COMPARISON OF SPRAY, LEPA, AND SDI FOR COTTON AND GRAIN SORGHUM IN THE TEXAS PANHANDLE [1]

Paul D. Colaizzi, Steven R. Evett, and Terry A. Howell [2]
USDA-Agricultural Research Service
P.O. Drawer 10
Bushland, Texas 79012-0010

ABSTRACT

Crop responses to MESA (mid-elevation spray application), LESA (low-elevation spray applicator), LEPA, (low energy precision application), and SDI (subsurface drip irrigation) were compared for full and deficit irrigation rates in the Texas Panhandle. Crops included three seasons of grain sorghum and one season of cotton; crop responses consisted of economic yield, seasonal water use, and water use efficiency (WUE). Irrigation rates were I_0, I_{25}, I_{50}, I_{75}, and I_{100} (where the subscript denotes the percentage of full irrigation, and I_0 is dryland). Yield and WUE was greatest for SDI and least for spray at the I_{25} and I_{50} rates, and greatest for spray at the I_{100} rate. Yield and WUE trends were not consistent at the I_{75} rate. Seasonal water use was not significantly different in most cases between irrigation methods within a given irrigation rate. For cotton, the irrigation method did not influence boll maturity rates, but SDI resulted in higher fiber quality at the I_{25}, I_{50}, and I_{100} rates.

INTRODUCTION

The Southern High Plains region, which includes the Texas Panhandle, is a major producer of corn, grain sorghum, and cotton. The area centered around Lubbock is one of the largest cotton producing areas in the country, and the area from Amarillo northward has traditionally produced corn, with some of the highest yields in the nation possible with irrigation (USDA -NASS, 2004; TDA -TASS, 2004). Grain sorghum is often rotated with cotton; sorghum does not require as many heat units as cotton or as much water as corn. Greater cotton yields have been reported when rotated with grain sorghum, although gross returns were greater for continuous cotton (Bordovsky and Porter, 2004). Producers in corn producing areas are considering cotton as an alternative crop because cotton

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[1] Contribution from the USDA-ARS, Southern Plains Area, Conservation and Production Research Laboratory, Bushland, TX.

[2] Agricultural Engineer, Lead Scientist (Soil Sci.), and Research Leader (Agric. Engr.), respectively. **e-mail**: pcolaizzi@cprl.ars.usda.gov.

has a similar revenue potential as corn for about one-half the water requirement, and there has been a net increase in recent years of cotton harvested in the Northern Texas Panhandle, Northern Oklahoma, and Southwestern Kansas (USDA-NASS, 2004).

High crop yields are possible with irrigation, with increases greater than 150% over dryland to be expected (TDA-TASS, 2004). Nearly all irrigation in the Great Plains is dependent on the Ogallala aquifer, a finite water resource that is declining because withdrawals have exceeded natural recharge. The rate of decline has been reduced in recent years because irrigated land area has been reduced (either converted to dryland or abandoned), and also from conversion from gravity to more efficient center pivot sprinkler systems (Musick et al., 1990). The earliest sprinkler configurations were high-pressure impact, but these have been replaced by low-pressure spray and LEPA (low energy precision application) (Lyle and Bordovsky, 1983) since the 1980s (Musick et al., 1988). Subsurface drip irrigation (SDI) also started being adopted by cotton producers in the Trans Pecos and South Plains regions of Texas in the mid 1980s (Henggeler, 1995; 1997; Enciso et al., 2003).

