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SURFACE RUNOFF DUE TO LEPA AND SPRAY IRRIGATION OF A SLOWLY PERMEABLE SOIL

A. D. Schneider, T. A. Howell

ABSTRACT. *Surface runoff during low energy precision application (LEPA) and spray sprinkler irrigation of diked and undiked furrows was measured from 20-m-long plots on a slowly permeable, Pullman clay loam. The control treatment (100% irrigation) was sufficient irrigation, applied in 25 mm applications, to maintain the plant available water level in the 1.4-m-deep profile at 75% or more. Deficit irrigation treatment plots received 0, 40, 60, and 80% of the control treatment amount on the same day. The plots were cropped to grain sorghum, and the field had a uniform 0.25% slope in the direction of the 0.76-m spaced furrows. Cultural practices were similar to those used for high-yield irrigated grain sorghum in the southern Great Plains. LEPA double-ended socks and spray heads with flat, medium-grooved deflector plates were both spaced 1.52 m apart over alternate furrows. Runoff was measured volumetrically in steel tanks from three wheel track and three non-wheel track furrows in each plot. No sprinkler runoff occurred in any treatments with the 40% irrigation amount and with the spray/diked combination. Two-year, seasonal average runoff from the spray/undiked combination with 100% irrigation was 12% of the applied water. For the LEPA/diked combination with 100% irrigation, runoff was about twice that of the spray/undiked combination with a two-year, seasonal average of 22%. With the LEPA/undiked combination, two-year, average seasonal runoff percentages were 37, 46, and 52% for the 60, 80, and 100% irrigation amounts. For 1997, a year of near average rainfall, grain sorghum yields were significantly reduced by runoff for the LEPA/undiked combination. A drought occurred during the early part of the 1998 crop season, and grain yields were significantly reduced both with and without furrow dikes for the LEPA sprinkler method.*
Keywords. *Irrigation, Runoff, Sprinkler irrigation, Furrow dikes, LEPA, Spray irrigation.*

The quantity of runoff from sprinkler irrigation depends on both the potential for runoff and factors aggravating or mitigating the runoff condition. Potential runoff is defined as the portion of sprinkled water that is applied in excess of the soil infiltration rate (Kincaid et al., 1969). Infiltration rate is primarily a function of the soil texture and soil surface condition at the time of irrigation. Classical infiltration theory assumes that the soil surface is instantly saturated; yet, sprinkler application like smaller rainfall rates may not initially saturate the soil. A modified infiltration function is required to compensate for the interval, often referred to as the "time to ponding", before the soil surface is saturated. After ponding and runoff start, the severity of runoff depends on both the magnitude of the potential runoff and factors such as surface slope, soil surface roughness, and residue cover. Kincaid et al. (1969) presented data indicating larger runoff with the irrigation system moving upslope as compared to moving downslope. They reasoned that in the downslope condition, larger cumulative infiltration occurs before the potential runoff condition begins.

Soil surface modification and crop residues enhance soil infiltration and compensate for sprinkler application rates exceeding the soil intake rate. These techniques may be needed with spray irrigation, but are mandatory with LEPA irrigation. "LEPA was designed to be, for the most part, independent of soil intake rate" (ASAE, 1999). Instead of irrigating at less than the soil infiltration rate, LEPA design is based on the application volume per irrigation not exceeding the surface storage volume. Although the wetted diameter with spray heads greatly exceeds that with LEPA, surface runoff from an irrigated field can reduce the application efficiency and redistribution within the field can reduce the uniformity.

The effectiveness of soil surface modification and crop residues depends primarily on the sprinkler method, soil type, and surface slope. Aarstad and Miller (1973) used basin tillage and hay incorporated at 4.5 Mg/ha or mulched at 1.8 Mg/ha to control surface runoff from high pressure impact sprinklers on center pivot sprinkler systems. With basin tillage, runoff was reduced to only 1% of applied water. Without soil surface modification, runoff percentages were 11 and 16% for two silt loam soils with 3% slope and 17 and 41% for two loam soils with 7% slope. Runoff was less than 6% with the residue treatments, except for the hay mulch on the 7% slope that had 30% runoff. Michelson and Schweizer (1987) evaluated till-plant systems for reducing runoff from high-pressure (345 kPa) and low-pressure (138 kPa) center pivot

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sprinkler systems. For three till-plant systems, runoff from low-pressure averaged 30% larger than from high-pressure. Both runoff and soil erosion were best controlled by the least amount of tillage and by surface layer incorporation of residue before planting. Kranz and Eisenhauer (1990) used a rainfall simulator to irrigate a Hastings silt loam with a 1.0% slope at 139 mm/h and a Nora silt loam with a 10% slope at 119 mm/h. For 50 mm irrigations, the runoff amount with conventional and implanted reservoir tillage was 2.6 and 2.7 mm for the 1% slope and 12.4 and 3.9 mm for the 10% slope. Spurgeon et al. (1995) evaluated the effect of the LEPA bubble and flat (in-canopy) spray sprinkler methods and conventional, basin, or implanted reservoir tillage on corn yields. For the three respective tillage treatments, their data analysis showed yield reductions of 1.46, 1.60, and 0.90 Mg/ha for each 1% increase in slope with the LEPA bubble method and 0.71, 0.85, and 0.16 Mg/ha with the flat spray method. Buchleiter (1992) evaluated a LEPA-equipped center pivot sprinkler system with calculated application depths of 30 to 37 mm. Measured runoff amounts exceeded 30% of applied water for a 3% slope and 55% for an 8% slope.

