

Comparison of SDI, LEPA, and Spray Irrigation Efficiency

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Written for Presentation at the
2001 ASAE Annual International Meeting
Sponsored by ASAE

Sacramento, California
July 29-August 1, 2001

Summary: The SDI, LEPA, and spray irrigation methods were compared for irrigation of grain sorghum on a fine textured soil in the southern High Plains. Full irrigation was defined as that required to meet evapotranspiration calculated using grass reference ET computed with a Penman-Monteith equation and locally derived crop coefficients. With deficit irrigation at 25 and 50% of full irrigation, grain yields with SDI were significantly larger than with the other irrigation methods. At the 75% and full irrigation levels, however, the grain yields with spray irrigation exceeded 10.0 Mg/ha and were significantly larger than those for the SDI, and LEPA methods.

Keywords: SDI, LEPA, Spray Irrigation, Grain Sorghum, Sprinklers

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Abstract

The subsurface drip irrigation (SDI), low energy precision application (LEPA) and two spray irrigation methods were compared for both full and deficit irrigation of grain sorghum during the 2000 growing season. The two spray methods were LESA (low elevation spray application) applied at about the 0.3-m height and MESA (mid-elevation spray application) applied at about the 1.5-m height. Irrigation amounts ranged in 25% increments from no seasonal irrigation to 100% irrigation to fully meet evapotranspiration (ET) calculated using grass reference ET computed with a Penman-Monteith equation and locally derived crop coefficients. Cultural practices and fertility levels were similar to those used for high-yield, on farm grain sorghum production in the Southern High Plains. The four high efficiency irrigation methods were all evaluated under a lateral move irrigation system, so that all sorghum plots could be uniformly established with spray irrigation. The 2000 growing season was hotter and drier than normal, and the grain yield with zero seasonal irrigation was only 0.65 Mg/ha. At the 25 and 50% irrigation levels, yields with SDI of 4.51 and 7.36 Mg/ha were significantly larger than for the other irrigation methods. At the 75 and 100% irrigation levels, however, yields with the LESA and MESA spray methods averaging 10.1 and 10.5 Mg/ha were significantly larger than for the SDI and LEPA methods. Water use efficiencies calculated from total seasonal water use and seasonal irrigation followed the same trends as the grain yields. Among the four high efficiency irrigation methods tested, the optimum irrigation method for grain sorghum is likely to vary more with the irrigation amount than with the application technology. This emphasizes the need for accurate ET information for scheduling irrigations.

Introduction

Subsurface drip irrigation (SDI), low energy precision application (LEPA) and spray irrigation are all highly efficient irrigation methods (Camp, 1998; Ayars et al., 1999; Schneider and Howell, 1999). Reported application efficiencies are in the 95 to 98% range for LEPA and can exceed 90% for spray irrigation (Schneider, 2000). Application efficiencies for well-designed SDI systems applying small, frequent irrigations approach 100% (Ayars et al., 1999). Uniformity coefficients can exceed 0.85 for the LEPA and spray methods and 0.90 for the SDI method (Schneider, 2000; Ayars, et al. 1999). Verifying that these high irrigation efficiencies and uniformities result in larger crop yields and water use efficiencies is best done by directly comparing the irrigation methods for specific sites and crops.

Cropping studies comparing drip irrigation with LEPA or spray irrigation are limited. Kincaid (1999) measured yields and water use efficiency (WUE) from equal amounts of irrigation water applied by surface drip and spray irrigation. During the first two years, yields and water use efficiency of dry beans were larger with drip than with spray. The irrigation treatment effect reversed during the third year, and yields and WUE were larger with spray irrigation. Three-year averages of yield and WUE were essentially equal for the drip and spray irrigation. Bordovsky and Lyle (1998) evaluated SDI and LEPA irrigation of cotton and found both lint yield and water use efficiency (WUE) to be slightly larger with SDI.

