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LEPA IRRIGATION MANAGEMENT FOR CORN

by

T.A. HOWELL, A. YAZAR, A.D. SCHNEIDER,
D.A. DUSEK, and *K.S. COPELAND*

USDA-Agricultural Research Service
Conservation and Production Research Laboratory
P.O. Drawer 10
Bushland, Texas USA

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Summary:

LEPA irrigation of corn was evaluated on Pullman clay loam at Bushland, TX, during 1992 and 1993. The 1992 growing season was wetter than normal, and the 1993 season was more representative of normal. Corn responded similarly to LEPA irrigation compared to more traditional methods such as graded furrow and sprinkler; however, LEPA permitted greater partitioning of the applied water into crop water use.

Keywords:

center pivots, corn, cultural practices, evapotranspiration, irrigation, LEPA, management, soil water use, sprinkler irrigation, water, water use efficiency

LEPA IRRIGATION MANAGEMENT FOR CORN [1/]

T. A. Howell [2/], A. Yazar [3/], A. D. Schneider [2/],
Fellow Member

D. A. Dusek [2/], and K.S. Copeland [2/]

ABSTRACT

Center pivot sprinklers are rapidly expanding on the Southern High Plains, and LEPA application methods are widely used in this region to reduce water application losses, to use the low and marginal well yields, and to reduce energy requirements for pressurization. This study was conducted to evaluate LEPA irrigation response of corn [*Zea mays* L.] on the slow permeability Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll). The effects of irrigation amount were investigated in a field study during the 1992 and 1993 cropping seasons at Bushland, TX. In 1992, a wetter than normal season, grain yields varied from 0.6 to 1.2 kg/m^2 while in 1993, which was a season with slightly less than normal rain, grain yields varied from 0.4 to over 1.5 kg/m^2 as irrigations increased from no post plant irrigations to fully meeting the crop water use. Irrigation amounts for the full irrigation varied from only 279 mm for the wet year to over 640 mm for the more normal year. A significant relationship was found between grain yield and water use for the two years described as GY (kg/m^2) = 0.00169 [WU (mm) - 147] with an r^2 of 0.882 and a $S_{y/x}$ of 0.10 kg/m^2. Deficit irrigation of corn, even with LEPA, reduced yields by affecting both seed mass and kernels per ear. Generally, the grain yield was proportional to dry matter yield. LEPA irrigation was shown to be efficient in terms of partitioning the applied water into crop water use. Irrigation amounts should not exceed 25 mm for alternate row (0.76-m rows) LEPA on the Pullman type soils with furrow dike basins.

KEYWORDS

center pivots, corn, cultural practices, evapotranspiration, irrigation, LEPA, management, soil water use, sprinkler irrigation, water, water use efficiency

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2/Research Leader (Agric. Engr.), Agricultural Engineer, Agronomist, and Biological Technician, USDA-ARS, P.O. Drawer 10, Bushland, TX 79012.

3/Associate Professor, Cukurova University, Department of Agricultural Engineering, Adana, Turkey (visiting Fulbright Fellow).

INTRODUCTION

Irrigation is important for sustainable agriculture on the Southern High Plains, an area encompassing the high plains of Texas, New Mexico, Oklahoma, southwestern Kansas, and southeastern Colorado. Irrigation water supplies in this region are mainly from groundwater sources (Ogallala aquifer) and are being depleted. Musick et al. (1990) reviewed the irrigation trends on the Texas High Plains portion of this region and reported a 28% decline in irrigated area from 1974 to 1989 with a 44% corresponding decline in groundwater use during this period.

The major irrigated crops on the Texas High Plains are cotton, winter wheat, grain sorghum, and corn (Musick et al., 1990). Of these crops, corn has the greatest reported seasonal irrigation requirement (Musick et al., 1990). Major expansion of the sprinkler irrigated land area, predominately center-pivot sprinklers, has reduced water applications and sustained irrigated production in this region (Musick et al., 1990; and Musick and Walker, 1987).

Low energy precision application (LEPA) irrigation was developed to reduce sprinkler irrigation losses associated with droplet evaporation and drift in the high winds which commonly occur in this region, thereby saving water and energy (Lyle and Bordovsky, 1981). Originally, bubble mode LEPA applications were made to individual furrows (Lyle and Bordovsky, 1981) using furrow dikes or dams to provide temporary surface detention for the water. Later, Lyle and Bordovsky (1983) reported advantages for alternate-furrow LEPA compared to every-row LEPA besides the obvious reduction in hardware costs. Currently, LEPA devices are commercially available to operate in the bubble, spray, or chemigation modes (inverted canopy spray) (Fipps and New, 1990) as well as, double-ended socks (Fangmeier et al., 1990). Lyle and Bordovsky (1983) reported irrigation application efficiencies for LEPA of 88% for conventional tillage and 99% for basin tillage compared to 81% and 84% for sprinkler applications, respectively, and 86% to 87% for furrow applications, respectively. Schneider and Howell (1990) reported application efficiencies based on weighing lysimeter irrigations of 96% for LEPA, 82% for impact sprinklers, and over 100% for spray heads, which were affected more than the impact sprinkler applications by local catch from edge plants on the weighing lysimeter (inside and outside the lysimeter) caused by the close position of the spray heads to the top of the canopy.

Howell and Phene (1983) reported static uniformities of 98% similar to those found by Lyle and Bordovsky (1981) and suggested that below canopy spray LEPA application losses were about 10%. Hanson and Wallender (1986) found higher dynamic application uniformities for lateral-move sprinklers near the more constant move end towers and lower uniformities near the center of typical electrical powered systems. Hills et al. (1988) reported that application efficiency, however, was not related to system speed for a lateral-move sprinkler. Hanson et al. (1988) simulated LEPA infiltration uniformity using measured tower movements and soil infiltration characteristics for various lengths of furrow dike spacings. For short dike spacings, they found infiltration uniformity was controlled by system movement uniformity, but for longer dike spacings, infiltration uniformity was controlled more by soil infiltration variability. Buchleiter (1988) reported no runoff from LEPA applications on slopes of 1% or less, but for slopes greater than 3%, runoff was excessive and redistribution of LEPA applications occurred even for a system with a static uniformity of 96%. Fangmeier et al. (1990) reported no effects of system movement variations on simulated application uniformity with furrow dike spacings greater than 3 m. Lyle and Bordovsky (1986) have developed continuous move electric-powered LEPA systems (both for lateral moves and center pivots, personal communication W.M. Lyle, 1992) to achieve greater movement and application uniformity with LEPA systems.

Bordovsky et al. (1992) reported that 3 d irrigation frequencies performed well with deficit LEPA irrigation of cotton. Bordovsky and Lyle (1991) reported that 3 d and 6 d irrigation frequencies performed better than 9 d and 12 d frequencies for LEPA irrigated corn, but that corn could not be deficit irrigated as effectively as cotton at Halfway, TX, in the Southern High Plains. Spurgeon and Makens (1991) reported that LEPA irrigation frequencies between 3.5 and 10.5 d did not greatly affect corn yields at Garden City, KS, in the Central High Plains. They also reported that a 0.7 deficit treatment only reduced corn yields by about 10%. Howell et al. (1991) reported that LEPA performed similarly to other more traditional methods at Bushland, TX, for irrigating corn and sorghum, but that LEPA was more effective in partitioning the applied water into actual crop water consumption. Schneider and Howell (1993) found LEPA methods using the double-ended Fangmeier sock and the bubble mode produced better grain yield than LEPA in a below-canopy spray and overhead spray irrigation for sorghum. The LEPA methods produced higher yields than the other methods as the irrigation deficit increased.

