Irrigation Methods and Capacities for Cotton in the Northern High Plains

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Abstract

The Texas Panhandle has a significant concentration of corn under center pivot irrigation with various application methods (e.g., low energy precision applicator, or LEPA, mid- or low-elevation spray, etc.). Producers in this area, however, are showing interest in cotton, which has a similar revenue potential with a reduced irrigation requirement. Although this area is adjacent to one of the largest cotton producing areas in the United States (centered around Lubbock), the limited growing season (length and lower cumulative growing degree days) and undeveloped industry infrastructure (gins, custom harvesters, etc.) have limited the northward expansion of cotton. We hypothesized that subsurface drip irrigation (SDI), which has been successfully adopted by cotton producers elsewhere, would result in less evaporative cooling following an irrigation event compared with sprinkler methods. This would increase heat unit accumulation and promote earlier maturity. We evaluated lint yield, water use efficiency, and fiber quality for several irrigation methods (SDI, LEPA, and spray) and several irrigation capacities (dryland, 25%, 50%, 75%, and full irrigation) during the 2003 season. We did not observe any clear differences in growth and maturity rates among irrigation methods. However, final lint yield and water use efficiency were greater with SDI under low irrigation capacities (25% and 50% of full irrigation), and increased with LEPA and spray under full irrigation. Fiber quality, as indicated by total discount, was greater with SDI for all capacities except full irrigation. We are continuing this experiment for two more seasons.

Introduction

Cotton production is expanding northward in the High Plains regions of Texas, Oklahoma, and Kansas where corn has been traditionally produced (USDA, 2004), because cotton has a similar revenue potential for about one-half the water requirement (Howell et al., 2004). There is a general perception by some cotton producers in West Texas that subsurface drip irrigation (SDI) enhances seedling emergence and plant maturity due to reduced evaporative cooling compared with mechanically-moved irrigation systems, a critical consideration in thermally-limited climates further north. Mechanically moved systems have numerous variants of applicator packages, with the more common configurations being mid- and low-elevation spray application (MESA and LESA, respectively) and LEPA (Low Energy Precision Applicator) (Lyle and Bordovsky, 1983; Bordovsky et al., 1992). SDI has been widely adopted by commercial cotton producers throughout West Texas beginning in the early 1980s (Henggeler, 1995; 1997; Enciso et al., 2003). Although SDI has significantly greater initial costs than spray or LEPA systems (O'Brien et al., 1998; Segarra et al., 1999), it has been documented to slightly outperform LEPA and spray in terms of lint yield, lint quality (as reflected by loan prices), and water use efficiency (Segarra et al., 1999; Bordovsky and Porter, 2003).

There is, however, limited data supporting the premise that SDI enhances cotton earliness, as this has been more attributed to soil water depletion (Guinn et al., 1981; Mateos et al., 1991; Orgaz et al., 1992). Nonetheless, a few studies may indirectly support this premise and are briefly described here. Wang et al. (2000) reported that mean soil temperatures were 4.4°C greater for plots irrigated with surface drip laterals than stationary rotating sprinklers, and they observed greater emergence rates and seedling development of soybeans. They noted, however, that their results may have been influenced by the solar heating of water as it passed through the black plastic drip laterals rather than the greater evaporating surface area of the sprinkler plots. Tolk et al. (1995) showed that corn transpiration rates, canopy temperature, and vapor pressure deficits were significantly reduced for several hours following irrigation by overhead impact sprinklers, but not greatly changed following irrigation by LEPA in alternate furrows. The reduced evaporative cooling thought to be associated with SDI, on the other hand, may be countered by the greater cooling effect of increased irrigation frequency (Wanjura et al., 1996). Constable and Hodgson (1990) reported that cotton under SDI matured several days later than cotton under furrow irrigation.

The objectives of this study are to compare cotton yield and quality for spray, LEPA, and SDI under full and deficit irrigation in the Texas Panhandle, which has a marginal climate for cotton production. This paper presents the results of the first (2003) season of data, and some preliminary soil temperature data from the second (2004) season.

