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Canopy temperature based system effectively schedules and controls center pivot irrigation of cotton

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ABSTRACT

Cotton is a perennial plant with an indeterminate growth pattern that is typically produced like an annual, but requires proper management to effectively produce high yields and good fiber quality in a thermally limited environment like the northern Texas High Plains. In 2007 and 2008, we investigated the effect of irrigation scheduling/control method and amount on cotton (*Gossypium hirsutum* L.) yield and water use efficiency. Methods were automatic irrigation scheduling and control of a center pivot system, and manually scheduled irrigation to replenish soil–water to field capacity. Cotton was irrigated with LEPA (low energy, precision application) drag socks in furrow dikes; three blocks were irrigated manually and three were irrigated automatically. Six replicates of the manual and automatic irrigation treatments were included in the randomized block design. Manual irrigations were based on the weekly replenishment of soil–water to field capacity in the top 1.5 m of the soil profile and included a fully irrigated treatment (I_{100}), and treatments receiving 67% (I_{67}) and 33% (I_{33}) of the I_{100} amount, plus a non-irrigated treatment (I_0). Automatic irrigations were triggered using a time temperature threshold (TTT) algorithm, which was designated as the I_{100} treatment, and treatments receiving 67%, 33%, and 0% of that amount (I_{67}, I_{33} and I_0, respectively). In 2007, overall mean lint yields (102.3 and 101.6 g m^{-2}, manual and automatic, respectively) were not significantly different. Similarly, yields were not significantly different across automatic and manual treatments in the same treatment level, with the exception of the I_{67} treatment where the manual treatment yields were 11% greater. In 2008, the mean yields were 70% less than those in 2007 for both methods of irrigation (30.3 and 30.9 g m^{-2}, manual and automatic, respectively) due to harsh climatic conditions at emergence and heavy rainfall and cooler temperatures in the month of August. Yields from the automatically irrigated plots in the I_{100} and I_{67} treatments, however, were significantly greater than yields from the corresponding manually irrigated plots; though there was no significant difference between yields in the drier treatments (I_{33} and I_0) plots. These results indicate that the TTT algorithm is a promising method for auto-irrigation scheduling of short season cotton in an arid region. However, further studies are essential to demonstrate consistent positive outcomes.

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1. Introduction

Scientific irrigation scheduling (manual or automatic) is an aspect of irrigation management intended to determine the appropriate timing of irrigations and the necessary amount of water to apply to control plant water stress at critical growth stages. Scheduling methods are typically generalized into the categories of soil–water measurements [indirect methods using soil–water content sensors are explained in detail by Evett (2007)], soil–water-balance calculations, plant stress-sensing techniques (Jones, 2004), and weather-based methods using reference evapotranspiration (Al-Kaisi et al., 1997; Ko and Piccinni, 2009). Research studies have been conducted on various cotton cultivars to determine the most advantageous irrigation scheduling method to meet crop water needs and optimize productivity. Pitts et al. (1990) completed a study on the practicality of four irrigation scheduling techniques on cotton in the lower Mississippi River Valley. These included monitoring soil–water potential (SWP) with tensiometers, measuring leaf-water potential (LWP), evaluating a crop water stress index (CWSI), and performing daily calculations to estimate soil–water depletion (SWD). They determined that the SWD method used the least amount of labor but required an accurate estimate of evapotranspiration (ET). The SWP method produced the greatest yield. The CWSI required less labor than the SWP method, but was less reliable on overcast days, while the LWP method was impractical on a production scale.

Vories et al. (1991) investigated sprinkler irrigation scheduling of cotton on silty clay in Keiser, Ark., for 3 consecutive years. Irriga-

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tion timing was based on three levels of SWD (25, 50, and 75 mm). The amount of water applied was calculated from the estimation of pan evaporation and crop coefficients. The average seed-cotton yield for the 3 years was not significantly different across scheduling treatments. Hunsaker et al. (1998) investigated high frequency surface irrigation and its effect on growth, lint yield, and water use of cotton in southern Arizona. Cotton yields were maximized under high frequency surface irrigations, which were scheduled with predetermined SWD levels, determining the amount of water to apply using AZSCHED (a computer-based program that estimates daily crop evapotranspiration, ET_c, from crop coefficients and a grass-reference evapotranspiration, calculated using the modified Penman–Monteith equation). Bajwa and Vories (2007) studied subsurface drip irrigated (SDI) cotton in Arkansas. Irrigation scheduling was based on the Arkansas Irrigation Scheduler (Cahoon et al., 1990), and the applied amount of water was calculated as 100% and 60% replacement of daily estimated ET, plus a non-irrigated treatment. The non-irrigated treatment significantly out yielded the 100% replacement of estimated ET treatment in both years studied, indicating the negative effect that irrigation may have on cotton when vegetative growth and boll set are promoted at the expense of boll filling and opening.

