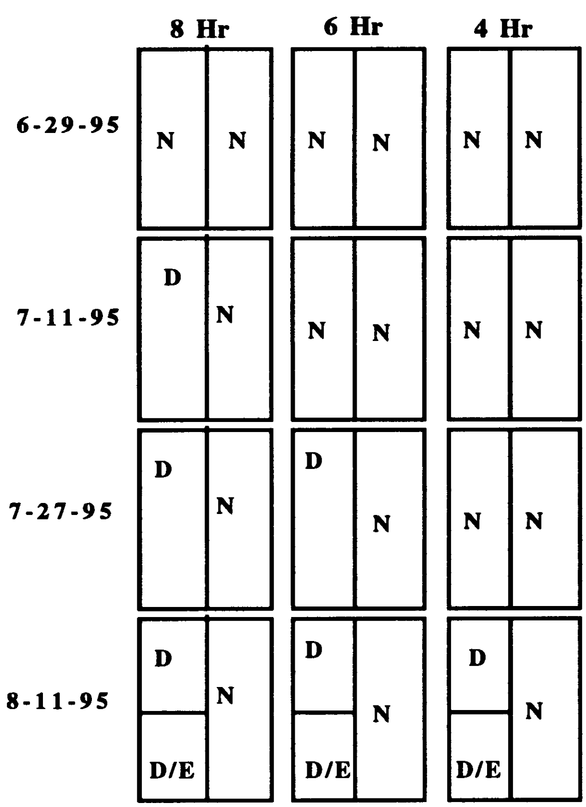


Figure 1. Treatment diagram showing dates when normal (N), drought (D), and drought and excess (D/E), water levels were superimposed on time thresholds of 4, 6, and 8 hours.

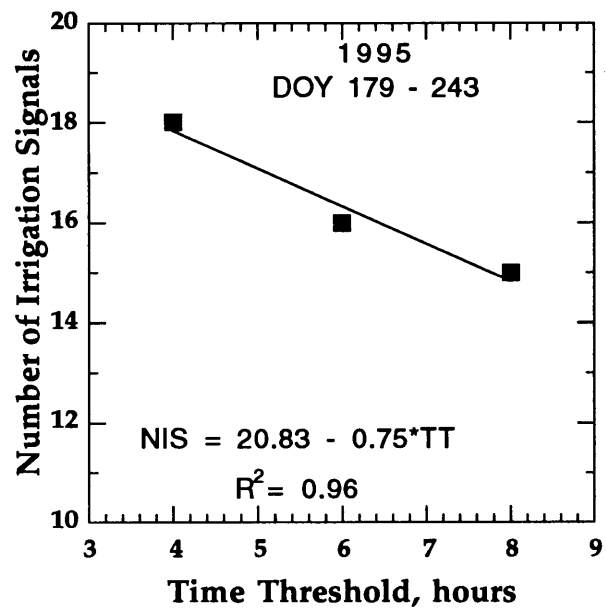


Figure 2. Relationship between number of irrigation signals and time threshold values between DOY 179 and DOY 243 in 1995.

