TILLAGE METHOD AND DEPTH EFFECTS ON FURROW IRRIGATION INFILTRATION

R. R. Allen, J. T. Musick

ABSTRACT. *Methods of primary tillage between annual crops of corn or sorghum on the Southern High Plains commonly include disking followed by chiseling or occasional deeper loosening by ripping or moldboard plowing. This study was conducted during 1992-1994 at Bushland, Texas, to evaluate the effect of tillage method and depth on furrow irrigation infiltration, soil water storage, grain yield, and water use efficiency (WUE). Treatments included both chiseling and sweep undercutting to 150 and 250 mm (6 and 10 in.) depths. Extending tillage depth from 150 to 250 mm (6 to 10 in.) increased irrigation infiltration from 20 to 28% for the first irrigation after primary tillage, but had little effect during successive irrigations. The deeper tillage increased power requirements by about 60%. Sweep tillage was as effective as the more common chiseling for soil loosening and required only about 75% as much power. Tillage method and depth did not significantly affect average sorghum yield or WUE for the years studied which received average to above average precipitation.* ***Keywords.** Irrigation, Tillage, Furrow irrigation, Infiltration.*

Methods of primary tillage between annual crops of corn or sorghum on the Southern High Plains commonly include disking followed by chiseling or occasional deeper loosening by ripping or moldboard plowing. With graded-furrow irrigation; relatively shallow tillage [100 mm (4 in.)] frequently results in less than 25 mm (1 in.) of loosened soil below the furrow bottom which can reduce infiltration. Repeated disking can also leave a relatively thin 25 to 40 mm (1-1.5 in.) dense layer (pan) below the tillage depth. Subsequent tilling slightly deeper than the pan usually alleviates the pan effect. Chiseling on 0.3 m (1 ft) centers is a common method for loosening soil at 125 to 200 mm (5 to 8 in.) depths, which leaves a roughened surface requiring further smoothing before planting. As an alternative, sweep under cutting leaves a smoother surface and reduces the amount of secondary tillage needed for smoothing.

Observations from research (Allen, 1985; Allen and Musick, 1990) and field observations by the Natural Resource Conservation Service (Pringle, 1994) have indicated that sweep undercutting can effectively loosen the soil and underlying pans on the medium to fine-textured soils of the Southern High Plains. V-shaped sweep blades are commonly used for relatively shallow [< 100 mm (4 in.)] undercutting in dryland stubble-mulch culture, but have not generally been considered for deeper primary tillage with surface irrigation. With sweep tillage, the soil is lifted 50 to 100 mm (2 to 4 in.) and loosened as the soil flows over the blade. Based on research observations, sweep tillage has resulted in more lateral wetting between 1.5 m (5 ft) spaced furrows than has disking, especially during the first irrigation after tillage (Allen, 1985). This is apparently the result of increased water flow through larger pores in the loosened beds.

Musick et al. (1981) reported that moldboard plowing to the 400 mm (16 in.) depth increased irrigation infiltration from 25 to 50% for the first irrigation after tillage, compared with 200 mm (8 in.) plowing on a Pullman clay loam. The 150 mm (6 in.) Ap horizon of the Pullman soil is moderately permeable having a medium granular structure; but the B21t and B22t horizons, extending from about 150 to 750 mm (6 to 30 in.) deep, are slowly permeable having a relatively dense blocky structure (Unger and Pringle, 1981). We hypothesized that extending the primary tillage depth from 150 to 250 mm (6 to 10 in.), which would penetrate 75 to 100 mm (3 to 4 in.) into the dense B horizon, can increase irrigation infiltration up to 30%. The primary objectives were to evaluate the effect of tillage method and depth on furrow irrigation infiltration, soil water storage, crop water use, grain yield, and water use efficiency (WUE). Secondary objectives were to compare power requirements and cost with deeper tillage.

