Irrigated Wheat Grazing and Tillage Effects on Subsequent Dryland Grain Sorghum Production

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ABSTRACT

Use of conservation tillage has improved sorghum [*Sorghum bicolor* (L.) Moench] grain yield 10 to 20% in ungrazed wheat (*Triticum aestivum* L.)–fallow–sorghum production systems. Our objective in this 2-yr field study was to develop tillage guidelines for systems where the wheat was grazed. Grazing duration on winter wheat and tillage during the fallow period preceding dryland grain sorghum were treatments on Pullman clay loam (Torrertic Paleustoll). Grazing increased surface soil compaction and reduced wheat residues. Surface soil (0–5 cm) penetration resistance was 0.36, 0.52, 0.75, and 0.92 Mpa, and wheat residue in 1996 was 6.0, 4.8, 3.5, and 1.2 Mg ha for ungrazed and early, normal, and late cattle removal dates, respectively. As a result, sorghum grain yield in 1996, an exceptionally wet season, was 7.9, 7.5, 7.0, and 3.8 Mg ha^{-1}, respectively, with no tillage (NT). In 1997, a dry season with low runoff, only the late cattle removal with NT had reduced yield (3.4 Mg ha^{-1} compared with 3.9 Mg ha^{-1} for ungrazed NT). Use of one-time sweep tillage early in fallow resulted in an increase in sorghum grain yield of 1.9 Mg ha^{-1} in 1996 for the late cattle removal treatment compared with NT, but it had no effect on yield with the normal cattle removal treatment. In 1997, one-time sweep tillage increased yield by 0.3 Mg ha^{-1} with late removal. When wheat residue was ≤2.4 Mg ha^{-1} following grazing, sweep tillage reduced surface compaction, increased soil water at planting an average of 26 mm over 2 yr, and improved grain yield of sorghum compared with NT. If wheat residues were ≥3.5 Mg ha^{-1} after grazing, NT was as effective as any tillage treatment. Results agree with conservation tillage guidelines developed on ungrazed wheat.

The climate on the Southern High Plains is semiarid with variable precipitation. Mean growing season precipitation for the grain sorghum production season averages about 200 to 250 mm at the study site, depending on planting date and maturity of the grain sorghum cultivar selected. Total precipitation from June through September averages 260 mm but has ranged from 65 to 545 mm during 59 yr of record. Sorghum normally is planted from late May through June and matures in September or October. Mean 0°C frost dates are 21 April and 22 October for a mean frost-free growing season of 184 d.

Conservation tillage, including stubble mulch (SM) tillage and NT, has proven to be a successful dryland management technique on clay loams of the Southern High Plains (Jones and Popham, 1997). This management system increases soil water storage by maintaining residues on the surface to reduce runoff and evaporation. Stubble mulch tillage, a technique that uses large V-shaped blades to undercut residues and weeds, is better adapted to lower residue conditions than NT (Jones and Popham, 1997). With low residues such as after dryland sorghum or cotton (*Gossypium hirsutum* L.), a surface crust can form that results in very low water infiltration. Unlike NT, SM tillage disturbs this crust, which temporarily results in increased infiltration rates. No tillage is an effective water conservation technique with higher residue levels that typically follow wheat harvest. In a dryland winter wheat–grain sorghum–fallow rotation, use of SM is recommended during fallow from sorghum harvest to wheat planting, and NT is recommended from wheat harvest to sorghum planting (Jones et al., 1994).

Conservation tillage guidelines have been well documented in ungrazed systems; however, much of the winter wheat grown on the Southern High Plains is grazed. Grazing reduces wheat residues remaining after harvest (Winter and Thompson, 1987) and increases soil compaction (Worrell et al., 1992).

The objective of this research was to extend management guidelines for conservation tillage from ungrazed to grazed production systems. We wanted to know when use of NT was appropriate after grazing wheat and when use of some type of tillage would be necessary to help alleviate the compaction and low residues associated with grazing.

MATERIALS AND METHODS

This cropping systems research was conducted at the Bush Research Farm, 3 km north of Bushland, TX. The soil at this location is a Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll) with a 0.25 to 1.0% slope. Graded furrow irrigation is used at the site. This soil is capable of holding about 225 mm of plant available water in the 1.8-m profile. However, only about 175 mm of this water is available for dryland sorghum due to shallow rooting that is associated with a dense subsoil and the short vegetative growth period of sorghum. A complete description of Pullman soil has been published (Unger and Pringle, 1981).