Crop yields with SDI equal or exceed those with sprinkler irrigation, and crop water use is sometimes less with SDI (Camp, 1998). Adamsen (1989, 1992) compared SDI and rotor sprinklers

for irrigation of peanut and corn with sodic and good quality water. The peanut yield was larger for SDI than for sprinklers with sodic water but not with good quality water. Corn yields were not different for the two irrigation methods with either sodic or good quality water. In Hawaii annual alfalfa yields of 26.8 t/ha with SDI and 26.3 t/ha with solid set sprinklers were essentially equal (Bui and Osgood, 1995). In Virginia, sweet corn yields were 9.5 Mg/ha with SDI and 8.3 Mg/ha with sprinkler irrigation, a 14% increase (Phene and Beale, 1976).

In comparisons of LEPA and spray irrigation, crop yields with deficit irrigation are sometimes larger for LEPA. But, with full irrigation, yields for the two irrigation methods tend to be similar. Schneider and Howell (1999) compared the LEPA and spray sprinkler methods for corn, grain sorghum, and winter wheat. With 25 and 50% soil water replenishment, grain sorghum yields were significantly larger for LEPA, but with 100% replenishment, yields for the two sprinkler methods were essentially equal. Corn and wheat yields were essentially equal for the two sprinkler methods for all irrigation amounts. Kincaid (1994) compared LEPA and a low elevation spray system to irrigate forage corn using reservoir tillage. Forage yields were 48.9 and 54.3 Mg/ha, respectively, for the LEPA and spray methods, but with larger soil water depletion on the spray irrigated plots, the WUE with LEPA was larger than with spray.

Selection of the most effective irrigation method among SDI, LEPA, and spray will likely depend on site specific conditions such as crop, soils, topography, and water supply. The objective of this study was to compare the SDI, LEPA and spray irrigation methods for irrigation of grain sorghum on a clay loam soil in the Southern High Plains.

Procedure

The research was conducted at the USDA Conservation and Production Research Laboratory at Bushland, TX (35°11' N lat., 102°06' W long., 1170 m msl elevation) during the 2000 grain sorghum season. The soil at the research site is Pullman clay loam, a fine, mixed, thermic torrertic Paleustoll, with a dense B21t subsoil from about the 0.15 to 0.4 m depths and a calcic horizon from about the 1.5 to 2.0 m depths. For the upper 1.0 m soil profile, Unger and Pringle (1981) measured 139 mm of available water capacity between the -0.033 and -1.5-MPa matric potentials. The research field had a uniform slope of 0.0025 m/m in the direction of travel of the lateral move irrigation system and a 0.0022 m/m cross slope.

Experimental Design

The SDI, LEPA, and two spray irrigation methods were evaluated across a range of five irrigation amounts. The two spray methods were LESA (low elevation spray application) applied at about the 0.3-m height and MESA (mid-elevation spray application) applied at about the 1.5-m height. A full irrigation treatment, designated as I_{100} , received sufficient irrigation, to meet the recommendations of the North Plains ET Network (Howell et al., 1998). Four deficit irrigation treatments, designated as I_0 , I_{25} , I_{50} , and I_{75} , received the percentage of full irrigation designated by the subscript. All irrigation treatment plots were located under a 3-span lateral move irrigation system. Irrigation amounts were blocked in the direction of movement of the irrigation system, and the four irrigation methods were replicated under each of the three sprinkler spans.

Irrigation Equipment

The Valmont¹ Model 6000 (Valmont Industries, Inc., Valmont, NE) lateral move sprinkler system was a 3-span, hose-fed system equipped with a CAMS speed controller for accurate speed control. Each span irrigated forty eight, 0.76-m spaced beds and furrows with the sprinkler devices located above alternate furrows. The LEPA and spray application devices were:

LEPA -- double-ended drag sock connected with an adapter and hose to a Senninger Super Spray head.

LESA – Senninger Quad IV spray head in the irrigate mode with a flat, medium-grooved spray pad.