Plant-based methods that have been utilized to evaluate water stress in cotton and schedule irrigations include thermally-based techniques such as elevated crop canopy temperature (Pinter and Reginato, 1982), the empirical crop water stress index (CWSI) developed by Idso et al. (1981), the theoretical CWSI formulated by Jackson et al. (1981), and the time temperature threshold (TTT) method investigated extensively by Evett et al. (1996, 2001, 2006) and Peters and Evett (2004, 2007, 2008), and patented by Upchurch et al. in 1996 (Wanjura et al., 2004). The TTT method lends itself to automatic irrigation scheduling as demonstrated for both subsurface drip irrigation (Evett et al., 2002) and center pivot (Peters and Evett, 2008) systems. Replicated studies from each system demonstrated that corn and soybean yields were not significantly different when irrigated with the TTT method as compared to manual irrigations scheduled to replenish soil–water to field capacity on a weekly interval. Also to the advantage of the producer, the TTT method does not require extensive ancillary inputs for triggering irrigations. As described by Wanjura et al. (1992), the algorithm incorporated a predetermined crop-specific canopy temperature based on the peak in thermal kinetics of photosynthetic activity and a region-specific time threshold. If crop canopy temperature was greater than the threshold value for greater than the accumulated time threshold (within a 24-h period), irrigation was scheduled automatically by the controlling micro-computer. Evett et al. (1996, 2001, 2002) showed that the temperature threshold could be varied without reducing the effectiveness of the algorithm. In addition, Evett et al. (2002) showed that water use efficiency (WUE) could be controlled by varying time and temperature thresholds for corn (a C4 plant) but not for soybean (a C3 plant).

Lamm and Aiken (2008) compared TTT irrigation scheduling to that based on crop water use (ET_c) replacement using a weather-based water budget scheduling method. The results indicated that a time threshold of 2.5 h at a temperature threshold of 28 °C corresponded reasonably well to a 100% ET_c replacement treatment. Wanjura et al. (2006) performed a study for cotton and SDI to determine signals for irrigation control and determined that crop canopy temperature best characterized crop water stress. They also confirmed that there was a significant linear relationship between lint yield and stress time. However, this work did not compare yields between automatically and manually scheduled irrigation methods. This comparison is crucial for commercial adoption of the algorithm since cotton, being a warm-season perennial species produced like an annual, requires a delicate balance of water and water deficit controls to effectively produce high yields in a thermally limited environment (Howell et al., 2004). Our study was designed to investigate the effectiveness of using a TTT method for automatic irrigation scheduling of cotton irrigated with LEPA drag socks under a center pivot system in the Texas High Plains. Our main objectives were to compare average lint yields, WUE, and irrigation WUE (IWUE) between manual and automatic methods of scheduling and between irrigation amount or TTT stress index level treatments.

2. Materials and methods

Cotton (*Gossypium hirsutum* L.), variety Paymaster 2280[1], was planted on day of year (DOY) 149 in 2007, and variety Deltapine 117 B2RF[1] was planted on DOY 141 in 2008 (both varieties were Bollgard II® Roundup Ready®). The crop was grown in 18-row plots on beds spaced 0.76 m apart under a three span center pivot at Bushland, Texas (35°11′N, 102°06′W, 1174 m above mean sea level).

Manual irrigations were applied weekly on even-numbered DOY at treatment levels of 33%, 67%, and 100% of full replenishment of soil–water in the top 1.5 m of soil to field capacity (treatments designated MI_{33}, MI_{67} and MI_{100}), and a non-irrigated treatment designated MI_0 was included. Manual irrigations were based on neutron probe readings taken weekly using methods described by Evett (2008) at 10-cm depth to 230-cm depth in 20-cm increments. Soil–water depletion (SWD) levels were calculated as

$$\mathrm{SWD} = \frac{\theta_{fc} - \theta_v}{\theta_{fc} - \theta_{pwp}} \quad (1)$$

where θ_{fc} = soil–water content at field capacity, 0.33 m^3 m^{-3}, Evett (2008); θ_v = mean soil–water content (m^3 m^{-3}) in the top 1.5 m, and θ_{pwp} = soil–water content at permanent wilting point, 0.18 m^3 m^{-3}, Evett (2008).

