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Ridge Height and Furrow Blocking Effects on Water Use and Grain Yield

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ABSTRACT

Because water supplies are limited for crops in the Great Plains, use of water-conserving practices is important. This study determined the influence of ridge height and furrow blocking on water conservation and use, and yields of irrigated winter wheat (*Triticum aestivum* L.) and dryland grain sorghum [*Sorghum bicolor* (L.) Moench] grown in rotation. The rotation results in two crops in 3 yr with a 330-d fallow between each crop. The study was conducted from 1981 to 1990 at Bushland, TX, on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll). Ridge heights were 12 to 15 or 5 to 8 cm and furrows were blocked or open. The ridge-height and furrow-blocking treatments were imposed every 3 yr before planting wheat. No-tillage was used during fallow after wheat and reduced tillage was used to reform the ridges during fallow after sorghum. Water infiltration was little affected by treatments. Differences in soil water content at planting and harvest were significant in some cases, but trends were inconsistent. Total water use was not affected by ridge height, but was greater with open than with blocked furrows for wheat. Although significant in some years, mean wheat and sorghum yield differences were small. On gentle (<0.5%) slopes, furrow blocking in combination with no-tillage and reduced tillage did not increase soil water storage or crop yields over those obtained with no-tillage alone. There was no indication that long-term no-tillage and reduced-tillage practices adversely affect wheat and grain sorghum production.

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LIMITED PRECIPITATION and water for irrigation greatly influence crops grown and crop yields in parts of the southern and central Great Plains. Winter wheat and grain sorghum are well-adapted crops for these regions under both irrigated and nonirrigated (dryland) conditions. Each crop often is grown continuously, but a rotation involving both crops is well adapted to these regions. When grown in rotation, one wheat and one sorghum crop are produced in a 3-yr period, and a fallow period of about 330 d follows each crop. The fallow periods afford an opportunity for increasing storage of precipitation as soil water, thus reducing the dependence on irrigation and providing some additional water for achieving more favorable crop yields under limited irrigation or dryland conditions.

The percentage of precipitation stored as soil water increases with increasing amounts of crop residue retained on the soil surface during fallow (Greb et al., 1967; Smika and Wicks, 1968; Unger, 1978, 1984; Unger and Wiese, 1979; Wicks and Smika, 1973; Wilhelm et al., 1986). No-tillage usually increases soil water storage when relatively large amounts of residue are available. Although residue production by

Abbreviations: WSF, winter wheat–grain sorghum–fallow; HR–OF, high ridge, open furrow; HR–BF, high ridge, blocked furrow; LR–OF, low ridge, open furrow; LR–BF, low ridge, blocked furrow; Prot. LSD, protected least significant difference.

dryland crops often is relatively low and water storage may be little affected by the tillage method, water storage was greater when irrigated winter wheat residues were managed by the no-tillage method than by disk or sweep tillage (Unger, 1984; Unger and Wiese, 1979). In those studies, soil water contents to a 1.8-m depth at sorghum planting averaged 212 mm for no-tillage, 174 mm for sweep tillage, and 155 mm for disk tillage. Subsequent dryland grain sorghum yields averaged 3.23, 2.61, and 2.12 Mg ha^{-1} with the respective tillage methods.

These studies showed that no-tillage management of irrigated winter wheat residues followed by dryland grain sorghum is an effective cropping system for improving water use and sorghum grain production. However, water storage with this system averaged only 40% of fallow-period precipitation, indicating that substantial amounts of water were lost by runoff and evaporation. Precipitation storage was 29% with sweep tillage and 25% with disk tillage, indicating even greater water losses. Water percolation beyond a 1.8-m depth is slight on Pullman soils, especially from precipitation (Aronovici and Schneider, 1972). Hence, deep percolation was not considered as a water-loss factor in this study.