MESA – Senninger Low Drift Nozzle (LDN) spray head with a single, convex, medium-grooved spray pad.

The sprinkler devices were spaced 1.52 m (5 ft) apart and equipped with 69-kPa pressure regulators. Nozzle size was selected to apply a 25-mm irrigation with a 25% timer setting and a 6.25-mm irrigation with a 100% timer setting. All three sprinkler devices used the same type and size plastic spray nozzle and pressure regulators supplied by Senninger (Senninger Irrigation, Inc., Orlando, FL). The instantaneous flow rate for the 25-mm (1-inch) irrigations was equivalent to that at the end of a 400-m (¼-mile) center pivot with a system flow rate of 2500 L/min (660 gal/min). Water pumped from the Ogallala aquifer was temporarily stored in a surface reservoir, and then pumped to the irrigation system through underground pipeline and a polyethylene drag hose.

SDI irrigations were applied with Netafim drip tape spaced 1.52 m apart and chiseled under alternate furrows to a depth of 0.30 m. Dripline with the four flow rates for the irrigated plots and smooth tubing for the dryland plots was spliced together in the field as the dripline was installed. Emitter flow rates, spacing, and application rates for the five irrigation amounts were:

I ₀	Smooth tubing - no emitters
I ₂₅	0.61 L/h on 0.45 m spacing - 0.87 mm/h
I ₅₀	1.51 L/h on 0.60 m spacing - 1.63 mm/h
I ₇₅	1.51 L/h on 0.40 m spacing - 2.45 mm/h
I ₁₀₀	1.51 L/h on 0.34 m spacing - 3.26 mm/h

The six driplines for each replicate were manifolded with 50-mm diameter, PVC pipe on both the inlet and outlet ends. The design allowed all eighteen SDI plots to be irrigated with only three supply laterals and three flush-out laterals.

¹The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation or exclusion by the USDA-Agricultural Research Service.

Irrigation Procedure

Two emergence irrigations applied uniformly across the entire experiment with the MESA spray heads were required to ensure timely crop emergence. A 25-mm irrigation was uniformly applied on May 27 for seed germination, and an additional 12.5-mm was applied on May 31 to soften the surface soil and insure emergence. For LEPA, the first irrigation after furrow diking was also applied with the MESA spray heads to settle and firm up the furrow dikes. All additional irrigations were applied with the specific sprinkler devices or the SDI dripline.

Seasonal sprinkler irrigations were applied when the soil water deficit calculated from North Plains ET data reached 25 mm, Figure 1. The target, plant-available soil water level was 70% in the 1.4-m profile or approximately 409 mm of total soil water. Irrigation depth for the SDI treatments was equal to that of the sprinkler treatments, but the plots were irrigated daily with smaller irrigation amounts. Soil water measurements at 0.2-m increments to the 2.4-m depth were made every 2 to 3 weeks in the I_{100} irrigation treatment plots to verify the adequacy of the irrigation scheduling and modify the irrigation amount if necessary. Comparable measurements were made in the I_{50} treatment plots to evaluate soil water depletion in comparison to the I_{100} treatment. These measurements were made with a locally field calibrated, CPN Model 503DR (Campbell Pacific Nuclear, Martinez, CA) depth moisture gage (Evet and Steiner, 1995). Soil water was also measured gravimetrically to the 1.8-m (6-ft) depth on all plots at planting and at harvest for calculating soil water depletion and estimating seasonal water use.

Cultural Practices

Agronomic practices and crop management were similar to those used for high-yield on-farm grain sorghum production in the Southern High Plains. Disk bedding was used for primary tillage during the spring, and 0.76-m spaced beds were formed with a disk bedder. On May 23, 4.7 L/ha of Bicep herbicide was applied with a ground spray rig for weed control. Pioneer variety 86G62 grain sorghum was then planted on May 26 at a rate of 30 seed/m². After the last cultivation, all furrows were diked with a Sunco (Sunco Marketing, North Platte, NE) propeller type diker that formed dikes at a 45° angle with the furrows. This dike design allows easier movement of harvesting equipment over the diked furrows. The greenbug population gradually increased during the middle of the growing season, and 0.58 L/ha of Lorsban insecticide was applied as a spray through the lateral move irrigation system on August 23.