Treatments included a combination of grazing systems plots from previous research on irrigated winter wheat and tillage methods used during the approximately 335-d (11 mo) fallow period between wheat harvest and planting of dryland grain sorghum. The grazing systems treatments, layout, and experimental design that form the framework for the research in this paper have been previously described in detail (Winter et al., 2000). Major variables in the grazing systems research were wheat planting date and cattle removal dates. Grazed wheat was planted on two dates each year between 23 August and 29 September. Dates varied because of weather delays. Ungrazed wheat was planted 26 Sept. 1994 and 9 Oct. 1995. Planting dates, grazing, and other variables were confounded because treatments are production systems (Winter et al., 2000). Cattle removal dates averaged 4 wk before, near, and 4 wk after first hollow stem for early, normal, and late cattle removal dates, respectively. Date of first hollow stem averaged 23 Feb. 1995 and 7 Mar. 1996. Removing cattle at first hollow

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Abbreviations: ET, evapotranspiration; HI, harvest index; NT, no tillage; PT, paratillage; SM, stubble mulch.

stem has been shown to maximize economic return (Redmon et al., 1996).

Wheat was irrigated by the graded-furrow method (1-m furrow spacing) at 30 to 60% of evapotranspiration (ET). Soil was near the wilting point at wheat harvest. The dry soil at harvest would provide soil water contents at the beginning of fallow similar to those found in dryland rotations. Using irrigated wheat allowed a greater range in wheat residue levels. A wide range in grazing duration was used to provide a large range in wheat residue levels and variable soil compaction.

Plot sizes for the grazing systems research were 6 by 360 m for the ungrazed check and early cattle removal treatments, 36 by 360 m for the normal removal treatment, and 24 by 360 m for the late removal treatment. These plot sizes were dictated by the needs of the grazing systems research (Winter et al., 2000). Because the only feasible size for tillage treatments and sorghum plots was 6 by 360 m, all tillage treatments were not used on all plots of the grazing system treatments. Putting two or more tillage plots within the 360-m length would have resulted in runoff from plots of one treatment onto plots of the adjacent treatment. Runoff across the plots did not occur because the wheat was grown on six 1-m-wide beds that were about 0.15 m tall.

The ungrazed and early removal plots had only one tillage treatment (NT during the entire fallow period). With the high residue levels on these plots, this treatment was deemed appropriate based on prior research results (Unger, 1978, 1994). The greatest range of tillage treatments occurred on the plots of the normal date of cattle removal treatment, which had the largest available plot area. Tillage treatments were: (i) NT during the entire fallow period until sorghum planting (Treatments 1, 2, 3, 7, and 9); (ii) one sweep operation after wheat harvest to reduce surface compaction followed by NT using herbicide until sorghum planting (Treatments 4 and 8); (iii) paratillage (PT), one pass with a paraplow soon after wheat harvest to cause major soil loosening to a 30-cm depth while maintaining most surface residue (Unger, 1993), followed by NT with herbicide (Treatments 5 and 9); and (iv) conventional SM tillage during fallow (Treatment 6). Conventional SM tillage was performed with the same implement used for Treatments 4 and 8. This implement has seven 1.1-m sweeps spaced at 1.0-m intervals. Shanks of these sweeps were centered in the furrow with the sweep undercutting the bed. Tillage Treatments i, ii, and iii were also applied to the late removal area, but Treatment iv was not included to allow adequate border areas around plots. All tillage treatment plots were 6 by 360 m, and each treatment was replicated three times on each of the two wheat planting date areas. Because wheat planting date had no significant effect ($P = 0.05$) on any facet of sorghum production, results for wheat planting date plots were averaged in the presentation of the data.

In 1996 and 1997, treatments were identical for sorghum following wheat. In 1997, sorghum was also planted back on the 1996 plot area. Tillage between the 1996 and 1997 sorghum crops was strictly NT to test the residual effects of prior treatments on the second sorghum crop. All wheel traffic throughout all experiments was confined to alternate furrows, which were spaced 1 m apart. Two furrows per plot were heavily compacted by tractor wheels. The furrow between plots was moderately compacted by gauge wheels of the planter and other implements.

Pioneer[1] brand '8699'sorghum seed saftened with Concep was planted in mid-June on 6- by 360-m plots at a row spacing of 0.25 m in 1996 and 0.5 m in 1997. Row spacing changed due to differing planter availability. Seeding rates were 16 seeds m^{-2} in 1996, 12 seeds m^{-2} in 1997 for sorghum after wheat, and 8 seeds m^{-2} in 1997 for sorghum after sorghum.