High ridges on furrow-irrigated land may result in rapid runoff of rainfall and irrigation with resultant poor wetting of ridges. Lower ridges (shallower furrows) should increase the wetted areas, thus increasing the potential for water conservation through increased infiltration and more effective wetting of the ridges. Additional water conservation is possible by capturing potential runoff water from precipitation in blocked furrows (Clark and Jones, 1981; Gerard et al., 1984; Jones and Stewart, 1990; Stewart et al., 1981). Furrow blocking involves mechanically constructing small earthern dams in furrows at 1- to 3-m intervals to capture potential runoff water, thus providing more time for water infiltration. With low ridges and blocked furrows, relatively high yields should be possible without fully irrigating the wheat. In addition, irrigated wheat residues should be adequate to enhance infiltration and suppress evaporation during fallow, thus providing more stored water for the subsequent dryland grain sorghum crop. The objective of this study was to determine the influence of ridge-height and furrow-blocking treatments on (i) soil water storage, (ii) wheat and grain sorghum yields, and (iii) the potential of growing wheat and grain sorghum in rotation for a prolonged period when using no-tillage or minimum-tillage methods.

METHODS AND MATERIALS

The study was conducted at the USDA-ARS Conservation and Production Research Laboratory at Bushland, TX, from 1981 to 1990, on a furrow-irrigated Pullman clay loam having <0.5% slope. Three separate, but adjacent, blocks of land were used so that each phase of the WSF rotation was in place each year.

The initial crop on each block was irrigated winter wheat, with the first crop being established in fall 1981. On that block, wheat was harvested in June 1982, and a fallow period ensued until sorghum planting in May 1983. Sorghum was harvested in the fall of 1983, and the land was fallowed until establishing wheat again in fall 1984 on that block,

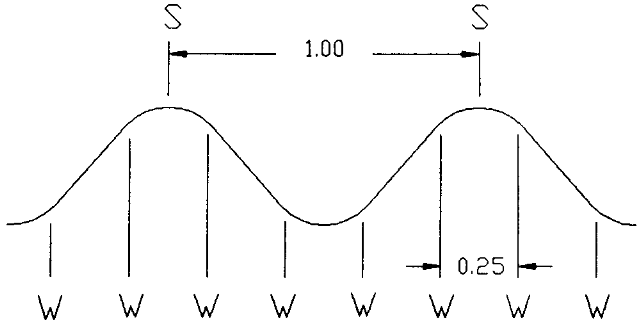

Fig. 1. Diagram illustrating ridge–furrow spacings and row positions for wheat (W) and sorghum (S). Distances are in meters; vertical distance is not to scale.

completing the 3-yr rotation. Wheat was established on the two other blocks in successive years, following the same sequence to establish the WSF rotation. Two cycles of the rotation were completed on each block of land.

Before establishing wheat, the land had been in fallow since sunflower (*Helianthus annuus* L.) harvest in 1980 on the first block, in fallow since wheat harvest in 1981 on the second block, and in wheat during the 1982–1983 season on the third block. In all cases, the land was disked to control weeds and planed to remove minor surface irregularities before lister-plowing in preparation for imposing the ridge-height and furrow-blocking treatments. Before applying tillage treatments, soil NO_3 to a depth of 1.2 m was supplemented with anhydrous NH_3 to provide 170 kg N ha^{-1}. No additional N was applied before planting sorghum, but anhydrous NH_3 was applied again for the next wheat crop to provide 170 kg N ha^{-1}. Crops on Pullman soil generally do not respond to P and K, and these nutrients were not applied in this study.

Ridge heights, established by reducing the initial height of ridges with a rolling cultivator, were 12 to 15 cm for the high-ridge treatment and 5 to 8 cm for the low-ridge treatment. Plots for ridge-height treatments were 12 m wide and 150 m long. Spacing between ridge tops was 1 m (Fig. 1). The ridge-height plots were split lengthwise, with six furrows remaining open (unblocked) and alternate furrows of the remaining rows being blocked mechanically. The experiment had a randomized block, split-plot design, and each treatment was replicated four times.