Automatic irrigation scheduling protocols, infrared thermometer sensors (IRTs) (Exergen model IRt/c.5:1-Type T, Watertown, Mass.), and canopy-temperature data collection methods were similar to those described by Peters and Evett (2008). Automatic irrigations were triggered only after canopy temperatures exceeded 28 °C for more than 452 min accumulated in a 24 h period on an odd-numbered DOY. Stationary IRTs, wired in 2007 and wireless in 2008, were located in the field within automatically irrigated treatment plots and provided reference crop canopy temperatures. The automatic irrigation treatment considered fully irrigated received 20 mm of water each time irrigation was triggered (treatment AI_{100}). This amount is equivalent to the week-long peak cotton water use measured by weighing lysimeters at Bushland, which is 10 mm/day. Since automatic irrigation can occur only every other day, the full irrigation is 2 × 10 = 20 mm. Three other automatic irrigation treatments received 67% (AI_{67}), 33% (AI_{33}), and 0% (AI_0) of the fully irrigated amount.

Methods were applied in alternate blocks arc-wise across one half of the center pivot circle in each year with two replicates of each irrigation amount treatment randomized in each block (Fig. 1). Irrigation was applied using low energy precision application (LEPA) drag socks (Lyle and Bordovsky, 1983) in every other furrow. Preplant fertilizers containing nitrogen and phosphorous were applied after evaluating results from soil samples analyzed at a commercial soil testing laboratory in March of 2007 and 2008.

Treflan (a.i., trifluralin) was sprayed as a pre-emergent herbicide at a rate of 2.4 L ha^{-1} (Table 1). Roundup [a.i., glyphosate (N-(phosphonomethyl) glycine)] was sprayed throughout both

[1] The mention of trade names of commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