The objectives of the field study were to:

- Measure surface runoff from full and deficit irrigation of a slowly permeable soil with the LEPA and spray sprinkler methods.
- Measure the effect of the runoff on soil water storage and grain sorghum yields.

PROCEDURE

The research was conducted at the USDA Conservation and Production Research Laboratory, Bushland, Texas (lat 35°11′N, long 102°06′W, 1170 m M.S.L. elevation) during the 1997 and 1998 grain sorghum seasons. The Pullman clay loam at the site is a fine, mixed, thermic *Torrertic Paleustoll* with a dense B21t subsoil from about 150 to 400 mm and a calcic horizon extending from about the 1.5 to 2.0 m depths. For the upper 1.47 m profile, Unger and Pringle (1981) measured 167 mm of soil water storage between the −0.033 and −1.5 MPa water potentials. At seven sites, they measured infiltration during the first 10 min of ponding ranging from 20 to 42 mm and infiltration for 20 h ranging from 81 to 120 mm. The research field had a uniform slope of 0.25% along the furrows and 0.22% perpendicular to the furrows.

EXPERIMENTAL DESIGN

The LEPA double-ended sock and Mid-Elevation Spray Application (MESA) sprinkler methods were evaluated with and without basin tillage (furrow dikes) at five irrigation amounts ranging from 0 to 100% of soil water replenishment. Full irrigation or 100% soil water replenishment is designated as I_{100}. Deficit irrigation with 0, 40, 60, and 80% of the full irrigation amount is designated as I_0, I_{40}, I_{60}, and I_{80}, respectively. Grain sorghum, planted on 0.76-m spaced beds, was the crop used to evaluate the irrigation and tillage treatments. Field plots were arranged in a randomized block design with irrigation amount treatments being the blocks and sprinkler methods being randomized within each block. The 20 treatment combinations were replicated three times, once under each span of the irrigation system. Plot size was twelve, 0.76-m rows wide along the mainline of the lateral move irrigation system by 20 m long in the direction of the furrows.

Soil water content was measured gravimetrically on all plots for determining seasonal soil water depletion and with a neutron meter on the I_{100}, LEPA/diked plots for scheduling irrigations. The gravimetric samples were collected in 0.30 m increments to the 1.8 m depth after planting and at harvest. The neutron measurements were made weekly in 0.2 m increments to the 2.3 m depth, except when rainfall made irrigation unnecessary. These measurements were made with a locally field-calibrated CPN Model 503DR (Campbell Pacific Nuclear, Martinez, California) neutron moisture meter (Evett and Steiner, 1995). The replenishment soil water level for irrigation scheduling was 75% of the plant available amount in the 1.4 m profile, which is about 410 mm of total water for the Pullman soil. Grain sorghum utilizes soil water to this depth on Pullman clay loam, but it generally does not utilize soil water from the calcareous zone (Musick and Sletten, 1966). This is a high soil water level for grain sorghum and would be a moderate to high level for corn.

IRRIGATION EQUIPMENT

Irrigations were applied with a three-span, hose-fed, Valmont Model 6000 (Valmont Industries, Inc., Valley, Nebraska) lateral move irrigation system that moved in the direction of the beds and furrows. The irrigation supply was groundwater pumped from the Ogallala aquifer, temporarily stored in a surface reservoir, and then pumped to the irrigation system at 22.8 L/s. Each system span was 39 m long and provided space for forty-eight, 0.76-m-wide beds and furrows. The LEPA and MESA sprinkler devices were both spaced 1.52 m apart to apply water into or above alternate furrows. LEPA double-ended socks (Quest & Sons, Lubbock, Texas) were attached to Senninger Super Spray (Senninger Irrigation, Inc., Orlando, Florida) heads and pulled through the furrows with the full length of the sock in contact with the soil. MESA sprinkler devices were Senninger Super Spray heads with flat, grooved deflector plates having 36 medium-sized grooves. They were positioned about 1.5 m above the ground surface or about 0.3 m above the height of the mature grain sorghum crop. The spray heads for both LEPA and MESA were equipped with 6.75 mm nozzles and 41 kPa pressure regulators. For the 25 mm irrigations, the instantaneous application rate was equivalent to that at the end of a 400-m-long center pivot with a system flow rate of 41.7 L/s. Irrigation amount was varied by varying the speed of the lateral move irrigation system with the computerized Valmont CAMS controller.

