Tractor Wheel Compaction of Wide-Spaced Irrigated Furrows for Reducing Water Application

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ABSTRACT

THE Southern High Plains has approximately 1.2 million hectares (3 million acres) of moderately permeable irrigated soils. Graded-furrow irrigation can result in large applications of water and intake that exceeds profile storage capacity, resulting in losses to deep profile drainage and reduced irrigation application efficiency. A 2-yr field study of irrigated corn (*Zea mays* L.) was conducted on Olton clay loam (fine, mixed, thermic Aridic Paleustoll) near Friona, TX, in 1982-83. The objective was to evaluate the use of tractor-wheel compaction of irrigated furrows in reducing excessive water intake and profile drainage. Treatments evaluated were irrigation only 1.5-m (60-in.) spaced furrows (a) compacted to about 1.6 Mg/m^3 (1.6 g/cc) bulk density, designated as HARD, and (b) nonwheel traffic furrows having bulk densitites of 1.2 to 1.3 Mg/m^3, designated as SOFT. Four seasonal irrigations were evaluated in 1982 and seven in 1983. In 1983, a management option was tested in which the fourth and fifth seasonal irrigations in the HARD furrow treatment were switched to SOFT furrows for "catch up" and to meet water requirements during a high evaporative demand period. HARD furrows reduced water advanced time for 400-m (1,320-ft) field length by 48%, water intake by 33%, and estimated profile drainage by about one-half without affecting grain yields. In the 1983 test, utilizing a system of alternating SOFT and HARD furrows permitted flexibility in managing irrigation water intake to meet conditions of varied evaporative demand and profile storage needs. We conclude that combining wide-spaced furrows with tractor-wheel compaction permits a reduction of 20 to 30% in irrigation water requirements for graded-furrow irrigation of the moderately permeable soils in the Southern High Plains.

INTRODUCTION

Graded-furrow irrigation is extensively practiced on large areas of moderately permeable soils in the Southern High Plains. Concerns about declining groundwater storage in the Ogallala aquifer surfaced in the mid-1960's when irrigation development reached its peak. Since then, a continuing decline in well yields and, more recently, increased energy costs for pumping have caused farmers to seek alternative conservative practices which reduce irrigation water requirements.

The first major practice to reduce water application on the more permeable soils was the conversion to primarily center pivot sprinkler irrigation. This trend developed rapidly during the 1970's but had greatly slowed by the end of decade. By this time, irrigators of graded-furrow systems were beginning to adopt wide-furrow or alternate-furrow irrigation practices (Allen and Musick, 1972; Musick and Dusek, 1974; Musick and Dusek, 1982; Stone et al., 1979 and 1982; Stewart et al., 1981 and 1983). The use of 0.75-m (30-in.) crop rows came into extensive use for summer row crops as a moderately narrow row spacing compatible with field cultivation and wide-furrow irrigation mostly standardized on 1.5-m (60-in.) spacing. Previous studies by Musick and Dusek 1974) indicated that irrigation of 1.5-m furrow spacing, compared with 0.75 m, reduced seasonal water intake by 13% for potatoes, 17% for sorghum, and 27% for sugar beets in tests on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll).

The effects of wheel-traffic compaction on reducing graded-furrow irrigation advance time and intake have been reported by Eisenhauer et al., 1982; Elliott et al., 1983; Kemper et al., 1982; and Trout and Kemper, 1983. Kemper et al. (1982), in a study at Twin Falls, ID, found that tractor-wheel compaction reduced water intake from 12 to 18% on 15 fields for an average of 46%. The variance of water intake within fields was associated mostly with wheel or nonwheel track furrows. They hypothesized that irrigating only wheel or nonwheel track furrows would substantially reduce intake variance.

In tests by Trout and Kemper (1983), establishing furrows in tractor wheel tracks, compared with between wheel tracks, reduced water advance time to one-third and intake to one-half. During the second irrigation without additional wheel traffic, 80% of the differences still existed.

Elliott et al. (1983) found that additional compaction effects from multiple operations further reduced intake, while Eisenhauer et al. (1982) found that wheel compaction effects on graded furrow intake were much greater in reduced tillage system that only partially incorporated crop residues.