Weed control when using NT during fallow, including after the one-time tillage operations, was accomplished by broadcast-spraying Landmaster BW {glyphosate [*N*-(phosphonomethyl)glycine] and 2,4-D [(2,4-dichlorophenoxy)acetic acid]} at 2.3 L ha^{-1}. A pre-emergence treatment of Bicep {atrazine [6-chloro-*N*-ethyl-*N*'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] and metolachlor [(2-chloro-*N*-2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide} was broadcast on all sorghum plots immediately after planting at label rates for this soil (5.2 L ha^{-1}). No other herbicides or means of weed control were needed prior to sorghum harvest. All sorghum was sprayed once with Lorsban {chlorpyrifos [*O*,*O*-diethyl *O*-(3,5,6-trichloro-2-pyridyl)phosphorothioate]} in 1996 to control head worms (*Heliothis zea* Boddie) and once in 1997 to control greenbugs (*Schizaphis graminum* Rond.).

Sorghum was harvested for grain yield using a field combine with a 6-m-wide header. Plots were trimmed to about 345 m in length before harvest. Grain from each plot was weighed, and a sample was taken to determine moisture content. The sample was oven-dried to determine dry grain mass. Samples from 1-m^2 areas were collected by hand before grain harvest to determine harvest index (HI). Stand and head counts were made on two 2-m^2 areas per plot at the five-leaf stage and at maturity, respectively. Crop residue levels were calculated using combine-harvested grain yield data and HIs determined from hand-harvested samples.

Soil water contents were determined at planting and harvest by gravimetric sampling of one core per plot to a 1.8-m depth. Samples were weighed, dried at 105°C for 2 d, and reweighed. Rainfall was recorded daily 0.6 km from the experimental site. Pan evaporation was recorded daily from a 0.6-m (2 ft) Young screened pan. Potential ET was estimated for a short-season sorghum hybrid using the North Plains potential ET network, which has a site that is 0.6 km from the experimental area (Marek et al., 1996).

Soil penetration resistance was determined to a 30-cm depth using a hand-held recording penetrometer (Bush Soil Penetrometer SP10, Findlay, Irvine, Penicuik, UK). Soil water content was determined at four depths in association with penetration resistance. Penetration resistance reported is a mean of wheel track furrow, non-wheel track furrow, and center of bed locations. The experiment had a randomized complete block design with tillage treatments applied as an incomplete factorial across grazing systems. Analysis of variance was performed using the general linear models procedure of SAS (SAS Inst., 1990). Treatment means were separated using analysis of variance, Duncan's multiple range test, and least significant differences at $P = 0.05$ unless otherwise stated.

RESULTS AND DISCUSSION

Growing Conditions

Growing conditions for dryland grain sorghum were good in 1996 but below average in 1997. The 1996 growing season followed a record dry winter from October 1995 until May 1996. As a result, soil water was only partially recharged at planting in 1996. Modest rainfall in late May and early June was followed by ideal precipitation during the remainder of the growing season (Table 1). Precipitation totals were recorded at 2-wk intervals beginning with the last 2 wk of June through the first

[1] The mention of trade or manufacturer names is for information only and does not imply an endorsement, recommendation, or exclusion by the USDA-ARS or the Texas Agricultural Experiment Station. Mention of a pesticide does not constitute a recommendation for use, nor does it imply registration under FIFRA as amended.

Table 1. Precipitation, pan evaporation, and estimated evapotranspiration (ET) at the research site during two growing seasons.

Year	June	July	Aug.	Sept.	Total
	mm				
			Precipitation		
1996	74	156	155	55	440
1997	22	28	76	27	153
Normal†	75	67	70	48	260
			Pan evaporation‡		
1996	196	192	136	107	631
1997	142	227	149	159	677
Normal§	178	210	178	154	720
			Potential ET¶		
1996	60	143	175	104	482
1997	50	173	183	110	516

† 59-yr average, 1939–1997.
‡ Measured evaporation from a 0.6-m (2 ft.) Young screened pan.
§ 20-yr average, 1978–1997.
¶ Estimated potential ET of short-season sorghum planted 15 June.

2 wk of September in 1996; they were 51, 94, 63, 55, 99, and 49 mm. With heading on about 10 August and physiological maturity near 20 September, the amount and distribution of precipitation in 1996 was nearly ideal for the crop's needs. Precipitation intensity was not excessive for this region; however, there were 8 d with 25 to 51 mm of precipitation, giving ample opportunity for runoff on this soil.

Precipitation was much less in 1997 than in 1996 and totaled about 59% of the average (Table 1). About one-third of the summers at Bushland are drier than they were in 1997 while two-thirds are wetter. Precipitation was adequate through sorghum heading with 76 mm falling over an 11-d period near heading in the first half of August. However, no more precipitation occurred before physiological maturity, which resulted in severe late-season drought. Daily rainfall amounts were low with >13 mm of precipitation occurring on only 2 d. As a result of low rainfall intensity and amount during the growing season, there was minimal potential for runoff from plots of any treatment in 1997.