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PROCEDURE

The study was conducted during 1992 to 1994 at Bushland, Texas, on a fine-textured and slowly permeable Pullman clay loam (*Torrertic Paleustoll*), described by Unger and Pringle (1981). The clay fraction is dominated by montmorillonite, and the soil profile, when dry, develops shrinkage cracks that result in a relatively high initial water infiltration rate. After filling of cracks or saturation of a loosened tillage layer, infiltration rates decline to a low rate after 2 to 3 h and reach a basic rate after 8 to 12 h. Plant available soil water (ASW) at field capacity (FC) is about 180 mm (7.2 in.) for sorghum to the 1.2 m (4 ft) depth. The experimental design was a randomized block with four replications on 400 m (1/4 mi) furrows having a 0.15% grade. Each tillage treatment strip was 4.5 m (15 ft) wide. Three furrows spaced 1.5 m (5 ft) were formed in each plot. The treatments were: (1) Chisel 150 mm (6 in.) deep (Ch-150) Check; (2) Chisel 250 mm (10 in.) deep (Ch-250); (3) Sweep 150 mm (6 in.) deep (Sw-150); and (4) Sweep 250 mm (10 in.) deep (Sw-250).

Primary tillage operations were performed in the fall to early winter and treatment conditions were allowed to remain during the over-winter weathering period. A 93 kW (125 HP) IH 1066 tractor (Larsen, 1974) was used to pull both a 4.5 m (15 ft) wide, three-point mounted chisel plow and sweep plow to perform tillage treatments. The chisel plow (Graham-Hoeme) had fifteen 0.3 m (1 ft) spaced shanks with V-shaped 150 mm (6 in.) points. The sweep plow (Roll-A-Cone) had five 1.0 m (3.3 ft) wide V-blades with a 75° inside angle. Three-point mounted plows were selected to improve traction and to reduce wheel slippage power loss. Power and traction are the limiting factors in accomplishing tillage to 250 mm (10 in.) deep. All primary tillage operations were performed at the maximum ground speed obtainable while maintaining rated engine rpm at full throttle (maximum engine power) as a basis for estimated relative power use. Power requirements were inversely increased as maximum attainable ground speed was reduced.

Shallow rotary tillage 75 to 100 mm (3-4 in.) in depth was performed in April to incorporate surface residue after an anhydrous ammonia application to at 170 kg N/ha (150 lb N/acre). Rotary tillage results are similar to disking but do not leave surface ridges, which is helpful in research plots. A triazine herbicide and Dual™ were applied for broadleaf weed and grass control during late April. Furrows were formed with adjustable-wing openers to minimize ridging of clods along the edges of the wide flat beds (in the path of planter seed-row openers). Tractor traffic for all operations was confined to the centers of the relatively wide beds between 0.75 m (2.5 ft) spaced crop rows in order to avoid differential furrow compaction effects on irrigation advance and infiltration that would occur with traffic in some, but not all furrows (Allen, 1985).

Soil strength was measured to the 0.3 m (1 ft) depth after field preparation and furrowing (about 1 May) and before the first irrigation (preplant). Soil strength was measured with a hydraulic powered cone penetrometer, equipped with an X-Y plotter, providing penetration resistance (relative soil strength) versus depth readings. The cone penetrometer, designed and constructed by G. L. Barker (USDA-ARS, Lubbock, Tex.), is similar to a unit described by Williford et al. (1972). Voorhees et al. (1978) and Allen and Musick (1996) reported penetrometer resistance to be more sensitive than bulk density to differences in compaction, especially for relatively thin compacted layers such as 25 to 75 mm (1 to 3 in.).

A flowing furrow infiltrometer similar to that reported by Dedrick et al. (1985) was used to measure infiltration from 3.7 m (12 ft) length furrow sections just prior to the first irrigation (preplant) application. The infiltration tests were conducted after forming furrows in 1993 and 1994.

Irrigation water was applied through gated pipe and measured with a propeller meter. Individual furrow inflow rates were measured and adjusted by use of volumetric container and stopwatch. Irrigation runoff through furrow outflow was measured through individually calibrated portable H-flumes having float-operated, electric-clock-driven, FW-1 type water-level recorders. Gross irrigation is described as the total amount applied including runoff. Net irrigation is the gross amount less runoff. Furrow inflow rates, during the first application, were set to complete the advance phase in about 24 h. Based on prior experience with 1.5 m (5 ft) spaced furrows with the same soil and slope, we anticipated that this would require furrow inflow rates of 0.95 and 1.25 L/s (15 and 20 gpm) for the 150 and 250 mm (6 and 10 in.) tillage depth treatments, respectively. Gross preplant application amounts were anticipated to be about 190 and 250 mm (7.5 and 10 in.) for the 150 mm and 250 mm tillage treatments, respectively, which would require about 28 to 30 h set times in order to allow 4 to 6 h infiltration opportunity times on the lower end of the furrows. Growing season irrigations were applied when soil water content had been depleted to about 40% of field capacity to the 1.0 m (3.3 ft) depth. For the second and succeeding irrigations, furrow inflow rates were reduced by 20% to 0.75 and 1.0 L/s (12 and 16 gpm) for the 150 and 250 mm tillage treatments, because of lower intake resulting from surface consolidation. Soil water was measured gravimetrically by core samples in 0.3 m (1 ft) increments to the 1.8 m (6 ft) depth. Samples were obtained before and after the first and second applications and at harvest. Growing season water use, referred to as evapotranspiration (ET), was determined by the water balance method, using beginning and ending soil profile water contents, net irrigation, and precipitation.