In the late 1970's, extensive measurements indicated that tailwater runoff amount were mostly in the range of 25 to 35% of water applied (Musick, 1984). Schneider et al. (1976) found that on Pullman clay loam tailwater runoff could be reduced substantially with only slight effects on the lower-section crop yields. More recent tests

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by Stewart et al. (1981 and 1983) indicate potential for completely eliminating tailwater runoff in a Limited Irrigation-Dryland system. In this system, a lower-field irrigated section was used to manage tailwater retention on the field and a subsequent lower section as dryland with furrow dams to prevent irrigation or rainfall runoff leaving the field. Recent observations of farmer irrigation practices suggest that tailwater runoff has been reduced substantially below the 25 to 35% measured earlier on farmer fields (Musick, 1985).

This paper reports of a 2-yr test to evaluate the effect of tractor-wheel compaction of irrigated furrows to reduce water requirements. System losses and corn yields on a moderately permeable soil were also evaluated.

PROCEDURE

Furrow compaction tests were conducted on uniform Olton clay loam (fine, mixed, thermic Aridic Paleustoll) in Parmer County (near Friona), TX. The soil is clay loam and has a blocky subsoil structure to the 1.1- to 1.3-m (3.6- to 4.3-ft) contact with caliche. Below this depth, the soil contains about 50% calcium carbonate by volume to a depth of about 1.8 m (6 ft) and about 25% to 3.0 (10 ft). The caliche layer defined an abrupt boundary for rooting depth by corn plants. The average available water capacity is 16% by volume for a profile available capacity of 208 mm (8.2 in.) to the 1.3-m depth. The SCS water intake family curve is 7.6 mm/h (0.3 in.).

Tests were conducted on a field with 400-m (1,320 ft) furrow length and 0.25% grade. Corn was planted in 0.75-m (30-in.) rows and irrigated in 1.5-m (60-in.) spaced furrows. Treatments were irrigation of (a) nonwheel track furrows designated as SOFT and (b) tractor and wheel track furrows designated as HARD. A separate tractor pass was used prior to the preplant irrigation in early April to compact the HARD furrows. The use of 8-row equipment for crop cultural operations resulted in additional tractor or implement wheel passes in the HARD furrows. After plants were tall enough for cultivation, SOFT furrows were opened in the flat inter-row area, permitting the option of irrigating 1.5-m furrow spacing as either nonwheel track or wheel track. Irrigation of the HARD furrow treatment permitted the option of irrigating SOFT furrows if additional water intake was desired or needed.

Treatments were tested on irrigation sets of 40 crop rows irrigated by 20 furrows. Water was applied through gated pipe and measured with in-line propeller meter. Tailwater runoff from all irrigated furrows was measured with a long-throated flume equipped with a stage recorder (Replogle and Clemmens, 1981). Furrow flow rates averaged 1.9 L/s (30 gpm) for all applications except SOFT furrow tests in 1983, when flow rates wree increased to 2.4 L/s (38 gpm). Irrigations were mostly 12-h sets except the first irrigation of SOFT furrows required a longer set time (20.5 h in 1982 and 22.0 h in 1983).

Soil water content data were used to schedule irrigations when profile available water was depleted to about 50%. The climatic environment is semiarid with relatively high evaporative demand. Normally, about five graded furrow seasonal irrigations are needed on this soil for high yields. (The hybrids in use are 125 to 130-day maturity class.) With favorable rainfall in 1982, four seasonal irrigations were applied (June 28-29, July 17, Aug. 2-3, and Aug. 27-28). In the drier 1983 season, six seasonal irrigations were applied (June 29-30, July 11-12, July 22, July 29-30, Aug. 12, and Aug. 27-28). Several days of afternoon plant water stress were observed before the first seasonal irrigation in 1983. However, the high yields obtained indicated the early season stress probably had no significant effects on grain yields. The 2-yr test data does not include the preplant irrigation in March 1982 which was not measured.

The field was sampled for soil water and grain yields by 100-m (328-ft.) length of run blocks. Block-treatment interaction variance was used as an error estimate for statistical analysis of variance.