RUNOFF MEASURING EQUIPMENT

Irrigation runoff was collected at the lower end of the plots and pumped into tanks for volumetric measurement. The 20-m-long plots were diked at each end, and three wheel track and three non-wheel track furrows (beneath the sprinkler devices) were isolated for runoff measurements. The runoff water was collected in sumps constructed of 300-mm diameter, PVC irrigation pipe and then pumped into the tanks using sump pumps and 38-mm polyethylene pipe. The circular livestock watering tanks had diameters ranging from 2.13 to 2.44 m and volumes ranging from

2060 to 2700 L. The largest tanks were used for the LEPA/undiked plots, and the smallest ones were used for the spray/undiked plots. We have never observed runoff from the spray/diked combination so no runoff measuring equipment was required for these plots. The diameters of all tanks were individually measured to calculate tank areas that were used with water depth to calculate volumes. Water depths at the four quadrants of the tanks were averaged for each runoff measurement.

Cultural Practices

Cultural practices were similar to those used for high-yield, sprinkler-irrigated grain sorghum in the southern Great Plains. Table 1 lists fertility, pesticide, and crop variety information plus planting and harvesting dates for the two crop years. Both crops were grown on land that had been fallowed with sweep or disk tillage during the previous year to replenish soil water and hopefully to reduce weed, soil-borne disease and insect populations. All tillage and planting was done with six, 0.76-m-row-wide farm machinery to match the 48-row-wide spans of the irrigation system. After anhydrous ammonia fertilizer was chiseled in with 0.76-m spaced chisels during the early spring (table 1), the plot area was tandem disked and bedded with a disk bedder. The beds were then firmed and shaped with a rolling cultivator, and the grain sorghum was planted with a John Deere Max-Emerge (John Deere, Moline, Illinois) planter. When the sorghum was about 0.2 m tall, it was cultivated with a rolling cultivator, and the furrow-diked plots were diked with a Bigham (Bigham Brothers, Lubbock, Texas) trip and roll diker. During both years, additional nitrogen as 28-0-0 liquid urea was applied with the irrigation water (table 1).

Grain yields were measured by either combine harvesting or hand harvesting. In 1997, a 1.52-m-wide Hege plot combine was used to harvest the full length of the four center rows of each plot. In 1998, hand samples were collected from 9.1 m of the center rows of each plot and threshed with the Hege combine. After weighing the grain samples, a sub-sample was dried to determine grain moisture content, and duplicate or triplicate weights of 500 seeds were determined. Grain yields and water use efficiencies are based on 14% grain moisture content (wet basis).

Irrigation Procedure

Dates and amounts of preplant and emergence irrigation for the two crop years are listed in table 1. In 1997, an emergence irrigation and a small irrigation to soften the soil crust were sufficient to obtain germination and crop establishment. Drought conditions existed during the spring of 1998, and two preplant irrigations were required in addition to two emergence irrigations. Preseason and emergence irrigations were applied with Senninger Super Spray heads to obtain crop emergence with the minimum amount of irrigation water. The first seasonal irrigation after furrow diking was also applied with spray heads to settle the soil in the furrow dikes before LEPA irrigating.

The dates and amounts of the I_{100} irrigations are illustrated in figure 1, and seasonal irrigation amounts for all irrigation treatments are listed in table 1. The target I_{100} irrigation amount was 25 mm, but actual irrigation amounts were calculated from the time of irrigation over each plot. Irrigation frequencies for the two years reflect the rainfall distribution. With near normal rainfall during late May and early June of 1997, the first seasonal irrigation was applied on 24 June. Later, an interval of above average rainfall during late July and early August made seasonal irrigation unnecessary for a 17-day interval in early August. With the limited amount of rainfall in 1998, the first seasonal irrigation was applied on 16 June, and 21 additional irrigations, generally two per week, were applied until 31 August.

Tables 2 and 3 list values for total water use, seasonal water use efficiency (WUE) and irrigation water use efficiency (IWUE). Total water used is defined as the sum of seasonal soil water depletion, irrigation during the growing season and rainfall. It includes the runoff amounts for evaluation of the total irrigation water applied. WUE is reported as grain yield divided by total water use, and

Table 1. Agronomic and irrigation data for the two grain sorghum crops

Variable	1997	1998
Fertilizer applied to I_{100}	140 kg(N)/ha preplant 50 kg(N)/ha with irrigation	140 kg(N)/ha preplant 40 kg(N)/ha with irrigation
Herbicide applied	Atrazine 2.2 kg(AI)/ha	Atrazine 2.2 kg(AI)/ha
Grain sorghum variety	Pioneer 8212Y	Pioneer 8212Y
Planting date	23 May	18 May
Harvest dates	24 September	25 September
Preplant irrigations	None	11 May-25 mm 13 May-25 mm
Emergence irrigations	27 May-25 mm 2 June-6 mm	21 May-25 mm 27 May-10 mm
First seasonal irrigation	24 June	16 June
Last seasonal irrigation	2 September	31 August
I_{40} Seasonal irrigation	173 mm	236 mm
I_{60} Seasonal irrigation	252 mm	357 mm
I_{80} Seasonal irrigation	329 mm	471 mm
I_{100} Seasonal irrigation	398 mm	578 mm