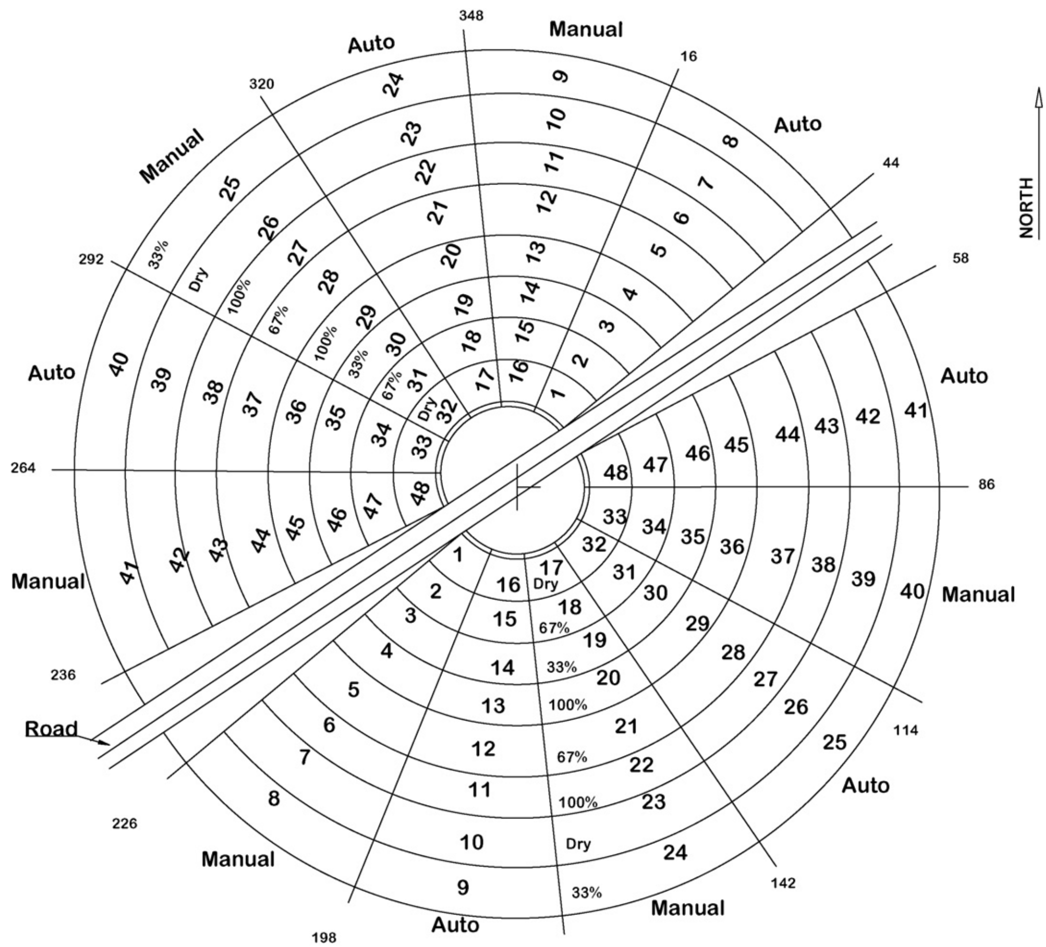

Fig. 1. Layout of treatment plots under 3-span center pivot system. The southeast half was cropped during the 2007 growing season (48 plots) and the northwest half was cropped during the 2008 growing seasons (48 plots).

growing seasons as necessary to control weeds. An aerial application of Stance [a mixture of mepiquat chloride and cyclanilide], a plant growth regulator, was applied to all plots in 2008 to minimize vegetative growth and promote boll retention after the heavy rainfall.

Preplant and postplant irrigations of 44 and 27 mm, respectively, were applied to the crop in 2007 to ensure a uniform stand. In 2008, the total preplant irrigation was 101 mm, applied to fill the soil profile. Due to dry, windy conditions during emergence and seedling establishment in 2008, postplant irrigations totaling 236 mm were applied uniformly to all treatment blocks. The irrigations were intended to help the stressed cotton seedlings thrive and prevent wind-blown soil from cutting the delicate cotyledons.

Table 1
Agronomic practices.

Events	2007	2008
Chemical application		
Fertilizers	N 135 kg ha^{-1} P 84 kg ha^{-1}	N 152 kg ha^{-1} P 84 kg ha^{-1}
Herbicides	Treflan 2.3 L ha^{-1}	Treflan 2.3 L ha^{-1}
Growth regulator	None	Stance
Cotton		
Variety	Paymaster 2280BG2R	DP117B2RF
Planting date (DOY)	May 29 (149)	May 20 (141)
Planting rate	19.8 seeds m^{-2}	20.3 seeds m^{-2}
Emergence date (DOY)	158	148
Plant density	14 plants m^{-2}	14 plants m^{-2}
Harvest date (DOY)	306	326
Cover crop: non-experimental half of pivot field	Sorghum	Sorghum

The soil was Pullman clay loam, a fine, mixed, superactive, thermic, Torrertic Paleustoll (Soil Survey Staff, 2004). The field capacity and wilting water contents were assumed uniform across the center pivot field. Water use or ET was calculated using the soil–water-balance equation (Evett, 2002):

$$\mathrm{ET} = P + I + F - \Delta S - R \qquad (2)$$

where ET is the evapotranspiration, ΔS is the change in soil–water stored in the profile, R is the runoff, P is the precipitation (mm), I is the irrigation water applied (mm), and F is the flux across the lower boundary of the control volume (taken as positive when entering the control volume), all in units of mm.

Water use efficiency (kg m^{-3}) was calculated as

$$\mathrm{WUE} = \frac{Y_g}{\mathrm{ET}} \qquad (3)$$

where Y_g is the economic yield (g m^{-2}), and ET is the crop water use (mm).

Irrigation water use efficiency (IWUE, kg m^{-3}) was calculated as

$$\mathrm{IWUE} = \frac{Y_{gi} - Y_{gd}}{\mathrm{IRR_i}} \qquad (4)$$

where Y_g is the economic yield (g m^{-2}), Y_{gd} is the dryland yield (g m^{-2}), and IRR is the irrigation water applied (mm), Howell (2002).