Treatments were imposed before planting wheat ('Tamwheat 105') at 67 kg ha^{-1} with a single-disk opener drill having row spacings of 0.25 m (Fig. 1). Wheat planting dates ranged from 24 September to 21 October. A limited-irrigation approach was used for wheat, resulting in two to four irrigations per crop, depending on precipitation received, to achieve relatively high yields. If necessary, weeds were controlled with 2,4-D [(2,4-dichlorophenoxy) acetic acid][1] and greenbugs (*Schizaphis graminum* Rondani) were controlled with methyl parathion (*O,O*-dimethyl-*O*-4-nitrophenyl phosphorothioate) at recommended rates. Residue and grain yields were determined by clipping entire plants near the soil surface from two 1-m^2 areas per plot when wheat was mature. The samples were dried at 60 °C, and residue and grain yields are reported on a dry-weight basis. Harvest dates ranged from 18 June to 7 July. Hail destroyed the wheat on 16 May 1989.

Wheat residues on all plots were managed by the no-tillage method, with atrazine (2-chloro-4-ethylamino-6-iso-

[1] Mention of a trade name or product does not constitute a recommendation or endorsement for use by the U.S. Department of Agriculture, nor does it imply registration under FIFRA as amended.

Table 1. Precipitation during a wheat–sorghum–fallow study, Bushland, TX, 1981 through 1990.

Period or year†	Wheat GS‡		Fallow after wheat		Sorghum GS		Fallow after sorghum	
	Actual	Long-term§	Actual	Long-term	Actual	Long-term	Actual	Long-term
	mm							
1981–1982	250	298	—	—	—	—	—	—
1982–1983	216	308	364	378	137	268	—	—
1983–1984	256	291	197	355	304	312	390	459
1984–1985	333	291	421	399	298	261	595	475
1985–1986	204	237	410	462	265	237	533	503
1986–1987	346	291	571	450	318	249	625	448
1987–1988	321	291	466	355	402	298	584	461
1988–1989	276	291	—	—	—	—	433	448
1989–1990	126	281	—	—	—	—		

† Years for sorghum growing season are underlined.
‡ GS — growing season.
§ Long-term precipitation is the mean for 1939 to 1990 for periods of the year corresponding to the actual rotation phases.

propylamino-1,3,5-triazine) and 2,4-D at rates of 0.34 and 0.11 g a.i. m^{-2}, respectively, applied soon after harvest to control weeds and volunteer wheat during the fallow period. If required, glyphosate [isopropylamine salt of *N*-(phosphonomethyl) glycine] was applied for additional fallow-period weed control. For weed control in sorghum, terbutryn (2-tert-butylamino-4-ethylamino-6-methylthio-*s*-triazine) was applied at a rate of 0.18 g a.i. m^{-2} before planting.

Grain sorghum 'DK-42Y', a medium-maturity hybrid, was planted one row per ridge on ridges that were established before planting wheat. It was planted with a no-tillage planter equipped with double disk openers preceded by straight coulters at a rate to obtain about 130 000 plants ha^{-1}. Sorghum planting dates ranged from 24 May to 17 June. Sorghum planting was accomplished without difficulty, even though relatively large amounts of wheat residue were present. Planting was on ridge tops between drill rows of the previous wheat crop (Fig. 1). This zone had relatively low amounts of residue, which minimized planting problems for sorghum. In most years, most residues of the previous wheat crop were still standing at sorghum planting time, which further minimized planting problems. The sorghum was not irrigated. If required, methyl parathion was applied at recommended rates to control greenbugs on the sorghum.

Head samples for determining sorghum grain yields were hand harvested from plants on 2-m-long sections of the center two rows at two locations in each plot. After drying at 60 °C, the heads were threshed and grain was cleaned and weighed. Stover yield samples were obtained at the same locations as grain yield samples by cutting plants at the soil surface after the heads were removed. After weighing, subsamples were removed, weighed, oven dried at 60 °C, and weighed again to determine stover water contents. Grain and stover yields are reported on a dry-weight basis. Sorghum harvest dates ranged from 20 September to 20 October.

After sorghum harvest, the stover was allowed to stand until the next spring (usually April) when it was shredded close to the soil surface. Ridges were then rebuilt in the same position as before with a disk bedder. Afterwards, all furrows were blocked to help retain fallow-period rainfall. Chlorsulfuron (2-chloro-*N*-[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)aminocarbonyl]-benzenesulfonamide) was applied at 0.003 g a.i. m^{-2} to control weeds and volunteer sorghum during the fallow period. In August, N fertilizer was applied as needed, and the ridge-height and furrow-blocking treatments were reimposed in preparation for the next wheat crop.

