Grain Sorghum Response to Sprinkler Application Methods and System Capacity

A. D. Schneider, T. A. Howell

Abstract. *The crop yield response of grain sorghum to four sprinkler methods and four irrigation amounts which simulated varying irrigation capacities was evaluated during 1992 and 1993 at Bushland, Texas, in the Southern High Plains. Irrigation methods were LEPA sock, LEPA bubble, in-canopy spray near ground level, and overhead spray. The application devices were installed on a three-span, hose-fed, lateral-move sprinkler system. Irrigations were scheduled from neutron soil water measurements in a designated control treatment receiving 100% irrigation by the LEPA sock method. Soil water in the control plots was maintained above 75% of the plant available level by simultaneously applying 25-mm irrigations with all four sprinkler methods as the 100% irrigation amount. Deficit irrigation treatments received 75, 50, and 25% of the control treatment application on the same date. All furrows were diked to minimize runoff and enhance surface storage from irrigation and rainfall. The 100% irrigation treatments received 250 and 325 mm of irrigation in 1992 and 1993, respectively, along with 310 and 223 mm, respectively, of rainfall from emergence to the last irrigation. Grain sorghum yields were primarily affected by irrigation amount and to a lesser extent by sprinkler method, especially for the two smaller irrigation amounts. With deficit irrigation, the LEPA bubble and sock methods yielded better than the spray methods likely due to reducing evaporation from the crop canopy and soil and thus increasing the amount of water available for transpiration. For example with LEPA in 1992, grain sorghum yields were reduced only 1% while the irrigation amount was reduced from 250 mm for 100% irrigation to 125 mm for 50% irrigation.*
Keywords. *Grain sorghum, LEPA, Sprinkler, Spray, Irrigation, Deficit.*

Spray irrigation was introduced to reduce droplet evaporation and drift losses from impact sprinklers and the pumping energy for the application device. For center pivot irrigation sprinkler systems in the Southern High Plains, Musick et al. (1988) reported application efficiencies of 85% for 100 systems equipped with spray heads and 82% for 123 systems equipped with impact sprinklers. Howell et al. (1991) reported on sprinkler evaporation losses and efficiency measured with 9-m^2 weighing lysimeters and showed an increase in application efficiency of about 5% by changing from impact sprinklers to spray heads.

Low energy precision application (LEPA) irrigation was introduced by Lyle and Bordovsky (1981) to further reduce sprinkler evaporation losses due to droplet evaporation and drift. Originally, bubble mode LEPA applications were made to individual furrows, but Lyle and Bordovsky (1983) later reported advantages of alternate-furrow irrigation over every-furrow irrigation using LEPA. Several bubble and spray LEPA devices are commercially available (Fipps and New, 1990), and double-ended drag socks (Fangmeier et al., 1990) are also being marketed. Application efficiencies for LEPA irrigation have been reported in the range 96 to 98% (Lyle and Bordovsky, 1983; Schneider and Howell, 1990). In obtaining these high application efficiencies, eliminating or reducing the evaporation of sprinkled water from the crop canopy and ground is equally as important as eliminating the air droplet evaporation and drift losses (Schneider and Howell, 1993).

In general, the cost of sprinkler application devices and the management skill required to efficiently use the devices increases with the potential increase in application efficiency. Increased sprinkler application efficiencies with spray heads and LEPA devices are achieved by concentrating the sprinkled water into smaller areas and applying it at greater application rates. Runoff and surface redistribution must be controlled with both of these methods, especially LEPA, and precision tillage is needed to insure that LEPA drops travel between the rows of the crop. Closely spaced drops and expensive application devices add to the cost of using spray heads and LEPA devices.

The goal of this research was to investigate high efficiency spray and LEPA sprinkler application methods over a fourfold range of irrigation system capacity.

Procedures

The research was conducted at the USDA-Conservation and Production Research Laboratory at Bushland, Texas, during the 1992 and 1993 grain sorghum cropping seasons.

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The soil at the experimental site was Pullman clay loam (fine, mixed, thermic torrertic Paleustolls), and the field had a uniform slope of 0.0023 m/m in the direction of the rows and a 0.0018 m/m cross-slope.

