Residue management for continuous winter wheat production with limited irrigation

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*ABSTRACT: Crop residue management was chosen as a key practice to help control erosion on nearly 75% of the highly erodible land covered by conservation plans. This study determined the effects of treatments that involved retaining all residues on the surface (NT+Res), removing some residues at harvest (NT-ResH) or at planting (NT-ResP), and conventional tillage (ConvT) on soil water storage and use, and yields of continuous winter wheat (*Triticum aestivum *L.) produced with limited irrigation. Water storage between crops was greater with NT+Res (95 mm) and NT-ResH (100 mm) than with ConvT (79 mm), but soil water depletion was not affected by treatments. Grain yield was greater with NT+Res (4.56 Mg ha^{-1}) than with ConvT (4.26 Mg ha^{-1}) and NT-ResH (4.18 Mg ha^{-1}), but straw yield was not affected by treatments. Grain and straw yields differed among crops. Continuous wheat production with limited irrigation resulted in an estimated 2.2 Mg ha^{-1} of residues on the surface at planting with the NT-ResH and NT-ResP treatments. The initial amount was 9.0 Mg ha^{-1} with the NT+Res treatment, and much of this remained on the surface at planting of the next crop. In all cases, the residue amounts provided considerably more (a minimum of about 70%) than the 30% surface cover usually required to control erosion on highly erodible land. Hence, use of limited irrigation and no-tillage can help producers meet the surface residue requirements established for their conservation plans for highly erodible lands in the southern Great Plains.*

Retention of crop residues on the soil surface is being widely promoted for controlling erosion. While the value of surface residues for this purpose has long been recognized, renewed emphasis for use of this practice developed as a result of the 1985 Food Security Act and the 1990 Food, Agriculture, Conservation, and Trade Act. These acts mandated that producers farming highly-erodible land must have approved conservation plans implemented by 1995 in order to remain eligible for other U.S. Department of Agriculture programs. To meet the requirements, producers have selected crop residue management as a key practice on nearly 75% of the land covered by conservation plans (Schertz and Bushnell). Hence, production practices are needed that retain adequate residues on the soil surface, but do not unduly interfere with crop production operations or adversely affect the economics of production.

Retaining sufficient residues on the surface to control erosion may be difficult where residue production is low as, for example, with dryland crops in semiarid regions. Crop residue production on dryland usually is greater where fallow is used to increase soil water storage for the next crop, but residues also disappear during fallow, especially where tillage is used for weed control. In addition, using fallow reduces crop production intensity, which may not be acceptable from a cash flow viewpoint to some producers.

Where irrigation is possible, adequate residues usually are produced to control erosion. In some cases, residue production may even be excessive and cause problems with subsequent crop production when using no-tillage (Allen et al.; Unger 1977). These problems include weed and volunteer plant control, crop seeding, and seedling establishment and growth. In these studies (Allen et al.; Unger 1977), grain yields declined when continuous wheat was no-tillage planted on the same area in two or more consecutive seasons. Hence, an intermediate production level that provides adequate residues to control erosion and largely avoids problems associated with large amounts of residues seemingly would be appropriate. Such a production level is favored by using a limited-irrigation approach to crop production.

Limited irrigation is adaptable to the semiarid southern Great Plains, especially the Texas High Plains subregion and surrounding areas where annual precipitation ranges from about 300 mm (12 in) at the western edge to about 500 mm (20 in) at the eastern edge. Precipitation is greatest from May through August, but some precipitation usually occurs each month. Soils normally used for irrigated crops in the region range from clay loams to sandy loams. Soil profile depths range from about 1.2 to 1.8 m (4 to 6 ft).

A dryland crop such as winter wheat, which is well adapted and widely grown in the southern Great Plains, often produces limited amounts of residues, often from 1.5 to 2.5 Mg ha^{-1} (1300 to 2200 lb/ac). Limited irrigation is suitable for winter wheat because it possesses considerable water stress tolerance and it responds favorably to well-timed irrigations (Musick 1985; Musick et al. 1984; Schneider; Schneider et al.). In addition, water for irrigation is limited in the region and water-pumping costs are high, thus making limited irrigation a desirable alternative to full irrigation. When limited irrigation is used for winter wheat, water usually is applied at the late-boot (just before seed head emergence) or during grain-filling growth stages.

The purpose of this study was to evaluate the effects of different residue management practices on production of continuous winter wheat managed with limited irrigation. Specific management options considered involved different levels of crop residue retention, which ranged from incorporation with soil using conventional tillage to retention on the surface with no-tillage. If most or all residues could be retained on the surface without reducing yields of subsequent crops, then producers could use this practice to achieve improved erosion control on croplands subject to erosion.