Soil water contents were determined gravimetrically at or near wheat and sorghum planting and harvest time by core sampling to a 1.8-m depth in 0.3-m increments. Precipitation was measured near the plots and totaled for the growing seasons and fallow periods (Table 1). Runoff from three furrows of each plot was diverted through 0.30-m H-flumes equipped with water stage recorders.

Table 2. Water infiltration as affected by ridge-height and furrow-blocking treatments,† Bushland, TX, 1981 through 1990.

Rotation phase and water source	Amount received	Infiltration			
		HR–OF	HR–BF	LR–OF	LR–BR
	mm				
Wheat GS‡					
Irrigation	453	357a§	342a	363a	340a
Precipitation	258	243a	242a	246a	243a
Fallow after wheat					
Precipitation	405	387a	382a	387a	381a
Sorghum GS					
Precipitation	287	265a	270a	268a	258a

† Treatments were: HR–OF—high ridge, open furrow; HR–BF—high ridge, blocked furrow; LR–OF—low ridge, open furrow; LR–BF—low ridge, blocked furrow.
‡ GS—growing season.
§ Mean values in a row followed by the same letter are not significantly different (Duncan's multiple range test).

Data were analyzed by analysis of variance. When the *F*-test showed statistical significance, the Prot. LSD test or Duncan's multiple-range test was used to separate the means.

RESULTS AND DISCUSSION

Irrigation and Precipitation Infiltration

Wheat was irrigated from two to four times each season. Amount of irrigation water applied is shown in Table 2. To wet adequately the lower end of the field, tailwater runoff was allowed in most cases. High application amounts in some cases resulted from difficulty in wetting the ridge tops in high-ridge plots when alternate furrows were irrigated. Because of this difficulty, all furrows were irrigated starting with the 1984–1985 crop. Irrigating blocked furrows did not wash out the blocks because the wheat was well established when the irrigations were applied, and the blocks remained intact during the ensuing fallow period and sorghum growing season. Net infiltration amounts (Table 2) are water application amounts less measured runoff amounts.

Differences in irrigation water infiltration due to treatments were relatively small in most years (data not shown). An exception was in 1983–1984, when infiltration was much higher with open than with blocked furrows, apparently due to compaction of the traffic furrows during the blocking operation. Overall mean infiltration differences due to treatments were not significant (Table 2).

Infiltration of precipitation was little affected by ridge height or furrow blocking treatments (Table 2). For precipitation that caused measurable runoff, total infiltration was 78% during the wheat growing season, 89% during fallow after wheat, and 88% during the sorghum growing season. Considering total period precipitation, infiltration totaled 94, 93, and 95% during the respective periods.

Soil Water Content

At wheat and grain sorghum planting and harvest times, differences in plant-available soil water content due to ridge-height and furrow-blocking treatments were significant only occasionally, and there was no consistent advantage for any treatment (data not shown). Maximum differences among treatments, averaged across years, were 7 mm at wheat planting and 5 mm at harvest. Overall mean contents were 182 mm at planting and 90 mm at harvest of wheat.

For sorghum, differences among treatments averaged across years were not significant and were 5 mm at planting and 2 mm at harvest. Overall mean soil water contents were 211 mm at planting and 123 mm at harvest of sorghum.

Water Use by Crops

Wheat

Differences among treatments in net soil water extraction (planting minus harvest values) by wheat were <31 mm in all cases, except in 1989–1990 when it was 64 mm (data not shown). Mean soil water extraction was almost identical on low- and high-ridge plots and slightly greater on open-than on blocked-furrow plots. Overall mean soil water extraction was 92 mm.

Mean soil water extraction varied greatly among years, ranging from 21 mm for 1983–1984 to 168 mm for 1986–1987. Low extraction indicates limited soil water depletion because the crops were irrigated, and possibly replenishment by late-growing-season precipitation. Large extraction in 1986–1987 was associated with large water contents at planting and relatively low contents at harvest (data not shown), greatest growing-season precipitation (Table 1), and least irrigation.