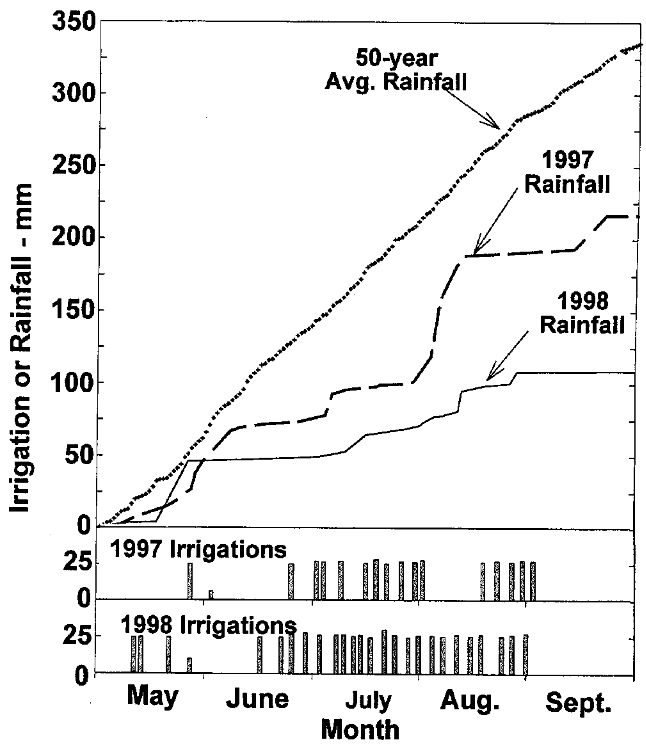

Figure 1–Irrigation and rainfall amounts for the 1997 and 1998 grain sorghum seasons and 50-year average rainfall for the grain sorghum season.

Table 2. Seasonal soil water depletion, total water use, water use efficiencies, and seed mass for 1997

Irrigation Amount (%)	Sprinkler Method	Furrow Dike	Soil Water Depl. (mm)	Total* Water Use (mm)	WUE† (kg/m^3)	IWUE (kg/m^3)	Seed Mass (mg/ seed)
0			177	401	0.42	---	17.4
40	LEPA	Diked	116	488	1.25	2.54	19.1
	LEPA	Undiked	139	512	1.23	2.65	21.3
	Spray	Diked	127	500	0.96	1.80	20.0
	Spray	Undiked	155	527	1.09	2.34	20.2
60	LEPA	Diked	126	577	1.29	2.28	22.5
	LEPA	Undiked	144	596	0.97	1.61	21.3
	Spray	Diked	144	595	1.13	2.00	21.7
	Spray	Undiked	154	605	1.18	2.16	24.3
80	LEPA	Diked	121	649	1.33	2.11	23.4
	LEPA	Undiked	125	653	1.15	1.76	21.9
	Spray	Diked	101	629	1.44	2.23	25.5
	Spray	Undiked	114	642	1.39	2.20	25.1
100	LEPA	Diked	98	696	1.20	1.67	23.0
	LEPA	Undiked	118	715	1.01	1.39	23.6
	Spray	Diked	83	680	1.42	2.00	25.9
	Spray	Undiked	133	730	1.30	1.96	25.1
			Irrigation Amount Averages				
0			177	401	0.42c	---	17.4
40			135	507	1.13b	2.33b	20.2
60			140	593	1.14b	2.01a	22.4b
80			117	646	1.33a	2.08b	24.0ab
100			108	705	1.23ab	1.75a	24.4a
			Sprinkler Method Averages				
LEPA			134	568	1.02a	2.00a	21.1a
Spray			137	571	1.08a	2.09a	22.2a
			Diking Averages				
Diked			128	562	1.08a	2.08a	21.6a
Undiked			143	578	1.02a	2.01a	21.8a

* Includes soil water depletion, irrigation, and 199 mm of precipitation during the growing season.

† Averages followed by the same letter are not significantly different ($p \le 0.05$).