In late fall, corn stubble was shredded and plot areas were chisel and disk tilled. During winter, liquid fertizer (17 kg N, 22 kg P, 17 kg K, and 17 kg sulfur per ha) was applied with atrazine herbicide and plots were disk tilled. In early spring, NH_3 was chisel applied as 230 kg N/ha (205 lb/ac), plots were floated for field smoothing, and furrows were established. The 1.5-m (60-in.) spaced furrows were compacted as a separate tractor pass [4-wheel drive row crop, rated 8,100 kg (17,800 lb) weight] with attached cultipacker and drag pipe section "furrow slickers." Following preplant irrigtion in early April, bed-furrows were cultivated and corn hybrid 'NK PX72' was bed planted on April 21, 1982, and May 1, 1983. Plant densities were similar both years and averaged 5.7/m^2 (23,000/ac). Three cultivations were used to control crop volunteer, weeds, and maintain bed-furrows. Crabgrass developed below the crop canopy during mid- to late-season and may have influenced late season water use.

Soil water data were obtained by the neutron method from two access tubes per site centrally located in the crop rows of a 4-row field strip. Tube sites were spaced at 100-m intervals at four sites for a total of eight tubes per treatment. Data were taken before and after preplant irrigation, at plant emergence, before and one to three days after season irrigations, and after maturity. Additional measurements were taken between some irrigation events. The data were taken by 0.2-m (8-in.) increments to 1.2-m (4-ft) and by 0.3-m (12-in.) increments from 1.2 to 3.0 m (4 to 10 ft). Soil water contents to 1.35-m depth were used to calculate seasonal water use.

Deep profile drainage was estimated by irrigation wetting below the root zone in the 1.4- to 3.0-m zone, determined from sampling before and one to three days following irrigation, and by drainage from this zone before the first seasonal irrigation and between the last irrigation and harvest. Depth to water table was about 50 m (160 ft), and because of the frequent irrigation schedule and water intake quantities, water flux from the 1.35- to 3.0-m profile was assumed to be downward during the season. Soil water data before and after some irrigation events indicated probable soil water movement below the 3.0-m (10-ft) depth. Also, not measured as profile drainage was water that may have moved from the 0- to 1.4-m root zone into the 1.4- to 3.0-m zone during intervals between irrigations.

Soil bulk density data were taken on several dates (Fig. 1) from cores [50 mm diameter by 75 mm (2 by 3 in.) depth] collected in the furrow zone after removal of the surface 25-mm (1-in.) crust or loose soil. Four to eight

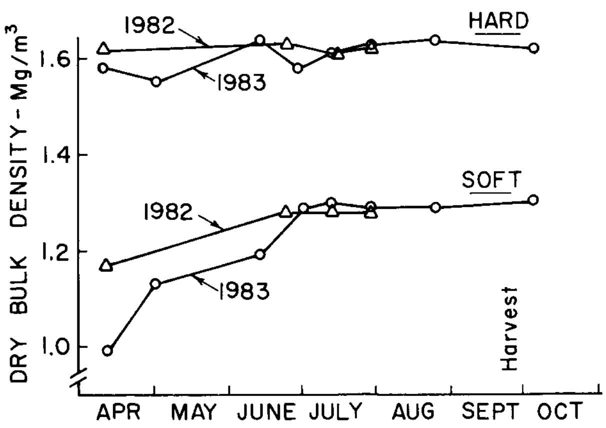

Fig. 1—Average dry bulk densities, 25- to 100-mm depth, below HARD and SOFT furrows, 1982-83.

cores per treatment data were taken, oven-dried, and weighed for dry densities.

Four 5-m² (53.8-ft²) grain yield samples were hand harvested from the 4-row test strip for grain yield on Sept. 20, 1982, and Sept. 22, 1983, from each length of run block for a total of 16 yield samples per treatment. Ears were oven-dried to constant weight in a forced draft oven, shelled, weighed, and grain yields adjusted to 15.5% moisture.