A "safened" commercial grain sorghum hybrid was planted on 19 May 1992; 14 June 1993; and 9 June 1994 in 0.75 m (2.5 ft) spaced rows [two rows per 1.5 m (5 ft) wide bed] using a 6-row (IH 800 Cyclo) planter with staggered double-disk openers. Grain yields were determined from combine harvested samples obtained from 45 m (150 ft) length sections of four rows near the centers of the three length-of-run increments on 29 Oct. 1992; 4 Nov. 1993; and 1 Nov. 1994. Grain yields were adjusted to 13.5% moisture (w.b.). Water use efficiency (WUE) was determined as the ratio of grain yield to ET. Treatment means were tested for significance at the $P < 0.05$ level using Statgraphics (Manugistics, 1992) for analysis of variance.

Results and Discussion

Soil Conditions Before Infiltration Tests and First Irrigations

After early winter tillage, the chiseling treatment left a cloddy roughened surface and sorghum stalks were partially mixed with the soil. Sweep tillage left a relatively smooth surface with a broken crust and stalks lying flat or partially standing. Winter frost action loosened clods on the chisel treatment and after shallow rotary tillage on all treatments in the spring to control weeds and mix residue with the soil, surface conditions were similarly fluffed to the 100 mm (4 in.) depth for all treatments. After furrowing, roughness in furrows was similar in all treatments having some moderate sized clods up to 17 mm (0.7 in.) diameter.

Infiltrometer Tests

Cumulative infiltration obtained by the infiltrometer tests is presented in figure 1. In both 1993 and 1994, total infiltration amounts ranged from 20 to 27% more with the deeper primary tillage which was significant. Sweep tillage had a relatively small effect on increasing total infiltration compared with chisel tillage. Cumulative infiltration in 1994 was greater for all treatments than in 1993 because of less winter precipitation and drier soil conditions below the 300 mm (12 in.) depth. Infiltration rates (fig. 2) were relatively high during the first hour, then declined rapidly after the tilled layer reached saturation. Infiltration rates with the deeper tillage treatments were visibly higher during the first 2 to 3 h compared with normal tillage depth because of greater void space to be filled with water.

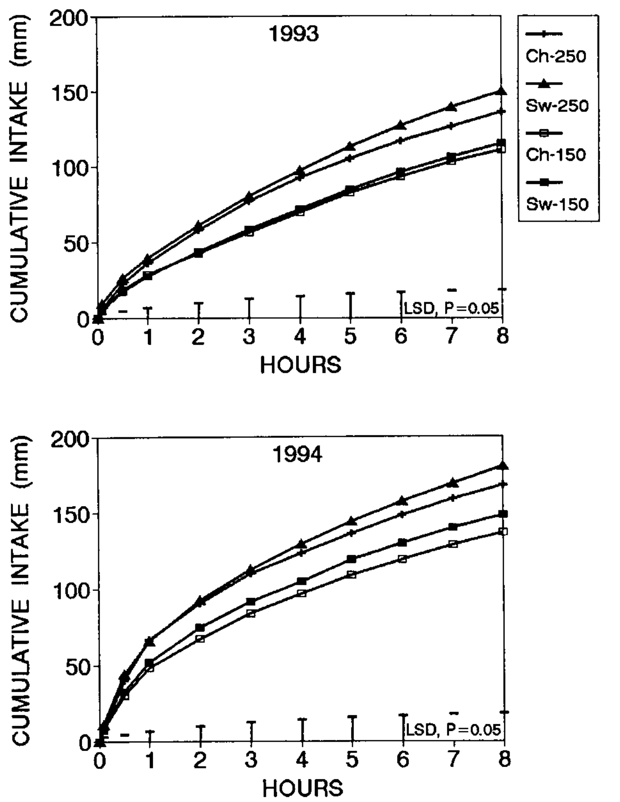

Figure 1–Cumulative infiltration measured by flowing furrow infiltrometer before the first (preplant) irrigation (LSD = least significant difference) (25 mm = 1 in.).