Table 3. Seasonal soil water depletion, total water use, water use efficiencies, and seed mass for 1998

Irrigation Amount (%)	Sprinkler Method	Furrow Dike	Soil Water Depl. (mm)	Total* Water Use (mm)	WUE† (kg/m^3)	IWUE (kg/m^3)	Seed Mass (mg/ seed)
0			145	250	0.61	---	18.7
40	LEPA	Diked	103	444	1.24	1.68	21.0
	LEPA	Undiked	154	495	1.12	1.71	22.4
	Spray	Diked	145	486	1.14	1.69	23.3
	Spray	Undiked	152	493	1.22	1.91	24.1
60	LEPA	Diked	40	502	1.12	1.15	17.0
	LEPA	Undiked	107	569	0.92	1.04	20.4
	Spray	Diked	65	527	1.24	1.40	18.1
	Spray	Undiked	74	536	1.14	1.27	18.5
80	LEPA	Diked	29	605	0.82	0.73	17.6
	LEPA	Undiked	89	665	0.85	0.88	19.8
	Spray	Diked	36	612	1.12	1.13	18.3
	Spray	Undiked	17	593	1.03	0.97	17.0
100	LEPA	Diked	53	736	0.63	0.54	15.3
	LEPA	Undiked	92	775	0.61	0.56	17.5
	Spray	Diked	–38	645	1.16	1.03	18.9
	Spray	Undiked	88	770	0.91	0.94	19.1
			Irrigation Amount Averages				
0			145	250	0.61	---	18.7b
40			127	480	1.18c	1.75a	22.7a
60			57	533	1.10bc	1.22b	18.5b
80			23	619	0.96ab	0.93c	18.2b
100			49	731	0.83a	0.77d	17.7b
			Sprinkler Method Averages				
LEPA			96	530	0.85b	1.04b	18.8a
Spray			82	516	1.02a	1.29a	19.5a
			Diking Averages				
Diked			71	504	0.97a	1.17a	18.7b
Undiked			108	541	0.90b	1.16a	19.6a

* Includes soil water depletion, irrigation, and 105 mm of precipitation during the growing season.

† Averages followed by the same letter are not significantly different ($p \le 0.05$).

IWUE is reported as irrigated grain yield minus the I_0 grain yield divided by the seasonal irrigation amount.

Results

Runoff

Runoff was measured during 13 of 15 seasonal irrigations in 1997 and 16 of 22 seasonal irrigations in 1998. Runoff as a percent of total irrigation applied during the measured irrigations is illustrated in figure 2. For all treatments, runoff was essentially zero for I_{40} but then increased with irrigation depth for the three larger irrigation amounts. For the spray/undiked treatment, runoff was minimal with I_{60} but then increased to an average of 7% for I_{80} and 12% for I_{100}. Runoff for the LEPA/diked treatment was approximately twice that of the spray/undiked treatment with average runoff percentages of 6, 12 and 22% for I_{60}, I_{80} and I_{100}, respectively. Runoff for the LEPA/undiked treatment increased from a negligible amount with I_{40}, to 37% for I_{60} and 46 and 52% for I_{80} and I_{100}. The main difference between the LEPA/undiked treatment and the others was the large increase in percent runoff between the I_{40} and I_{60} irrigation amounts. For the three larger irrigation amounts, furrow diking reduced seasonal runoff from LEPA by 30 to 32%.

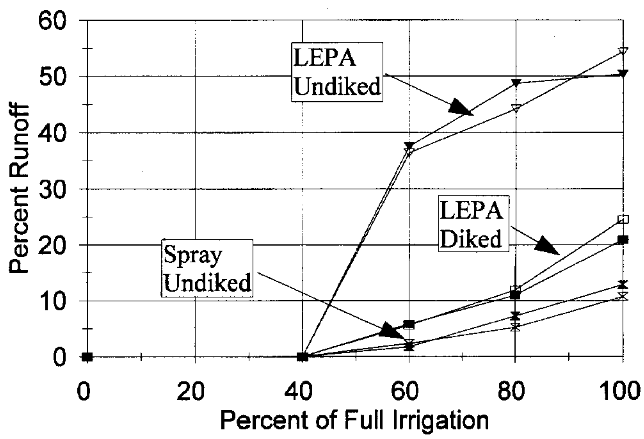

Figure 2–Seasonal runoff as a percent of sprinkler applied water. Solid symbols are for 1997, and open symbols are for 1998.

Runoff amounts increased during the growing season for the LEPA and the spray/undiked treatments. With recently tilled soil and new furrow dikes, there was little or no runoff from any treatments during the first three or four irrigations. The largest temporal increase occurred with the LEPA/diked treatments that were affected by both reduced infiltration and furrow dike erosion. The smallest temporal increase was with the spray/undiked treatments. In 1997, runoff amounts were slightly larger with the irrigation system moving downslope, but in 1998 this trend reversed.

Soil Water

Changes in soil water storage for the I_{100} irrigation plots illustrate the effect of runoff from the plot areas. As illustrated in figure 3, the LEPA/diked irrigation control treatment had little change in soil water during the 1997 cropping season. Soil water in both spray treatments was similar to the control treatment. In the LEPA/undiked treatment, soil water depletion occurred during most of the growing season except for the 19 August measurement. Then, early-August rainfall caused the soil water contents for all irrigation treatments to return to near their early season level.