Adequate fertilizer, based on soil samples analyzed by a commercial soils testing laboratory, was applied to insure that fertility did not limit yields. On March 1, 10-34-0 and 32-0-0 dry fertilizers were applied to provide 58 kg(N)/ha and 76 kg(N)/ha. During the growing season, the I_{100} treatment plots received 45 kg(N)/ha as liquid urea in the irrigation water, and the deficit irrigated treatments received proportionately less. The small nitrogen applications were due to the large nitrogen residual in the previously fallowed soil.

Grain yields were measured by combine harvesting one full length of each plot with a Hege (Hege Equipment, Inc., Colwick, KS) plot combine having a 1.52-m wide header. Three 500-seed

subsamples were weighed to determine seed mass. Data were analyzed with a general linearized model for split-split plot designs (SAS Institute, Inc., Gary, NC)

Results

The crop season started with near normal temperatures and rainfall, but after mid-July, there was no additional rainfall and temperatures were above normal. Cumulative rainfall remained near average until July 20 even with a 17 day interval with essentially no rain in June, Figure 1. No additional rain occurred after that date, and cumulative rainfall for the 4-month interval was only 49% of the 60-y average. During the drought interval, maximum daily temperature exceeded 39°C on six days and 38°C on fifteen days.

Soil water before planting averaged 427 mm in the 1.8-m profile, and was uniformly distributed across the irrigation treatment plots and replicates. During the growing season, the soil water in the SDI-I₁₀₀ plots remained at or above the 409 mm target until the irrigation cutoff on Sept.1. Soil water in the 100% irrigated LESA and MESA treatment plots was slightly above the target amount until July 18, and then dropped slightly below the target amount by the last irrigation. For the LEPA-I₁₀₀ plots, however, soil water dropped markedly after the rainfall ended on July 20, and by Aug. 29, the soil water was 80 mm below the target level. This major soil water depletion was due to the large amounts of sprinkler runoff from the LEPA irrigated I₁₀₀ and I₇₅ plots (Schneider and Howell, 2000). After irrigation cutoff, major soil water depletion occurred in the root zone on all plots. Seasonal soil water depletion to the 1.8-m depth averaged 62,69,39,39, and 34 mm for the I₀ through I₁₀₀ irrigation treatment plots, respectively. Below the root zone, soil water in most plots increased during the growing season with the largest increases in the SDI plots. Soil water accumulation in the 1.4 to 2.4-m profile of the SDI plots averaged 28 mm, and this suggests deep percolation similar to that reported by Lamm et al. (1995).

Grain Yields

Grain yields averaged across irrigation methods were significantly different ($p \leq 0.0028$) and ranged from 0.65 Mg/ha on I₀ to 9.63 Mg/ha on I₁₀₀, Figure 2. Within individual irrigation methods, all irrigation amounts were significantly different ($p \leq 0.020$). Averaged across irrigation amounts, grain yields ranged from 5.58 Mg/ha for LEPA to 6.04 Mg/ha for SDI with only the LEPA to MESA ($p \leq 0.049$) and the LEPA to SDI ($p \leq 0.0013$) differences being significant.

Seed mass ranged from less than 20 mg/seed for I₀ and I₂₅ to more than 26 mg/seed for LESA and MESA with 100% irrigation. Averaged across irrigation methods, the seed masses were significantly larger for I₇₅ and I₁₀₀ than for the three smaller irrigation amounts, and I₁₀₀ was significantly larger than I₇₅ ($p \leq 0.001$). Seed mass averaged across irrigation amounts also varied significantly with the MESA average of 22.5 mg being significantly large than the LEPA average 21.1 mg ($p \leq 0.033$). Seed mass was not significantly different among the LESA, MESA and SDI irrigation methods.