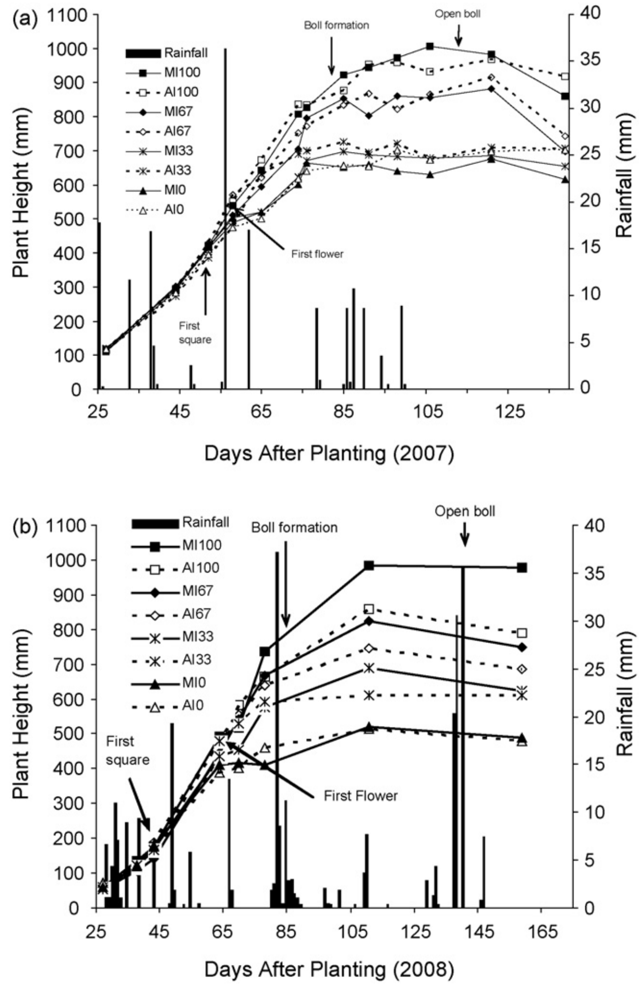

Fig. 2. Plant heights and rainfall for: (a) 2007 and (b) 2008 irrigation season. Plant heights represent the average of three measurements from two replicate treatment plots.

Crop height and growth stage were measured periodically during the season. Yield samples were taken on DOY 288 (November 2, 2007) and DOY 326 (November 21, 2008) over a 10 m^2 area in each plot. Air temperature, relative humidity, solar irradiance, and wind speed were measured at an adjacent weather station and reported as half-hourly means. Growing degree-days (GDD) were calculated as the mean of the daily minimum and maximum air temperatures less the base temperature of 15.6 °C (Howell et al., 2004).

Yield data, ET, WUE, and IWUE were analyzed using SAS (SAS Institute, Inc., Cary, NC) Proc Mixed models. Significantly different treatment means were compared with the least significant difference test. Differences were considered to be significant at the $p < 0.05$ level. Statistical results were analyzed for individual seasons.

3. Results and discussion

In growing season 2007, 214 mm of precipitation was received between planting and harvest with 54 mm occurring between first flower and boll formation and 62 mm occurring after boll formation through harvest (Fig. 2). Cumulative growing degree-days (CGDDs) were 998 °C for the season. In early June, 2008, daily temperatures of 37 °C to 40 °C, and 2-m wind speeds of 16–22 m s^{-1}, coupled with low humidity made it difficult to maintain the soil–water near field capacity levels. Despite uniform postplant irrigations across irrigated treatment plots made through the 55th day after planting (DAP), soil–water depletion levels for the AI_{100} treatment plots were always >0.55 until heavy rainfall [70 mm in 10 days, beginning 83 DAP (Fig. 3)]. The SWD levels in the MI_{100} typically ranged from 0.50 to 0.45 during the postplant irrigation season. The extensive period of precipitation, may have prematurely triggered cut-out, dropping daily average air temperatures below normal, reducing solar irradiance and retarding boll maturation. These conditions resulted in 7% less CGDDs and 41% more precipitation from plant to harvest than in the previous year (Table 2). The mean number of bolls harvested per plant was 2.9 and the average weight per boll was 5.4 (g) in 2008, compared with 4.2 (bolls per plant) and an average weight of 6.5 (g) in 2007.

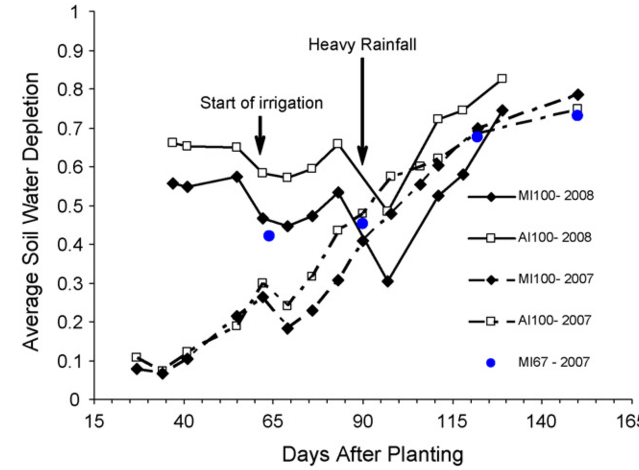

Fig. 3. Average weekly soil–water depletion levels for the manually and automatically plots in the in the $I_{100\%}$ treatment for 2007 and 2008.