Numerous studies have been conduced to document and compare the performance of various sprinkler application packages for a variety of crops and tillage configurations. These usually consisted of spray and LEPA (Schneider, 2000; Schneider and Howell, 1995; 1997; 1998; 1999; 2000). Relatively few studies also included SDI; most comparisons involving SDI were made with gravity (surface) irrigation systems (Camp, 1998; Ayars et al., 1999). A few studies did compare relative performance of spray, LEPA, and SDI for grain sorghum (Colaizzi et al., 2004a) and cotton (Segarra et al., 1999; Bordovsky and Porter, 2003; Colaizzi et al., 2004b), and reported that SDI outperformed other irrigation methods in terms of crop yield and water use efficiency at deficit irrigation rates. Nonetheless, Segarra et al. (1999) analyzed four years of cotton data at Halfway, Texas and concluded that SDI may not always provide economic returns as high as those from LEPA. But, this largely depended on system life, installation costs, pumping lift requirements, and hail damage that commonly occurs in West Texas. Some cotton producers perceive that SDI also enhances seedling emergence and plant maturity due to reduced evaporative cooling compared to LEPA or spray, which is a critical consideration in a thermally limited environment and is seldom considered in economic analyses. There is, however, limited data in direct support of this view. Soil water depletion in the root zone appears most responsible for inducing cotton earliness, regardless of the type of irrigation system used (Guinn et al., 1981; Mateos et al., 1991; Orgaz et al., 1992).

The purpose of this paper is to summarize recent research findings where crop responses to spray, LEPA, and SDI were compared directly for grain sorghum (Colaizzi et al., 2004a) and cotton (Colaizzi et al., 2004b). The research was conducted in the Texas Panhandle, where grain sorghum can be produced reliably, but the climate is marginal for cotton production.

PROCEDURE

The experiment was conducted at the USDA Conservation and Production Research Laboratory near Bushland, Texas (35° 11′ N, 102° 06′ W, 1070 m elevation MSL). Crops included grain sorghum in 2000, 2001, and 2002 and cotton in 2003 and 2004. The 2004 data have not yet been analyzed so only the results of the 2003 cotton season will be reported. We plan to continue this experiment for several more seasons of cotton. The climate is semi-arid with a high evaporative demand of about 2,600 mm per year (Class A pan evaporation) and low precipitation averaging 470 mm per year. Most of the evaporative demand and precipitation occur during the growing season (May to October) and average 1,550 mm and 320 mm, respectively. The climate is also characterized by strong regional advection from the South and Southwest, where average daily wind runs at 2 m height can exceed 460 km especially during the early part of the growing season. 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 yield of grain sorghum and cotton in the Texas Panhandle (table 1). Grain sorghum (Sorghum bicolor (L.) Moench, cv. Pioneer [3] 84G62) was planted in the 2000, 2001, and 2002 growing seasons. In 2001, two plantings (22 May and 5 Jun) of this variety failed to emerge, so a shorter season variety (Pioneer 8966) was planted on 22 June and emerged by 2 July. It is thought that the first two plantings in 2001 failed to emerge because of excessive herbicide residual from the previous year. So in 2002, a different herbicide that was successful in earlier studies (Schneider and Howell, 1999) was used. Cotton (*Gossypium hirsutum* L., cv. Paymaster 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 plants m^{-2}. All crops were planted in east-west oriented raised beds spaced 0.76 m. Furrow dikes were installed after crop establishment to control runoff (Schneider and Howell, 2000).

The experimental design consisted of four irrigation methods, including MESA (mid-elevation spray application), LESA (low-elevation spray application), LEPA (low energy precision application), and SDI (subsurface drip irrigation), and five irrigation rates (I_0, I_{25}, I_{50}, I_{75}, and I_{100}, where the subscripts are the percentage of irrigation applied relative to the full irrigation amount). The I_{100} rate was sufficient to prevent yield-limiting soil water deficits from developing, based on crop

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[3] The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

evapotranspiration (ET_c) estimates from the North Plains ET Network (NPET, Howell et al., 1998). The different irrigation rates were used to estimate production functions, and to simulate the range of irrigation capacities typically found in the region. The I_0 rate received irrigation for emergence only and to settle and firm the furrow dikes and represents dryland production. The MESA, LESA, and LEPA irrigations were applied with a hose-fed Valmont (Valmont Irrigation, Valley, NE) Model 6000 lateral move irrigation system. Drop hoses were located over every other furrow at 1.52 m spacing. Technical details of applicators are given in table 2. The SDI consisted of Netafim (Netafim USA, Fresno, CA) Typhoon dripline that was shank injected in 1999 under alternate furrows at 0.3-m depth below the surface (before bedding). Irrigation treatment rates were controlled by varying the speed of the lateral-move system for the spray and LEPA methods, and by different emitter flow and spacing for the SDI method (table 3). All treatments were irrigated uniformly with MESA at the I_{100} rate until furrow dikes were installed to ensure crop establishment.