Center pivot sprinkler systems are an economical, practical irrigation method for the Southern High Plains region, particularly since growing season rainfall can be relied on to partially meet the crop water needs thereby reducing the gross irrigation capacity. Center pivot sprinkler irrigation (Splinter, 1976) is well suited to this environment where land resources are not the major limitation, but water resources are restricted. Variable irrigation application rates have been used with center pivots (Gilley et al., 1983; Helweg, 1988; Howell et al., 1989) to study infiltration and crop production functions for crops. Heermann et al. (1994) chronicled the U.S. advances of center pivots from under 1/4 million ha in 1966 to over 5.5 million ha of pivots and lateral moves in 1993, and they described the many advances made in irrigation application methods and management. The driving force for center pivot expansion in the Southern High Plains continues to be 1) water conservation, 2) labor savings and convenience, and 3) more effective use of low yielding wells in pressurized distribution application systems. The main impetus seems to be a stable energy price outlook and favorable interest rates to finance the capital improvement — two important factors in the economics of center pivot adoption in the Southern High Plains.

Crop yield response to irrigation and water use have been widely studied for corn. Reviews of crop yield responses to irrigation are available in Doorenbos and Kassam (1979), Stegman et al. (1980), Hanks and Rasmussen (1982), Taylor et al. (1983), Howell (1990), and Howell et al. (1990) as well as several other reviews. Production functions have been widely used to describe the yield response of crops to applied water (Hexem and Heady, 1978; Vaux and Pruitt, 1983; Yaron and Bresler, 1983; etc.).

The objective of this paper is to report two years of research on the water use and yield response of corn to LEPA irrigation on a soil with slow permeability in the Southern High Plains environment. In addition, water use efficiency and water use partitioning from the applied irrigation water were investigated.

METHODS

This study was conducted at the Conservation and Production Research Laboratory, Bushland, TX [35°-11′ N lat.; 102°-06′ W. long.; 1170 m elev. MSL] during 1992 and 1993. The soil at this site is classified as Pullman clay loam [fine, mixed, thermic Torrertic Paleustoll] (Unger and Pringle, 1981; Taylor et al., 1963) which is described as slow permeability because of a dense B22 horizon about 0.3 to 0.5 m below the surface. This soil has a water holding capacity of approximately 200 mm of plant available water to the 2.0 m depth. A calcic layer at about 1.5 m significantly limits water extraction by corn below this depth (Musick and Dusek, 1980). This soil is common to over 1.2 million ha of land in this region and about 1/3 of the sprinkler irrigated area in the Texas High Plains (Musick et al., 1988). The field slope is less than 0.3%.

A 3-span Lockwood [1/] center pivot sprinkler system (135 m long) was used in this study. The system was equipped with 19 mm O.D. (3/4 in.) metal drop pipes to about 2 m above the ground spaced 1.5 m apart along the system. A 1/4 turn 19 mm ball valve was placed directly beneath the steel pipe, and a Senninger Quad IV LEPA head with a 41 kPa pressure regulator was mounted on a flexible hose to about 0.3 m above the ground on each drop pipe. A Senninger adapter replaced the Quad IV spray plate and permitted a short length of flexible hose and a double-ended Fangmeier LEPA sock to be attached to the Quad IV LEPA head. The system operated with the normal Lockwood pivot controls at 0.033 Hz (30 s) motor controls. In 1993, a Valmont CAMS (computer assisted management system) was added for pivot control, but the same 0.033 Hz movement was maintained. Water to the system was pumped from an above-ground regulating reservoir supplied from

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[1/] 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.

wells in the Ogallala aquifer. Water was metered at the center pivot with a Rockwell turbine water meter. The design nozzle sizes were determined from

$$q_i = C\,A_i \qquad ...[1]$$

where q_i is the flow rate in L/s for the ith LEPA applicator, C is the irrigation capacity in L s^{-1} m^{-2}, and A_i is the service area in m^2 of the ith LEPA applicator, which is given as:

$$A_i = 2\,\pi\,(R_i\,r) \qquad ...[2]$$

where r is the spacing in m served by the LEPA applicator (1.52 m) and R_i is the radius in m from the pivot point to the LEPA applicator. The nozzle diameter was selected from the Senninger handbook (nearest actual nozzle diameter was 0.397 mm). The design value of C was selected to simulate the outer application rate for a 400 m (1/4 mi.) center pivot with a 8.1 mm/d (6 gpm/ac) irrigation capacity (flow rate/unit area). The outer LEPA drop flow rate was 0.32 L/s (5.1 gpm) to apply a uniform 25 mm application in about 27 hr for a full circle. The maximum outer tower travel speed was 0.038 m/s (7.5 ft/min). Irrigation application amounts were determined by the application rates and system travel speed, set and measured with stopwatches. The wheel tracks were maintained on raised beds for each tower and kept dry from irrigations to avoid any wheel slippage.

The northwest quarter of the field was planted with Pioneer 3245 in 1992, and the south half was planted in 1993 with the same hybrid. The entire field had been fallowed in 1991 and both crops were started on previously fallowed soil (1 year of fallow for the 1992 experiment and 2 years of fallow for the 1993 experiment). Plots were laid out circularly around the center pivot using six rows per plot with a row spacing of 0.76 m. Each plot had three LEPA applicators which applied water to alternate furrows, which were non-wheel traffic furrows. The LEPA nozzle size for each plot was determined by equations [1 and 2] based on the radius to the central furrow of each plot. The three LEPA applicators in each plot used the same nozzle diameter despite the small difference in radius. Each plot was diked on the end to minimize runoff from the plot, although water movement was permitted around the plot.

Commercial farm equipment was used in all farming operations. Prior to planting, nitrogen fertilizer was applied each year (Table 1) and beds were formed using a disk bedder. Furrow dikes were installed following lay-by cultivation prior to LEPA irrigations in both years using a Roll-A-Cone bump-wheel diker in 1992, and a Bingham Brothers trip-roll diker in 1993. The dike spacings in both years was about 3 to 4 m.

TABLE 1. Agronomic data for the LEPA experiments.

Parameters	1992	1993
Planting Date	21 April [112] 1/	20 April [110]
Emergence Date	30 April [114]	3 May [123]
Tasseling Date	11 July [193]	15 July [196]
Harvest Date	6 October [280]	22 September [265]
Plant Density	4.5 plants/m^2	8.4 plants/m^2
Fertilizer (preplant) Material Rate Date	NH_4 13.4 g(N)/m^2 25 March [85]	NH_4 6.7 g(N)/m^2 March 29 [88]
Pesticides Material Date Material Date Material Date Material Date	Atrazine 23 April [114] Accent 19 May [140] Lorsban 1 August [214]	Atrazine 12 April [102] Accent 23 June [174] Capture/Dimethoate 24 July [205] Ambush/Dimethoate 18 August [230]

1/ Numbers in brackets are the day of year corresponding to the date.

The experimental design was a complete randomized block with three replications, and the main treatments were irrigation levels. The treatments were named T-100, T-80, T-60, T-40, T-20, and T-0, respectively. T-100 was designed to be a full replenishment of soil water use from a 1.5 m profile. A control soil water content profile amount of 500 mm for the 1.5-m depth (0.333 m^3/m^3 mean soil water content) was maintained for T-100. The other treatments received proportional amounts to T-100 as indicated, respectively, and were all irrigated simultaneously. T-0 was a non-irrigated (no post emergence irrigation) control treatment and should not be considered as a "normal dryland" treatment because of the irrigated plant density.