3.1. Yields

In 2007, the averaged yields for all manually and automatically irrigated plots were not significantly different (Table 3). Comparing manually and automatically irrigated yields within the same irrigation level treatment, the only significant difference was in the I_{67} treatment, where the manually irrigated plots yielded 12.5% more lint per m^2. Lint yield results were similar to irrigated yields measured by Howell et al. (2004) who reported yields under deficit irrigation of 85–120 g m^{-2} versus 2007 yields produced in AI_{33} and AI_{67} treatments of 92–112 g m^{-2}. Similarly, Wanjura et al. (2004) reported yields of 120 g m^{-2} for a treatment receiving 67% of their full irrigation amount; but their 50% treatment yielded only 30 g m^{-2}. Howell et al. (2004) reported yields from fully irrigated fields of 110–150 g m^{-2}, which brackets the yield from AI_{100} of 134 g m^{-2}. In a climate with more CGDD, Wanjura et al. (2004) observed yields of 150 g m^{-2} for well-watered cotton. Automatic irrigations produced yields that were linearly and positively correlated to water use where the average yield increment rate was 4.61 kg ha^{-1}/mm of water consumed. Manual irrigations closely followed the linear relationship for the MI_0, MI_{33} and MI_{67} treatments, but there was no yield increase between the MI_{67} and MI_{100} treatments (Fig. 4). This suggests that there was sufficient water in the soil profile in the MI_{67} treatment plots to meet crop ET and the upper yield threshold. The SWD for these irrigation levels were consistently similar towards the end of the irrigation season (Fig. 3). Fewer neutron probe readings were taken in the non-fully irrigated plots because of limited manpower.

In 2008, cotton lint yields declined from 2007 by as much as 75%. The harsh climatic conditions at emergence impacted root development and vegetative growth, while cooler average daily temperatures and the excessive rainfall in mid August reduced boll

Table 2
Key climatological and irrigation data for each growing season.

Irrigation season	2007	2008
Weather		
Precipitation (mm)		
May	40.1	18.4
June	56.4	57.3
July	36.6	49.3
August	63.7	73.1
Total (plant to harvest)	214.1	300.7
Average daily temperature (°C)		
May	17.0	18.5
June	21.6	24.3
July	23.9	23.8
August	24.5	22.6
Average daily relative humidity (%)		
May	68.3	47.3
June	64.6	47.1
July	62.8	60.8
August	64.2	66.1
Cumulative GDD (plant to harvest)	998	934
Start date automatic irrigations (DOY)	July 17 (198)	July 18 (200)
Preplant irrigation (mm)	44	101
Postplant irrigation (mm)	27	176
End date automatic irrigations (DOY)	August 29 (241)	August 12 (225)
Total irrigations during scheduling (mm)		
Manual		
I_{100}	190	232
I_{67}	128	180
I_{33}	63	123
I_0	0	0
Automatic		
I_{100}	139	158
I_{67}	88	111
I_{33}	43	63
I_0	0	0

formation and retarded boll maturation, resulting in yield losses ranging from 31 to 64 g m^{-2}. An analysis of the data between irrigation method and amount demonstrated a negative trend between lint yield and water use for the manually irrigated treatment plots (MI_{33}, MI_{67}, and MI_{100}), similar to results reported by Bajwa and Vories (2007). There was a positive linear trend between yield and

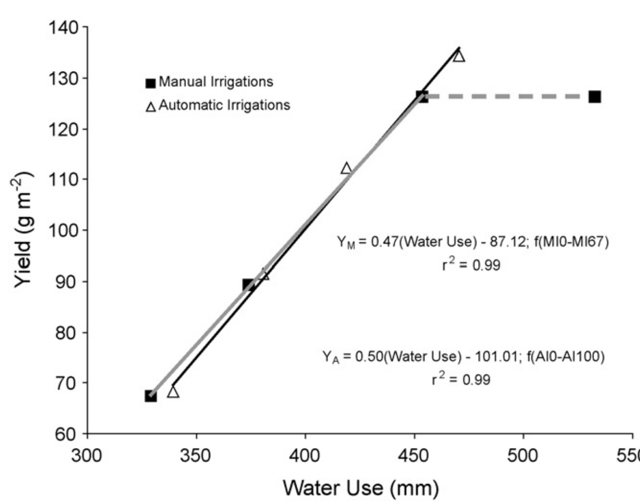

Fig. 4. The average of six yield measurements versus mean water use from each irrigation treatment (I_{100}, I_{67}, I_{33}, and I_0) for both the manually and automatically irrigated plots, 2007. The average yield was 0.461 g m^{-2} of lint per mm of ET.