Procedure

An experiment was conducted during the 2003 and 2004 growing seasons using MESA, LESA, LEPA, and SDI to irrigate cotton at the USDA Conservation and Production Research Laboratory in Bushland, Texas (35° 11′ N lat., 102° 06′ W long., 1070 m elevation MSL). As of this writing, only the 2003 season is complete, so most data presented here reflect a single season. Cumulative heat units for cotton average 1,050°C-d during the growing season (mean daily air temperature minus base temperature of 15.6°C); however, Peng et al. (1989) state that about 1,450°C-d was required for full maturity cotton in the region to our south centered around

Lubbock, TX. The soil is a Pullman clay loam (fine, mixed, thermic torrertic Paleustoll; Unger and Pringle, 1981; Taylor et al., 1963), with slow permeability due to a dense B21t layer that is 0.15 to 0.40 m below the surface and a calcic horizon that begins about 1.2 to 1.5 m below the surface.

Agronomic practices were similar to those practiced for high lint yield in the High Plains region of Texas. Cotton (*Gossypium hirsutum* L., Paymaster[1] 2280 BG RR) was planted on 21 May 2003, and disked and replanted on 10 June 2003 (following severe hail damage to seedlings) at 17.3 plants m^{-2}, on east-west oriented raised beds spaced 0.76 m. The same variety was planted on 20 May 2004 at 19.0 plants m^{-2}. Furrow dikes were installed after crop establishment to control runoff (Schneider and Howell, 2000). In 2003, preplant fertilizer containing nitrogen (N) and phosphorous (P) (10-34-0) was incorporated into the raised beds, at rates resulting in 31 and 107 kg ha^{-1} of N and P, respectively, which were based on a soil fertility analysis. In 2004, similar rates of preplant fertilizer were applied (34 and 114 kg ha^{-1} of N and P, respectively). Additional N (32-0-0) was injected into the irrigation water from first square to early bloom, resulting in a total N application of 48 kg ha^{-1} in both seasons for the full irrigation treatment while deficit irrigation treatments received proportionately less. Treflan was applied at one time before planting at 2.3 L ha^{-1} to control broadleaf weeds in both seasons. No other in-season chemical inputs were required in either year, and no post harvest chemical inputs were required in 2003.

The experimental design consisted of four irrigation methods (MESA, LESA, LEPA, SDI, described in more detail shortly), and five irrigation levels (I_0, I_{25}, I_{50}, I_{75}, and I_{100}). The I_{100} level was sufficient to prevent yield-limiting soil water deficits from developing, based on crop evapotranspiration (ET_c) estimates from the North Plains ET Network (NPET, Howell et al., 1998), and the subscripts are the percentage of irrigation applied relative to the full irrigation amount. The different irrigation levels were used to estimate production functions, and to simulate the range of irrigation capacities one might encounter in the region. The I_0 level received sufficient irrigation for emergence only and to settle and firm the furrow dikes and represents dryland production. Plots were 25 m long by 9 m wide with 12 rows each, and 5 m planted borders separated irrigation level strips.

Soil water was measured gravimetrically near the center of each plot prior to planting and just after harvest in the 1.8 m profile in 0.3 m increments, oven dried, and converted to volumetric contents using known soil bulk densities by profile layer. During the season, soil water was measured volumetrically near the center of each plot on a weekly basis by neutron attenuation in the 2.4 m profile in 0.2 m increments according to procedures described in Evett and Steiner (1995) and Evett et al. (2003). The gravimetric samples were used to compute seasonal water use (irrigation + rainfall + change in soil water), and the neutron measurements were to verify that irrigation was sufficient so that no water deficits developed in the I_{100} treatment.

Plants were mapped both seasons in all plots on a weekly basis beginning with 1st square, which included data on height, width, nodes, and number and position of fruit forms. In 2003, hand samples of bolls were collected from each plot on 19 Nov from a 10 m^2 area that was sequestered from other activity during the season. Samples were weighed, ginned, and analyzed for micronaire, strength, color grade, and uniformity at the International Textile Center, Lubbock, Texas. Seed cotton was harvested on 21 November with a commercial cotton stripper.