Evaporative demand was somewhat below average both years (Table 1). Below-normal temperatures and above-normal dew points moderated evaporative demand in 1996 at about 88% of the average. Evaporation was 94% of the average for the June through September total in 1997. Estimated potential ET was slightly higher in 1997 (516 mm) than in 1996 (482 mm). The deficit of growing season precipitation compared with estimated potential ET was 42 mm in 1996 and 363 mm in 1997. The ET deficit in 1996 was easily supplied by stored soil water, assuming minimal runoff, whereas the deficit in 1997 was about double the maximum available water storage capacity of the soil.

There were no significant non-water production constraints for dryland sorghum production in either year. Plant stands were uniform and near optimum for the prevailing conditions. There were no significant losses due to weeds, diseases, or insects. Visual appearance of the sorghum was very good both years, except for the late-season drought stress in 1997. No lodging occurred and harvest losses were low in 1996. Some lodging associated with late-season drought stress occurred in 1997, but harvest losses were <10%. The harvest losses were probably not serious enough to affect treatment differences.

Grain Sorghum, 1996

The plant available water content was moderate to low in the upper 1.8 m of soil at planting in 1996 compared with the approximately 225-mm total available water-holding capacity of Pullman clay loam (Table 2). Available water contents ranged from 141 mm for the ungrazed NT treatment (Treatment 1) to 63 mm for the late cattle removal NT treatment (Treatment 7). These differences in available soil water at planting are likely due to the amount of wheat residue and soil conditions for water infiltration after wheat harvest. Rainfall totaled 276 mm from July through September 1995. This resulted in considerable soil water recharge where residue levels and soil conditions were favorable. However, rainfall totaled only 64 mm during the ensuing 210 d,

Table 2. Dryland grain sorghum response in 1996 to wheat grazing treatments and tillage during fallow after wheat on Pullman clay loam, Bushland, TX.

Treatment no.	Cattle removal	Tillage†	Prior crop residue‡	Sorghum Stand	Sorghum Heads	Soil water Available at planting	Soil water Seasonal use	Sorghum Dry grain mass	Sorghum HI§
			Mg ha^{-1}	no. m^{-2}		mm		Mg ha^{-1}	
1	Ungrazed	NT	6.0a	14.7a	22.5a	141a	49a	7.92a	0.49a
2	Early	NT	4.8b	14.5a	21.3ab	132a	48a	7.53ab	0.49a
3	Normal	NT	3.5c	13.3a	18.7a-d	114bc	40ab	7.02bc	0.47a
4	Normal	Sweep	3.5c	13.5a	18.8abc	108bcd	32bc	7.16bc	0.48a
5	Normal	PT	3.5c	13.5a	16.9cd	117b	49a	6.65cd	0.45a
6	Normal	SM	3.5c	11.4b	17.1cd	99cd	39ab	5.99de	0.47a
7	Late	NT	1.2d	10.1b	16.5cd	63f	23e	3.78g	0.38b
8	Late	Sweep	1.2d	10.7b	17.9cd	81e	24c	5.64ef	0.46a
9	Late	PT	1.2d	10.3b	14.6d	95de	44ab	5.17f	0.46a
	CV%		30.3	10.2	17.3	12.7	27.7	9.64	9.06
	Model R^2		0.78	0.70	0.42	0.82	0.52	0.85	0.45
	Treatment sign.		0.0001	0.0001	0.0009	0.0001	0.0001	0.0001	0.0012
	LSD (0.05)		1.1	1.5	3.6	16	12	0.70	0.05

† NT, no tillage; Sweep, undercut once after wheat harvest with 1-m sweeps, then NT for the remainder of the fallow period; PT, paratill once after wheat harvest, then NT; SM, conventional sweep tillage from wheat harvest until planting sorghum.
‡ Wheat residue measured after wheat harvest.
§ HI, harvest index (grain dry mass ÷ total aboveground dry mass).

which resulted in considerable losses of soil water, even in the absence of a significant weed population. For the NT treatments, soil water at planting and wheat residue declined with later cattle removal dates (Table 2). Previous research at Bushland indicated that available soil water content at planting increased from 123 mm with no mulch to 159, 172, and 205 mm with 1, 4, and 8 Mg ha^{-1} of wheat residue, respectively (Unger, 1978). Compared with NT for the entire fallow period, the one-time tillage operations, sweep and PT, resulted in increased soil water contents at planting with the late cattle removal treatment but not with the normal removal treatment (Table 2). Residue levels and soil conditions likely influenced this interaction. Stubble mulch tillage resulted in an intermediate water level of 99 mm at planting. Both wheat residue levels and tillage methods significantly ($P = 0.05$) affected available soil water contents at planting.