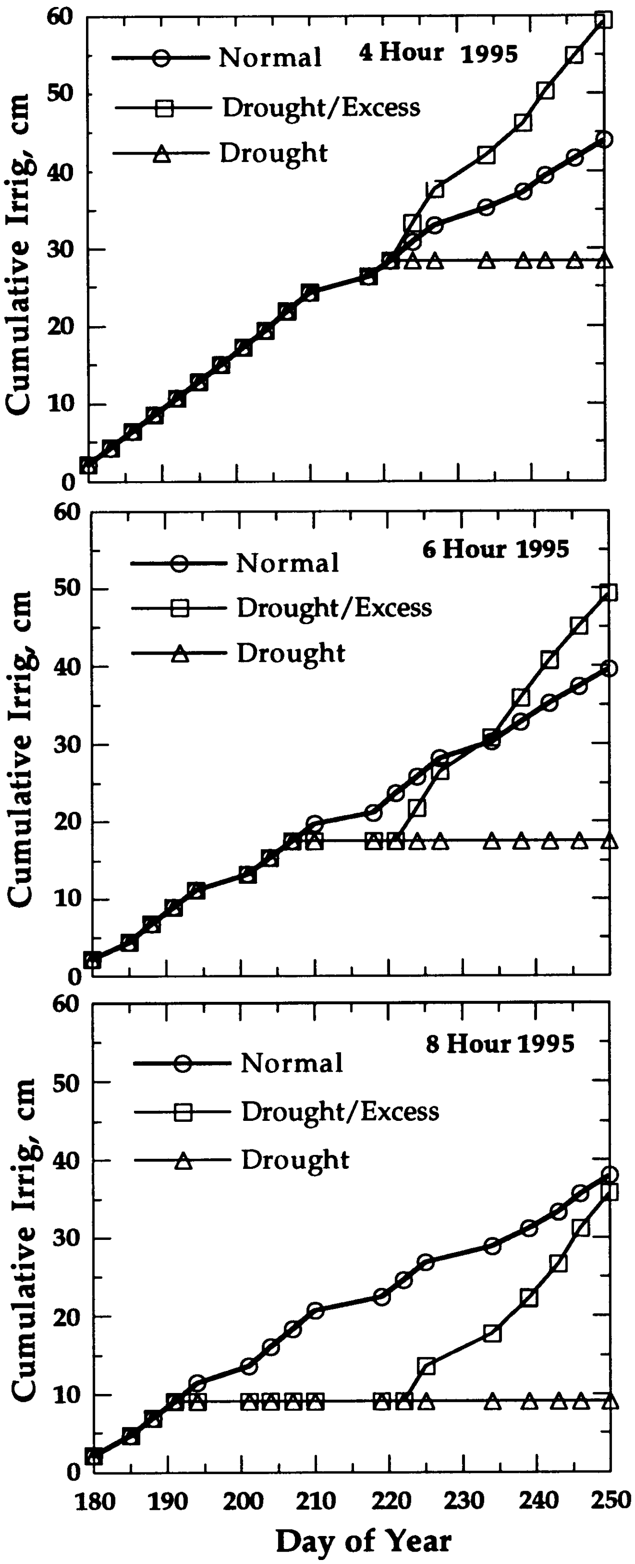


Figure 3. Cumulative irrigation of treatments controlled by three time thresholds with three water levels imposed on each threshold.

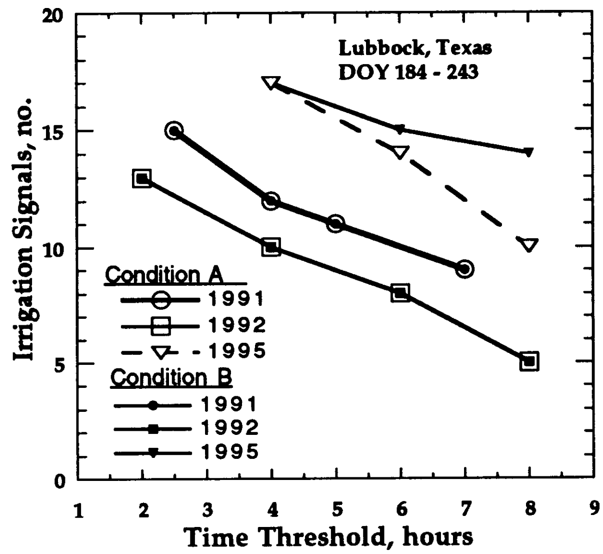


Figure 4. Comparison of the relationship between time threshold level and number of irrigation signals for 1991, 1992, and 1995 using either Condition A or Condition B for daily accumulation of stress time while canopy temperature was above 28°C. For Condition A (open symbols) temperature stress was accumulated only when solar radiation level was also above 200 wm$^{-2}$ and for Condition B (solid symbols) temperature stress was accumulated regardless of the radiation level.

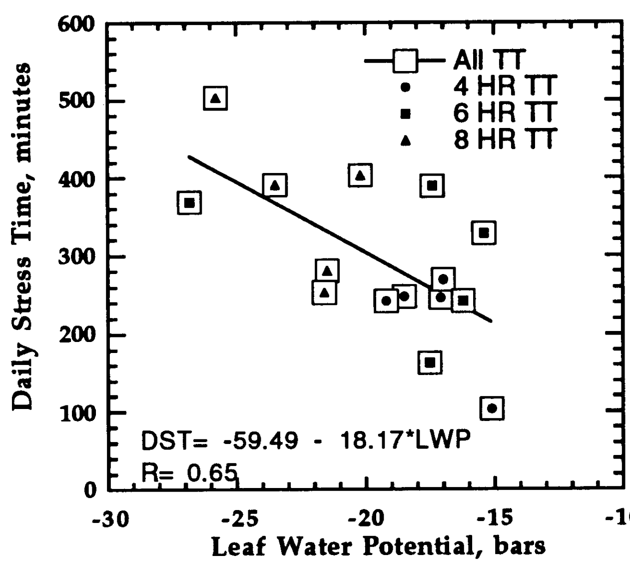


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Figure 5. Relationship between daily stress time and leaf water potential for all days of one irrigation cycle for three time threshold treatments between August 28 and September 1, 1995.