The drought conditions in 1998 caused a different pattern in soil water storage (fig. 4). Even with 22 seasonal irrigations, soil water in the LEPA/diked treatment declined except for a short interval during mid-August. Soil water storage in the spray/undiked treatment remained the most consistent. In the spray/diked treatment, soil water storage increased, especially during the later half of the growing season. A major reduction in soil water storage occurred for the LEPA/undiked treatment with only a minor recovery from the August rainfall.

Profile soil water after the last seasonal irrigation is illustrated in figures 5 and 6 for the I_{100} irrigation treatment. On 4 September 1997 soil water for both spray treatments and the LEPA/diked treatment was similar, but for the LEPA/undiked treatment it was much lower. For example, in the 1.4-m profile, the LEPA/diked and spray/diked treatments had 49 and 56 mm more soil water than the LEPA/undiked treatment. On 6 September 1998, both spray treatments had larger soil water contents than the LEPA treatments, and for the spray/diked treatment the difference was especially large. The 1.4-m-profile soil water contents for the spray/diked and spray/undiked treatments were 118 and 59 mm larger than for the LEPA/undiked treatment. The 0.31-m^3/m^3 soil water content at the 2.3 m depth of the spray/diked treatment suggests that deep percolation was occurring.

Grain Yields and Water Use Efficiency

Grain yields are illustrated in figures 7 and 8 for the two respective years. In 1997 grain yields for the I_0 through I_{80} irrigation amounts and the sprinkler methods were all significantly different. There was no significant yield difference between diked and undiked furrows. Significant interactions ($p \le 0.05$) occurred between the irrigation amounts and methods and between the methods and diking. The reduced grain yields for LEPA/undiked treatments with I_{60}, I_{80}, and I_{100} irrigation amounts illustrate the effect of large runoff amounts and reduced soil water storage. The similar grain yields with 80 and 100% irrigation of the

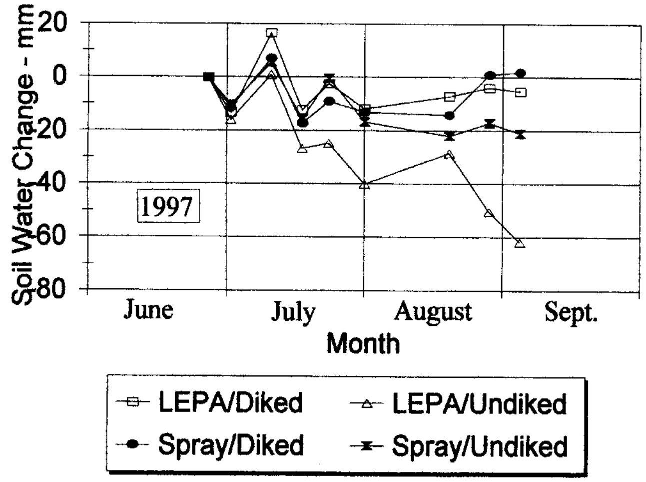

Figure 3–Change in soil water in the 1.4 m profile of the I_{100} plots during the 1997 irrigation season.

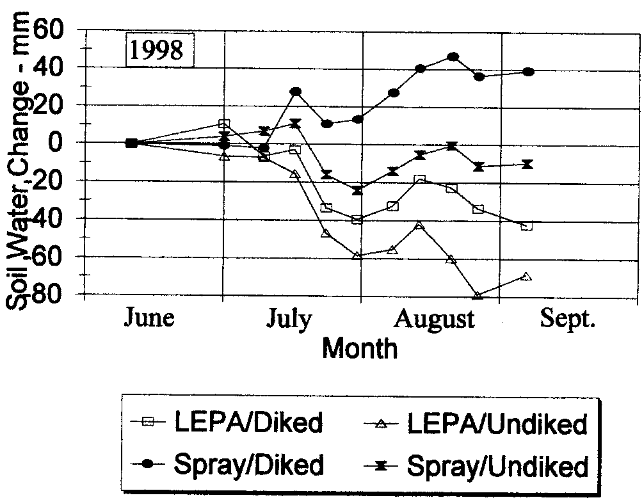

Figure 4–Change in soil water in the 1.4 m profile of the I_{100} plots during the 1998 irrigation season.