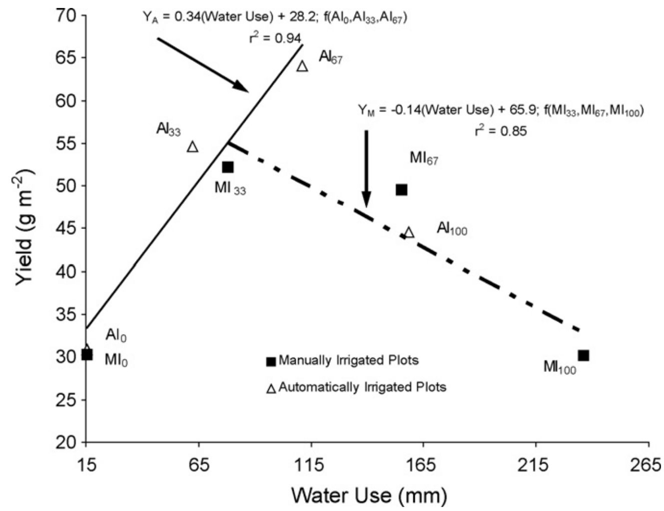

Fig. 5. The average of six yield measurements versus mean water use from each irrigation treatment separated by method; manual (MI_{100}, MI_{67}, MI_{33}, and MI_0) and automatic (AI_{100}, AI_{67}, AI_{33}, and AI_0), 2008.

the deficit automatic irrigation treatments AI_{33}, and AI_{67}) while the yield decline for the 100% automatic treatment (AI_{100}) was less severe than that associated with the 100% manual treatment (MI_{100}) (Fig. 5). The positive trend between lint yield and irrigations for the AI_{33} and AI_{67} treatments is similar to findings by Vories et al. (1991) and Colaizzi et al. (2009). Irrigations at the highest level for the manual method (MI_{100}) resulted in yield that was significantly less than for any deficit irrigated plots, while the AI_{100} treatment yield was not significantly different from that for the MI_{67} treatment but was significantly less than yields for the AI_{67}, AI_{33} and MI_{33} treatments. Ibragimov et al. (2007) also reported a decline in yield with their largest irrigation amounts for cotton in Uzbekistan.

3.2. Water use efficiencies

In 2007, averaged WUE values between irrigation methods and across irrigation treatments were not significantly different except in the I_{100} level where the averaged automatic WUE value was significantly greater (0.29 vs. 0.24 kg m^{-3}, for the MI_{100} treatment). In 2008, the averaged WUE value for the automatic method of irrigation was significantly greater than that for the manual method (0.13 and 0.09 kg m^{-3}, respectively). The WUE values for all automatic irrigation treatments were significantly greater than those for the corresponding manually irrigated plots. The 2007 WUE values were greater than the largest reported by Howell et al. (2004) for Bushland, TX. The 2008 WUE values were smaller for full irrigation (MI_{100} and AI_{100}) and about the same for deficit irrigation using the automatic system (AI_{67} and AI_{33}) as those reported by Howell et al. (2004). Manually applied deficit irrigation treatments (MI_{67} and MI_{33}) achieved WUE values only as large as those for dryland cotton as reported by Howell et al. (2004). For both years, the averaged IWUE values were greater for the automatically irrigated plots. The IWUE values for our fully irrigated treatments in 2007 (0.31 and 0.47 kg m^{-3}) were within the range obtained by Tennakoon and Milroy (2003) for irrigated cotton grown in Australia (0.12–0.49 kg m^{-3}). Similarly, IWUE values across automatic irrigation treatments were significantly greater than those for the manually irrigated plots, except in the case of the MI_{67} and AI_{67} treatments in 2007, where there was no significant difference, but a similar trend of greater IWUE for the automatic treatment. Values of IWUE for manual irrigations were similar to those reported by Ibragimov et al. (2007), but mean values of IWUE for automatic irrigations were larger overall.

Table 3
Yield, total water use, water use efficiency, and irrigation water use efficiency for manually and automatically irrigated cotton plots for 2007 and 2008. Numbers in a column followed by the same letter are not significantly different at the 5% level.