The cultural management was uniform as outlined in Table 1, except post emergence fertility. Overall, fertility management for T-100 was based on pre-plant soil samples and laboratory fertilizer recommendations. Post emergence fertilizer (Urea; 28-0-0) was applied by chemical injections proportional to flow rate (Inject-O-Meter and Howard Hutchings in 1992 and 1993, respectively). The T-100 treatment was designed to receive water needs to meet the crop demand and adequate fertility so that fertility would not limit yield. The other treatments received reduced nitrogen applications (proportional to their irrigation rates), but fertility was not designed to be a limiting variable. The soil water contents in T-100 were determined weekly by soil water measurements using a neutron probe (Campbell Pacific model 503DR Hydroprobe) at 0.2-m depth increments over a 2.4 m profile with 32 s counts and every three weeks in the other treatments during the seasons. The probe was field calibrated for the Pullman soil. Irrigation amounts were between 12 and 38 mm (25 mm was the typical amount to T-100), and irrigation frequency did not exceed three or four per week. Table 1 provides information on planting dates for the crops and other agronomic information.

Biomass samples of eight consecutive plants in a single row were harvested at three-week intervals in the T-100, T-60, and T-20 plots. The length of the sample (midpoint between the end plants and the next outside plant) was measured to compute the sample area. A single representative plant subsample was selected, and its leaves were separated from the stem and their area determined using an optical leaf area meter. The leaves from all the plants were removed as well. The ears (if present) were removed and counted, and then the ears, stems, leaves, and the leaf subsample were oven dried at 70°C. Biomass and leaf area index were computed from these data. The leaf area for the whole sample was estimated as the product of the total leaf mass and the specific leaf area (m^2/kg) of the subsample.

Final grain and biomass yield were determined by hand harvesting two adjacent center rows in each plot in close proximity to the neutron tube sites. The harvest area was 4.56 m^2 in 1992 and 10 m^2 in 1993. The number of plants and ears was counted in each row, and the plants from a single row were used for a harvest index subsample and the whole yield sample was used for grain yield. The biomass and ears were dried at 70°C in an oven, and seed mass was determined for a 500 kernel subsample. Yield components of kernel numbers and kernels per ear were computed based on the grain yield, mean kernel mass, and numbers of ears. The ears were shelled by hand.

Water use was estimated based on a one-dimensional soil water balance using the neutron soil water measurements and assuming that runoff and deep percolation were negligible. Water use was the total of seasonal soil water depletion (emergence to harvest) plus rainfall and irrigations during the same time period. Water use efficiency was computed as the ratio of grain (dry basis) to water use.

RESULTS and DISCUSSION

The 1992 growing season had higher than normal rainfall of 431 mm during the season (Table 2 and Figure 1), and the 1993 season was more typical of normal rainfall patterns with only 241 mm of rainfall during the season. Both seasons had single-day rainfall amounts exceeding 50 mm. Air temperatures in 1992 were

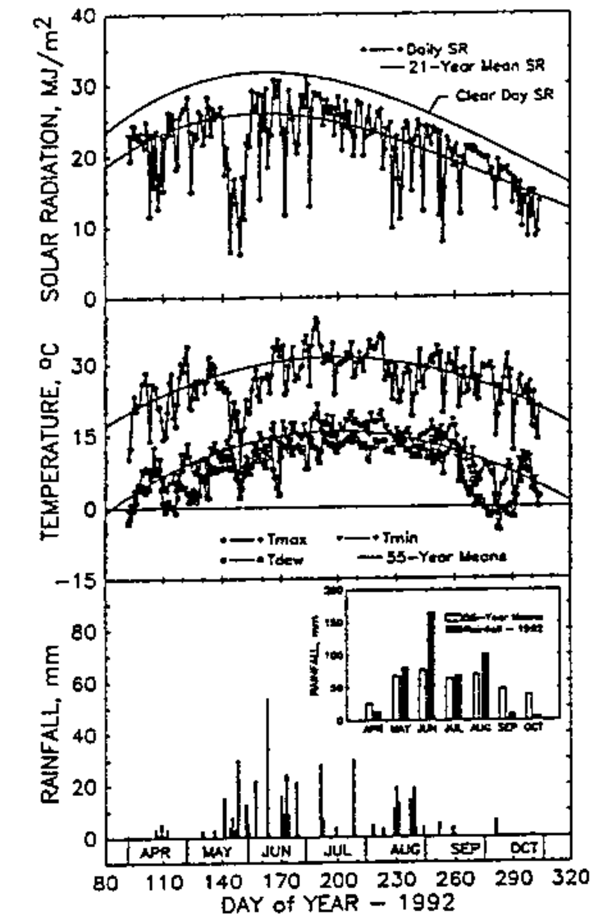

Figure 1. Climatic data summary for 1992 at Bushland, TX.

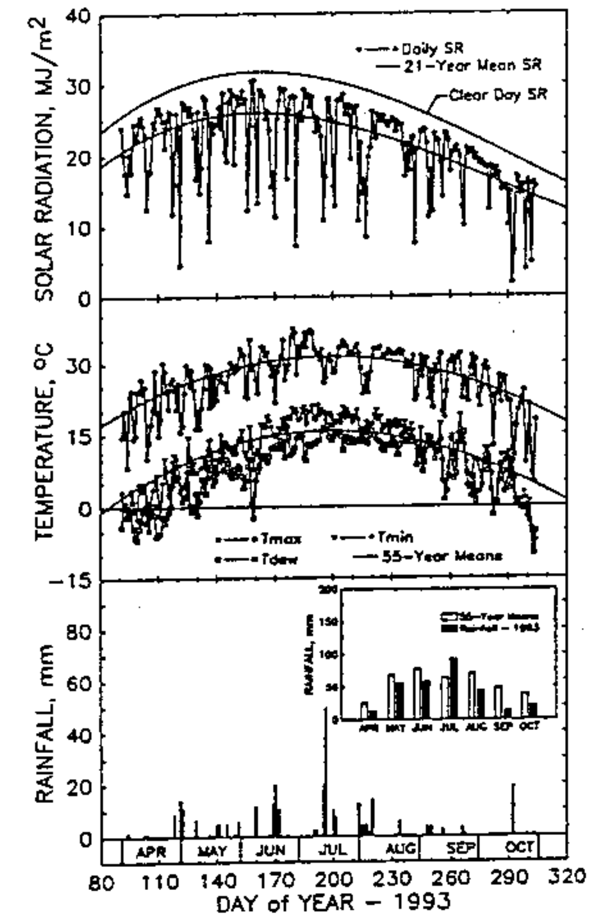

Figure 2. Climatic data summary for 1993 at Bushland, TX.

somewhat cooler than normal, and 1993 had more normal air temperatures (Table 2, Figures 1 and 2). The reference evapotranspiration (ET) values computed for 0.5-m tall alfalfa using the Kimberly-Penman equation (REF-ET, V2.14; Allen, 1990) are shown in Figure 3, and 1993 had about 70 mm more reference ET compared to 1992 for the April through October months. Reference ET was noticeably lower at DOYs 140-160 (late May) in 1992. These growing season environments are typical of the diversity to be expected in the Southern High Plains. Figures 1 and 2 depict some of the daily climatic conditions during the study. Table 2 summarizes the monthly climate data compared to long-term climate data for Bushland.