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.

In 2000, 2001, and 2002, grain yields were measured by harvesting the full length of each plot (25 m) using a Hege (Hege Equipment, Inc., Colwick, KS) combine with a 1.52 m wide (2 row) header. Each plot sample was weighed and three subsamples were dried to determine moisture content. Grain yields reported here were converted to 14% moisture content by weight. 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.

Grain or lint yield, seasonal water use, and water use efficiency (WUE) were tested for differences for each irrigation method using the SAS mixed model (PROC MIXED, Littell et al., 1996). Differences of fixed effects were tested using least square means ($\alpha = 0.05$) within each irrigation rate. The WUE is defined as the ratio of economic yield (i.e., grain or lint yield, LY) to seasonal water use (WU): $WUE = LY\ WU^{-1}$. Further details of experimental design, procedures, and equipment can be found in Colaizzi et al. (2004a) for grain sorghum and Colaizzi et al. (2004b) for cotton.

RESULTS AND DISCUSSION

Rainfall was much less than the approximately 350-mm average during the 2000, 2001, and 2003 growing seasons, but slightly less than average during the 2002 growing season (table 1). A large portion of the 2002 rainfall did not occur until the grain sorghum was in its reproductive growth stages (boot, heading, and flowering), after most of the irrigations were complete, and continued into the winter. This resulted in the 2002 irrigation totals being the same as those in 2000, despite much less rainfall in 2000. The 2001 irrigation totals were less than 2000 or 2002 because a shorter season grain sorghum variety was used. Although cotton and grain sorghum have similar water requirements, the 2003 irrigation totals (cotton) were much less than other years (grain sorghum) because more water was stored in the soil profile beginning in the 2003 season from the greater rainfall in 2002, and possibly because the shortened cotton season (following replanting from hail damage) required less water (table 1).

The cotton 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 the irrigation rate. Dryland (I_0) had the greatest soil water depletion and matured earliest, and maturity proceeded through each subsequent rate, with I_{100} maturing last. This was in agreement with Guinn et al. (1981), Mateos et al. (1991), and Orgaz et al. (1992).

Yields had greater variability by irrigation rate than by irrigation method, and increased with irrigation rate in all years except 2002 (figure 1). In some cases the increase in grain sorghum yield from I_0 (dryland) to I_{25} was nearly ten times for both relatively dry (2000) and wet (2002) years. Yield of both grain sorghum (2000, 2001, and 2002) and cotton (2003) tended to be greatest under SDI at low irrigation rates, but greatest under spray at high irrigation rates. Yield of grain sorghum under SDI was significantly greater than MESA, LESA, or LEPA at the I_{25} irrigation rate, and either numerically or significantly ($\alpha = 0.05$) greater than the other irrigation methods at the I_{50} rate in all three years. At the I_{25} and I_{50} rates, yield with LEPA was usually greater than spray but less than SDI. Cotton lint yield showed a similar trend at the I_{25} and I_{50} rates. At the I_{100} rate, yields of both grain sorghum and cotton were either significantly or numerically greatest under spray. At the I_{75} rate, this was also true for grain sorghum (except for LESA in 2002); however, lint yield of cotton under LEPA was numerically greater than SDI, and SDI was numerically greater than spray. We speculate that under low irrigation rates (i.e., I_{25} and I_{50}), more water is partitioned to transpiration and less is lost to evaporation under SDI and to a lesser extent LEPA compared to spray.