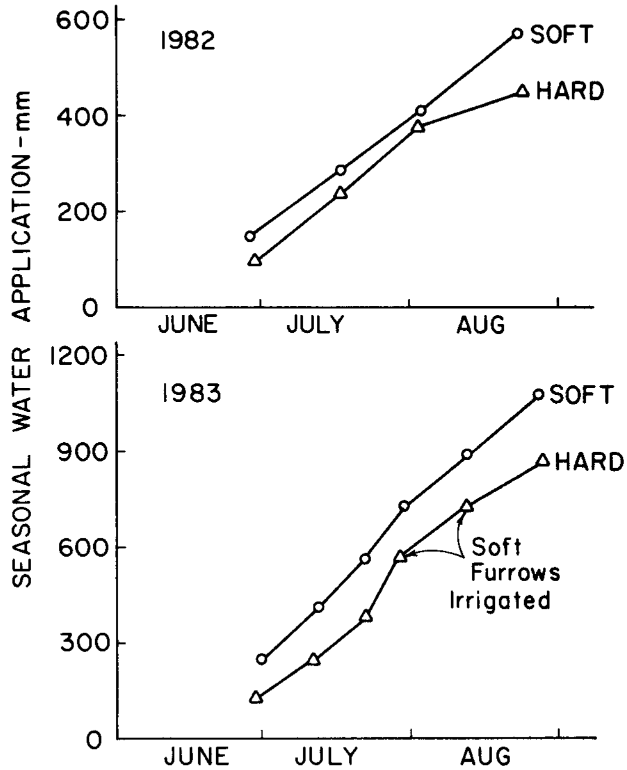

Fig. 2—Cumulative seasonal water application to HARD and SOFT furrows, 1982-83.

RESULTS

Seasonal rainfaill in 1982 (205 mm or 8.1 in.) was near normal and air temperatures were predominantly normal to below normal, resulting in a favorable corn growing season. The 1983 season received 120 mm (4.7 in.) rainfall during May and June and was exceptionally dry (26 mm or 1.0 in.) during the irrigation season to maturity. The 1983 montly maximum air temperatures averaged 30 to 35°C (86 to 95°F) for the June-September growing season (1 to 2°C above normal).

Furrow Bulk Densities

Furrows were compacted when the surface soil layer was in a moist state. Subsequent visual observations revealed a compressed soil layer to about 100-mm (4-in.) depth. Dry bulk density data taken from the compression zone are presented in Fig. 1. Densities in HARD furrows averaged about 1.6 Mg/m³ at planting time and remained essentially unchanged throughout the season. Prior tillage left the soil surface layer in a lossened condition. Densities in the SOFT furrows at the beginning of the season were in the range of 1.0 to 1.2 Mg/m³. After the first seasonal irrigation, soil densities had consolidated to about 1.3 Mg/m³ and thereafter remained unchanged. Tractor-wheel compaction effects on bulk densities were equal to or slightly greater than obtained from tractor wheel compaction studies under dryland conditions in the Northern Corn Belt (Lindstrom et al., 1981; Voorhees et al., 1978 and 1979; Young and Voorhees, 1982).

Water Application, Advance Time, Intake, and Runoff

Cumulative water application for SOFT and HARD furrows is shown in Fig. 2. Cumulative intake is displayed in Fig. 3. Irrigation of HARD furrows reduced water-advance time during four seasonal irrigation by 56% in 1982 and 40% in 1983, an average effect of 48% for eight irrigations. Intake by the same irrigations in HARD furrows was reduced by 34% in 1982 and 33% in 1983. The reduction in intake was not appreciably different from simulated rainfall effects of tractor-wheel compaction from tests in the Northern Corn Belt (Lindstrom and Voorhees, 1980; Lindstrom et al., 1981; Young and Voorhees, 1982).

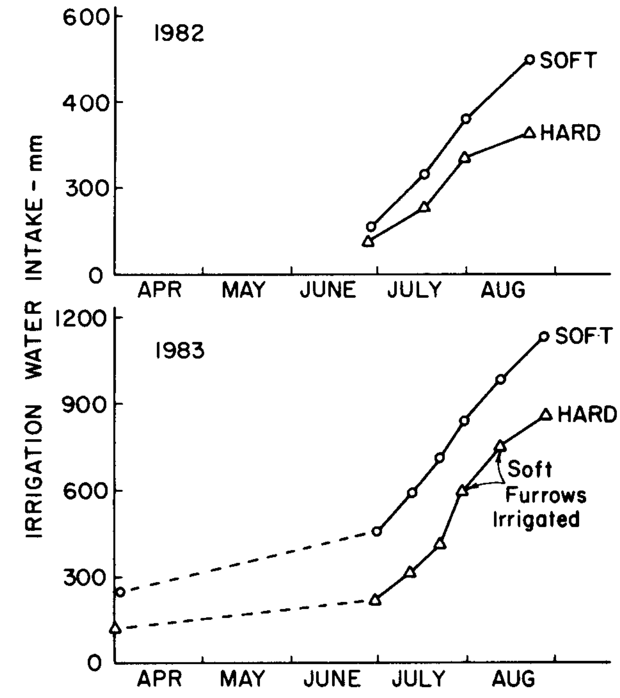

Fig. 3—Cumulative irrigation water intake by HARD and SOFT furrows, 1982-83.