The high rainfall during May and June in 1992 interfered with plans to fertigate the crop, and only two applications of 3.0 g(N)/m^2 were made on 15 July [197] and 21 July [203] just after tasseling. In 1993, T-100 received 21 g(N)/m^2 from late May until 26 July [207] just after silking. The other treatments received proportionately less fertigation. The total nitrogen application to T-100 was 19 (N)/m^2 in 1992 and 28 g(N)/m^2 in 1993; both very similar to the recommended

TABLE 2. Climatic data summary for the experimental years contrasted to historical data for Bushland, TX.

Month	Max. Temp.	Min. Temp.	Dew Point Temp.	Solar Rad.	2-m Wind	Rain	ET_r PMon [1]	ET_r KPen [2]
	°C			MJ/m^2	m/s	mm	mm/d	
-- 1992 --								
April	22.0	6.0	2.9	21.9	3.9	15	7.5	6.0
May	23.5	9.8	6.0	20.7	4.0	81	7.8	6.9
June	28.1	13.9	10.4	24.9	3.7	165	8.9	8.5
July	31.5	17.1	12.8	25.8	4.5	68	11.0	10.5
August	28.7	15.6	12.2	21.4	4.3	102	9.0	8.5
Sept.	28.0	12.5	7.8	20.0	4.7	9	9.8	8.5
Oct.	23.6	6.1	1.5	15.2	4.0	6	7.7	6.0
-- 1993 --								
April	21.0	3.4	-1.4	21.9	5.2	15	8.8	7.0
May	25.0	9.9	5.2	23.5	5.1	16	9.6	8.4
June	30.2	15.4	9.8	24.3	5.5	57	12.0	11.0
July	32.4	18.9	13.9	24.7	4.8	96	11.7	10.9
August	30.0	16.5	13.4	21.2	3.5	43	8.5	7.9
Sept.	27.7	11.0	9.0	19.6	3.7	15	8.1	7.0
Oct.	20.3	4.2	2.6	14.8	4.1	22	6.0	4.9
-- Mean Climatic Data --								
	55-Year Means			21-Yr Mean		55-Yr Mean		
April	21.8	4.2		22.5		26		
May	26.0	9.6		24.4		68		
June	30.7	14.8		26.3		78		
July	32.5	17.2		25.6		65		
August	31.6	16.4		22.8		71		
Sept.	27.9	12.2		19.2		49		
Oct.	22.7	5.9		15.4		40		

[1] Alfalfa reference ET Penman-Monteith equation (Allen, 1990).
[2] Alfalfa reference ET Kimberly-Penman equation (Allen, 1990).

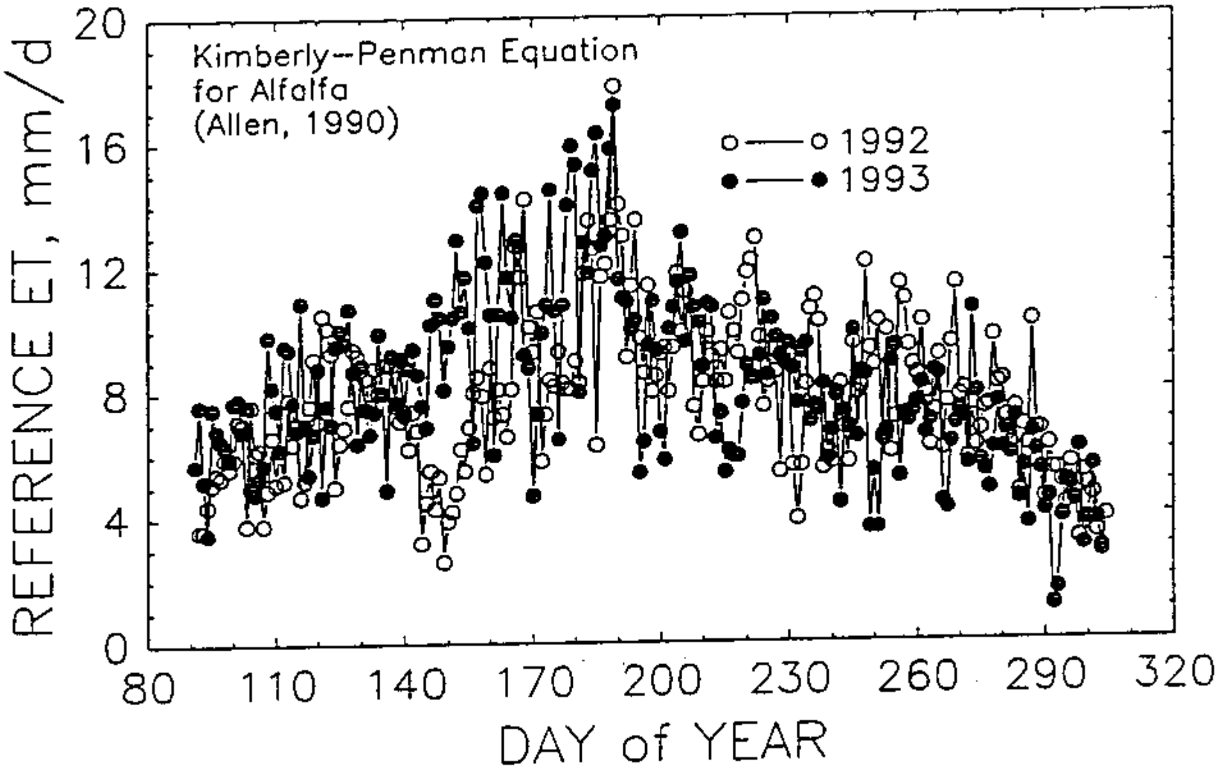

Figure 3. Reference ET for 1992 and 1993 seasons at Bushland, TX, computed with the Kimberly-Penman equation for 0.5-m tall alfalfa (Allen, 1990).

amounts for those years based on the soil samples and the yield goal of 1.6 kg/m^2 (250 bu/ac). Eck (1984) reported fertilizer nitrogen requirements between 14 and 30 $g(N)/m^2$ to maximize the response of corn to nutritional status on the Pullman soil with surface irrigation methods and adequate irrigation.

Germination and emergence irrigations were applied in the spray mode uniformly in both years. In 1992, 25 mm was applied on 23 April [114], and another uniform irrigation of 25 mm was applied on 11 May [132] using the LEPA bubble mode. In 1993, three germination and emergence irrigations were uniformly applied on 20-21 April [25 and 38 mm, respectively; 110 and 111] and on 27 April [15 mm; 117], all in the spray mode.

Alternate row LEPA irrigations of 25 mm filled the furrow dike storage volume. Occasionally a dike overtopped, but usually the bed overtopped, spilling water into the adjacent diked furrow (normally dry) before a dike failed. The dikes were effective in holding the 50 to 70 mm of single event rains [note with alternate rows that the rainfall storage volume is twice the LEPA storage volume] that occurred in each year with minimal field runoff (some redistribution likely occurred around the circular plots). In 1993, the large rain (70 mm; see Figure 2 on DOY 195 and 196) occurred the evening after an irrigation of 25 mm that day. Clearly LEPA, without surface storage capacity, would not be expected to function as envisioned even for this relatively flat topography. Actually, LEPA applications of 20 mm (the amount applied to T-80 for a 25 mm T-100 application) appeared to be about optimum for filling the furrow dike basins and preserving the dikes on Pullman clay loam. Applications with the double-ended Fangmeier LEPA socks performed superior to the LEPA bubble and spray modes that we used in previous years (Howell et al., 1991) by avoiding erosion and siltation of the furrows and erosion of the furrow dikes by the irrigation water. LEPA should be managed to apply as much water as can be efficiently stored in the furrow-dike basins, and then the irrigation frequency is simply determined by the gross irrigation capacity. For most systems in this region, maximum LEPA applications with alternate row systems should not exceed 25 mm for 0.76-m rows for corn, and the resulting frequency would be 3.1 to 3.8 days depending on the gross irrigation capacity [8 mm/d (6 gpm/ac) to 6.5 mm/d (5 gpm/ac)].