With larger irrigation rates (i.e., I_{75} and I_{100}), the yield depression observed for SDI and sometimes LEPA may have been linked to poor aeration or the leaching of nutrients below the root zone (Lamm et al., 1995). We did observe increases in volumetric soil water from about 1.8 m to 2.4 m; we conjecture that this indicates deep percolation (Colaizzi et al., 2004a). Also, the enhanced yields under spray may have been due to enhanced plant respiration while reducing transpiration during and after an irrigation event (Tolk et al., 1995).

In 2002, rainfall during the reproductive stages masked differences in grain sorghum yield among the I_{50}, I_{75}, and I_{100} rates (except LESA); the greatest grain yield of all three years occurred under I_{75} MESA at 12.2 Mg ha^{-1} (figure 1c). Grain yield for LESA in 2002 at the I_{25}, I_{50}, and I_{75} rates was less than the other methods. We are uncertain why this occurred as we observed no malfunction in irrigation or chemical application equipment. We did, however, observe a rapid and unexplained decrease in available soil water early in the season, which may have resulted in less water being available during reproductive stages later in the season. This was not observed again in 2003 for cotton lint yield.

Seasonal water use also had greater variability by irrigation rate than by irrigation method (figure 2). In most cases, there were no significant differences between irrigation methods within an irrigation rate, with the following exceptions. In 2000 at the I_{75} and I_{100} rates, and in 2001 at the I_{75} rate, water use under SDI was significantly less than under spray. In 2002, water use under SDI was significantly more than under MESA and LEPA at the I_{25} rate, and LESA and LEPA at the I_{100} rate. In 2003, SDI used significantly more water than MESA at the I_{25} rate, and LESA at the I_{50} rate. The greater seasonal water use under SDI was often linked to greater grain or lint yield. Since irrigation amounts at a given rate were the same for each irrigation method, differences in seasonal water use resulted in different amounts of soil water depletion.

Water use efficiency (WUE) generally had greater variability at smaller irrigation rates than at larger rates (figure 3). Overall trends paralleled those of crop yield, where SDI yield was greatest at small irrigation rates and spray yield was greatest at large irrigation rates. At the I_{25} rate, yield under SDI was significantly greater than that under spray and LEPA for grain sorghum and spray for cotton. At the I_{50} rate, yield under SDI was significantly greater than spray in 2000 and 2003, and MESA only in 2001. At the I_{75} rate, yield trends were not consistent, but at the I_{100} rate, yield under MESA was numerically greater than under all other methods in all years. Note that irrigation had a similar effect on WUE as it did on crop yield, where WUE was increased two to eight times from the I_0 (dryland) to the I_{25} rate.

Finally, cotton premium as determined by fiber quality parameters (micronaire, strength, length, and uniformity) were significantly greater under SDI and LEPA at the I_{25} and I_{50} rates, and numerically greater under SDI at the I_{100} rate. Further details on fiber quality and resulting premiums are given in Colaizzi et al. (2004b).

CONCLUSIONS

Yield and WUE at the I_{25} and I_{50} irrigation rates under SDI were greater than for the other irrigation methods, and yield under LEPA was usually greater than that under spray irrigation but less than that under SDI. These trends were reversed at the I_{100} rate, where yield and WUE under spray irrigation were greater than that under LEPA or SDI. Yield and WUE trends at the I_{75} rate were less consistent. Seasonal water use had greater variability by irrigation rate than by irrigation method; in most cases, there were no significant differences between irrigation methods within an irrigation rate. We speculate that under low irrigation capacities, SDI and to a lesser extent LEPA resulted in more water being partitioned to transpiration and less to evaporation. Under greater irrigation rates, SDI may have resulted in poorer soil aeration and greater nutrient leaching, while the evaporative cooling effect of spray may have enhanced plant respiration and reduced transpiration. No differences in cotton maturity were observed between irrigation methods; however, fiber quality was slightly enhanced under SDI. The lack of differences in cotton maturity may have been related to applying spray irrigation (MESA) to all plots to ensure uniform establishment. This experiment has therefore been redesigned beginning with the 2005 season to make better use of SDI to germinate the crop, which may avoid early-season evaporative cooling associated with using MESA in SDI plots.