The slow advance time for the SOFT furrows resulted in extending the application time for some irrigations, and intake was correspondingly increased. This was particularly true for the first irrigation of SOFT furrows when application time was extended by 5.2 h beyond the normal 12-h set.

Since the root zone of the HARD furrow treatment was 31 mm (1.2 in.) drier than the SOFT furrow treatment during pollination, the option to switch to a "catch up" irrigation of SOFT furrows was exercised for the June 29, 1983, irrigation. The SOFT furrows on the HARD furrow treatment were previously nonirrigated, and soil bulk densities in furrows averaged about 1.25 Mg/m^3. The slow advance resulted in extending application time by 43%, and intake increased by 42% over the SOFT furrow treatment that had been previously irrigated. The fifth seasonal irrigation was applied also to the SOFT furrows of the HARD-furrow treatment to meet continued high evaporative demand. Application time and intake were moderately high but only slightly higher than for the continuous SOFT furrow treatment, Fig. 3.

Cumulative tailwater runoff for seasonal irrigations is shown in Fig. 4. For the 1982 season, the more rapid advance time for the HARD furrows resulted in increased surface runoff. The reduction obtained in 1983 resulted from (a) the use of shorter application times and reduced amounts applied during some irrigations, and (b) very low runoff by the SOFT furrow irrigations. Data for the 1983 test indicated that irrigations of HARD furrows can be managed for moderate tailwater runoff.

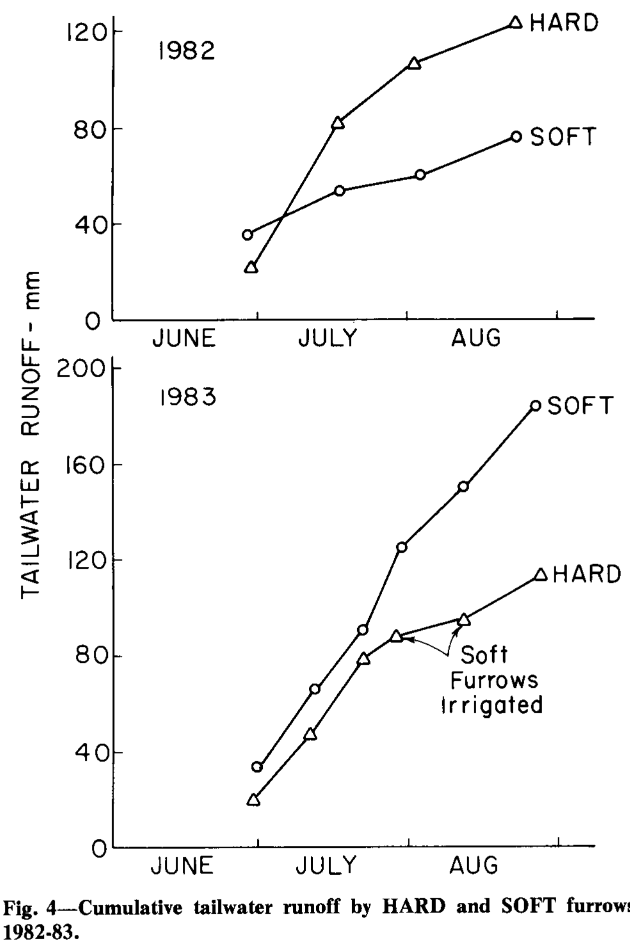

Fig. 4—Cumulative tailwater runoff by HARD and SOFT furrows, 1982-83.