The maximum leaf area index (LAI) occurred at tasseling both years with 1993 having a slightly greater maximum LAI (Figures 4 and 5). LAI declined more rapidly following anthesis in 1992 than in 1993. Maximum dry matter growth rates

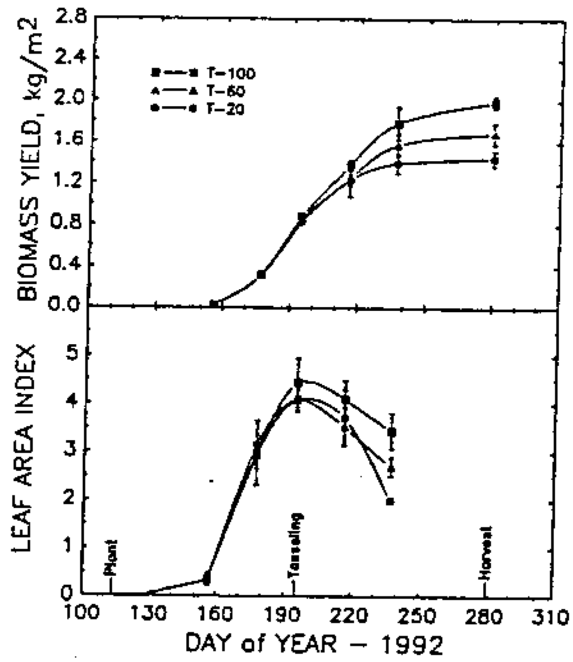

Figure 4. Above-ground biomass and leaf area index for T-100, T-60, and T-20 treatments in 1992. The error bars are standard deviations.

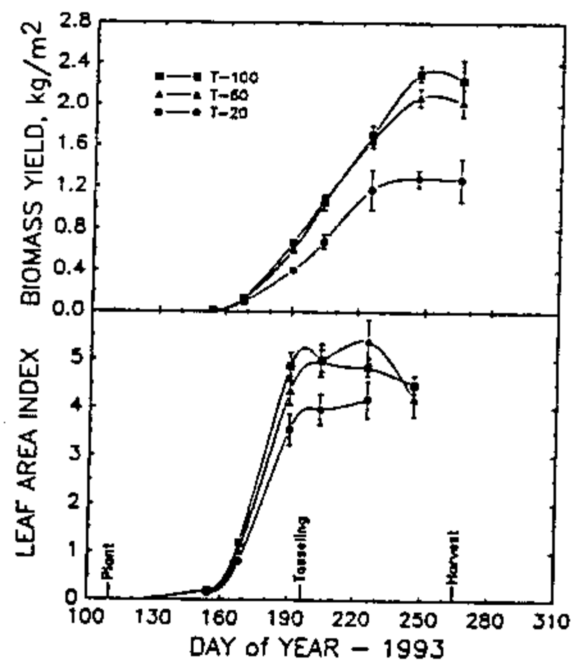

Figure 5. Above-ground biomass and leaf area index for T-100, T-60, and T-20 treatments in 1993. The error bars are standard deviations.

were similar in both years at about 25 g m^{-2} d^{-1} for the T-100 treatment. Maximum above-ground biomass was about 2.0 kg/m^2 in 1992 while it was slightly over 2.3 kg/m^2 in 1993. Both of these years had LAIs and biomass values for the T-100 treatment typical for high yielding corn. The T-20 treatments drastically reduced biomass in both years but mainly reduced LAI compared to T-60 and T-100 only in 1993. T-60 biomass was not different from T-100 until after anthesis in both years and achieved equivalent LAIs to T-100 in both years.

Grain yield and yield components data are summarized in Table 3. Grain yields ranged from 0.4 to over 1.5 kg/m^2 in 1993, but ranged only from 0.6 to 1.2 kg/m^2 in the wetter 1992 year. Yields were limited in 1992 by the growing conditions and possibly the lower plant density of only 4.5 plants/m^2 (Table 1), although it was seeded at about 7 plants/m^2 in that year. Harvest index was not reduced by the irrigation level in 1992 but was more affected in 1993 by the more severe soil water deficits that developed. Likewise, kernel mass was not affected in 1992 when yield effects were almost entirely related to reduced numbers of kernels per ear. In 1993, grain yield was equally affected by both reduced kernel mass and kernels per ear. The large difference in kernels per ear between the two years was due to the much lower plant density in 1992 compared with 1993 (Table 1). Basically, about 4000 to 4100 kernels/m^2 are necessary to maximize grain yield for this hybrid. Grain yields were affected similarly to dry matter production.

The soil water contents were slightly wetter in 1993 at emergence (Figure 6) compared with 1992. Water uptake by corn occurred mainly in the 0 to 1.5 m layer as found by Musick and Dusek (1980). However, in 1993 corn was able to apparently extract more water from below the 1.5 m depth (perhaps due to the differing onsets of soil water deficits before anthesis). Table 4 shows the seasonal soil water depletion information. Both T-20 and T-0 were affected by early water deficits that reduced their rooting density and depths so they extracted less soil water than even T-60 or T-80. In 1993, however, soil water extraction extended below the 1.5-m depths particularly for the T-40, T-20, and T-0 treatments. Although drainage (either steady- or non-steady-state) could be occurring, the temporal distributions of these deeper soil water content changes clearly indicate that they were the result of root water uptake and not drainage. Even corn can root into the caliche layer of the Pullman soil profile and extract small amounts of water which was thought mainly possible only by wheat, sugarbeet, and sunflower (Ratliff et al., 1983).

Table 4 provides a summary of the water use and water use efficiency data. Water use varied only from 533 to 786 mm in 1992 but varied from 383 to 973 mm in the normal year of 1993. Water use has been reported to vary from 670 to 790 mm by Musick and Dusek (1980), from 783 to 1003 mm by Eck (1984), 838 mm by Howell et al. (1989), and from 699 mm to 785 mm by Steiner et al. (1991), which was measured using weighing lysimeters for adequately irrigated corn at Bushland. The 187 mm difference in water use for the T-100

TABLE 3. Yield and yield component data.

Treatment	Grain Yield [1/]	Harvest Index [2/]	Biomass Yield [2/]	Kernel Mass	Kernel Numbers	Kernels per Ear
	kg/m^2	kg/kg	kg/m^2	mg/kernel	no./m^2	no./ear
– 1992 –						
T-100	1.246 a [3/]	0.574	1.986 a	308	4386 a	716 a
T-80	1.236 a	0.568	1.879 a	318	4587 a	703 a
T-60	1.041 b	0.551	1.680 b	310	4054 ab	663 ab
T-40	0.972 bc	0.538	1.548 bc	330	3693 bc	522 bc
T-20	0.826 c	0.532	1.441 c	318	3135 c	474 c
T-0	0.603 d	0.505	0.934 d	301	2449 d	422 c
$LSD_{0.05}$	0.061	ns	0.073	ns	258	60
– 1993 –						
T-100	1.550 a	0.572 a	2.232 a	315 a	4165 a	512 b
T-80	1.482 a	0.573 a	2.228 a	325 a	3857 a	491 b
T-60	1.285 b	0.578 a	2.017 a	291 b	3740 ab	478 b
T-40	1.086 c	0.511 ab	1.671 b	268 c	3429 b	592 a
T-20	0.774 d	0.459 b	1.273 c	220 d	2986 c	461 b
T-0	0.400 e	0.337 c	0.830 d	193 e	1756 d	296 c
$LSD_{0.05}$	0.084	0.077	0.278	23	427	61

[1/] Grain yield adjusted to 15.5% wc (wb).
[2/] Harvest index and biomass samples were different areas than the grain yield samples.
[3/] Numbers followed by different letters are statistically different ($P < 0.05$ level) based on the least significant difference (LSD).

treatment in 1992 and 1993 is partially explained by the higher evaporative conditions in 1993 (Figure 3) and partly by the earlier leaf area development in response to the warmer environment (Table 2 and Figures 1 and 2). These water use amounts are within those reported from previous Bushland corn irrigation experiments for graded furrow, level border, and sprinkler methods and do not clearly show a large irrigation savings attributed to the LEPA method itself.