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Table 1: Agronomic and irrigation data for three grain sorghum seasons and one cotton season.

Variable	2000	2001	2002	2003
Crop	Grain sorghum	Grain sorghum	Grain sorghum	Upland cotton
Fertilizer applied	58 kg ha^{-1} preplant N 76 kg ha^{-1} preplant P 45 kg ha^{-1} irr N (I_{100}) [a]	179 kg ha^{-1} preplant N 18 kg ha^{-1} irr N (I_{100}) [a]	160 kg ha^{-1} preplant N 57 kg ha^{-1} preplant P	31 kg ha^{-1} preplant N 107 kg ha^{-1} preplant P 48 kg ha^{-1} irr N (I_{100}) [a]
Herbicide applied	4.7 L ha^{-1} Bicep	4.7 L ha^{-1} Bicep	1.6 kg ha^{-1} Atrizine	2.3 L ha^{-1} Treflan
Insecticide applied	0.58 L ha^{-1} Lorsban	none	none	none
Gravimetric soil water samples	19-May 11-Oct	21-May 30-Oct	3-Jun 18-Nov	20-May 24-Nov
Plant variety	Pioneer 84G62	Pioneer 8966	Pioneer 84G62	Paymaster 2280 BG, RR
Plant density	30 plants m^{-2}	23 plants m^{-2}	22 plants m^{-2}	17 plants m^{-2}
Planting date	26-May	22-Jun[b]	31-May	10-Jun [c]
Harvest date	21-Sep	29-Oct	14-Nov	21-Nov
Last irrigation	28-Aug	11-Sep	8-Sep	20-Aug
I_0 total irrigation	62 mm	112 mm	62 mm	25 mm
I_{25} total irrigation	169 mm	194 mm	169 mm	71 mm
I_{50} total irrigation	275 mm	275 mm	275 mm	118 mm
I_{75} total irrigation	381 mm	356 mm	381 mm	164 mm
I_{100} total irrigation	488 mm	438 mm	488 mm	210 mm
In-season precipitation	139 mm	124 mm	317 mm	167 mm

[a] Liquid urea 32-0-0 injected into irrigation water; deficit irrigation treatments received proportionately less.
[b] Two previous plantings on 22 May 2001 and 5 Jun 2001 failed to emerge.
[c] The first planting on 21 May 2003 sustained severe hail damage on 3 June 2003.

Table 2. Sprinkler irrigation application device information.[a]

Applicator	Model[b]	Options	Applicator height from furrow surface (m)
LEPA	Super Spray head	Double ended drag sock[c]	0
LESA	Quad IV	Flat, medium grooved spray pad	0.3
MESA	Low Drift Nozzle (LDN) spray head	Single, convex, medium grooved spray pad	1.5

[a] All sprinkler components manufactured by Senninger (Senninger Irrigation, Inc., Orlando, Florida) except where noted.
[b] All devices equipped with 69 kPa pressure regulators and #17 (6.75 mm) plastic spray nozzles, giving a flow rate of 0.412 L s^{-1}.
[c] A.E. Quest and Sons, Lubbock, TX.

Table 3. Subsurface drip irrigation (SDI) dripline information.[a]

Irrigation Rate	Emitter Flow Rate (L hr^{-1})	Emitter spacing (m)	Emitter application rate (mm hr^{-1})
I_0		Smooth tubing – no emitters	
I_{25}	0.68	0.91	0.49
I_{50}	0.87	0.61	0.97
I_{75}	0.87	0.41	1.45
I_{100}	0.87	0.3	1.93

[a] All SDI dripline manufactured by Netafim (Netafim USA, Fresno, CA).