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[1] "Use of company or product name by the U.S. Department of Agriculture does not imply approval or recommendation of the product to the exclusion of others which also may be suitable.

Cotton stalks were shredded on 8 December and rotary-tilled into the beds on 10 December. The same sampling, harvest, and fiber analysis procedure is anticipated for the 2004 season.

Lint yield, seasonal water use (estimated from total irrigation + in season rainfall + change in soil water content in the 1.8 m profile), micronaire, strength, uniformity, water use efficiency (WUE), and irrigation water use efficiency (IWUE), total discount, and total return were tested for differences for each irrigation method using the SAS mixed model (PROC MIXED, Littell et al., 1996). In PROC MIXED, fixed and random effects are specified separately. Random effects were block replicates, block by irrigation level, and block by irrigation method, and the fixed effect was irrigation method. Differences of fixed effects were tested using least square means ($\alpha \leq 0.05$) within each irrigation level. WUE is defined as the ratio of economic yield (i.e., lint yield, LY) to seasonal water use (WU) or $WUE = LY \ WU^{-1}$. Seasonal water use includes evapotranspiration, deep percolation (if any), and runoff minus run on (if any). IWUE is defined as the increase in irrigated yield (Y_i) over dryland yield (Y_d) due to irrigation (IR), or $IWUE = (Y_i - Y_d) \ IR^{-1}$ (Bos, 1980). Further details of experimental design, procedures, and equipment can be found in Colaizzi et al. (2004a, 2004b).

Results and Discussion

The 2003 crop reached full maturity with only 1076 °C-days (growing degree days based on a 15.6°C base temperature). This was considerably less than the 1450 °C-days thought to be required for full maturity cotton in the Southern High Plains (Peng et al., 1989), but only slightly less than that reported by Howell et al. (2004) for the 2000 and 2001 cotton seasons at our location, and was at the minimal range of growing degree days reported by Wanjura et al. (2002) for 12 years of data at Lubbock, TX. No differences in maturity rates (open harvestable bolls) were noted for any irrigation method. Differences in maturity rates appeared to vary primarily with irrigation level, beginning with dryland (I_0), which had the greatest soil water depletion, and proceeding through each subsequent level, in agreement with Guinn et al. (1981), Mateos et al. (1991), and Orgaz et al. (1992).

Overall, SDI tended to perform best at the I_{25} and I_{50} irrigation levels, followed by LEPA. At the I_{75} level, LEPA outperformed the other methods, and at the I_{100} level, MESA performed best (table 1). Most parameter differences within a given irrigation level were not significant. Fully irrigated MESA (I_{100}) had the highest lint yield (1,229 kg ha^{-1}), premium ($0.0950 kg^{-1}), and gross return ($1,515.96 ha^{-1}) of all treatments in this study, but these were not significantly greater than other irrigation methods at I_{100} (except for LESA, which had significantly less premium at $0.0466 kg^{-1}). SDI had the highest premiums at all levels except I_{100}, which suggests SDI generally results in higher fiber quality. Similar trends were observed with grain sorghum yield in a previous study using the same experimental design (Colaizzi et al., 2004a).

The greatest values of lint yield, seasonal water use, WUE, premium, and gross return occurred at the I_{100} level among irrigation methods (table 1, irrigation level averages). However, the greatest IWUE and most optimal fiber quality parameters (except fiber length) occurred at the I_{75} level. Note that WUE at I_{50} and I_{100} were more than doubled and almost quadrupled, respectively, compared to dryland (I_0). The lint yield, seasonal water use, and WUE were generally within the range of values reported by Howell et al. (2004) for the 2000 and 2001 cotton seasons under MESA irrigation at our location; however, total irrigation applied (including pre-season irrigation) in the present study was somewhat less due to both a shorter growing season and slightly greater pre- and early season precipitation. Lint yields were almost

as high as those reported by Wanjura et al. (2002) for their 1992 season, which only had 1092 °C-days, and they found that lint yield was more correlated to growing degree days than irrigation applied over their 12 years of data. For irrigation methods among levels (table 1, irrigation method averages), SDI had the greatest lint yield, seasonal water use, WUE, IWUE, premium, and gross return, followed by LEPA. Irrigation levels tended to result in parameter differences that were statistically significant, whereas for irrigation methods, parameter differences tended to be merely numerical.