Sorghum stands were generally good in 1996. Establishment ranged from 63 to 92% of the seeding rate of 16 seed m^{-2} (Table 2). Establishment was less on SM tillage and all three late removal treatment plots than on the ungrazed, early, or normal removal treatment plots (Treatments 1–5). The lower stands with later cattle removal probably were not detrimental to yield because soil water content and yield potential also were lower. In fact, lower soil water at planting may have been at least partially responsible for lower stands on plots for Treatments 6 to 9.

Head densities and grain yields were high for dryland production in 1996, reflecting the good growing conditions (Table 2). The yields achieved with the better treatments were average or above average for irrigated production in this region. Yield was highest with the ungrazed NT and the early cattle removal treatments. Yields declined with the later cattle removal treatments. The sweep and PT treatments resulted in yield increases with late removal but not with normal removal. With late removal, one-sweep tillage increased yield by 49% and PT increased yield by 37% compared with NT.

There was a positive correlation of 0.94 between available soil water content at planting and grain yield over all treatments. This indicated both the positive effect of increased soil water content on grain yield and that treatments continued to affect water infiltration after planting sorghum. The magnitude of the yield decline with late removal treatments, observations of runoff from large rainfall events, and depth of water penetration using a soil probe suggested major runoff during the growing season, especially for Treatment 7 (late NT). Excess runoff of about 174 mm occurred with the late NT treatment compared with the ungrazed NT treatment. This amount of runoff was estimated using yield of Treatment 1 to calculate a water use efficiency of 0.02 Mg ha-mm^{-1} assuming a linear increase in yield above 100 mm of total water use. Applying this water use efficiency to Treatment 7 yield and water use results in the estimate that roughly 174 mm less water should have been needed to achieve yield of Treatment 7 compared with that of Treatment 1. This water represents 40% of precipitation that either ran off due to poor intake conditions or evaporated from the soil surface. Field observations and the high yield achieved with the ungrazed NT treatment suggest that this treatment resulted in low runoff of growing season precipitation. The one-time sweep and PT treatments were moderately effective in reducing runoff as indicated by increased soil water at planting and yield increases compared with those using NT. One-sweep plowing was as effective as the PT treatment in promoting grain yield, and it is less energy intensive.

Harvest index was high in 1996, reflecting the good growing conditions (Table 2). The only treatment with a reduced HI was the late NT (Treatment 7). Severe water stress with this treatment apparently reduced grain production more than forage yield. The fact that Treatment 7 had a lower HI would somewhat lower the estimate of excess runoff presented above.

A lower sorghum grain yield following conventional SM tillage instead of NT is consistent with previous observations at this location. No tillage resulted in 17% more grain yield than SM tillage when both are compared at the normal cattle removal date. Previous dryland studies without grazing indicated increases in sorghum grain yield of 12, 21, 6, and 26% (Jones and Popham, 1997; Unger, 1984, 1994; Unger and Wiese, 1979). These increases have been attributed, in part, to greater soil water contents at planting with NT compared with those using SM tillage. While factors responsible for the yield increase cannot be separated, reduced evaporation and runoff during the growing season no doubt contributed to the greater yield with NT than with SM tillage.

Grain Sorghum, 1997

The 1997 growing season was in many ways the opposite of 1996. Fallow season precipitation was 160% of the normal amount (635 mm), resulting in high levels of available water at planting in 1997 (Table 3). Growing season rainfall, however, was 153 mm compared with 440 mm in 1996. Late-season drought stress was the dominant characteristic of the 1997 growing season.

Available soil water content was 155 to 226 mm at planting in 1997 (Table 3) compared with 63 to 141 mm in 1996 (Table 2). Soil of the driest treatment in 1997 was wetter at planting than that of the wettest treatment in 1996. In both years, the driest soil was with the late NT and the other late cattle removal treatments, which in general, resulted in drier soils than those with the earlier cattle removal treatments. Because of the wetter soil at planting and drier growing season, seasonal soil water use averaged 157 mm in 1997 compared with 39 mm in 1996.

Plant stands in 1997 were adequate to fully utilize available water in plots of all treatments. The ratio of head density to plant density averaged 1.14 in 1997 compared with 1.47 in 1996. This reflects the poorer growing conditions in 1997 and supports the idea that plant density was adequate.