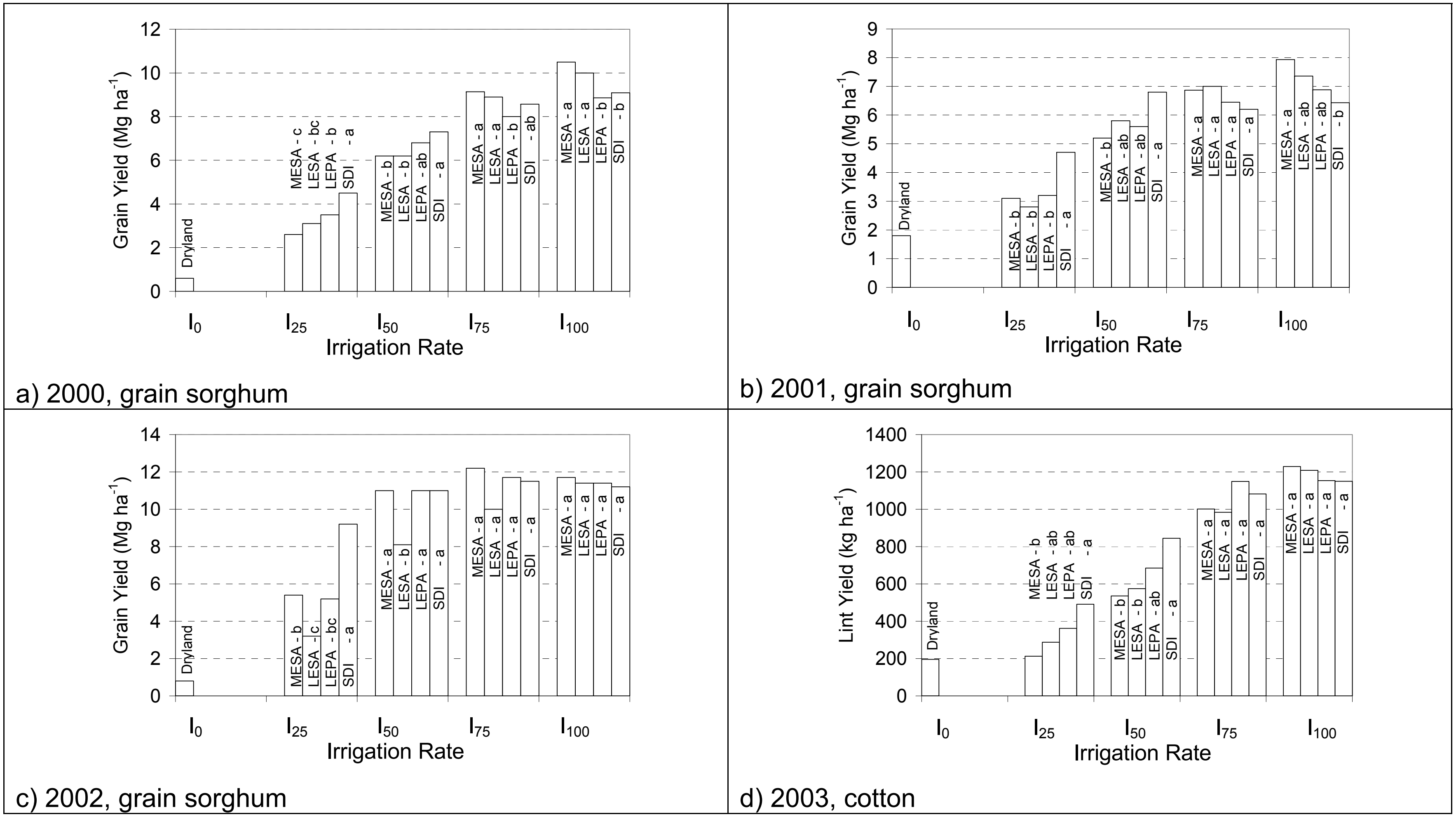

Figure 1: Economic yield for grain sorghum and cotton. Irrigation methods followed by the same letter are not significantly different (α = 0.05) within an irrigation rate.

