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Automatic drip irrigation control regulates water use efficiency

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The advantages of an automated irrigation scheduling and control system that could be set up to control irrigation to arrive at a given level of water use efficiency are obvious. This paper describes the water use efficiency results from an automatic irrigation scheduling and control system tested at Bushland, Texas from 1996 through 2001. The system evaluates crop canopy temperature at every minute of the day, and makes irrigation decisions every night based on the number of minutes in the day that the canopy temperature was above a threshold value. The studies proved the ability of an automated system to maintain high yields, and appeared to confirm that water use efficiency can be controlled for corn, but not for soybean.

Our objectives were to compare yields and water use efficiencies obtained using weekly replenishment of soil water to field capacity, and obtained using 33 and 67% of that amount, with yields and water use efficiencies obtained with a temperature-time threshold method; and to evaluate the feasibility of using a temperature-time threshold method to control water use efficiencies of corn and soybean production.

Materials and Methods

The study was done from 1996 through 2000 on a Pullman clay loam, fine, mixed, thermic Torrertic Paleustoll at Bushland, TX in the southern High Plains. Each of the 21 plots was 10.7 by 27.4-m and contained 12 rows with 0.76-m row spacing. Half of each plot was irrigated with drip lines buried at 0.3-m depth in every other interrow (1.52-m line spacing). The other half plot was surface irrigated with three drip lines in every other interrow. Integral pressure compensating emitters, rated at 2.7 L h^{-1} at the 69 kPa design pressure, were spaced at 0.45-m intervals along the tubing. Flow to each plot sub main was controlled at 908 L h^{-1} by a Dole Flow Control valve. Flow to each IRT plot was recorded from totalizing flow meters (Master Meter) on a weekly basis. Phosphoric acid was injected at 5.3 mg L^{-1} as a P source and to prevent root plugging.

Plots were leveled and bermed to prevent runoff and runon. Weekly measurement of soil water content was in one access tube in each plot by neutron moisture meter at depths of 0.1 through 2.3 m in 0.2-m increments (32-s counts at each depth). A depth control stand was used to ensure accurate depth positioning of the neutron probe. The meter was previously field calibrated for the A, B and calcic B-horizons with coefficients of determination of 0.90, 0.96, and 0.97, respectively, and RMSE < 0.01 $m^3\ m^{-3}$ for all horizons. The change in stored soil water to 2.4-m depth was calculated between the first measurement date and harvest. Seasonal crop water use was calculated from totals of irrigation, rainfall, and change in stored soil moisture.

Corn (Zea mays L., hybrid Pioneer 3162) was planted in 1997 after 186 kg N ha^{-1} was applied, and in 1999 after 230 kg N ha^{-1}. Atrazine was applied at 2.24 kg ha^{-1} in 1997 and 1999. For corn, liquid urea was injected into the irrigation water at 75 mg L^{-1}. Soybean (Glycine Max (L.), var.

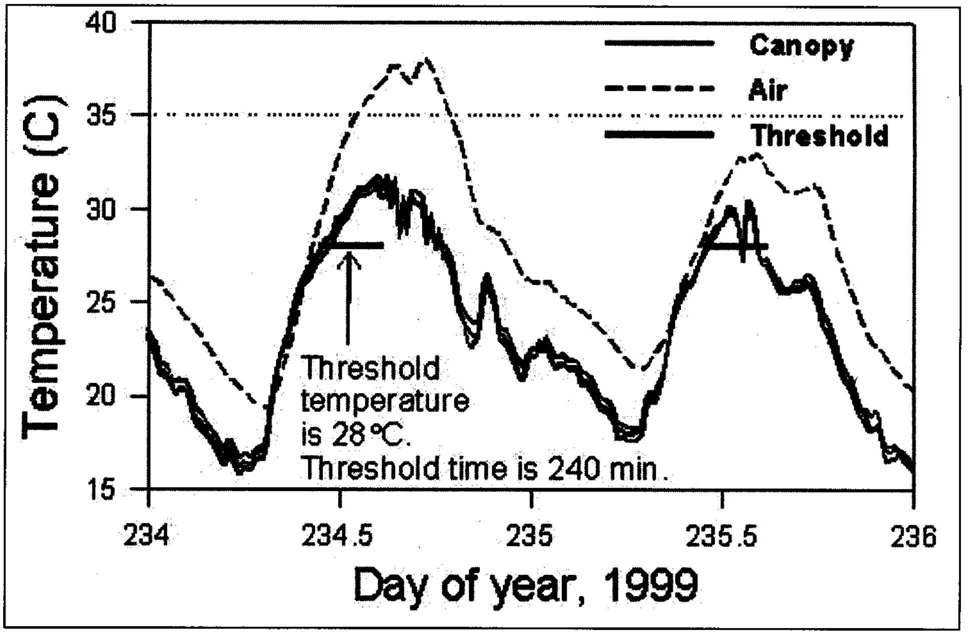

Figure 1. Canopy temperatures of three replicate plots of the 28°C, 240-min treatment on corn in 1999 compared with air temperature. Also shown are horizontal bars drawn at the value of threshold temperature and over the length of the threshold time. Because the canopy was above the threshold temperature for more than the threshold time on day 234, irrigation occurred in the evening of that day, but not in the evening of day 235.