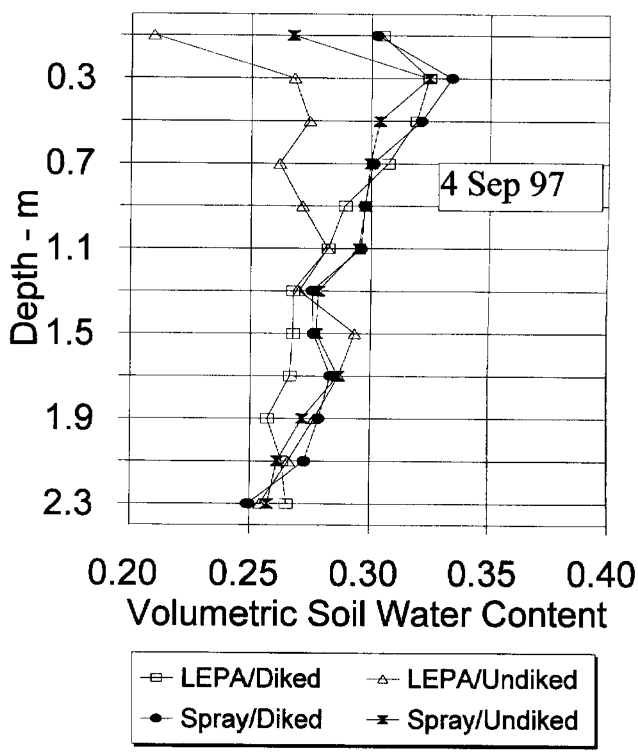

Figure 5–Soil water to the 2.3 m depth for the I_{100} plots on 4 September 1997.

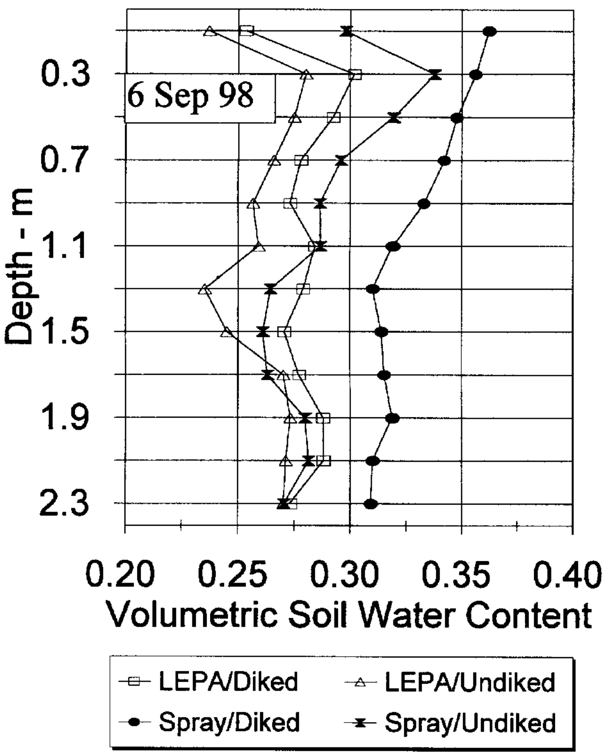

Figure 6–Soil water to the 2.3 m depth for the I_{100} plots on 6 September 1998.

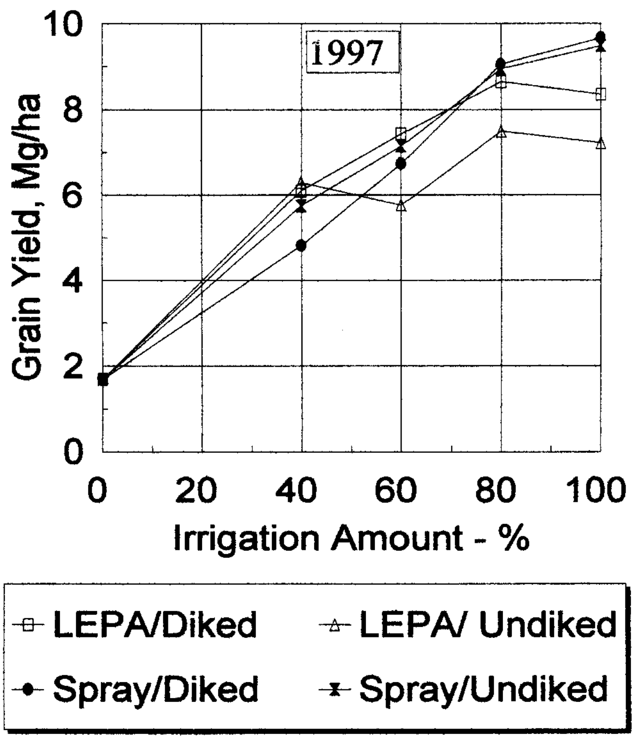

Figure 7–Grain sorghum yields for all treatments for 1997.

LEPA/diked treatment illustrate the effect of the increased runoff percentage for 100% irrigation.

Reduced grain yields in 1998 show the effects of extreme drought and heat during the early part of the growing season. For the spray method, yields continued to