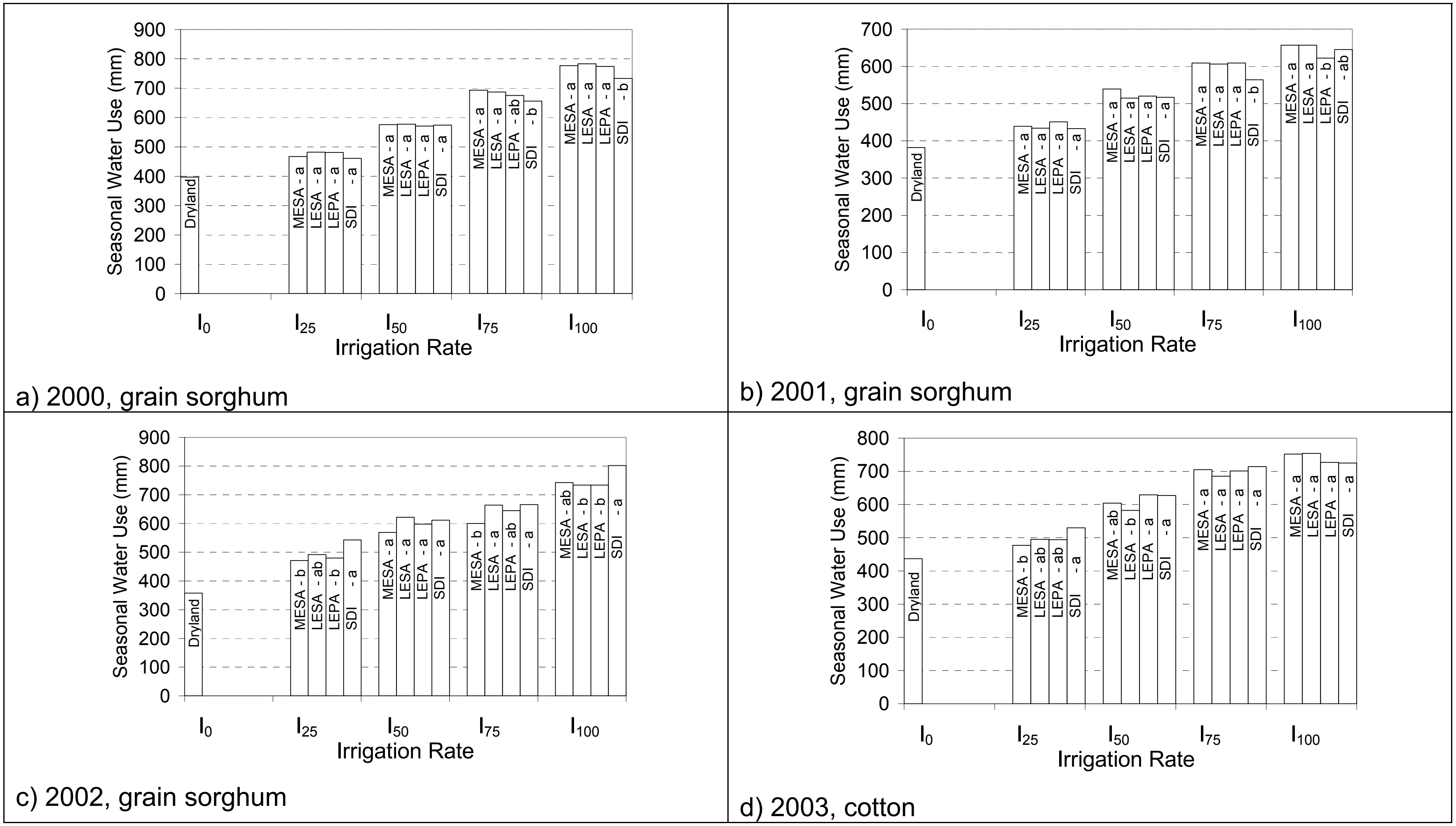

Figure 2: Seasonal water use for grain sorghum and cotton. Irrigation methods followed by the same letter are not significantly different (α = 0.05) within an irrigation rate.