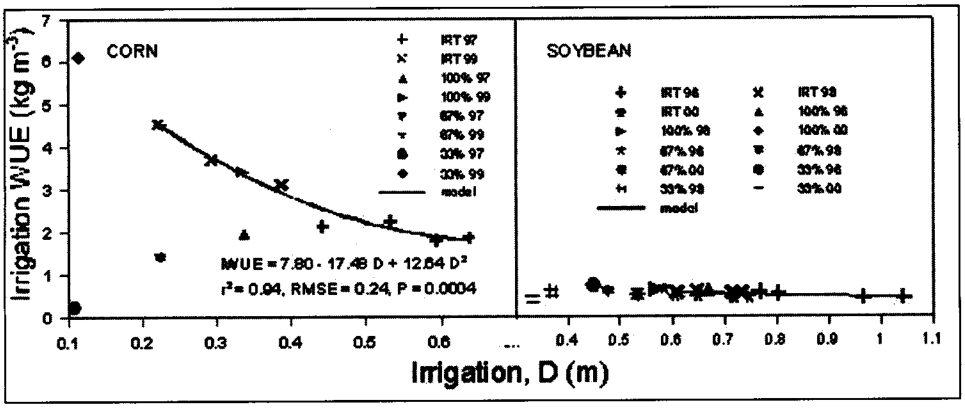

Table 2. Soybean (right) and corn (left) irrigation water use efficiencies vs. irrigation depth (D, m) for automatic and manual drip irrigation treatments.

Pioneer 9481, late maturity group 4) was planted in 1996, 1998, and 2000, after Treflan was applied and incorporated. Analysis of variance of the results and Student-Newman-Keuls multiple range tests on the means were carried out.

Seven irrigation treatments were randomized within blocks in a split plot (surface and subsurface drip) design with three replications. Treatments were randomized each year. For drip-irrigated field corn at Bushland, previous research showed no significant difference in yield between once-a-day and once-a-week irrigation treatments that replenished soil water to field capacity. Thus, a check treatment, designated 100%, consisted of weekly irrigations to replace 100% of crop water use as measured by neutron scattering (average of three replicates).

Crop water use was calculated as the difference between soil water storage in the top 1.5 m of soil and field capacity in that layer (0.333 m3 m^{-3} average water content). Two other treatments, designated 67% and 33%, were irrigated weekly to provide 67% and 33% of the amount provided to the 100% treatment.

Four other treatments were implemented with two threshold canopy temperatures, each of which was implemented with two threshold times to create four automatic irrigation treatments. The threshold temperatures were determined by the ARS Plant Stress and Water Conservation Laboratory, Lubbock, TX, on the basis of temperature kinetics of soybean and corn photosynthetic enzymes. The 28°C threshold is the center of the thermal kinetic window for corn and represents peak photosynthetic enzyme activity, and should be the optimum. Similarly, the optimum temperature threshold for soybean was determined to be 27°C. For corn, a 30°C threshold treatment was established to see if a 2°C increase would substantially change water use, water use efficiency, and yields. Similarly, for soybean, a 29°C threshold was used.

For corn, the time threshold was determined to be 240 min for a 28°C threshold temperature using the crop energy balance method proposed by Wanjura aligned with weather data from Bushland. The aims of this method were to calculate, over the irrigation season, the average time period over a day for which the canopy temperature of a well-watered crop, with a particular canopy resistance, exceeds the threshold temperature.

For irrigation system control, the time threshold is compared to a daily accumulation of measured time that the canopy is above the threshold temperature. During our experiment, the canopy temperature was measured every second and the mean calculated every minute. If the mean temperature was above the threshold temperature, and if the relative humidity was below a limiting value, then one minute was added to the sum of time for which canopy temperature exceeded the threshold. The limiting relative humidity was regarded as being equivalent to a wet bulb temperature of 2°C below the

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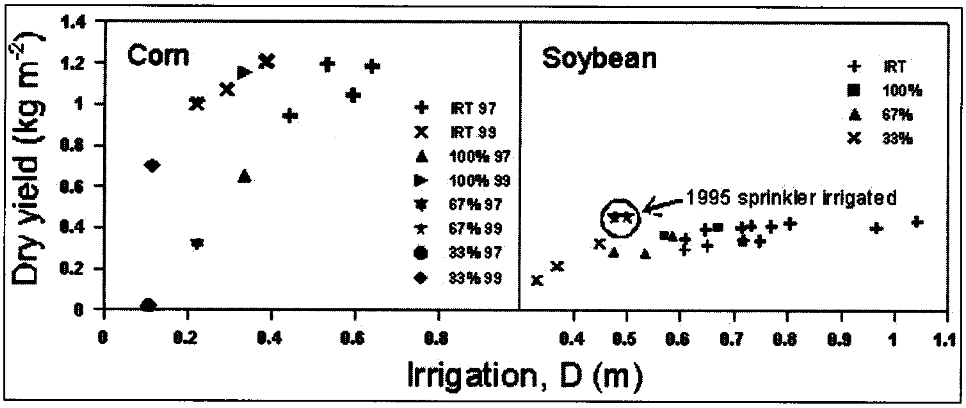

Figure 3.

threshold temperature.