Materials and methods

A field study was conducted at the USDA—Agricultural Research Service, Conservation and Production Research Laboratory, Bushland, Texas, from 1986 to 1992 on Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll). Plots were 8 m (26 ft) wide and 39 m (128 ft) long, and were leveled and individually surrounded by berms to prevent water runoff and runon before starting the study. The soil has 0.3% slope, and leveling has little effect on soil conditions of plots as small as those used for this study (Unger et al.).

Residue management treatments were NT+Res—no-tillage with all residues retained, NT-ResH—no-tillage with residues removed soon after harvest (June

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or July), NT-ResP—no-tillage with residues removed shortly before planting (September or October), and ConvT—conventional tillage involving disking and rebuilding beds (ridges and furrows) soon after harvest and shaping beds before planting. Beds were initially constructed on the no-tillage plots and were retained throughout the study. A forage chopper was used to remove some residues from the NT-ResH and NT-ResP treatment plots. Estimated amounts remaining after the chopper operation were about 2.2 Mg ha^{-1} (2000 lb/ac).

The study had a randomized complete block design with three replications. On no-tillage plots, chlorsulfuron [2-chloro-N[[(4-methoxy-6-methyl-1,3,5-triazin-2yl)amino]carbonyl]benzenesulfonamide] was applied soon after harvest at 3.5 mg m^{-2} (0.03 lb/ac) a.i. to control weeds and glyphosate[N-(phosphonomethyl)glycine] was applied at 60 mg m^{-2} (0.54 lb/ac) a.i. as needed to control volunteer wheat. If needed, 2,4-D was used to control weeds during the growing season. Anhydrous ammonia was chiseled into the furrows at a rate of 134 kg N ha^{-1} (120 lb/ac) less than 30 days before planting wheat.

Wheat ('TAM 105' in 1986 and 1987, and 'TAM 200' in the remaining years) was planted with a single-disk-opener drill having 0.25-m (10-in) row spacings at a rate of 95 kg ha^{-1} (85 lb/ac). Planting and harvest dates are given in Table 1. Hail destroyed the wheat on May 16, 1989, and no yields were obtained for that crop.

Crop water use calculations were based on growing season precipitation, soil water use (planting-time minus harvesting time soil water contents to the 1.8-m depth), and irrigation water applied. Precipitation was measured with a standard (0.2-m-diam) (8-in) gauge located adjacent to the plot area. Soil water contents were determined gravimetrically from core samples obtained at two sites per plot by 0.30-m (1-ft) increments to the 1.8-m (6-ft) depth at planting and harvest. The Pullman soil has capacity to store about 230 mm (9.1 in) of plant available water to a depth of 1.8 m, which is the depth to which winter wheat often extracts soil water. To this depth, the soil retains about 347 mm (13.7 in) of water that is unavailable to plants. Irrigation water, applied through gated pipes and measured with an in-line flow meter, flooded the level plots. Individual irrigation depths ranged from 100 to 150 mm (4 to 6 in), and were applied mainly at the boot and grain-filling growth stages. However, an irrigation was applied for crop establishment in 1989, and early-spring irrigations were applied in 1989 and 1991 at the start of the spring growth period when precipitation was limited.

Table 1. Precipitation during growing seasons and between crops, and irrigations of winter wheat, 1986-1992, Bushland, Texas

Period	Period date: Start	End	Precipitation: Period	Long-term*	Irrigation†
			mm	mm	mm
Growing season	10/17/86	07/06/87	359	278	254 (2)
	09/28/87	07/02/88	305	296	267 (2)
	10/05/88	05/16/89‡	68	170	406 (3)
	09/25/89	06/25/90	134	241	559 (4)
	09/19/90	06/27/91	274	295	429 (3)
	10/15/91	07/08/92	476	281	229 (2)
	Average		269	260	357
Between crop	07/06/87	09/28/87	245	171	—
	07/02/88	10/05/88	214	188	—
	05/16/89‡	09/25/89	489	287	—
	06/25/90	09/19/90	139	182	—
	06/27/91	10/15/91	159	214	—
	Average		249	208	

* Average from 1939 to 1991.
† Values in parentheses indicate the number of irrigations.
‡ The 1988-1989 crop was destroyed by hail on May 16, 1989.

Straw and grain yields were determined from samples obtained by hand from two 1-m^2 (40 × 40 in) areas of each plot by clipping the plants at the soil surface. After air drying, the samples were weighed and grain was threshed, cleaned, and weighed. Straw yields represented the difference between above-ground plant and grain sample weights. Yields are reported on an air-dry-weight basis (about 10% water content).