Field Plot Net Irrigation Infiltration

The net irrigation (table 1) for the first application in 1992 averaged 28% higher for the deeper tillage treatments compared with the Ch-150 check. Differences were less (13%) for the first irrigation in 1994 because of the relatively wet soil to the 300 mm (12 in.) depth from 44 mm (1.7 in.) of rain a week before the application. This irrigation was applied, although the surface was relatively wet, in order to wet the lower plant rooting profile without unduly delaying planting. Differences in irrigation amounts between the depth of tillage treatments during growing season applications were small or non-existent because of furrow surface consolidation after the first irrigation (table 1). During the furrow consolidation accompanying the soil particle wetting with the first irrigation, the aggregates separated leaving a relative smooth furrow surface which reduced infiltration rates and amounts for succeeding irrigations.

These 20 to 28% higher infiltration amounts for the first irrigation after relatively deep tillage into the "B" soil horizon, as measured by both furrow infiltrometer and full

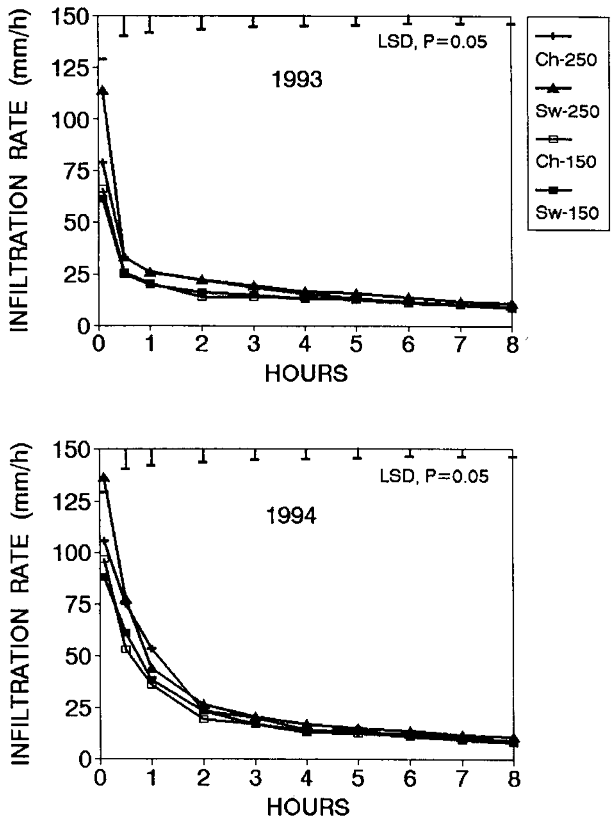

Figure 2–Infiltration rates before the first (preplant) irrigation (LSD = least significant difference) (25 mm = 1 in.).

Table 1. Seasonal rainfall, net irrigation, profile depletion, ET, sorghum grain yield, and WUE, Bushland, Texas

Treatment	Rain. (mm)	Net Irrigation: Pre-plant (mm)	Net Irrigation: Growing Season (mm)	Net Irrigation: Growing Season (mm)	Profile Depletion (mm)	ET (mm)	Grain (Mg/ha)	WUE (Kg/m³)
1992		5/11*	7/22					
Ch-150 (ck)	458†	132	82		64	604	8.11	1.34
Sw-150	458	129	97		59	613	7.94	1.30
Ch-250	458	165	97		53	608	7.65	1.26
Sw-250	458	168	97		68	623	8.01	1.29
						(NS)	(NS)	(NS)
1993			8/3	8/25				
Ch-150 (ck)	264		94	140	130	628	8.35	1.33
Sw-150	264		91	139	135	630	8.37	1.33
Ch-250	264		96	140	134	635	8.86	1.40
Sw-250	264		94	137	126	620	8.99	1.45
						(NS)	(0.32)‡	(NS)
1994		6/1	7/30	8/26				
Ch-150 (ck)	268	146	113	110	100	591	8.61	1.46
Sw-150	268	146	113	106	102	588	8.64	1.47
Ch-250	268	161	113	112	113	606	9.15	1.51
Sw-250	268	165	113	110	99	590	9.20	1.56
						(NS)	(NS)	(NS)

* Irrigation date.
‡ LSD at $P < 0.05$.
† Metric to English conversion: 25 mm = 1 in., 1 Mg/ha = 890 lb/ac, 1 kg/m³ = 226 lb/ac-in.