Total water use (net soil water extraction plus irrigation minus runoff plus growing-season precipitation minus runoff) was 688 mm with HR–OF, 671 with HR–BF, 698 with LR–OF, and 671 with LR–BF. Total use was not significantly affected by ridge-height treatments; use averaged 680 mm with high ridges and 685 mm with low ridges. The overall mean use was significantly greater with open (693 mm) than with blocked furrows (671 mm). This difference is largely attributable to the major differences in infiltration that occurred during the 1983–1984 season, presumably due to compaction of the traffic furrow during the furrow-blocking operation. The year × furrow blocking interaction was also significant, mainly because of the greater water use with open than with blocked furrows for the 1983–1984 season.

Grain Sorghum

Total water use (net soil water extraction plus growing-season rainfall minus runoff) averaged 361 mm with HR–OF, 355 with HR–BF, 354 with LR–OF, and 346 mm with LR–BF. Total use varied little for treatments within years, with the largest difference being 49 mm in 1988. Differences due to ridge-height and furrow-blocking treatments were not significant. Mean total water use ranged from 309 mm in 1983 to 438 mm in 1988, and averaged 374 mm. Despite the greatest soil water use during the study in 1983 (data not shown), total water use was low because of very low growing-season rainfall (Table 1). Grain yields in 1983 were second lowest for the study. Large total water use in 1987 was associated with relatively large soil water depletion and relatively large growing-season rainfall (Table 1), which resulted in the greatest grain yields for the study. Large total water use in 1988 was associated with well-above-average rainfall (Table 1). The year × ridge height × furrow blocking interaction was significant due to the differences that occurred in 1988.

Crop Yields

Wheat

Wheat grain yields varied considerably among years, but relatively little among treatments within a year or for treatment means across years. Means were 3.74 Mg ha^{-1} for HR–OF, 3.80 for HR–BF, 3.92 for LR–OF, and 3.89 for the LR–BF. The differences were not significant. Year-to-year variations were large because wheat was not managed for high grain yields (a limited-irrigation approach was used). The major emphasis was on straw production, and relatively high (>6.0 Mg ha^{-1}) straw yields were achieved in most cases. Mean straw yields were 7.97 Mg ha^{-1} for HR–OF, 7.70 for HR–BF, 8.03 for LR–OF, and 7.73 for LR–BF, with the differences being nonsignificant. Such straw yields are effective for increasing soil water storage and crop yields when managed by the no-tillage method (Unger, 1984; Unger and Wiese, 1979).

Although differences among treatments for a given year were relatively small, they were significant ($P \leq 0.05$) in some cases. Disregarding the 1989 crop destroyed by hail, grain yields were greater on low- than on high-ridge plots in 11 out of 16 comparisons (open or blocked furrows), with the maximum difference being 0.64 Mg ha^{-1} in favor of low ridges with blocked furrows in 1984. In 1986, grain yield was 0.39 Mg ha^{-1} greater on high- than on low-ridge plots that were blocked.

For 16 comparisons of blocked vs. open furrows, yields were greater with furrow blocking only seven times, with the maximum increase being 0.47 Mg ha^{-1} on low-ridge plots in 1985. The maximum difference in favor of open furrows was 0.55 Mg ha^{-1} on low-ridge plots in 1986. The overall means of 3.83 Mg ha^{-1} for open furrows and 3.85 for blocked furrows were not significantly different.

Straw yields were greater on low- than on high-ridge plots for nine of 16 comparisons, disregarding the 1989 crop that was destroyed by hail. The maximum advantage for low ridges was 0.85 Mg ha^{-1} with blocked furrows in 1983, whereas the maximum advantage for high ridges was 0.75 Mg ha^{-1} with open furrows in 1985. The overall means were 7.84 Mg ha^{-1} for low- and 7.88 Mg ha^{-1} for high-ridge plots. The difference was not significant.

Furrow blocking increased straw yields only four times, with the maximum increase being 0.47 Mg ha^{-1} on high-ridge plots in 1988. The maximum decrease with furrow blocking was 1.32 Mg ha^{-1}, which occurred on low-ridge plots in 1985. Mean straw yields (7.72 Mg ha^{-1} on blocked- and 8.00 Mg ha^{-1} on open-furrow plots) were not significantly different.