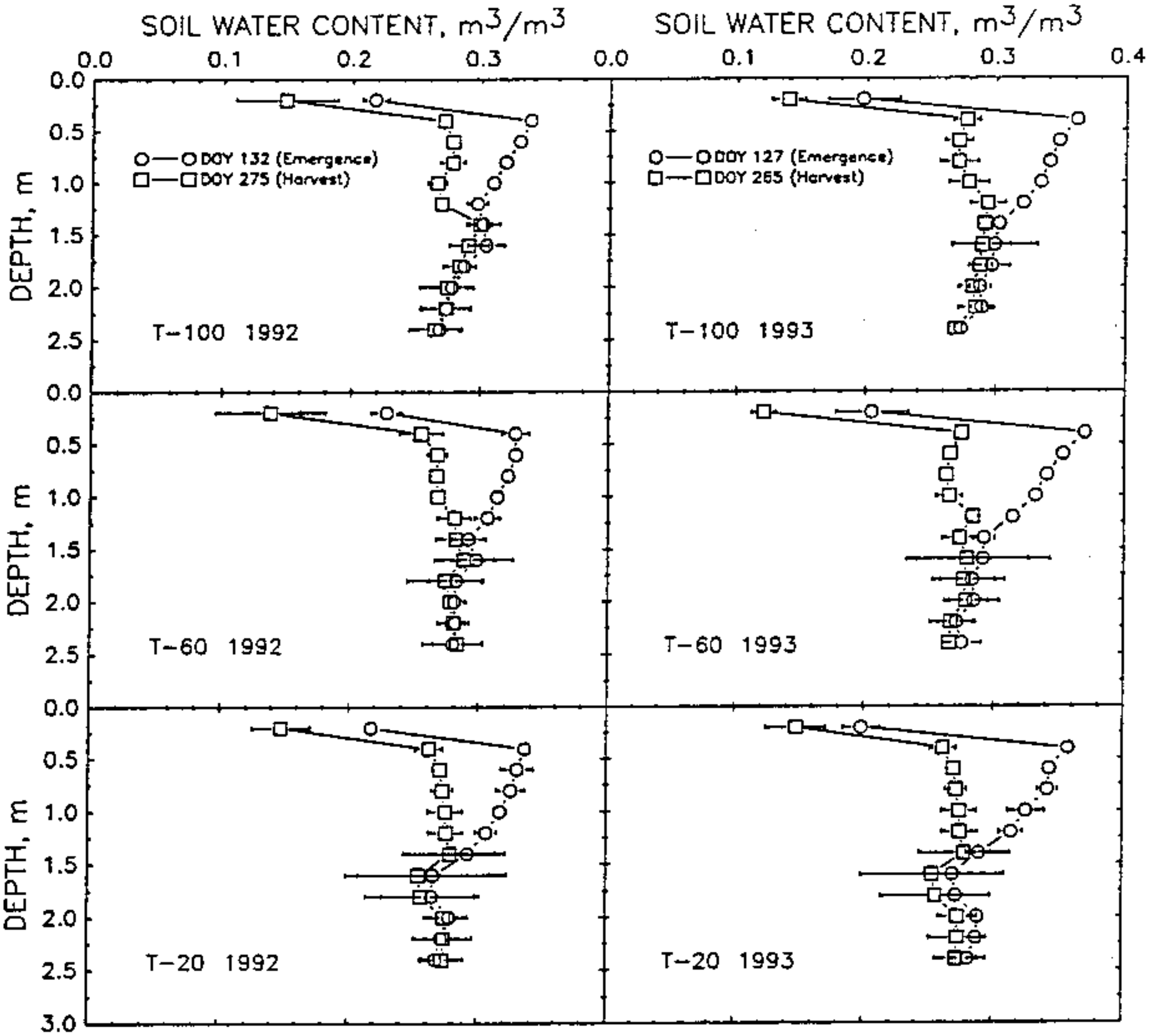

Figure 6. Soil water contents measured at emergence and harvest in 1992 and 1993 for the T-100, T-60, and T-20 treatments. The error bars are standard deviations.

Water-use efficiency values (Table 4) varied from 0.89 to over 1.5 kg/m^3 which are similar to reported values from 1.05 to 1.23 kg/m^3 by Musick and Dusek (1980), up to 1.41 kg/m^2 by Eck (1984), and 1.18 kg/m^3 by Howell et al. (1989) [note the grain water content was corrected to dry grain], but clearly indicative of the efficient use of water possible with LEPA. The irrigation water use efficiency (IWUE) was computed as

$$IWUE_t = (GY_t - GY_{ni})/IRR_t \qquad \ldots [3]$$

where $IWUE_t$ is in kg/m^3 of treatment "t," GY_t is the grain yield (dry) in g/m^2 of

TABLE 4. Water use and water use efficiency data.					
Treatment	Seasonal Irrigation	Soil Water Depletion [1/]	Water Use [2/]	Water Use Efficiency [3/]	Irrigation Water Use Efficiency [4/]
	mm			kg/m^3	
– 1992 –					
T-100	279	70	786 a [5/]	1.34 ab	1.95
T-80	228	72	737 b	1.42 a	2.35
T-60	178	79	695 c	1.27 ab	2.08
T-40	127	104	668 d	1.21 b	2.46
T-20	76	74	588 e	1.19 b	2.48
T-0	25	71	533 f	0.97 c	---
$LSD_{0.05}$		ns	13	0.09	
– 1993 –					
T-100	644	88 c	973 a	1.35 c	1.51
T-80	515	92 bc	848 b	1.48 ab	1.78
T-60	386	95 bc	731 c	1.48 ab	1.94
T-40	258	104 bc	593 d	1.55 a	2.25
T-20	129	113 b	483 d	1.36 bc	1.71
T-0	0	142 a	383 e	0.89 d	---
$LSD_{0.05}$		23	23	0.13	

[1/] Difference from initial soil water contents for a 2.5 m profile and ending soil water contents measured by neutron attenuation.
[2/] Total of soil water depletion, seasonal irrigations, and rainfall during the period of neutron measurements.
[3/] Ratio of grain yield (dry basis) and water use.
[4/] Ratio of treatment grain yield (dry basis) minus T-0 yield and seasonal irrigation.
[5/] Numbers followed by different letters are statistically different ($P < 0.05$ level) based on the least significant difference (LSD).

treatment "t," GY_{ni} is the grain yield in g/m^2 of a non-irrigated treatment, and IRR_t is the applied irrigation water in mm to treatment "t." GY_{ni} was taken as the yield from T-0. Except for T-20 in 1993, IWUE decreased from about 2.2 to 2.5 kg/m^3 at the highly deficit irrigation levels to about 1.5 to 1.9 kg/m^3 at the highest irrigation levels. Water use efficiency and irrigation water use efficiency are certainly not constants, and their use in evaluating irrigation performance should be avoided.