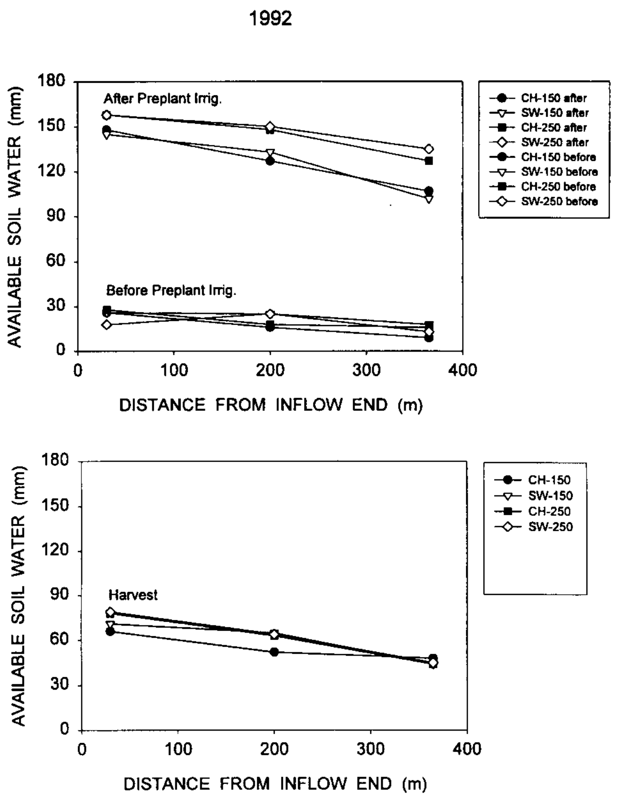

Figure 3–Plant available soil water contents to the 1.2 m (4 ft) depth with distance from furrow inflow end before and after preplant irrigations and at harvest, 1992 (25 mm = 1 in., 1 m = 3.28 ft).

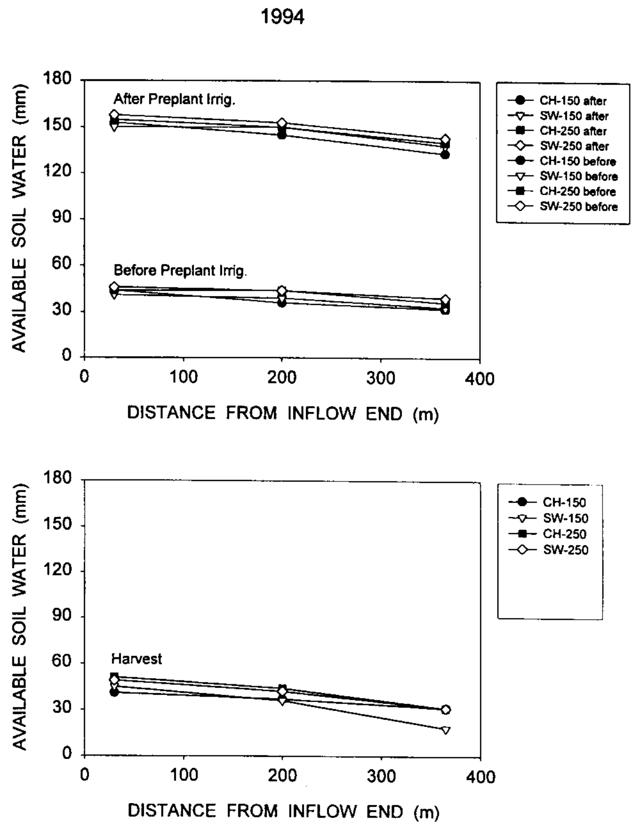

Figure 4–Plant available soil water contents to the 1.2 m (4 ft) depth with distance from furrow inflow end before and after preplant irrigation and at harvest, 1994 (25 mm = 1 in., 1 m = 3.28 ft).

field plot measurements, support the research hypothesis. These results are similar to those reported by Musick et al. (1981) and Allen et al. (1995) when the Pullman soil was loosened by moldboard plowing to deeper than the normal 150 to 200 mm (6 to 8 in.).