There is no strong evidence that either soil water at planting, precipitation amount, or irrigation amount was closely related to wheat grain or straw yield. Although more timely irrigations could have minimized yield differences among years, applications were not made to assure soil water contents above critical levels, and plant water stress may have occurred in some cases. However, adequate water was available from precipitation or irrigation to produce satisfactory wheat straw yields (>6.00 Mg ha^{-1}), an amount that has resulted in good responses to no-tillage by sorghum that followed wheat in the rotation (Unger, 1984; Unger and Wiese, 1979).

The limited response of wheat to the furrow-blocking treatment is attributed to the plants in furrows that minimized differences in runoff. Runoff from precipitation was especially low because few major storms occurred during the wheat growing seasons. Possible reasons for the tendency toward greater grain yields with low- than with high-ridge treatments were more uniform soil wetting and plant rooting with low ridges.

Grain Sorghum

Sorghum grain yields were affected little by ridge-height and furrow-blocking treatments, but varied greatly from year to year. Overall mean grain yields were 4.17 Mg ha^{-1} for HR–OF, 4.10 for HR–BF, 4.25 for LR–OF, and 4.24 for LR–BF, with the differences being nonsignificant. For 12 comparisons, sorghum yields were greater on low- than on high-ridge plots in eight cases, with the maximum increase being 0.34 Mg ha^{-1} on blocked-furrow plots in 1988. The maximum advantage for high-ridge plots was 0.14 Mg ha^{-1} on open-furrow plots in 1987. Mean yields were 4.14 Mg ha^{-1} on high-ridge plots and 4.25 Mg ha^{-1} on low-ridge plots.

Grain yields were greater with blocked than with open furrows in five of 12 comparisons, with the maximum increase being 0.46 Mg ha^{-1} on both the high- and low-ridge plots in 1984. The maximum decrease with blocked furrows was 0.47 Mg ha^{-1} on low-ridge plots in 1985. The overall mean yields were 4.21 Mg ha^{-1} with open furrows and 4.17 with blocked furrows. The differences were not significant.

Sorghum stover yields were greater on low- than on high-ridge plots for six of 12 comparisons, with the maximum difference being 0.36 Mg ha^{-1} on blocked-furrow plots in 1985. Stover yield was 0.24 Mg ha^{-1} lower on low- than on high-ridge plots with blocked furrows in 1984. Overall, mean yield differences due to ridge-height treatments were slight. For 12 open- vs. blocked-furrow comparisons, stover yields were greater with blocked furrows eight times. The maximum increase was 0.35 Mg ha^{-1} on high-ridge plots in 1984. However, there was also a decrease of 0.23 Mg ha^{-1} with blocked furrows on high-ridge plots in 1985. The overall differences were not significant, and means were 3.11 Mg ha^{-1} with open furrows and 3.18 Mg ha^{-1} with blocked furrows. Overall mean stover yield differences were not significant. Yields were 3.13 Mg ha^{-1} for HR–OF, 3.14 for HR–BF, 3.08 for LR–OF, and 3.20 for LR–BF.

Because sorghum was not irrigated, there seemingly should have been a greater response to ridge-height and furrow-blocking treatments by sorghum than by wheat, which was irrigated. A greater response, especially to furrow blocking, seemed logical because the blocks remained in place during fallow after wheat and during the sorghum growing season. Lack of response to furrow blocking indicates that no-tillage management of wheat residues is as effective as, or possibly more effective than, furrow blocking for enhancing water infiltration. Data of Duley and Russel (1939) and Russel (1939) indicated similar results. In addition, residues maintained on the surface with no-tillage decrease evaporation of stored water (Smika, 1976; Russel, 1939). For this study, the net result was that furrow blocking in combination with no-tillage was no more effective than no-tillage alone for managing wheat residues with respect to increasing soil water storage and sorghum yields. There was no indication that long-term use of no-tillage or minimum tillage was having an adverse effect on winter wheat and grain sorghum production when these crops are grown in rotation.

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