Experimental Design

Two spray and two LEPA sprinkler application methods were evaluated at four irrigation amounts ranging from 25 to 100% of soil water replenishment. Field plots were arranged in a randomized block design with irrigation treatments being the blocks and sprinkler methods being randomized within each replicate of a block. The sixteen treatment combinations were replicated three times. Plot size was twelve 0.76-m rows wide by 25 m long, and the irrigation treatment plots were separated from each other by 5-m-wide borders.

Spray irrigation methods were in-canopy spray, designated as M_{si}, with the level of application about 0.3 m above ground level and overhead spray, designated as M_{so}, with the level of application about 0.2 m above the mature crop canopy (1.5 m above ground level). LEPA irrigation methods were LEPA bubble, designated as M_{lb}, with the point of application about 0.3 m above ground level and Fangmeier LEPA socks (Fangmeier et al., 1990), designated as M_{ls}, which were double-ended plastic socks pulled through the furrows.

A fully irrigated control treatment and three deficit irrigation treatments were evaluated with the four sprinkler methods. Soil water for the fully irrigated control, designated as I_{100}, was maintained at a nonyield-limiting level. Irrigations were applied to maintain soil water in the 1.4-m-deep profile of the I_{100}/M_{ls} treatment above 75% of field capacity which is approximately 410 mm of total soil water for the Pullman clay loam soil. Deficit irrigation treatments designated as I_{75}, I_{50}, and I_{25} received 75, 50, or 25% of the applications to the fully irrigated treatments on the same days.

Soil water was measured in 0.2-m-depth increments to the 2.4 m depth with a locally field calibrated CPN model 503DR neutron moisture meter. Weekly measurements were made in the control treatment plots for scheduling irrigations except when rainfall made irrigation unnecessary. Additional soil water measurements were made about every four weeks on all M_{ls} and M_{so} treatments.

Irrigation Equipment

Irrigations were applied with a hose-fed Valmont model 6000 lateral move irrigation system. The system had three, 39-m-long spans providing space for forty-eight 0.76-m-wide beds and furrows under each span. Pressurized water, on demand from a surface reservoir, was supplied to the irrigation system through an underground pipeline and a 114-mm-diameter surface hose. Information about the four types of application devices is listed in table 1. Senninger 360° spray nozzles placed above the LEPA socks metered the flow to the socks at the same rate as the other devices. All application devices were spaced 1.52 m apart in alternate furrows, and discharged 19.0 L/min. Pressure to the application devices was 207 kPa, but the LEPA and in-canopy spray devices were equipped with 41-kPa pressure regulators.

Table 1. Irrigation application device information

Device	Manufacturer	Model	Nozzle Diameter (mm)
LEPA sock	A.E. Quest & Sons (Senninger)	(360°)*	(6.8)
LEPA bubble	Senninger	Quad IV*	6.8
In-canopy spray	Senninger	Quad IV*	6.8
Overhead spray	Nelson	Spray I	4.6

* Equipped with 41-kPa pressure regulators.

Cultural Practices

Cultural practices were generally similar to those used for high-yield grain sorghum production in the Southern High Plains. All field operations were performed with 6-row farm machinery to fit the 48-row-wide blocks under each irrigation system span. Fertilizer and herbicide application rates and dates of some cultural operations are listed in table 2 for the two-crop years. The experimental area for the 1992 crop was planted to dryland winter wheat during the previous fall to prevent wind erosion, and the wheat was sweep-plowed out on 9 April. For primary tillage, the field was tandem disked twice in mid-April, and then it was smoothed with a land plane. After application of anhydrous ammonia and liquid phosphorous fertilizer, the field was bedded with a disk bedder. Because of late spring rainfall, the beds had to be tilled with a rotary cultivator to kill emerging weeds before sorghum was planted at a uniform seeding rate on 11 June. Soil crusting from rainfall shortly after planting caused reduced seedling emergence and plant population in comparison to 1993. Atrazine was applied for broadleaf weed control, and all furrows on all treatments were furrow diked with a Roll-A-Cone shovel and bump diker

The field area for the 1993 crop, which was adjacent to the 1992 study site, had been cropped to grain sorghum and uniformly irrigated during 1992. The grain sorghum residue was tandem-disked during the fall and again during the early spring. After application of anhydrous ammonia, the field was bedded for planting on 1 May. Atrazine was applied for broadleaf weed control similar to 1992, and all plots were furrow-diked with a Bigham Brothers trip and roll diker. This diker controlled the placement of the dikes more accurately than the diker used in 1992.