Soil Water Storage

Precipitation amounts between the early winter primary tillage and the first irrigation were 175 mm (6.93 in.), 160 mm (6.22 in.), and 135 mm (5.30 in.) for 1992, 1993, and 1994, respectively. Plant available soil water (ASW) to 1.2 m (4 ft) deep versus distance from the upper furrow inflow end is presented in figures 3 and 4 for conditions before and after the preplant irrigation and at grain harvest in 1992 and 1994. In 1993, the soil was relatively wet to the 0.75 m (2.5 ft) depth in May and no preplant irrigation was applied. ASW before the preplant irrigation was 75 mm (3 in.) in 1992 and 100 mm (4 in.) in 1994. The ASW after the preplant irrigation in 1992 was about 25 mm (1 in.) higher for the deeper tillage treatments. There was no tillage effect on ASW. The high growing season rainfall in 1992 (fig. 5) eliminated differences in ASW among tillage treatments by harvest. In 1994, infiltration from the first irrigation was about equal for all tillage treatments at 150 mm (6 in.) (table 1), consequently there was no difference in ASW after the first application.

Grain Yield and WUE

Sorghum grain yields ranged from 7.6 to 9.2 Mg/ha (6,700 to 8,200 lb/ac) during the study. Grain yields were significantly higher for the deeper tillage treatments only in

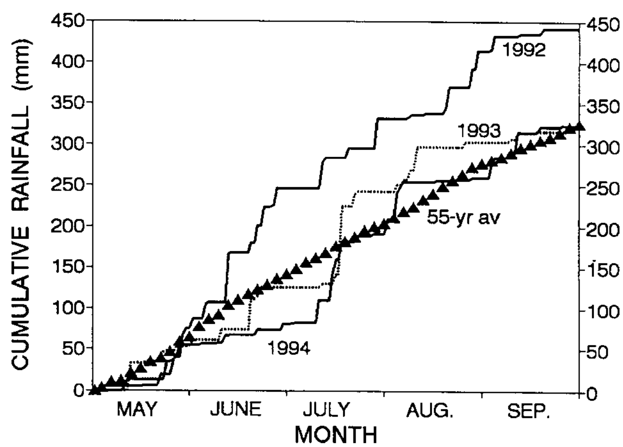

Figure 5–Cumulative rainfall during crop growing seasons, 1992, 1993, and 1994 compared with long-term average (25 mm = 1 in.).

1993 (table 1). WUE ranged from 1.26 to 1.56 kg/m^3 during the three crop seasons, but was not significantly affected by tillage depth or method in any year. The lack of a significant grain yield and WUE response to increased tillage depth probably resulted from the effects of average to above average rainfall (fig. 5) in maintaining adequate water levels for relatively high sorghum yields. Yield increases due to greater tillage depth are more likely in relatively dry seasons when water deficits are expected. Deep primary tillage can enhance water infiltration and storage deeper in the profile [0.6 to 1.2 m (2 to 4 ft)] for

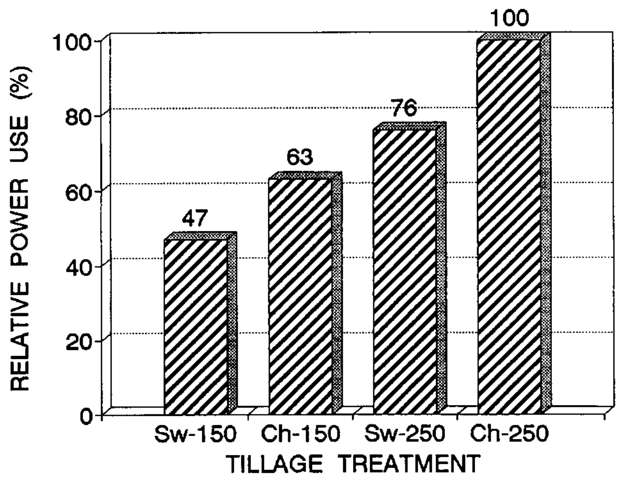

Figure 6–Relative estimated power use for tillage implements, Bushland, Texas.

later season use. However, in seasons of average or above average precipitation, the deep profile storage may not be needed or efficiently used in meeting seasonal ET requirements. In this case, the rewetting of a shallower profile depth [0 to 0.8 m (0 to 2.5 ft)] with rainfall and moderate irrigation can be adequate for high yields.