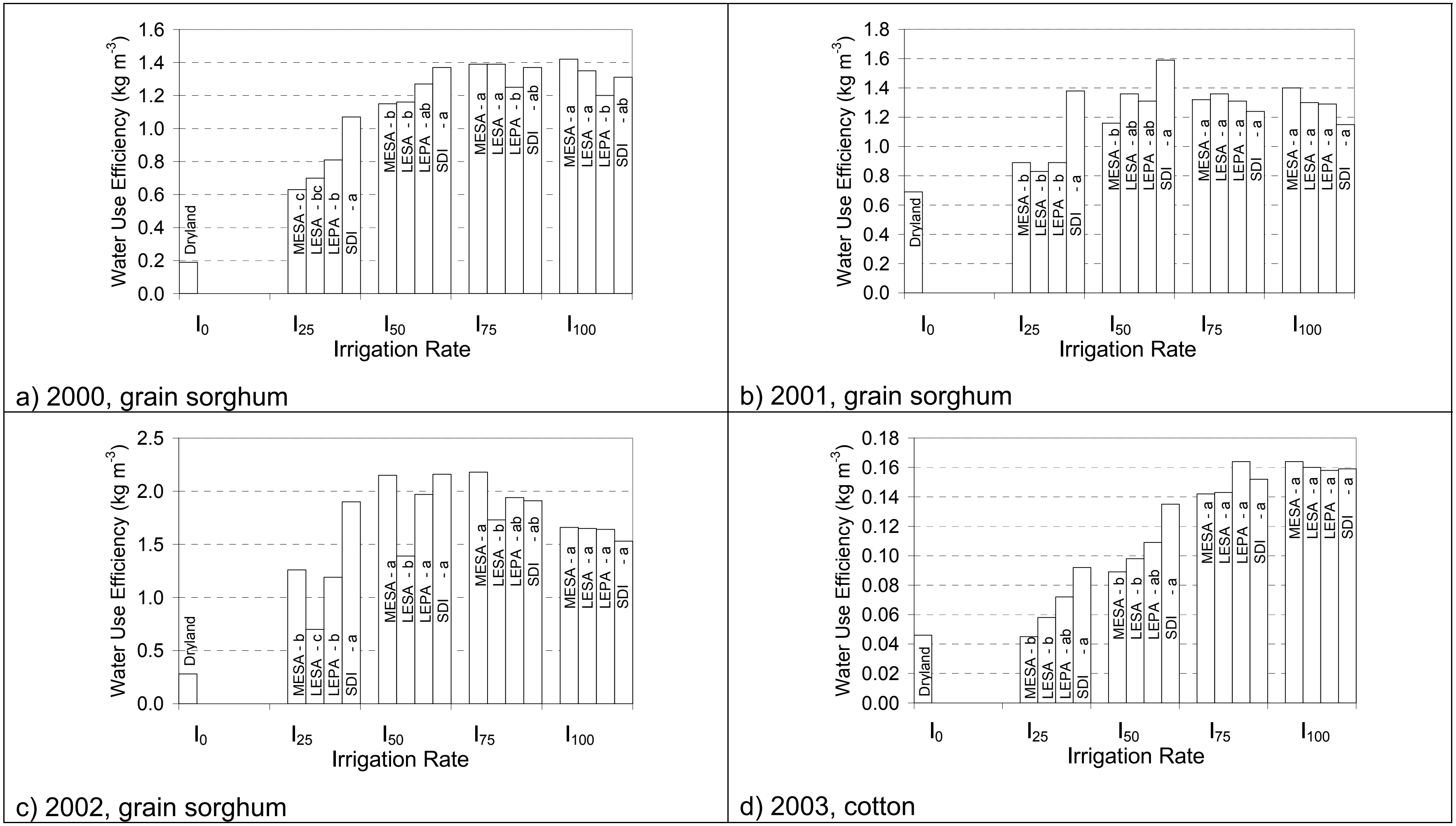

Figure 3: Water use efficiency (WUE) for grain sorghum and cotton. Irrigation methods followed by the same letter are not significantly different (α = 0.05) within an irrigation rate.