The relationship between lint yield and seasonal water use was highly significant ($P < 0.001$) following linear regression (fig. 1). This relationship was not significantly different from those for individual irrigation methods, not surprising since lint yield showed greater variability with irrigation levels than for irrigation methods (table 1). Note that this relationship represents a single season, and different responses should be expected for different years (Wanjura et al., 2002; Howell et al., 2004). The X-axis intercept was significantly different from zero ($P < 0.001$), where 400 mm of water was required for minimum lint yield. This was double that reported by Howell et al. (2004) for the 2000 and 2001 seasons at our location. WUE was highly responsive to irrigation level through lint yield, with maximum WUE achieved at maximum lint yield (fig. 2). Both linear and quadratic regressions were significant ($P < 0.001$) with zero intercepts (intercepts were not significantly different from zero, and should not be by definition of WUE).

Conclusion

Relative response of cotton to spray, LEPA, and SDI varied with irrigation capacity. At lower irrigation system capacity (I_{25} and I_{50}), SDI outperformed (either numerically or significantly) both spray and LEPA; whereas at full irrigation system capacity (I_{100}), spray outperformed both LEPA and SDI but only on a numerical basis. At the I_{75} level, LEPA numerically outperformed SDI, and SDI numerically outperformed spray. Cotton response had greater variation between irrigation capacities than irrigation methods, and highly significant relationships were observed between lint yield and seasonal water use, and water use efficiency and lint yield. Nonetheless, SDI had slightly greater premiums than other methods, suggesting SDI may enhance fiber quality. No differences in cotton maturity were observed among irrigation methods; however, this experiment has been redesigned to make better use of SDI to germinate the crop to avoid the possible early-season evaporative cooling associated with using MESA in the SDI plots. The experiment will be continued for at least two more seasons.

Acknowledgements

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Table 1. Yield, water use, fiber quality, and return parameters as affected by irrigation levels and methods. Numbers followed by the same letter are not significantly different ($\alpha \leq 0.05$).