Relative Tillage Power Use

All primary tillage operations were performed at full tractor power and the deeper 250 mm (10 in.) tillage operations could only be accomplished at relatively low ground speeds. Chiseling required 34% more power and time compared with sweep tillage at the 250 mm (10 in.) depth and 32% more for the 150 mm (6 in.) depth. The relative differences in estimated power requirements for the tillage treatments are illustrated in figure 6. Increasing the tillage depth from 150 to 250 mm (6 to 10 in.) increased power requirements by an average of 60% for both tillage methods. The apparent major reason for higher power requirements with chisel tillage is the greater number of shanks stirring the soil, 15 for the chisel tiller compared with 5 for the sweep tiller. Visual observations indicated that sweep tillage leaves more crop residue on the surface than chiseling; however, no residue measurements were made in this study. These observations agree with crop residue retention research results reported by Fenster (1973) where V-sweeps [0.75 m (2.5 ft)] wide or larger reduced surface residue by an average of only 10% for each operation compared with a 20 to 25% residue reduction for each operation with 0.3 m (1 ft) spaced chisel plow shanks.

Soil Compaction

Soil strength, as an indicator of compaction, is presented as the cone index in figure 7. Obtained on 5 May 1992, this data is typical of measurements made before the first irrigations were applied in other years. Cone index values show the compaction effects for wheel tracks in the center of the wide beds for both depths of primary tillage. A furrow compaction effect, apparently caused by the soil shearing/lifting action of furrow openers, is rather distinct and was unexpected because no wheel traffic occurred in the furrows. This peak in compaction occurred from 50 to 100 mm (2 to 4 in.) beneath the surfaces of both wheel tracks and irrigation furrows and the amount of compaction was not significantly affected by the depth of prior primary tillage. The furrow bottoms were about 75 mm (3 in.) below the field surface, which is reflected by the compacted layer under furrows being deeper relative to the field surface. as illustrated in figure 7.

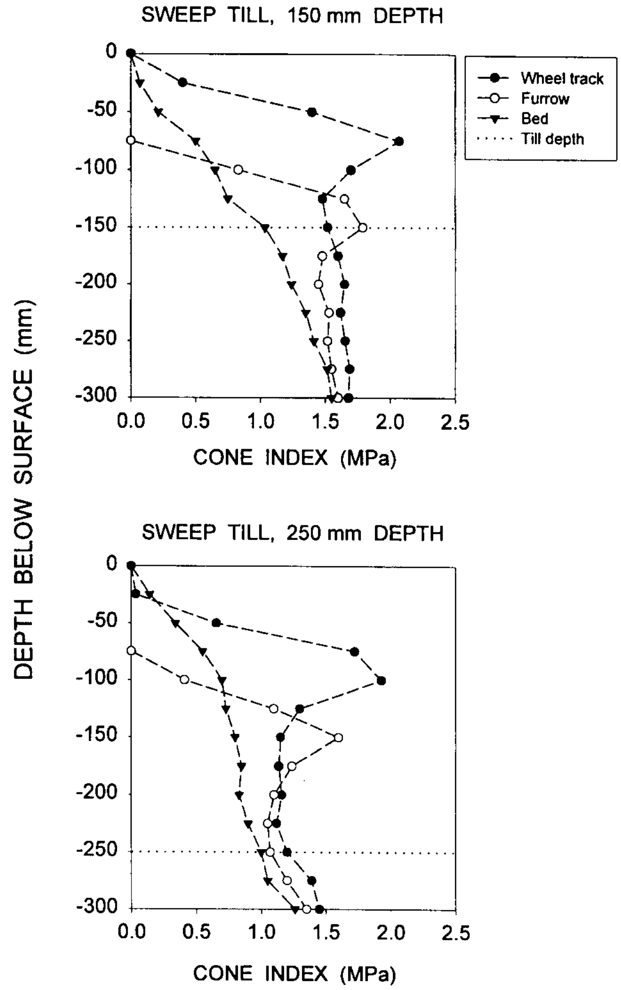

Figure 7–Cone index values for sweep tillage at 150 and 250 mm (6 and 10 in.) depths on 5 May 1992 (25 mm = 1 in., 1 MPa = 145 psi).