Treatment effects on grain yield after fallow in 1997 generally followed the same trends as in 1996; however,

Table 3. Dryland grain sorghum response in 1997 to wheat grazing treatment and tillage during fallow after wheat on Pullman clay loam, Bushland, TX.

Treatment no.	Cattle removal	Tillage†	Prior crop residue‡	Sorghum Stand	Sorghum Heads	Soil water Available at planting	Soil water Seasonal use	Sorghum Dry grain mass	Sorghum HI§
			Mg ha^{-1}	no. m^{-2}		mm		Mg ha^{-1}	
1	Ungrazed	NT	6.6a	11.0ab	12.2	207a	163	3.89a	0.41
2	Early	NT	5.5ab	9.8bc	11.8	211a	162	3.91a	0.42
3	Normal	NT	4.7b	10.3ab	11.7	218a	173	3.82a	0.41
4	Normal	Sweep	4.7b	11.9a	12.4	209a	154	3.71abc	0.42
5	Normal	PT	4.7b	11.2ab	12.0	226a	162	3.66abc	0.41
6	Normal	SM	4.7b	10.3ab	11.4	211a	158	3.55bc	0.40
7	Late	NT	2.4c	8.4c	10.7	155b	130	3.44c	0.39
8	Late	Sweep	2.4c	10.7ab	12.8	189ab	158	3.76ab	0.40
9	Late	PT	2.4c	10.4ab	11.9	188ab	150	3.65abc	0.41
	CV%		28.1	13.9	10.1	16.4	15.1	7.05	5.95
	Model R^2		0.66	0.34	0.23	0.39	0.22	0.42	0.30
	Treatment sign.		0.0001	0.0113	0.19	0.0235	0.18	0.0374	0.35
	LSD (0.05)		1.4	1.7	NS	38	NS	0.25	NS

† NT, no tillage; Sweep, undercut once after wheat harvest with 1-m sweeps, then NT; PT, paratill once after wheat harvest, then NT; SM, conventional sweep tillage from wheat harvest until planting sorghum.
‡ Wheat residue measured after wheat harvest.
§ HI, harvest index (grain dry mass ÷ total aboveground dry mass).

differences due to treatments were much less. The differences were less in 1997 because of previously discussed differences in precipitation patterns, amounts, and intensities. Fallow season precipitation was considerably in excess of the soil's water storage capacity in 1997. However, this heavy precipitation contributed to significant soil water recharge, even on plots of the late cattle removal treatments where infiltration conditions were poorest. Then during the growing season, runoff was limited by low total precipitation and low intensity of the precipitation that occurred. This combination of factors limited grain yield differences between treatments in 1997.

Dryland grain sorghum was planted in 1997 on the 1996 plot area to test for residual effects of treatments. Precipitation between harvest and planting was 275 mm, which resulted in an average available soil water content at planting of 166 mm (Table 4). There were no significant differences ($P = 0.05$) due to treatments for available water content at planting or for seasonal soil water use. Stand density was adequate with all treatments for conditions that prevailed. There were 1.45 heads per plant, which was nearly the same ratio as in 1996 and above that for 1997 sorghum planted after fallow. The previous treatments had no significant effect on yield of sorghum grown after sorghum in 1997. Environmental conditions did not favor treatment effect on grain yield for the same reasons as discussed for the 1997 sorghum planted after fallow.

Soil Penetration Resistance

Soil penetration resistance was measured to help characterize treatment effects on soil water infiltration, an important factor in dryland sorghum production. Penetration resistance was first measured on 23 Aug. 1995 about 5 wk after tillage treatments were initiated. About 150 mm of precipitation occurred between tillage and the first measurement of penetration resistance with 58 mm falling on 15 August. A second reading of penetration resistance was taken on 18 July 1996. Precipitation was 108 mm in the 8 d before this measurement.

Table 4. Dryland grain sorghum response in 1997 when grown on the same plots as the 1996 sorghum crop, Bushland, TX.

Treatment no.	Cattle removal	Tillage†	Prior crop residue‡	Sorghum Stand	Sorghum Heads	Soil water Available at planting	Soil water Seasonal use	Sorghum Dry grain mass	Sorghum HI§
			Mg ha^{-1}	no. m^{-2}		mm		Mg ha^{-1}	
1	Ungrazed	NT	4.6a	5.6	8.6a	181	85	2.84	0.45
2	Early	NT	4.3ab	5.8	9.3a	178	91	2.71	0.45
3	Normal	NT	3.8cd	4.7	8.5a	163	89	2.69	0.44
4	Normal	Sweep	4.1bc	7.0	8.0ab	159	93	2.80	0.43
5	Normal	PT	3.7d	4.4	6.3c	170	111	2.78	0.44
6	Normal	SM	3.6d	5.9	8.3ab	152	97	2.77	0.45
7	Late	NT	1.2f	6.5	8.4ab	166	88	2.50	0.45
8	Late	Sweep	2.8e	5.6	7.7abc	154	88	2.81	0.43
9	Late	PT	2.9e	4.1	6.8bc	167	85	2.74	0.43
	CV%		4.90	21.7	9.18	12.4	28.9	5.80	3.75
	Model R^2		0.98	0.45	0.71	0.40	0.12	0.46	0.32
	Treatment sign.		0.0001	0.31	0.0119	0.68	0.98	0.47	0.61
	LSD (0.05)		0.4	NS	1.5	NS	NS	NS	NS