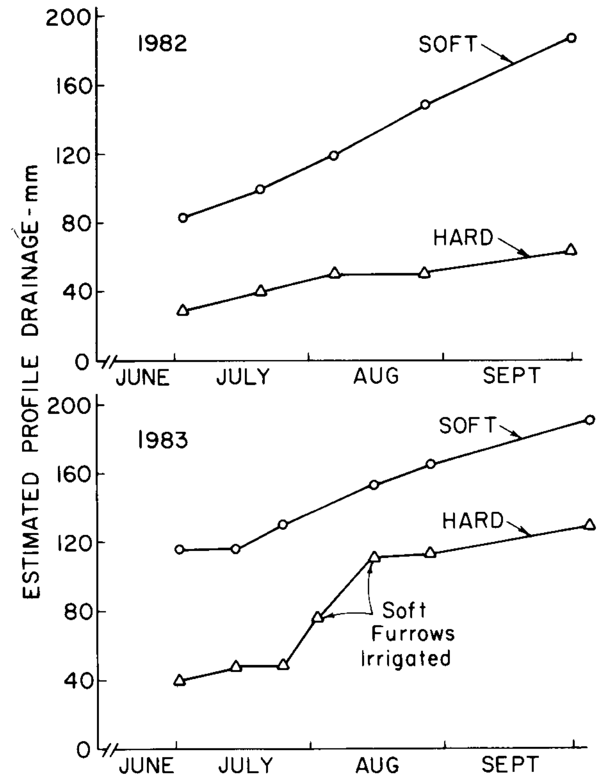

Fig. 5—Cumulative estimated profile drainage by HARD and SOFT furrow treatments, 1982-83.

Estimated Profile Drainage

Furrow compaction had a pronounced effect on reducing estimated profile drainage, Fig. 5. The estimated reduction in 1982 was from 185 to 63 mm (7.3 to 2.5 in.), and in 1983 from 189 to 130 mm (7.4 to 5.1 in.). About half of the 130 mm (5.1 in.) estimated deep drainage for the HARD furrow treatment in 1983 was associated with the two irrigations in the SOFT furrows. Data analysis suggests that only one irrigation in SOFT furrows was needed to "catch up" and provide adequate soil water supply during a critical development stage. If the fifth seasonal irrigation had been switched back to the HARD furrows, total estimated profile drainage by the HARD furrow treatment would have been reduced by about 20% and the seasonal total by about one-half of the SOFT furrow treatment.

Irrigation of SOFT furrows resulted in a proportionately high amount of the estimated profile drainage occurring early in the season, associated with the high intake conditions that existed when the surface soil layer was in a loosened condition by tillage. For example, intake by the June 29 irrigation in 1983 resulted in 207 mm (8.2 in.) intake by SOFT furrows compared with 102 mm (4.0 in.) intake by HARD furrows. The HARD furrow treatment was very beneficial in reducing excessive profile drainage during the first seasonal irrigation. Similar effects can be obtained with surge-flow application (Musick, 1985).

The effect of greatly reduced water intake or profile wetting to 3.0 m during preplant irrigation in 1983 is shown in Fig. 6. The 113-mm (4.4 in.) intake from the 11.5-h set was adequate to rewet the 1.4-m root zone and the soil water data taken after irrigation showed so significant wetting below 1.6 m (5.2 ft). The 245-mm

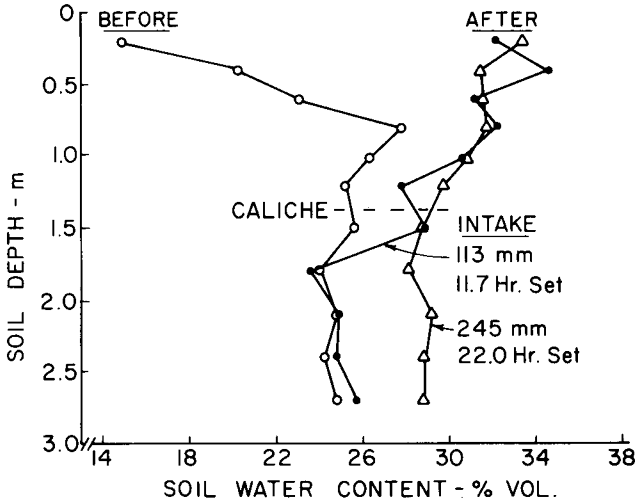

Fig. 6—Profile wetting to 3.0 m after preplant irrigations that resulted in 113 and 245 mm of water intake.