The furrow opener compaction effect can be understood from an explanation of the mechanics and theory of wedge forces with soil engaging tools by Goryachkin (1973). The downward force component resulting from a wedge lifting action of the furrow opener on soil was counteracted by the reaction of the supporting (furrow) surface which resulted in the furrow compaction.

Chisel versus Sweep Tillage

Sweep tillage required only about 75% as much power and time as did chiseling to the same depth, and it was just as effective in this soil. Under conditions where deeper than normal tillage is desired such as 200 to 250 mm (8 to 10 in.) to loosen compacted layers below normal tillage depth or to alleviate compaction from livestock grazing of crop residue, sweep tillage can be faster and lower in power and fuel requirement while leaving a smoother surface than chiseling. Fuel and time savings were also substantial when sweep tillage was performed at the normal 150 mm (6 in.) depth compared with chiseling at the same depth. Economic cost comparison of the primary tillage methods was not included in the scope if this study. However, when power requirements with sweep tillage were reduced and machine travel speed was inversely increased compared with chiseling, tillage costs, including labor, were reduced by sweep tillage.

CONCLUSIONS

1. Extending primary tillage depth from 150 to 250 mm (6 to 10 in.) increased irrigation water infiltration from 20 to 28% for the first application after primary tillage, but had little effect during successive irrigations because of furrow surface consolidation after the first application.
2. Extending primary tillage depth from 150 to 250 mm (6 to 10 in.) increased power requirements by about 60%.
3. Sweep tillage was just as effective as the more common chiseling for soil loosening and required only about 75% as much power and time.
4. Tillage method and depth did not significantly affect water use efficiency in the years studied which received average to above average precipitation. Tillage depth significantly increased grain yield in only one year, 1993.

REFERENCES

Allen, R. R. 1985. Reduced tillage—Energy systems for furrow irrigated sorghum on wide beds. *Transactions of the ASAE* 28(6):1736-1740.

Allen, R. R. and J. T. Musick. 1990. Effect of tillage and preplant irrigation on sorghum production. *Applied Engineering in Agriculture* 6(5):611-618.

________. 1997. Furrow irrigation infiltration with multiple traffic and increased axle mass. *Applied Engineering in Agriculture* 13(1):49-53.

Allen, R. R., J. T. Musick and A. D. Schneider. 1995. Residual deep plowing effects on irrigation infiltration for Pullman clay loam. *SSSA* 59(5):1424-1429.

Dedrick, A. R., L. A. Hardy, A. J. Clemmens, J. A. Replogle and L. M. Tomchak-Clemmens. 1985. Trailer mounted flowing furrow infiltrometer. *Applied Engineering in Agriculture* 1(2):79-83.

Fenster, C. R. 1973. Stubble mulching. In *Conservation Tillage*, 202-207. Ankany, Iowa: Soil & Water Cons. Soc. Am.

Goryachkin, V. P. 1973. *V. P. Goryachkin Collected Works* (in three volumes), ed. N. D. Luchinskii, vol. 1: 210-224. Springfield, Va: U.S. Dept. Commerce, Natl. Info. Serv.

Larsen, L. F. 1974. Nebraska tractor test No. 1124. In *Implement & Tractor Redbook* 89(3):A-310.

Manugistics. 1992. Statgraphics. Rockville, Md.: Manugistics.

Musick, J. T., D. A. Dusek and A. D. Schneider. 1981. Deep tillage of irrigated pullman clay loam—A long-term evaluation. *Transactions of the ASAE* 24(6):1515-1519.

Pringle, F. B. 1994. Personal communication, Soil Scientist, USDA-NRCS, Amarillo, Texas.

Unger, P. W. and F. B. Pringle. 1981. Pullman soils: Distribution, importance, variability and management. Texas Agric. Exp. Sta. Bul. B-1372. College Station, Tex.

Voorhees, W. B., C. G. Senst and W. W. Nelson. 1978. Compaction and soil structure modification by wheel traffic in the northern Corn Belt. *SSSA J.* 42:344-349.

Williford, J. R., O. B. Wooten and F. E. Fulgham. 1972. Tractor mounted field penetrometer. *Transactions of the ASAE* 15(2): 226-227.