† These tillage treatments were imposed before 1996 sorghum. No tillage was used on plots between 1996 and 1997 sorghum.
‡ Sorghum residue following harvest of 1996 treatment in Table 2.
§ HI, harvest index (grain dry mass ÷ total aboveground dry mass).

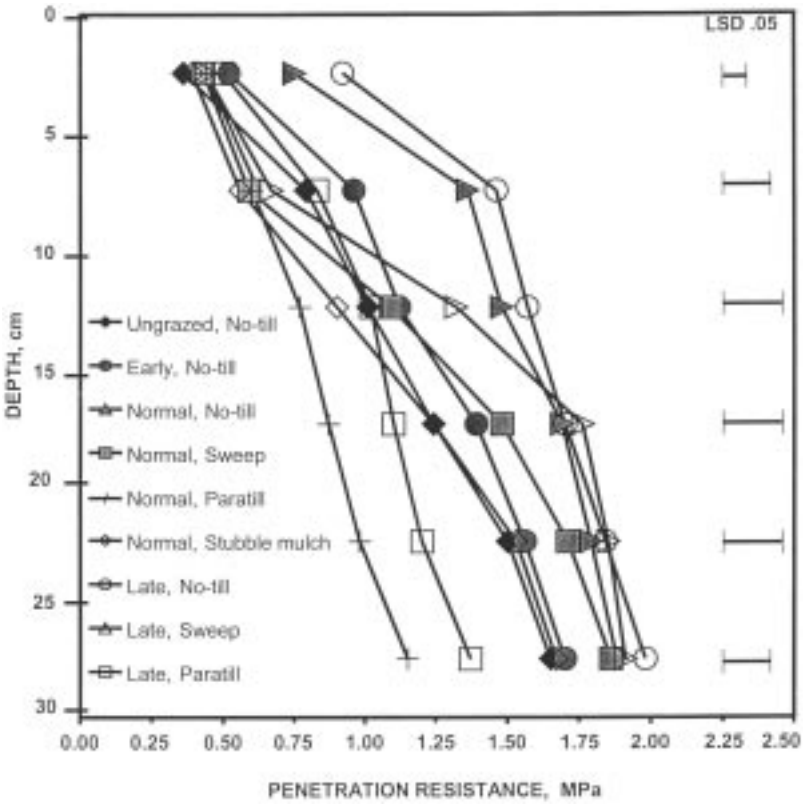

Fig. 1. Soil penetration resistance on 23 Aug. 1995 for ungrazed, early, normal, and late cattle removal treatments with no tillage (NT), sweep tillage, paratillage (PT), or stubble mulch (SM) tillage in nine treatment combinations.