Canopy temperature was measured with infrared thermometers (Exergen model IRt/c.2-T-80) digitized with a data logger (Campbell Scientific, Inc. model 21X) that also served to control flow to the 12 plots irrigated by canopy temperature control.

One infrared thermometer was allocated per plot, mounted on an adjustable mast one third of the distance from the south end of the plot, and adjusted to point down 45° from the horizontal and to point across the rows at 45° from north. Flow to each IRT plot was turned on and off by a solenoid valve actuated by the data logger via a control module. Irrigation decisions were programmed to take place after sunset; and all irrigations were done at night.

Results and Discussion

An example of canopy temperatures for the 28-240 treatment over two days in 1999 shows the typical deviation among temperature readings, and illustrates the evaporative cooling of the canopy to well below peak air temperatures for this well-watered treatment (Fig. 1).

Rainfall during the soybean irrigation seasons varied from 411 mm in 1996 to 85 mm in 1998 and 126 mm in 2000. In the relatively wet year 1996, soil water storage increased for most automatic irrigation treatments, whereas in 1998 and 2000, soil water was depleted for all treatments (Table 1). Total water use varied widely, and was largest in 1996 when yields were also the largest. Yields under 100% irrigation declined in the more stressful years 1998 and 2000.

Yields for the theory-based automatic treatments (27-256 and 29-171 in Table 1) were about the same in 1996 and 1998, only declining in 2000. The year 2000 was the most stressful due to the fact that most of the rainfall came in May, leaving the rest of the summer almost devoid of rain and unusually hot during flowering and pod filling. There were few significant differences in water use efficiency (WUE) or irrigation water use efficiency (IWUE) among treatments (Table 1, Fig. 2); and there was no clear difference between automatic and manual irrigation treatments across years. A regression of IWUE vs. total irrigation was not significant at P = 0.05. There were no clear yield differences between the automatic treatments and the 100% manual treatment. The 67% manual treatment always resulted in lower yields, often significantly so, while IWUE and WUE values for this treatment were sometimes significantly larger than those for some of the automatic treatments. However, this was not consistent across years. The theory-based automatic treatments resulted in yields as large as or larger than those from the 100% treatment except for the 29-171 treatments in 2000 for which there was a slightly but not significantly smaller yield. The automatic irrigation system can be relied upon to produce soybean yields as large as those obtained with manual irrigation, while reducing management decisions and time;

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but, there does not appear to be a way to control the efficient use of water with it. This seems to be largely due to the fact that efficient use of water in soybean cultivation is not strongly tied to the availability of water. Irrigation levels above 0.6 m per year do not increase yields

Results for corn are much different. The automatic treatments applied significantly more water to corn in six of eight cases than did the 100% treatment in 1997 and 1999 (Table 2). In the drier year 1997 (189 mm irrigation season rainfall vs. 323 mm in 1999), yields were significantly larger for the automatic treatments vs. the manual ones, and were more consistent across years.

In the wetter year 1999, yields from three of the automatic treatments were not significantly different from that of the 100% treatment. Yield from the more stressful 30-240 treatment was significantly smaller. The larger IWUE values from automatic treatments in the less stressful 1999 year, compared with those from 1997, indicate the ability of the automatic system to respond to less stressful conditions by applying less water (Table 2). The larger yield values from automatic treatments in 1997, compared with those from the manual treatments, indicate the ability of the system to relieve stress in a timely fashion. This is particularly important during silking in corn.

The differences between corn and soybean results may be due both to differences in photosynthetic mechanisms (corn is a C4 crop and soybean a C3) and to differences in plant development. Corn is able to efficiently use higher levels of radiation than is soybean) and probably would benefit more from the high levels of solar radiation available at Bushland (due to clear skies and the high elevation of 1170 m MSL). Also, it is well established that corn yield potential is sensitive to water stress level, particularly during silking.

In conclusion, for both corn and soybean, the automatic, canopy temperature based irrigation system was consistently able to produce yields as large as or larger than those from a more traditional weekly irrigation scheduling system that employed soil water measurements to determine the amount of water needed to bring the soil profile back to field capacity. However, only for corn was the automatic system clearly more capable of maintaining high yields while using rainfall efficiently and delivering efficient levels of irrigation water utilization in years with good rainfall.

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