Grain yields were determined by hand harvesting two 5-m-long rows within each treatment and threshing the sorghum with a small research combine harvester. Grain

Table 2. Agronomic data for the two grain sorghum crops

Variable	1992	1993
Fertilizer applied	112 kg(N)/ha 112 kg(P)/ha	112 kg(N)/ha*
Herbicide		
Kind	Atrazine	Atrazine
Rate	1.7 kg(AI)/ha	1.7 kg(AI)/ha
Date	25 June	21 May
Planting date	11 June	23 May
Furrow diking date	16 July	28 June
Harvesting date	29 October	27 September
Plant population (plants/m^2)	17	26

* 112 kg(P)/ha applied in 1992.

yields reported here are adjusted to 14% moisture content on a wet weight basis.

Results and Discussion

Irrigation and Rainfall

During 1992, all treatments were irrigated 10 times with the first irrigation on 9 July and the final irrigation on 11 September. Thirteen irrigations were applied during 1993 with the first application on 30 June and the last application on 1 September. Weekly irrigation and rainfall for the 1992 and 1993 irrigation seasons are listed in table 3. Soil water was sufficient for seed germination in 1992, but in 1993, an 18-mm emergence irrigation was applied on 21 May. Rainfall from crop emergence to the first irrigation totaled 135 and 66 mm, respectively, for the 1992 and 1993 grain sorghum crops. Essentially no runoff occurred from the irrigation season rainfall because of the furrow dikes and low-intensity storms.

Soil Water

Soil water was plentiful during the initial part of the 1992 growing season because of 55 mm of rainfall during the 10-day interval preceding planting and an additional 55 mm of rainfall during the week after planting. Soil water was uniform across the plot areas at the start of irrigation in early July, and on the I_{100} control treatment plots it remained essentially the same until after irrigation cutoff on 11 September (fig. 1). The increased soil water between the 1.1 and 1.9 m depths was measured on 3, 9, and 16 September after 89 mm of rainfall during the two weeks preceding 3 September. The lower curve represents the soil water on 6 October at crop maturity.

With limited rainfall during the early part of the 1993 crop season, soil water was slightly below the 75% available level until the rains occurring during the week of 11 to 18 July. This was a result of the Pullman clay loam subsoil being difficult to wet when sprinkler irrigating a vigorously growing summer crop. The mid-July rainfall replenished the soil water reservoir, which remained at a high level until mid-August. Then, soil water in the upper 0.4-m profile dropped somewhat, and was replenished by irrigation during the week of 15 to 21 August. With the drier initial profile and 38 mm less growing season rainfall than the previous year, soil water in the I_{25} and I_{50} treatment plots severely limited grain yields.

Table 3. Weekly irrigation to the fully irrigated treatments and rainfall during 1992 and 1993 crop years

Week	Irrigation I_{100} Treatment (mm)	Rainfall (mm)	Weekly Total (mm)
1992			
5-11 July	25	35	60
12-18 July	25	4	29
19-25 July	25	0	25
26 July-1 August	25	30	55
2-8 August	50	5	55
9-15 August	50	3	53
16-22 August	0	43	43
23-29 August	0	46	46
30 August-5 September	25	5	30
6-12 September	25	5	30
Totals	250	176	426
1993			
27 June-3 July	50	0	50
4-10 July	50	5	55
11-17 July	25	70	95
18-24 July	0	18	18
25-31 July	50	0	50
1-7 August	0	23	23
8-14 August	25	14	39
15-21 August	50	1	51
22-28 August	50	6	56
29 August-4 September	25	0	25
Totals	325	137	462