(9.6-in.) intake from extending an application overnight to 22.0 h resulted in fully wetting the profile to 3.0 m and probably significant wetting below the measured 3.0-m depth. The delay in determining soil water contents (9 to 11 days after irrigation) permitted profile drainage that significantly underestimated the deep profile wetting from this irrigation.

Seasonal Water Use and Grain Yields

Cumulative seasonal water use for the two seasons are presented in Fig. 7. Calculated seasonal water use was substantially lower for the HARD furrow treatment in

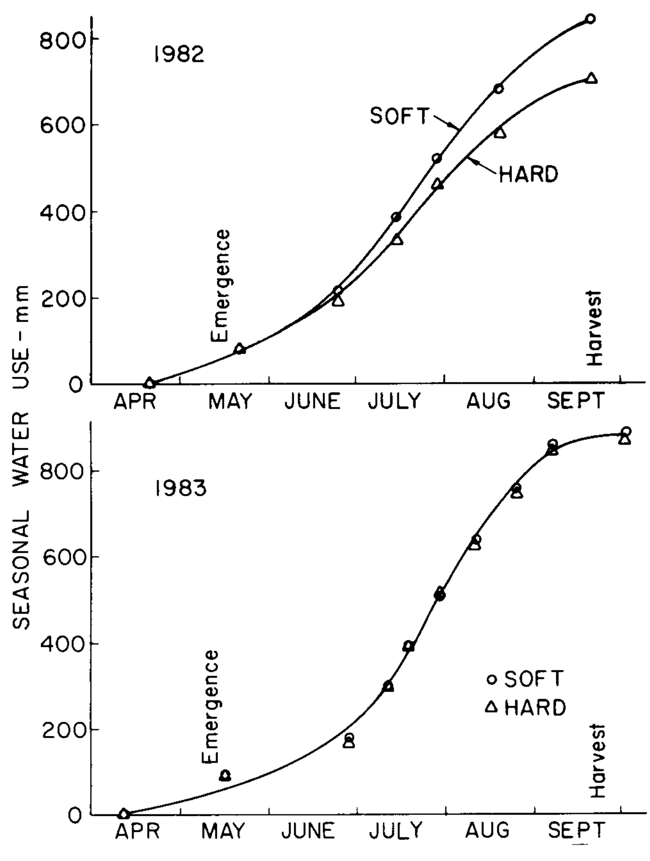

Fig. 7—Cumulative seasonal water use by corn, HARD and SOFT furrow treatments, 1982-83.

TABLE 1. GRAIN YIELDS BY LENGTH OF RUN BLOCKS FOR THE FURROW IRRIGATION TREATMENTS

Length of run blocks	Irrigation furrow treatments			
	SOFT		HARD	
	1982	1983	1982	1983
--- m ---	Mg/ha			
0-100	12.64	13.51	12.84	15.07
100-200	13.80	15.01	13.80	15.43
200-300	12.05	14.50	12.95	14.09
300-400	13.00	14.50	13.73	13.80
Mean	13.08 a*	14.38 b	13.34 a	14.60 b

*Mean values within years followed by the same letter are not significantly different at the 5% level (Duncan's multiple range test).

1982 but not in 1983. The reduced water use in 1982 did not affect grain yield, and yields for the two treatments were similar both seasons, Table 1.

The HARD furrow treatment showed water deficits that accelerated plant senescence approaching physiological maturity. However, the late season deficits could not account for the 104-mm (4.1-in.) reduction in seasonal water use as reduced evaportranspiration. Therefore, the higher water use calculated for the SOFT furrow treatment both seasons and for the HARD furrow treatment in 1983 very likely included some nonmeasured drainage that continued from the 1.4-m root zone followin the after-irrigation sampling dates. Although the seasonal water use values of 841 to 881 mm (33.1 to 34.7 in.) are high when compared with data by Musick and Dusek (1980), they are similar to values obtained on Pullman clay loam from 4-yr irrigation and nitrogen application study on corn by Eck (1984).