Water Use Efficiency

Water use efficiency (WUE) ranged from 0.45 kg/m³ for I₀ to 2.01 kg/m³ for the MESA-I₅₀ treatment, Figure 4. Averaged across irrigation methods, WUE increased significantly between the I₀ to I₂₅ and I₂₅ to I₅₀ irrigation amounts ($p \leq 0.001$). Then, there were no significant differences among the I₅₀, I₇₅ and I₁₀₀ irrigation amounts ($p \leq 0.05$). WUE averaged across irrigation amounts, was larger for the SDI irrigation method than for the LEPA method ($p \leq 0.011$), but average WUE among the other irrigation methods was not significantly different ($p \leq 0.05$). At the 25% irrigation level, WUE for SDI was significantly larger than for the other three irrigation methods ($p \leq 0.004$).

Irrigation water use efficiency (IWUE) tended to increase from I₂₅ to I₅₀ and then to decrease for the larger irrigation amounts, Figure 5. Averaged across irrigation methods, IWUE, was significantly larger for I₅₀ than for I₂₅ ($p \leq 0.035$), for I₇₅ than for I₁₀₀ ($p \leq 0.002$), and for I₂₅ and I₅₀ than for I₁₀₀ ($p \leq 0.007$). Averaged across irrigation amounts, IWUE, also varied significantly, with the mean for SDI being larger than for LEPA ($P \leq 0.013$) and for MESA ($p \leq 0.015$). At the I₂₅ irrigation level, IWUE was larger for SDI than for the other three irrigation methods ($p \leq 0.002$); and at the I₅₀ irrigation level, IWUE for SDI was larger than for LESA or MESA ($p \leq 0.049$).

Seasonal Water Use

Seasonal water use averaged across irrigation methods ranged from 144 mm for I₀ to 564 mm for I₁₀₀, Figure 6. The maximum value is similar to the 578 mm average seasonal ET reported by Howell, et al. (1997) for Bushland, TX. Seasonal water use did not vary appreciably among the irrigation methods, because any unequal soil water depletion among irrigation methods was only a small fraction of the crop water use.

Grain yield as a function of seasonal water use is illustrated in Figure 6. The regression coefficient of 0.0224 was highly significant ($p \leq 0.001$), and the r^2 value was 0.938. The regression coefficient is larger than for furrow irrigated sorghum by Musick and Dusek (1971) or for sprinkler irrigated sorghum by Schneider and Howell (1995). Both of these field studies were conducted over a large range of irrigation depths similar to this study.

Discussion

Grain sorghum yields and seasonal water use efficiencies in this study were larger than those in earlier field studies at the laboratory. With 100% irrigation, grain yields for both the LESA and MESA sprinkler methods exceeded 10 Mg/ha. In comparison, the maximum yield reported by Musick and Dusek (1971) was 7.86 Mg/ha and that by Schneider and Howell (1995) was 9.52 Mg/ha. WUE for the three larger irrigation amounts ranged from 1.5 to 2.0 kg/m³ with many of the treatment efficiencies being near 2 kg/m³. The maximum WUE reported by Musick and Dusek for furrow irrigation were in the 1.40 to 1.55 kg/m³ range, and those of Schneider and Howell (1995) were in the 1.50 to 1.80 kg/m³ range. Irrigation water use efficiencies tended to be larger than those of Musick and Dusek (1971), although the maximum value was less than in this previous study. Both the grain yields and the water use efficiencies illustrate effective use of the irrigation water by grain sorghum during the hot, dry summer.