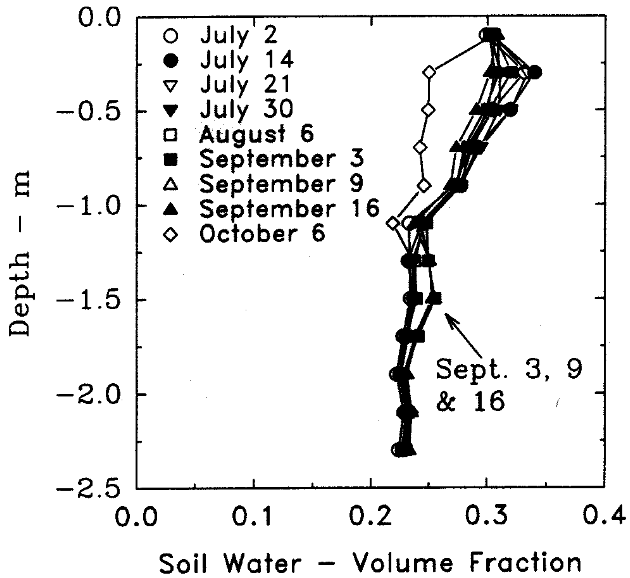

Figure 1–Average soil water in the plots fully irrigated with LEPA socks (I_{100}/M_{ls}) measured nine times during the 1992 growing season.

Grain Yields

Grain yields for the individual sprinkler methods and irrigation amounts are illustrated in figures 2 and 3 for 1992 and 1993. Grain yields for the four sprinkler methods averaged across irrigation amounts and the four irrigation amounts averaged across sprinkler methods are listed in table 4. The difference in grain yields due to sprinkler

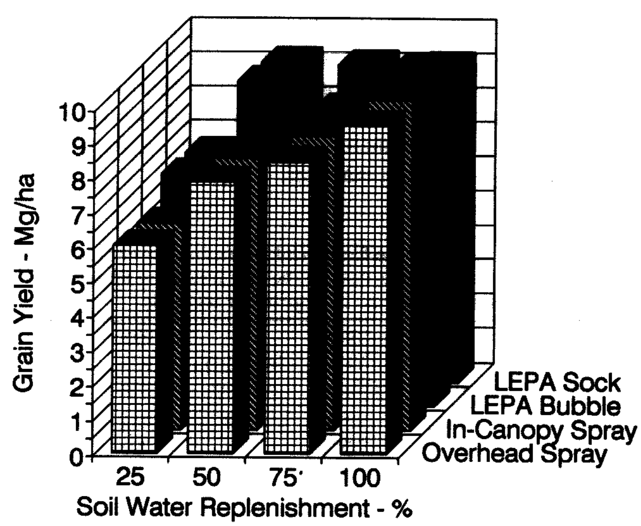

Figure 2–Grain sorghum yields for all combinations of the four irrigation treatments and four sprinkler methods during 1992.

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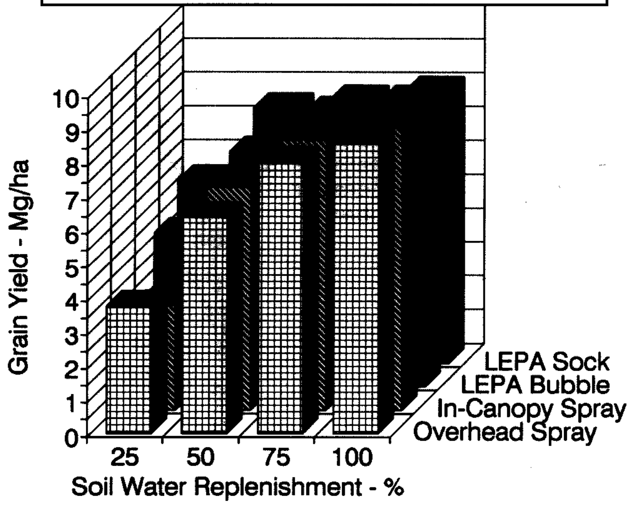