The average grain yields obtained, 13.2 mg/ha (11,790 lb/ac) in 1982 and 14.5 Mg/ha (12,940 lb/ac) in 1983, are the highest reported for experimental tests in the Texas High Plains. The yields compare with average farm irrigated yields of 9.0 kg/ha (8,040 lb/ac) in 1982 and 8.9 kg/ha (7,950 lb/ac) in 1983 (annual reports of field crop statistics, Texas Crop and Livestock Reporting Service, Austin, TX). The relatively high seasonal water use values calculated for the tests are, no doubt, associated with the irrigation and other management practices for high yields. Under irrigation management for high yields, the probability of including nonmeasured profile drainage in water budget calculation of seasonal water use in enhanced.

DISCUSSION

Graded furrow irrigation in the Southern High Plains is practiced on the slowly permeable clays to clay loams (predominantly the Pullman and Sherm series) and on the moderately permeable clay loams to fine sandy loams (predominantly the Olton, Acuff, Amarillo, and Estacado series). Land use inventories by soil types made by the Soil Conservation Service [using a 6 ha (15 ac) grid overlay of county soil maps to classify irrigated land by soil types] indicated soils of moderate permeability occurred on 52% of the 736,000 ha (1,820,000 ac) of irrigated land in seven counties (Carson, Castro, Floyd, Hale, Hockley, Lamb, and Lubbock). These seven counties contain about 30% of the irrigated land in the Southern High Plains Land Resource Area. Assuming the survey percentages apply to the total area, about 1.2

million ha (3 million ac) of moderately permeable soils are irrigated. The results from the furrow wheel compaction tests indicate a potential for reducing water application and intake by 20 to 30% on soils irrigated by graded furrow systems with little adverse effect on crop yields. An additional benefit can be reduced nitrate leaching. Deficiency symptoms have been observed to occur on the upper field sections where much lower N rates were applied than used in this study.

Irrigation water requirements for crops in the Southern High Plains vary primarily with seasonal rainfall and the evaporative demand of the climate. Higher water use rates associated with prevailing dry weather can appreciably increase irrigation water requirements. Having alternate SOFT and HARD furrows permits some flexibility in managing irrigation water intake to meet conditions of variable evaporative demand and profile storage needs.

During the early vegetative period, roots extend into moist soil and depth of soil water depletion is limited. Normally, smaller irrigations early in the season can replenish profile soil water, and irrigation of HARD furrows on the moderately permeable soils provides adequate water intake. Soil profile deficits are more likely to accumulate later in the season. The concept of the ssytem as developed and used by P. N. Johnson (Musick et al., 1985) was to apply an irrigation to SOFT furrows to "catch up" if needed to prevent mid- to late-season water deficits that reduce yields.

In 1983, when the HARD furrow treatment was 31 mm (1.2 in.) drier than the SOFT furrow treatment during the critical pollination period, the success of a "catch up" irrigation was demonstrated by applying the next irrigation in SOFT furrows. However, because these furrows were previously nonirrigated, water intake was 42% higher than for SOFT furrows that had been previously irrigated, resulting in increased deep profile drainage, Fig. 5. Because of the excessive application and profile drainage from switching an irrigation to SOFT furrows, we question the use of this management option. A more efficient alternative may be to continue irrigation of HARD furrows but slightly shorten the irrigation interval. When water supplies are adequate to schedule irrigations at about the 50% available soil water content, irrigation of SOFT furrows for increased water intake probably is not necessary. If significant later season water deficits develop, corn is more stress tolerant at this time (plants translocate previously stored assimilates to the filling grain to help complete final starch accumulation, Boyer and McPherson, 1975) and an additional late season irrigation may not be needed.

The reduced seasonal irrigation water applied by the HARD furrow treatment reduced irrigation pumping energy requirements. This reduction in water pumped by an electric-powered irrigation well [39.7-L/s (630 gpm) flow rate] reduced calculating pumping costs ($0.08/kWh) by $48.47/ha ($19.62/ac) in 1982 and $82.87/ha ($33.55/ac) in 1983.

Previous studies have shown that wide-furrow spacing reduces irrigation water intake. In this study, we combined wide-furrow spacing with wheel compaction to further reduce the excessive water intake that can occur on the moderately permeable soils. The 2-yr test demonstrated the success of the system in accomplishing the reduction in water intake to more closely correspond to profile storage needs on this soil which restricted corn rooting depth to an abruptly occurring caliche layer at about 1.3 m.

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