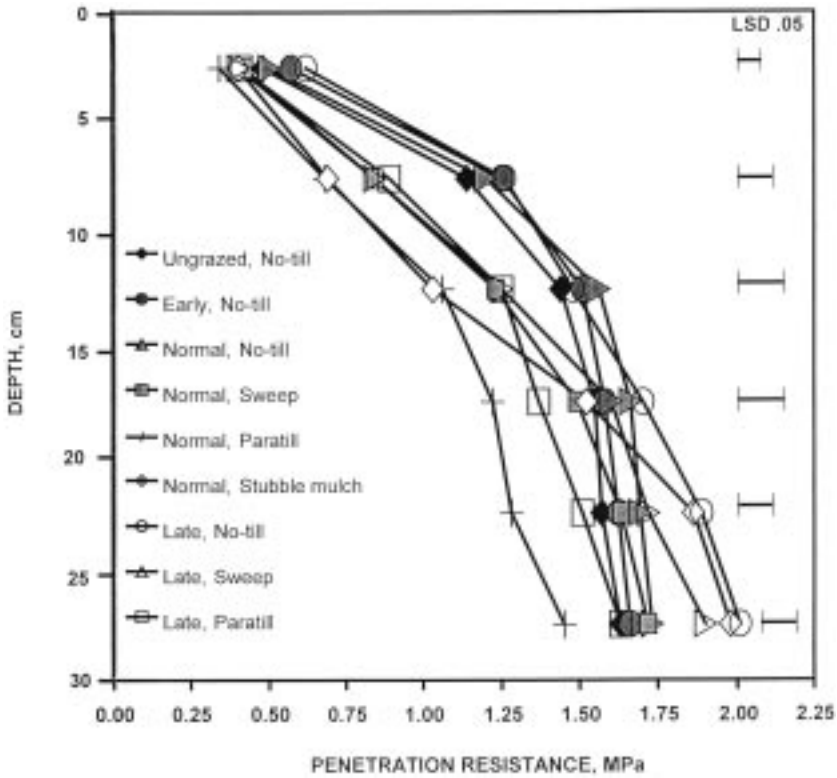

Fig. 2. Soil penetration resistance on 18 July 1996 for ungrazed, early, normal, and late cattle removal treatments with no tillage (NT), sweep tillage, paratillage (PT), or stubble mulch (SM) tillage in nine treatment combinations.

Thus, on both dates of measurement, soil water was near field capacity (23–30% by volume).

Surface compaction increased with grazing duration. In August 1995, penetration resistance at the 0- to 5-cm soil depth with NT averaged 0.36, 0.52, 0.75, and 0.92 MPa with ungrazed, early, normal, and late removal treatments, respectively. These results are similar to those observed in South Carolina where there was a linear relationship between soil compaction and grazing duration (Worrell et al., 1992).

There were large differences in both surface (0–15 cm) and subsurface (15–30 cm) compaction due to both grazing and tillage (Fig. 1). Compared with the ungrazed NT treatment, grazing with early removal resulted in minor increases in compaction only in the surface 10 cm. Normal and late removal treatments increased compaction throughout the 0- to 30-cm soil zone compared with NT or early cattle removal. The combination of increased compaction and lower wheat residues with later cattle removal no doubt contributed to observed differences in soil water content and grain yield in 1996.

Tillage affected surface and subsurface compaction (Fig. 1). One-time sweep tillage reduced surface compaction in August 1995 but had no effect below 15 cm. The PT treatments reduced compaction both in the surface and down to 30 cm. The additional loosening afforded by PT had no positive effects on soil water content or grain yield compared with sweep tillage. Since PT is more energy intensive than the one-time sweep tillage, it can not be recommended based on these data.

Soil penetration resistance was measured a second time about 5 wk after planting sorghum in 1996 (Fig. 2). Treatment effects were generally similar to those seen in August 1995; however, differences due to treatment were less. The PT treatment plots were still less compacted than plots of other treatments below 15 cm. The SM treatment (Treatment 6) increased compaction below 15 cm compared with its similarly grazed NT (Treatment 3) comparison treatment and compared with its condition in August 1995. Compaction of SM below 15 cm increased during fallow due to reduced depth of implement draft and compaction by wheel traffic below tillage depth.

These results indicate that NT management is appropriate after grazed wheat, provided adequate residues are present and the soil is not excessively compacted. In 1996, NT management resulted in as much sorghum grain production as any one-time tillage treatment and 1.0 Mg ha^{-1} more than SM tillage for the normal date of cattle removal with 3.5 Mg ha^{-1} of wheat residue. In 1997, with 4.7 Mg ha^{-1} of wheat residue on normal removal date plots, tillage was unnecessary and SM tillage slightly reduced sorghum grain yield compared with NT. One-time tillage treatment yields were statistically equal to NT ($P = 0.05$) when wheat residue was >3.5 Mg ha^{-1}. If residue levels or compaction are questionable for using NT, then an inexpensive one-time sweep tillage operation early in the fallow period will improve water infiltration and grain sorghum yield following grazed wheat. In 1996, wheat residue was 1.2 Mg ha^{-1} for late cattle removal, and the one-time sweep tillage treatment increased yield by 1.9 Mg ha^{-1} (49%). In 1997, a drier year with less runoff, one-time sweep tillage increased grain yield by 0.3 Mg ha^{-1} (9%) when wheat residue was 2.4 Mg ha^{-1}. Over the 2 yr of study, NT management during fallow was appropriate when wheat residue was ≥3.5 Mg ha^{-1}. When wheat residues were ≤2.4 Mg ha^{-1}, NT was not appropriate and a one-time sweep tillage operation increased sorghum yield. These results agree with conservation tillage guidelines developed on ungrazed wheat, which find NT superior to SM in high-residue conditions but not with low residue (Jones and Popham, 1997). In addition, these results provide actual residue levels at which differing actions seem appropriate.

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