Figure 3–Grain sorghum yields for all combinations of the four irrigation treatments and four sprinkler methods during 1993.

methods and irrigation amounts were both statistically significant at the P = 0.05 level. During both years grain yields with the two LEPA methods were significantly larger than with the two spray methods, and neither the LEPA nor the spray methods were significantly different from each other. In 1992, the largest and smallest irrigation amounts were statistically different from the two intermediate irrigation treatments and from each other. In 1993, the I_{100} and I_{75} irrigation treatments were significantly different from the I_{50} and I_{25} irrigation treatments, and the I_{50} and I_{25} irrigation treatments were significantly different from each other. The sprinkler methods by irrigation amount interaction was significant in 1993 (p = 0.009), but not in 1992.

Grain yields with the LEPA and spray methods followed different trends as the irrigation amount varied. With the LEPA methods, yields for the I_{50}, I_{75}, and I_{100} treatments were essentially equal each year and averaged 9.26 in 1992 and 7.79 Mg/ha in 1993. In contrast, the yield of the I_{25} treatment with LEPA irrigation averaged only 6.68 and 4.96 Mg/ha for 1992 and 1993, respectively. For the two spray methods in 1992, yields were nearly identical at each of the four irrigation amounts and increased almost linearly with increased irrigation. For the spray irrigation methods in 1993, grain yields for the I_{75} and I_{100} irrigation amounts were nearly equal, but there were large yield reductions for the I_{50} and I_{25} irrigation amounts.

Table 4. Grain yields for the four sprinkler methods averaged across four irrigation amounts and for the four irrigation amounts averaged across four sprinkler methods

Sprinkler Method	1992 Yield (Mg/ha)	1993 Yield (Mg/ha)	Irrigation Amount	1992 Yield (Mg/ha)	1993 Yield (Mg/ha)
LEPA sock	8.58a*	7.16a	100%	9.51a	8.34a
LEPA bubble	8.64a	7.00a	75%	8.70b	7.96a
Overhead spray	7.97b	6.69ab	50%	8.62b	6.86b
In-canopy spray	7.99b	6.49b	25%	6.34c	4.20c
LSD		0.54	0.46	0.54	0.46

* Yields followed by the same letter are not significantly different (p = 0.05) within each of the two years.

Deficit irrigation was more effective with the two LEPA methods, and grain yields for the I_{50} and I_{75} treatments were essentially the same as the yields for the I_{100} treatment. For the spray irrigation methods, there were larger yield reductions between the I_{100} or I_{75} irrigation treatments and the I_{50} irrigation treatment. For the I_{25} irrigation treatment, grain yields with the LEPA methods were considerably higher than those for the spray methods.

Water Use Efficiency

Water use efficiencies for the LEPA sock and overhead spray sprinkler methods are listed in table 5. Water use efficiency is computed as the grain yield divided by the seasonal evapotranspiration and is expressed as kilograms per cubic meter. Evapotranspiration is the sum of irrigation, rainfall from crop emergence to crop physiological maturity and soil water depletion. Deep percolation was considered negligible because of the small irrigations and unchanged soil water below 2 m throughout the growing season. During both years the highest and lowest water use efficiencies were obtained with the I_{50} and I_{25} irrigation amounts, respectively. For the two larger irrigation amounts, water use efficiency was in the narrow range of 1.46 to 1.56 kg/m^3 for both years. Average water use efficiency for the LEPA sock method exceeded that of the overhead spray method by 0.07 and 0.10 kg/m^3 during the two years. Grain yields were linearly related to seasonal water use for the LEPA sock and overhead spray sprinkler methods for all irrigation treatments across the two years (fig. 4).