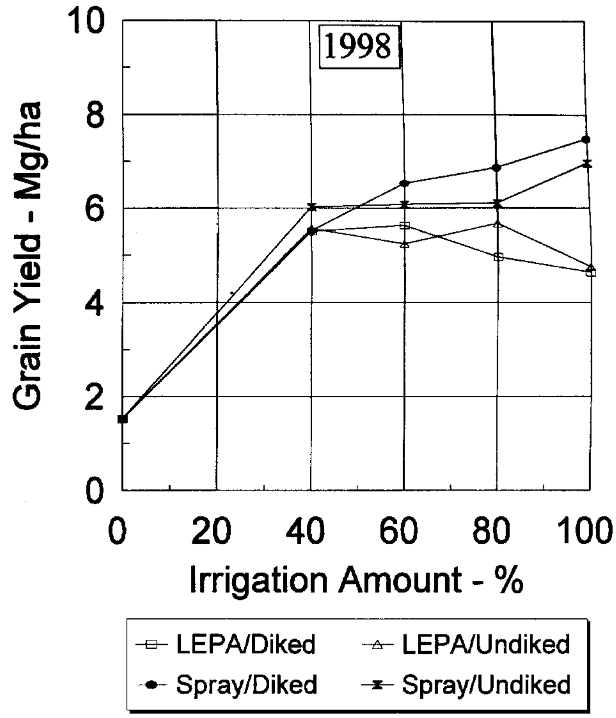

Figure 8–Grain sorghum yields for all treatments for 1998.

increase over the full range of irrigation but at a lesser rate for irrigation amounts larger than 40%. For the LEPA method, maximum yields occurred with 40% irrigation and then decreased slightly for the larger irrigation amounts. Significant yield differences occurred among the I_0 to I_{60} irrigation amounts and between the LEPA and spray sprinkler methods. As in 1997, there was no significant yield difference due to furrow diking.

WUE and IWUE for the two crop years are listed in tables 2 and 3. For both years, WUE varied significantly among irrigation amounts. In 1997, water use efficiencies were largest with I_{80} and I_{100}, but in 1998, the water use efficiency was largest with I_{60}. In the drought year of 1998, WUE was significantly larger with the spray method than the LEPA method and with the diked than the undiked furrows. IWUE also varied significantly among the irrigation amounts. For both years it was largest with I_{40} and smallest with I_{100}. In 1998, IWUE was significantly larger for the spray method than the LEPA method.

In 1997, seed mass increased with irrigation amount but the differences for the I_{60} to I_{80} and I_{80} to I_{100} increments were not significant. In 1998, the seed mass with I_{40} was significantly larger than for the other irrigation amounts, and seed mass with the diked and undiked furrows was significantly different.

Soil water depletion and total water use are listed in tables 2 and 3 for the two respective years. In 1997, seasonal depletion decreased with irrigation amount but averaged 100 mm or more for all irrigation amounts. Total water use in 1997 ranged from 401 mm for I_0 to 705 mm for I_{100}. In 1998, soil water depletion for I_0 and I_{40} was similar to that in 1997. For larger irrigation amounts, depletion was less than the previous year because of the small or negative depletion of the spray/diked treatment.

In 1998, total water use ranged from 250 mm for I_0 to 731 mm for I_{100}.

Discussion

This study quantifies the large amounts of runoff that can occur with LEPA and spray irrigation of a slowly permeable soil even with the relatively flat slope of 0.25% in the direction of the furrows. The largest runoff potential occurred when irrigating to maintain soil water levels in the upper half of the plant available range. Under drought conditions in 1998, LEPA-irrigated alternate furrows remained wet and lost the capacity to infiltrate the large instantaneous applications required to meet crop evapotranspiration. This reduced intake condition did not occur as readily for spray irrigation where the entire soil surface was available for infiltration.

The grain sorghum yields in 1997 are more typical of high-yield, irrigated production in the southern Great Plains than those in 1998. Yields with the I_{100} irrigation amount applied by the spray method averaged 9.58 Mg/ha in 1997, an above average yield for the area. Yields with the LEPA/diked combination were similar to those of the spray method except with the I_{100} treatment. Only the LEPA/undiked combination with large amounts of runoff resulted in reduced yields for the three larger irrigation amounts. In 1998, grain yields with the I_{40} treatment were similar to those in 1997. For the larger irrigation amounts, there were small incremental yield increases for the spray method and small reductions for the LEPA method. Because of extreme heat and drought, grain sorghum did not reach its yield potential as it did in 1997.

The soil water and grain yield data for the I_{100} treatment illustrate that rainfall during the growing season tends to mitigate the effects of runoff. In 1997, for example, soil water in the I_{100} treatment LEPA plots was beginning to be depleted by late July. The 100 mm of rainfall in early August then raised or maintained the soil water for all treatments through mid-August. In 1998, major soil water depletion began in early July for all treatments, except the spray/diked one. A slight recovery from the August rainfall occurred for all treatments, but major depletion then resumed for the LEPA treatments.

Conclusions

Furrow dikes and spray irrigation were a highly efficient combination that retained all irrigation and rainfall at the point of application. Without furrow dikes, maximum runoff from spray irrigation was 10% or more of the seasonal irrigation, but reductions in soil water storage and grain yields were small. Furrow diking provided adequate initial storage capacity for LEPA, but the storage capacity decreased during the irrigation season. Maximum seasonal runoff from LEPA with furrow dikes was 20% or more of the applied water, and reductions in soil water storage and grain yields became significant. Without furrow dikes, runoff from LEPA ranged from 35 to more than 50% of the applied water for the three larger irrigation amounts. Reductions in soil water storage and grain yields were unacceptably large.

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