Irrigation Level [a]	Irrigation Method	Lint Yield (kg ha^{-1})	Seasonal Water Use (mm)	WUE (kg m^{-3})	IWUE (kg m^{-3})	Micronaire value	Fiber strength (g tex^{-1})	Fiber length (mm)	Fiber Uniformity (%)	Total Discount or Premium ($ kg^{-1})	Gross Return ($ ha^{-1}) [b]
I$_0$ (25 mm)	---	196	437	0.046	---	5.17	28.8	0.76	79.1	-$0.1575	$192.71
I$_{25}$ (71 mm)	MESA	213b	477b	0.045b	0.024c	5.20a	28.4b	0.75b	78.9b	$-0.1646b	$208.19b
	LESA	288ab	495ab	0.058b	0.130bc	5.13a	29.4ab	0.79a	80.2ab	$-0.1386b	$288.55ab
	LEPA	362ab	494ab	0.072ab	0.234ab	4.50b	30.1a	0.79a	80.4a	$-0.0810a	$379.56ab
	SDI	491a	530a	0.092a	0.416a	4.70b	29.9a	0.80a	80.9a	$-0.0396a	$540.88a
I$_{50}$ (117 mm)	MESA	536b	604ab	0.089b	0.288b	5.07a	30.2ab	0.83ab	81.3a	$-0.0810b	$567.16b
	LESA	575b	582b	0.098b	0.321b	5.07a	29.2b	0.81b	81.2a	$-0.1111b	$591.89b
	LEPA	685ab	629a	0.109ab	0.415ab	4.77ab	31.3a	0.84ab	81.8a	$0.0150a	$797.32ab
	SDI	844a	627a	0.135a	0.549a	4.40b	30.3ab	0.85a	82.2a	$0.0587a	$1010.08a
I$_{75}$ (165 mm)	MESA	1001a	705a	0.142a	0.491a	4.53a	31.3a	0.86a	82.3a	$0.0623a	$1201.93a
	LESA	984a	685a	0.143a	0.480a	4.40ab	30.8a	0.86a	82.3a	$0.0605a	$1179.55a
	LEPA	1149a	701a	0.164a	0.581a	4.07bc	31.1a	0.87a	81.7a	$0.0500a	$1368.85a
	SDI	1082a	714a	0.152a	0.540a	3.80c	31.6a	0.87a	82.4a	$0.0829a	$1322.12a
I$_{100}$ (211 mm)	MESA	1229a	752a	0.164a	0.492a	4.07a	31.4a	0.88a	82.5a	$0.0950a	$1515.96a
	LESA	1208a	754a	0.160a	0.482a	3.57b	30.9a	0.87a	81.7a	$0.0466b	$1429.41a
	LEPA	1153a	727a	0.158a	0.456a	3.53b	30.9a	0.88a	82.2a	$0.0557ab	$1375.79a
	SDI	1150a	725a	0.159a	0.454a	3.67b	30.4a	0.88a	81.9a	$0.0818ab	$1402.89a
Irrigation Level Averages											
I$_0$ (25 mm)	---	196d	437e	0.046c	---	5.17a	28.8c	0.76c	79.1b	$-0.1575c	$192.71d
I$_{25}$ (71 mm)	---	339d	499d	0.067c	0.201c	4.88a	29.4c	0.79c	80.1b	$-0.1060c	$354.3d
I$_{50}$ (117 mm)	---	660c	610c	0.108b	0.393b	4.83a	30.2b	0.83b	81.6a	$-0.0300b	$741.62c
I$_{75}$ (165 mm)	---	1054b	701b	0.150a	0.523a	4.20b	31.2a	0.87a	82.2a	$0.0638a	$1268.12b
I$_{100}$ (211 mm)	---	1185a	739a	0.160a	0.471ab	3.71c	30.9a	0.88a	82.0a	$0.0697a	$1431.02a
Irrigation Method Averages											
---	MESA	745a	635a	0.110a	0.324a	4.72a	30.3ab	0.83a	81.3a	$-0.0220bc	$873.29a
---	LESA	764a	629a	0.115a	0.353a	4.54a	30.0b	0.83a	81.4a	$-0.0356c	$872.35a
---	LEPA	837a	638a	0.126a	0.421a	4.22b	30.8a	0.85a	81.5a	$0.0100ab	$980.39a
---	SDI	892a	649a	0.134a	0.490a	4.14b	30.6ab	0.85a	81.8a	$0.0460a	$1068.99a