The reduced grain yields for the fully irrigated LEPA and SDI treatments are believed to be due to unmeasured irrigation water loss. Surface water storage of the basins made with the propeller dike was insufficient to prevent runoff from the LEPA irrigated I₇₅ and I₁₀₀ plots. Schneider and Howell (2000) reported large grain yield reductions due to surface runoff from LEPA irrigation especially during a drought year similar to 2000. Soil water increased throughout the 1.4 to 2.4-m profile of the SDI plots so deep percolation may have been large enough to reduce crop yields during a drought year. Lamm et al. (1995), for example, estimated 47 mm of deep percolation during SDI irrigation of fully irrigated corn. This value with the 2.24 kg/m³ regression coefficient would result in a yield reduction of approximately 1 Mg/ha.

Conclusion

This one-year study suggests that the optimum irrigation method for grain sorghum is likely to vary with the irrigation amount. At the I₂₅ and I₅₀ irrigation levels, grain yield, WUE, and IWUE, with SDI were all larger than for the sprinkler irrigation methods. For the two larger irrigation amounts, the trends reversed and the larger yields and water use efficiencies were with the LESA and MESA spray methods. The reduced yields with full irrigation are believed to be due to surface runoff for LEPA irrigation and deep percolation for SDI irrigation.

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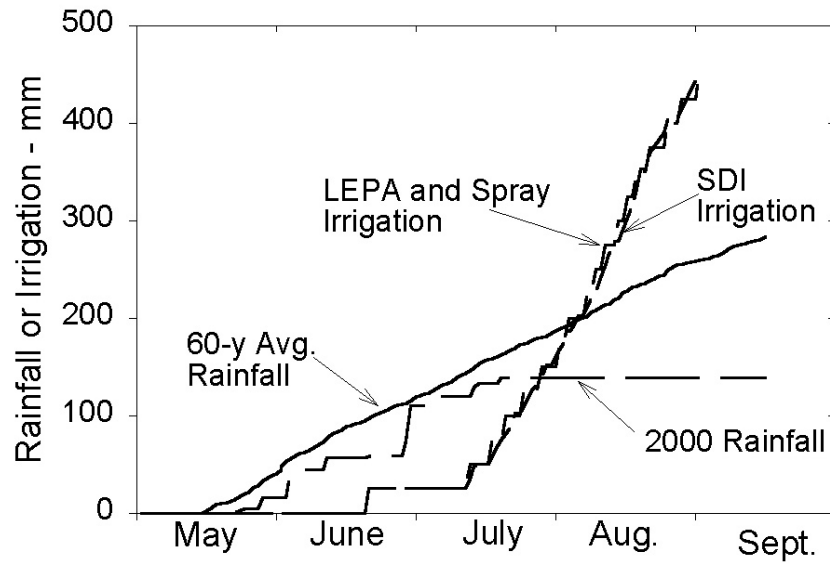


Figure 1. Rainfall and irrigation depths for the May 15 to Sept. 15 grain sorghum season.