Table 5. The effect of LEPA sock and overhead spray sprinkler methods on soil water depletion, seasonal water use, grain yields and water use efficiency

Irrig. Treat.	Sprinkler Method	Irrig. Amount (mm)	Soil Water Depl. (mm)	Seasonal ET* (mm)	Grain Yield (Mg/ha)	Water Use Effic. (kg/m^3)
1992						
100%	LEPA sock	250	58	618	9.17	1.48
100%	Overhead spray	250	43	603	9.52	1.58
75%	LEPA sock	188	91	589	9.21	1.56
75%	Overhead spray	188	79	577	8.46	1.47
50%	LEPA sock	125	81	516	9.31	1.80
50%	Overhead spray	125	42	477	7.87	1.65
25%	LEPA sock	63	106	479	6.63	1.39
25%	Overhead spray	63	64	437	6.03	1.38
Avg.	LEPA sock	156	84	550	8.64	1.57
Avg.	Overhead spray	156	57	523	7.97	1.52
1993						
100%	LEPA sock	325	2	550	8.01	1.46
100%	Overhead spray	325	19	567	8.59	1.52
75%	LEPA sock	244	38	505	7.76	1.54
75%	Overhead spray	244	46	513	8.01	1.56
50%	LEPA sock	163	54	440	7.51	1.71
50%	Overhead spray	163	52	438	6.39	1.46
25%	LEPA sock	81	71	375	5.38	1.43
25%	Overhead spray	81	54	358	3.77	1.05
Avg.	LEPA sock	203	41	467	7.16	1.53
Avg.	Overhead spray	203	43	469	6.69	1.43

* Includes 310 and 223 mm of precipitation for 1992 and 1993, respectively.

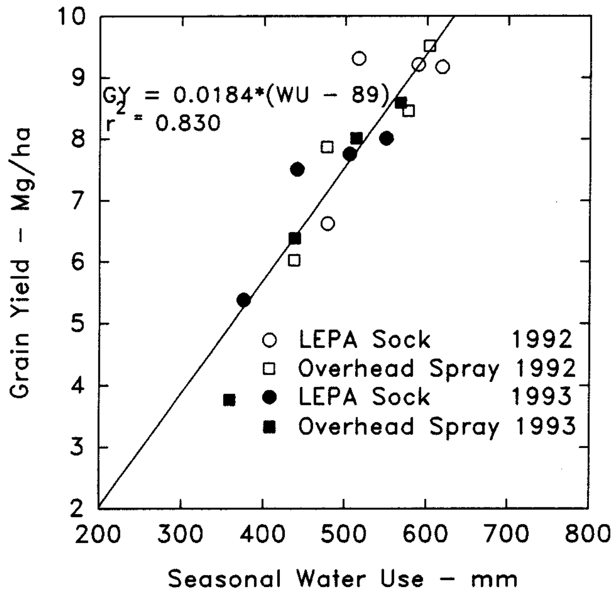

Figure 4–Grain yield as a function of seasonal evapotranspiration for the LEPA sock and overhead spray sprinkler methods with four irrigation depths across two years.

Discussion

The data presented here illustrate the potential to compensate for reduced irrigation system capacity by converting from spray heads to LEPA devices. By using the LEPA sock method with a 50% reduction in irrigation system capacity, grain yields were not decreased in 1992 and were decreased only 0.5 Mg/ha in 1993 (table 5). In comparison with overhead spray, grain yields were decreased 1.65 and 2.20 Mg/ha for the two respective years.

The yield differences between the LEPA and spray irrigation methods illustrate the importance of reducing or eliminating evaporation losses from the wetted soil and crop canopy. With the I_{100} and I_{75} irrigation amounts, sufficient water was applied so that the increased evaporation losses with spray irrigation had only a small effect on yields. For the two deficit irrigation amounts, the yield difference between the LEPA and spray methods likely reflects additional water lost from the wetted crop canopy and soil. Also, soil water depletion with the LEPA sock method was larger than with the overhead spray method for I_{25} during both years and for I_{50} in 1992.

With the in-canopy spray heads, the crop canopy and soil were wetted essentially the same as with the overhead spray method. These spray heads, which were suspended on flexible drops, often became entangled in the grain sorghum plants and sprayed into the crop canopy. Thus, evaporation losses and yields were likely about equal for the two spray head placements even though the spray heads were placed quite differently.