[a] Numbers in parentheses are in-season (planting to harvest) irrigation totals and do not include 100 to 200 mm of preplant irrigation.
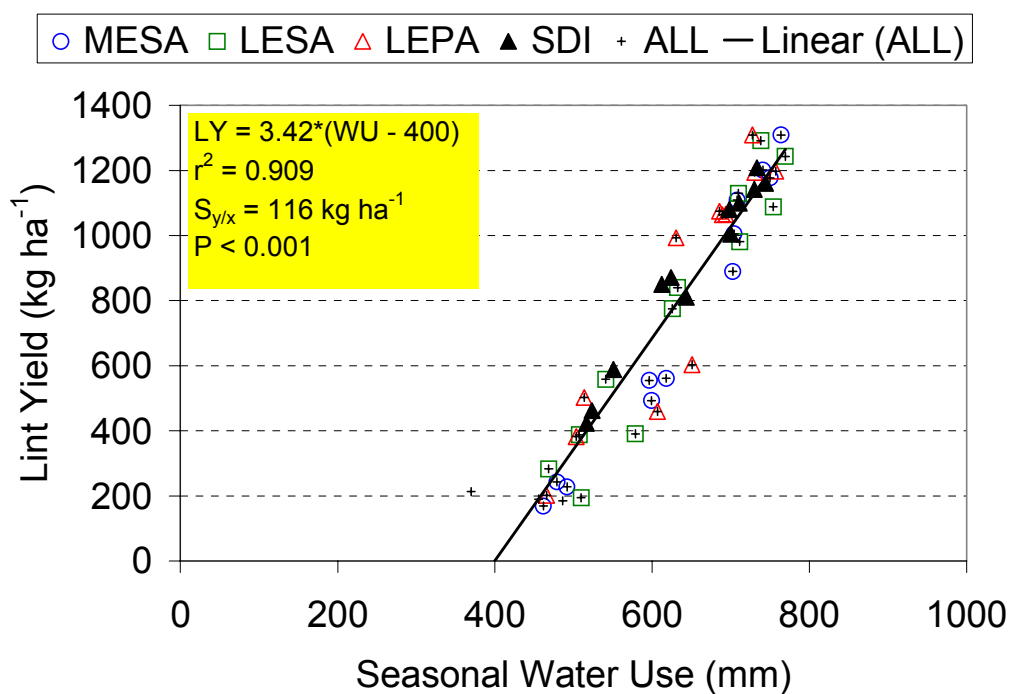[b] Based on a base loan value of $1.1352 kg^{-1}.

Figure 1. Cotton lint yield response (LY) to seasonal water use (WU) for the 2003 season, and coefficient of determination (r^2), standard error of the estimate ($S_{y/x}$), and significance (P).

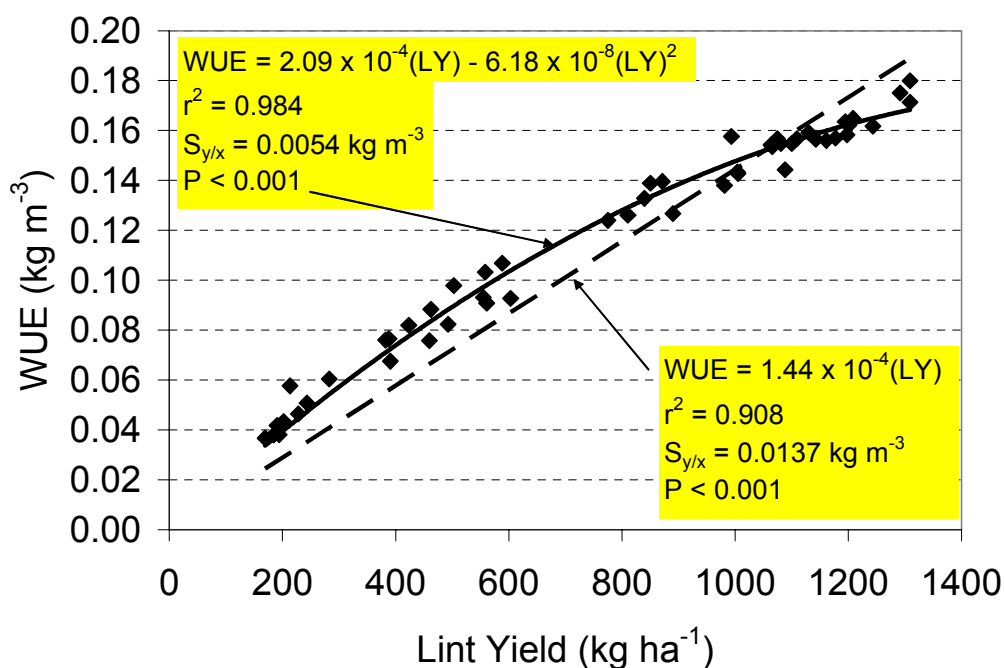Figure 2. Water use efficiency (WUE) response to lint yield (LY) for the 2003 season, and coefficient of determination (r^2), standard error of the estimate ($S_{y/x}$), and significance (P).