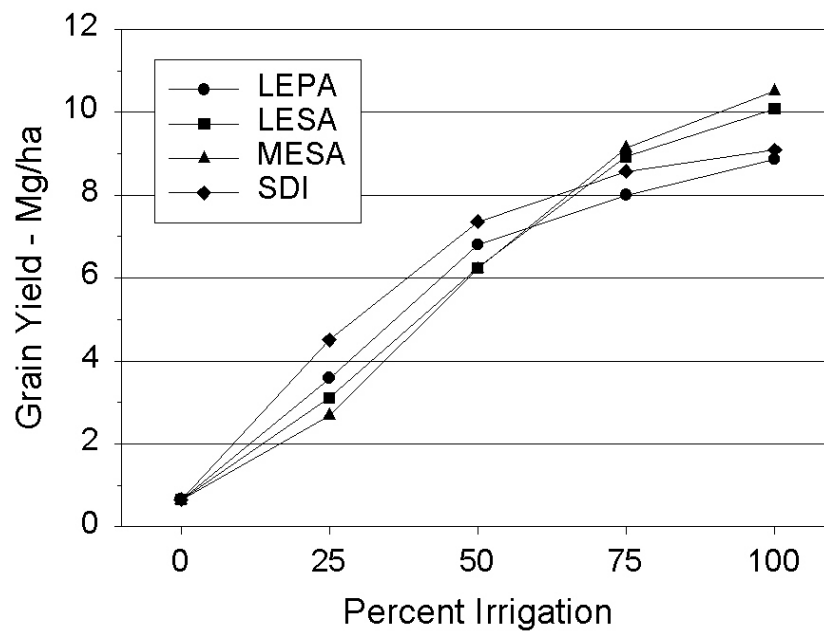


Figure 2. Grain yields for the irrigation amount and irrigation method treatments.

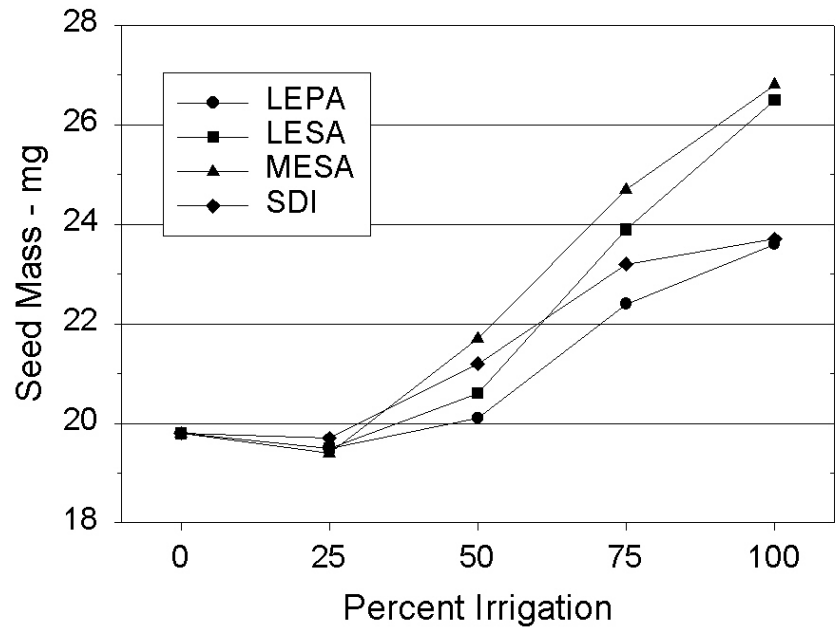


Figure 3. Seed mass for the irrigation amount and irrigation method treatments.

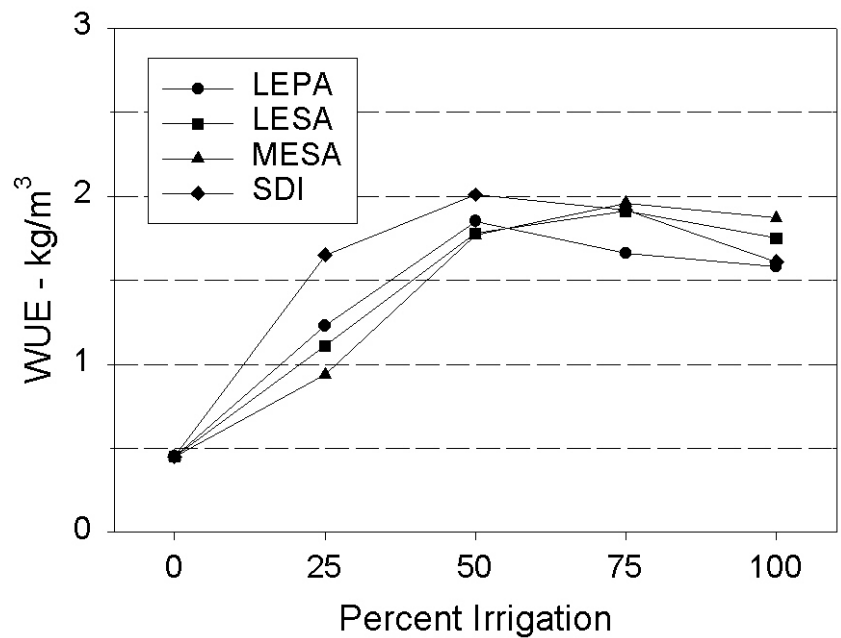


Figure 4. Seasonal water use efficiency for the irrigation amount and irrigation method treatments.