The relationship between grain yield and crop water use is shown in Figure 7. The intercept represents soil water evaporation (and possibly some crop transpiration necessary to establish some grain yield), and the slope is perhaps a better indication of the water use efficiency of corn of 1.69 kg/m^3. This slope can be compared with those varying from 1.46 to 2.06 kg/m^3 reported by Musick and Dusek (1990) and 2.87 kg/m^2 reported by Howell et al. (1989) at Bushland to 1.23 kg/m^3 reported by Wenda and Hanks (1981), 1.95 kg/m^3 reported by Stewart et al. (1975), 0.822 kg/m^2 determined for data presented in Hillel and Guron (1973), 2.36 kg/m^3 reported by Stegman (1982), 1.1 to 3.4 kg/m^3 reported by Hanks et al. (1978), and a range of other studies that could be cited [note in most cases the grain water content was corrected to dry grain]. Tanner and Sinclair (1983) proposed that this slope was inversely proportional to the mean atmospheric vapor pressure deficit (VPD), mainly daytime VPD. It may be impossible to prove that LEPA irrigation produced a different slope from other irrigation methods. Suffice to summarize, the slope of the grain yield and water use relationship for

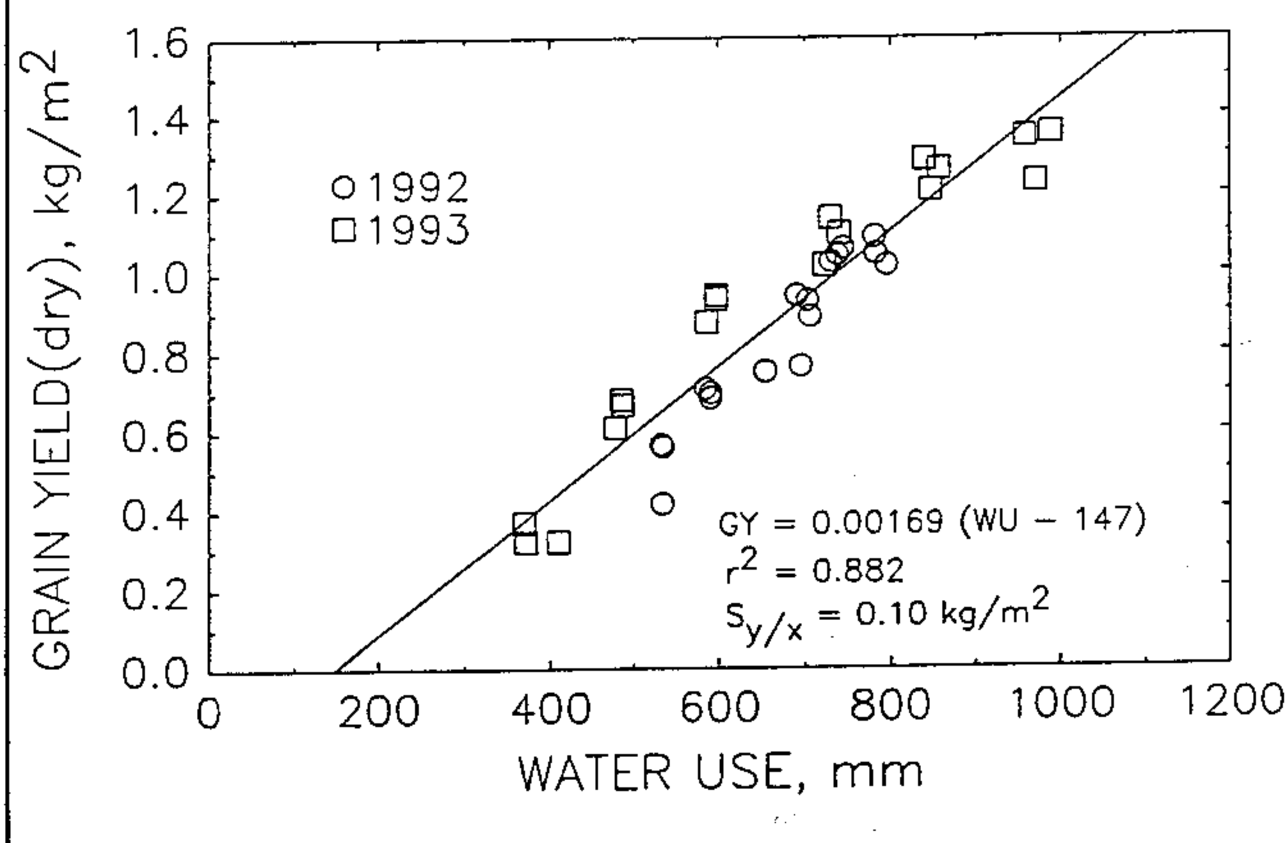

Figure 7. Relationship between grain yield and water use for LEPA irrigated corn at Bushland, TX, in 1992 and 1993.

corn at Bushland is similar to those reported for other locations and for other irrigation methods. Although some differences are apparent for the 1992 and 1993 data shown in Figure 7, the composite data are well represented by the single regression line. A quadratic fit was not significant. It does appear, as seen in Figure 7, that grain yield tended to level at a water use amount of about 850 mm. Attempts to fit the data with piece-wise linear segments to illustrate this leveling were not successful.

The distinct relationships between grain yield and irrigation can be seen in Figure 8. In 1992, the relationship was mainly linear (a quadratic regression was not significant), but in 1993 it was more quadratic. The reason for these relationships is more clearly seen when analyzed as water use partitioned from the applied irrigation water following the method of Martin et al. (1984) and earlier described by Stewart and Hagan (1973). Figure 9 shows that in both years a high proportion of the applied water was consumed in water use (admittedly some unknown amounts of runoff and drainage through the rootzone could be included in the water use values). In 1992, over 90% of the applied water was used and very