	Bolls [average number/average wt. (g)]	Yield ($g\,m^{-2}$)	Total water use (mm)	Water use efficiency ($kg\,m^{-3}$)	Irrigation water use efficiency ($kg\,m^{-3}$)
2007					
Method					
Manual	4.32 a/6.56 a	102 a	422 a	0.24 a	0.37 a
Automatic	4.04 a/6.52 a	101 a	402 a	0.25 a	0.50 b
Irrigation level					
I_{100}	5.60 a/6.66 a	130 a	502 a	0.26 a	0.39 a
I_{67}	4.88 b/6.62 a	119 b 90 c	436 b	0.27 b	0.48 b
I_{33}	3.48 c/6.58 a	68 d	377 c	0.24 c	0.44 c
I_0	2.78 d/6.30 a		334 d	0.20 d	
Treatments					
I_{100}					
Manual	5.97 a/6.40 a	126 a	533 a	0.24 a	0.31 a
Automatic	5.22 b/6.93 a	134 a	471 b	0.29 b	0.47 b
I_{67}					
Manual	5.21 b/6.72 a	126 a	454 c	0.28 b	0.46 b
Automatic	4.55 c/6.51 a	112 b	419 d	0.27 b	0.50 b
I_{33}					
Manual	3.44 d/6.65 a	89 c	374 e	0.24 b	0.35 c
Automatic	3.52 d/6.51 a	92 c	381 e	0.24 b	0.54 d
I_0					
Manual	2.67 e/6.46 a	67 d	329 f	0.21 c	N/A
Automatic	2.89 e/6.15 a	68 d	339 f	0.20 c	
2008					
Method					
Manual	2.79 a/5.27 a	30 a	453 a	0.09 a	0.29 a
Automatic	3.04 a/5.47a	31 a	376 b	0.13 b	0.58 b
Irrigation level					
I_{100}	2.68 a/5.29 a	37 a	495 a	0.08 a	0.07 a
I_{67}	3.51 b/5.03 b	57 b	441 b	0.13 b	0.25 b
I_{33}	3.63 b/5.30 b	53 c	402 c	0.14 b	0.34 c
I_0	1.84 c/5.84 c	31 d	320 d	0.10 c	
Treatments					
I_{100}					
Manual	2.28 a/5.23 a	30 a	540 a	0.06 a	0.13 a
Automatic	3.09 b/5.03 a	45 b	450 b	0.10 b	0.28 b
I_{67}					
Manual	3.35 c/4.98 a	50 b	488 c	0.10 b	0.33 c
Automatic	3.67c/5.08 a	64 c	395 d	0.16 c	0.58 d
I_{33}					
Manual	3.72 c/5.06 a	52 c	460 b	0.11 b	0.43 e
Automatic	3.53 c/5.54 b	55 c	345 e	0.16 c	0.87 f
I_0					
Manual	1.79 d/5.80 b	30 a	315 f	0.09 b	N/A
Automatic	1.88 d/5.88 b	31 a	325 f	0.10 b	

4. Conclusions

The TTT algorithm was used to schedule irrigations for alternating blocks under a 3-span center pivot in an automated center pivot irrigation system. Yields from the automatically irrigated treatments were compared to those from treatments in which irrigations were scheduled manually based on neutron probe readings. In 2007, yields and water use efficiencies were similar for both methods of irrigation and across the same irrigation treatments, and they were similar to other results reported in the literature. The TTT method of irrigation scheduling, when applied automatically, was successful in producing yields and water use efficiencies as good as those resulting from scientific irrigation scheduling using the neutron probe, and better irrigation water use efficiencies than achieved using the neutron probe.

In 2008, climatic conditions decreased the rate of plant growth, boll maturation, and overall lint yields. Preplant irrigation efforts and postplant applications were ineffective in completely filling the soil profile. However, the TTT method of automatic irrigation scheduling produced greater yields, WUE, and IWUE for cotton planted in the I_{100} and I_{67} treatment levels than did manual irrigation using the neutron probe.

Automated irrigation scheduling and control can be an important time management tool for a producer with multiple sprinkler irrigation systems or multiple systems relying on a single water source by prioritizing the order of irrigations field-by-field. During both growing seasons, IWUE was greater for the automatically irrigated plots. However, due to the inter-annual variability of weather in the Texas High Plains region, additional replicated irrigation scheduling studies need to be conducted to demonstrate that the

TTT method consistently optimizes cotton yields and water use efficiencies when applied in an automatic irrigation scheduling and control system.

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