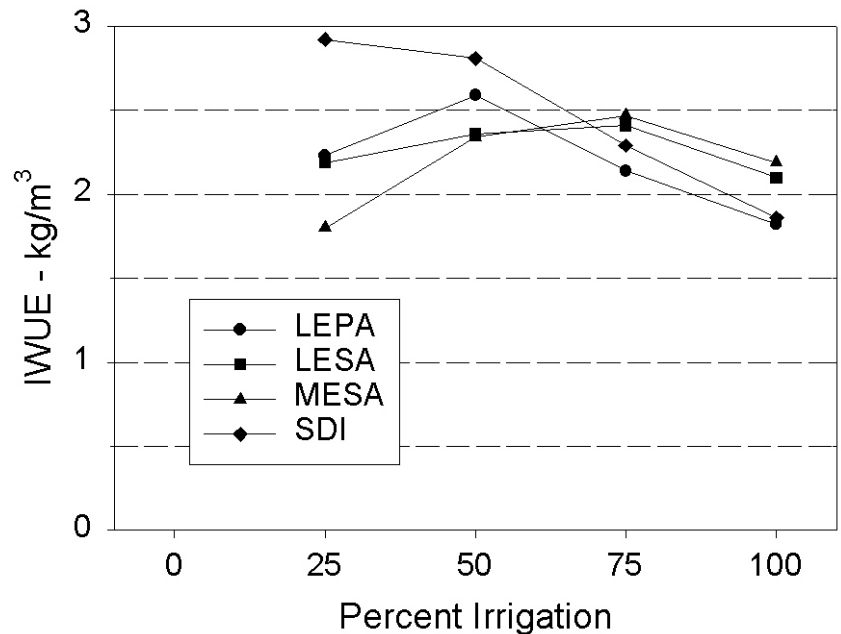


Figure 5. Irrigation water use efficiency for the irrigation amount and irrigation method treatments.

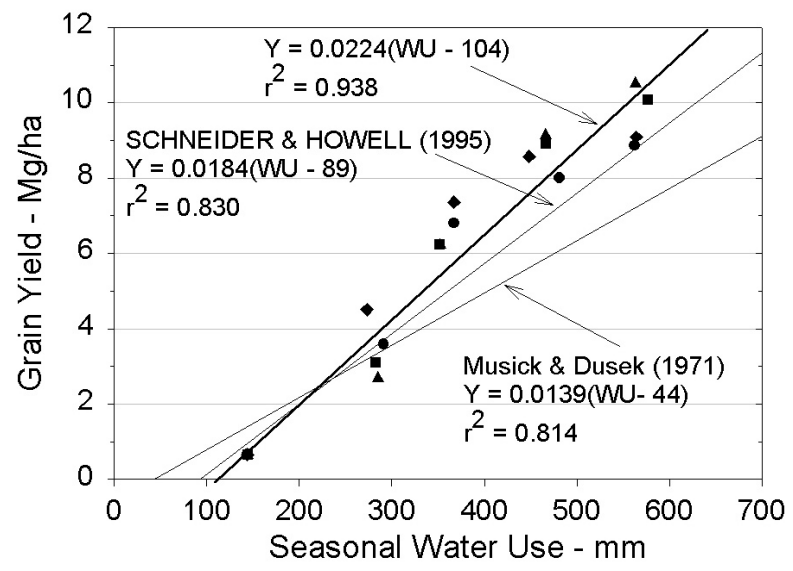


Figure 6. Grain yield as a function of seasonal water use and regression curves and equations for two earlier field studies.