Conclusions

- Grain sorghum yields with the in-canopy spray and overhead spray methods were essentially equal even though the application methods were quite different.
- The LEPA bubble and LEPA sock methods tended to outyield the spray methods especially at lower soil water replenishment levels, likely due to partitioning of the applied water into more transpiration and less evaporation.
- With deficit irrigation system capacity, LEPA irrigation appears to maximize crop yield potential when compared to spray irrigation.

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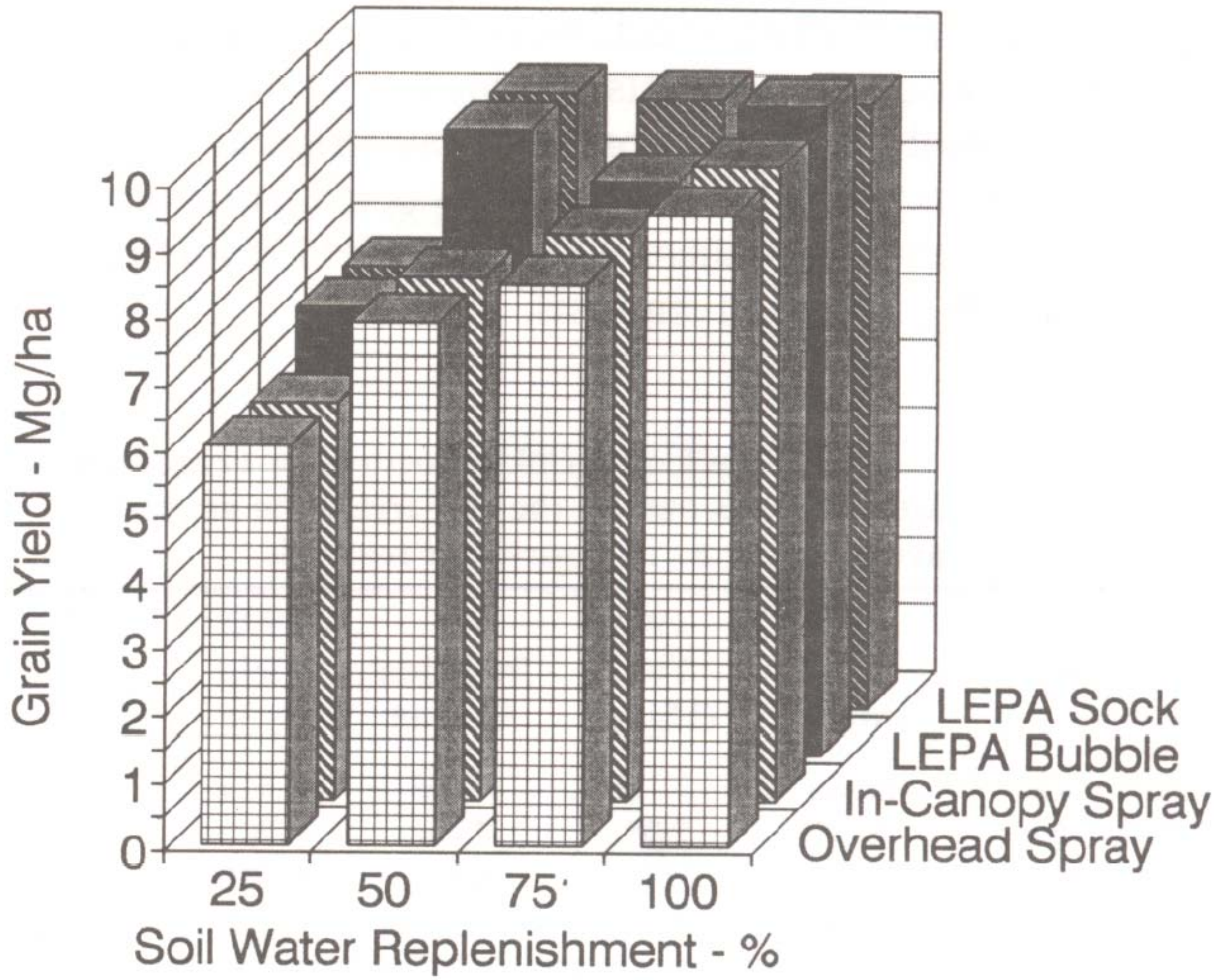
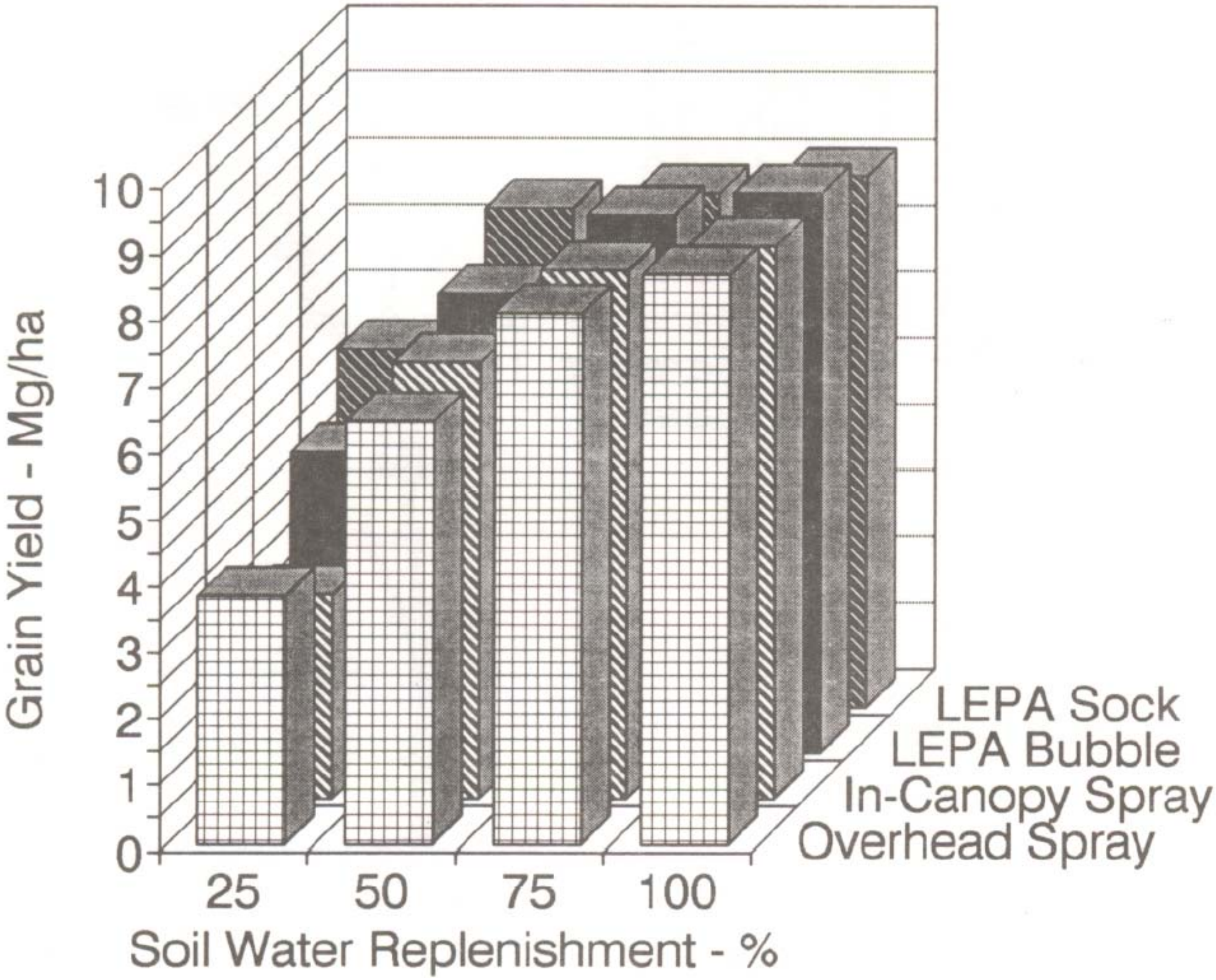


Figure 2 - Grain sorghum yields for all cominations of the four irrigation treatments and four sprinkler methods during 1992.



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