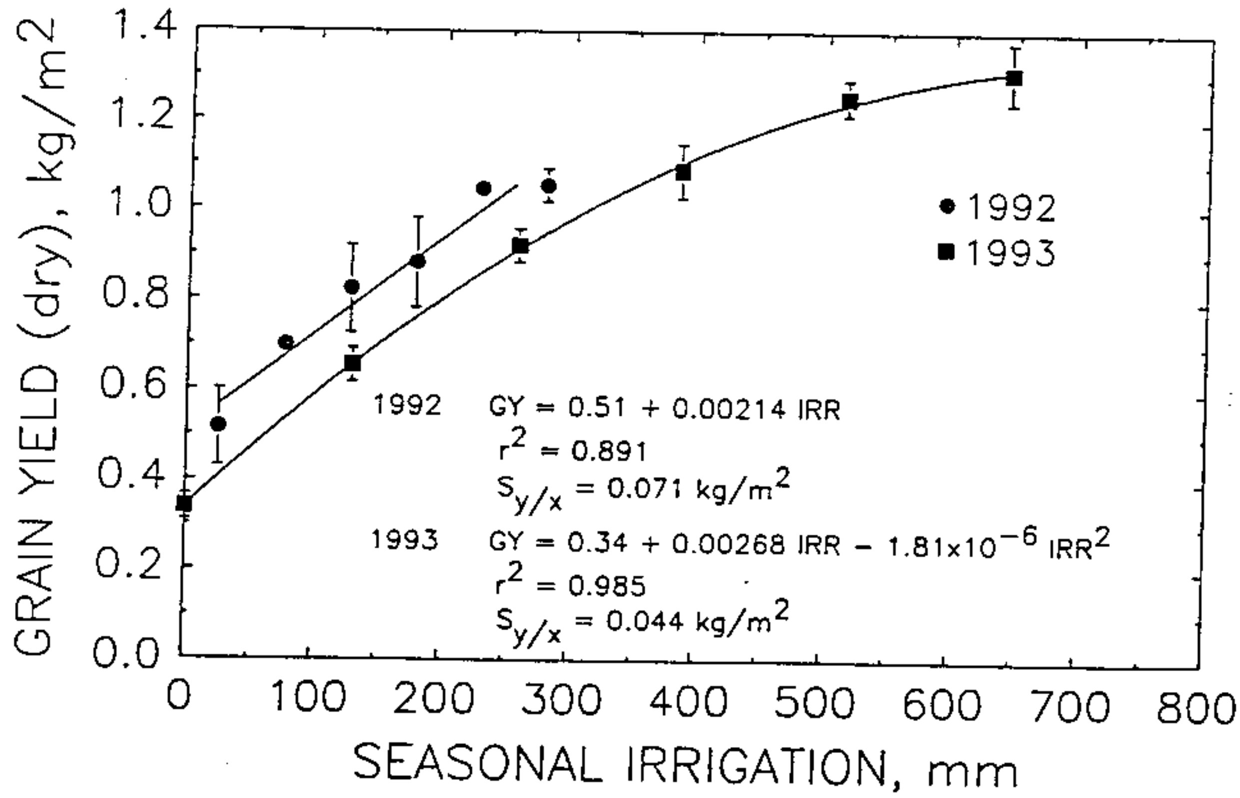

Figure 8. Relationships between grain yield and seasonal irrigations for LEPA irrigated corn at Bushland, TX, in 1992 and 1993. The error bars are standard deviations.

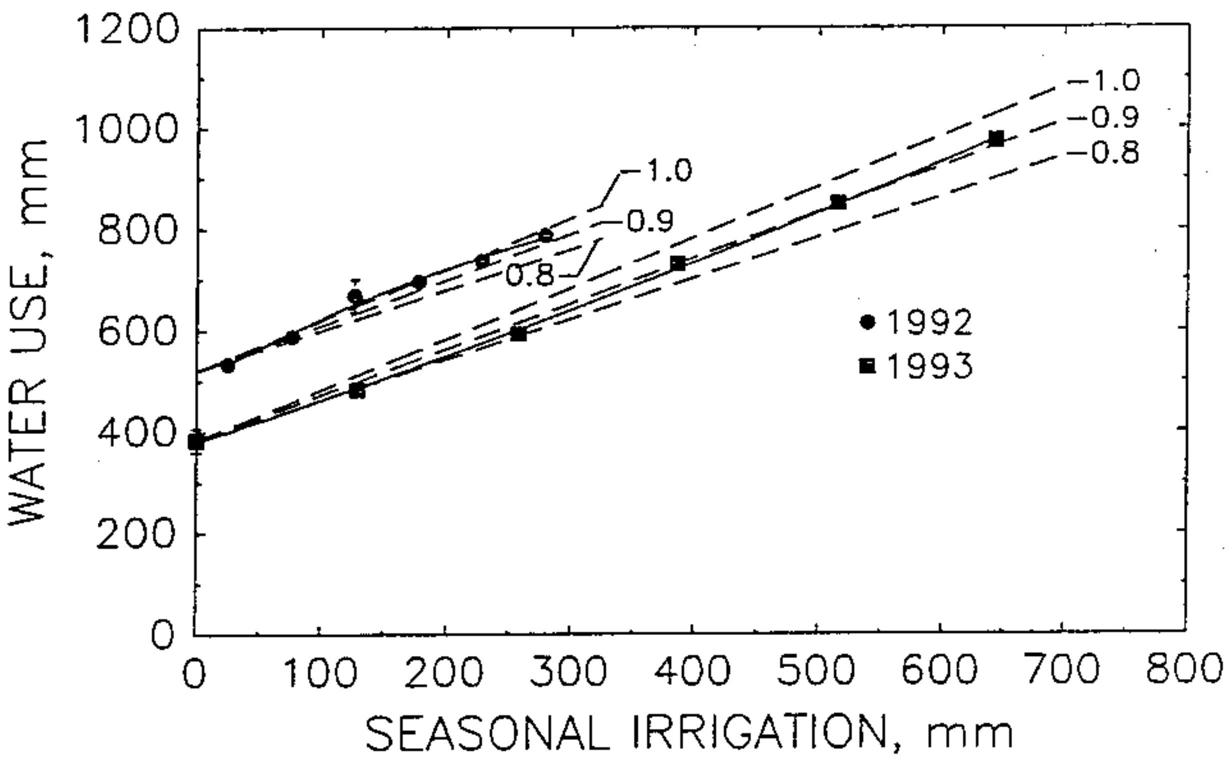

Figure 9. Relationships between water use of corn and seasonal irrigations applied with LEPA in 1992 and 1993 at Bushland, TX. The dashed lines represent constant partitioning fractions of 100, 90, and 80% of the applied water. The error bars are standard deviations.

little remained in the soil unused by the crop with the management levels used in these studies. Perhaps a better use was made of the rainfall in 1992 than in 1993 since the partitioning fell slightly in the second year. LEPA, if managed properly, can be extremely efficient in permitting a maximum amount of the applied water to be used by the crop and avoiding wastes to deep percolation, storm runoff, and application losses.

CONCLUSIONS

LEPA irrigation requirement for corn on Pullman clay loam was found to be comparable to other irrigation methods, although, the partitioning of the applied water into water use was better than for graded-furrow irrigation practices. LEPA applications on typical furrow-dike basins should not exceed 25 mm on Pullman soil to avoid over filling the basins. The double-ended Fangmeier LEPA socks permitted the furrow dikes to remain intact without significant deterioration throughout the season. The furrow-dike basins could store up to 50 mm of rain or 25 mm of LEPA applications applied to alternate furrows.

Deficit LEPA irrigation of corn at Bushland generally reduced grain yield by reducing both seed mass and kernels per ear. The grain yield in most cases was closely related to the dry matter yield, and generally the harvest index was relatively consistent across a wide range of water levels but did decline as the irrigation deficit increased. Deficit irrigated corn was shown to be able to extract soil water (to a limited extent) from the caliche layer occurring at about 1.5 m in the Pullman soil. Only rather severe deficit LEPA irrigation treatments reduced LAI, but even small deficits tended to reduce biomass. Maximum dry matter production rates of 25 g m^{-2} d^{-1} were maintained from before tasseling until late grain filling.

Irrigation demand depends strongly on the distribution and amount of growing season rainfall. In 1992 with a larger than normal rainfall amount of 431 mm, only 279 mm of irrigation was required for the T-100 treatment compared with 644 mm of irrigation required by T-100 in 1993 — a year with only 241 mm of rainfall during the season. Water use for the full irrigation level varied from 973 mm in 1993 to 786 mm in 1992.

The relationship between corn grain yield and water use for LEPA irrigation was shown to be similar to other irrigation methods at Bushland and at other locations. But the LEPA irrigation method permitted precise control of the irrigation application and provided uniform irrigations. LEPA can avoid some application losses. With proper management, LEPA should maximize partitioning of the applied water to meet the crop water use needs. However, LEPA requires surface storage or high-intake soils to avoid water application redistributions and runoff from both rainfall and irrigation.

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