Data were analyzed using the analysis of variance technique (SAS Institute), and means were separated by the protected least significant difference (Prot. LSD) method at the 0.05 level of statistical significance (Steel and Torrie).

Results and discussion

Precipitation and irrigation. Average growing-season precipitation for the study period was near the long-term average, but precipitation was highly variable among seasons. Precipitation was considerably above the long-term average for the 1986-1987 and 1991-1992 seasons, considerably below the average for the 1988-1989 and 1989-1990 seasons, and near average for the other two seasons (Table 1). The long-term average precipitation amounts, based on unpublished laboratory records, are for the same range of dates as indicated for the different periods of this study.

All crops were irrigated at least twice, the 1988-1989 and 1990-1991 crops were irrigated three times, and the 1989-1990 crop was irrigated four times (one for crop establishment and three in the spring) (Table 1). Full irrigation in the southern Great Plains usually involves four spring irrigations (Schneider et al.). Irrigation for the 1989-1990 crop approached full irrigation, which was necessary because of below average precipitation, both at crop establishment and in the spring. Precipitation from March 1 until harvest on June 25 totaled only 69 mm (2.7 in) for the 1989-1990 crop.

Precipitation was above the long-term average during three of the five between-crop periods, and the study average was 41 mm (1.6 in) above the long-term average (Table 1). The amounts are high for the 1989 period because hail destroyed the 1988-1989 crop on May 16, thus adding about 40 to 50 days to the between-crop period. This extended period included June, which is the highest precipitation month at Bushland, Texas.

Soil water contents and changes. Mean soil plant available water (PAW) contents at the start of between-crop periods were not affected by treatments (Table 2), but differences among periods were significant because of differences in precipitation amounts late in the growing seasons. Contents ranged from 56 mm (2.2 in) in 1990 to 173 mm (6.8 in) in 1989. Contributing to the high content in 1989 was 51 mm (2.0 in) of precipitation associated with the hailstorm on May 16. In addition, the wheat had been irrigated on the day of the hailstorm.

Mean storage (increase) of PAW during between-crop periods was greatest with the NT-ResH and least with the ConvT treatment (Table 2). Storage with the NT+Res treatment, which was not significantly different from that for the NT-ResH treatment, also resulted in greater storage that the ConvT treatment. Storage with the NT-ResP treatment was similar to that for the ConvT treatment. Greater storage with the NT+Res treatment than

Table 2. Mean available soil water contents and changes to a 1.8-m depth during between-crop periods and growing seasons of winter wheat, 1986-1992, Bushland, Texas

Factor	Treatment* NT+Res	NT-ResH	NT-ResP	ConvT	LSD†
Content at start of between-crop period—mm	99	91	109	98	NS
Change during between-crop period—mm	95	100	81	79	16
—% of average period precip.	38	40	33	32	—
Content at planting—mm	194	191	190	177	NS
Change during growing season—mm	-75	-74	-64	-63	NS

* Treatments were: NT+Res—no-tillage, all residues retained; NT-ResH—no-tillage, residues removed at harvest; NT-ResP—no-tillage, residues removed at planting; ConvT—conventional tillage.
† Protected least significant difference, 0.05 level.

with the ConvT treatment is logical, based on results of other studies on the Pullman soil (Musick et al. 1977; Unger 1984; Unger and Wiese). During the between-crop period, the NT+Res and NT-ResP treatments were managed the same, but storage tended to be lower with the NT-ResP treatment. It was also less than for the NT-ResH treatment. The reason for these results is not clear, but may be related to trends in PAW contents at the start of between-crop periods (Table 2). Although not significant, the trend was toward greatest PAW content with the NT-ResP treatment, which resulted in low storage, and least PAW content with the NT-ResH treatment, which resulted in the greatest storage.

Mean storage of PAW differed among periods (data not shown), with storage being least (40 mm) (1.6 in) in 1989 when the initial content was greatest. Storage was greatest (130 mm) (5.1 in) in 1987 when the initial content was among the lowest. These trends show the importance of initial PAW contents in Pullman soil on subsequent water storage. Similar trends were reported by Musick (1970) for this soil.

Based on average precipitation for the study and mean increases in PAW, storage efficiencies were greater with the NT+Res and NT-ResH treatments than with the NT-ResP and ConvT treatments (Table 2). Trends in water storage efficiency were, in a general way, inversely related to soil water contents at the start of the between-crop periods and to precipitation during those periods. For individual periods, mean storage efficiency ranged from 7% in 1989 when initial content and precipitation amount were greatest to 75% in 1990 when initial content and precipitation amount were lowest. Storage efficiency was also 75% in 1991 when initial content was intermediate, but precipitation amount was next to lowest.

Treatments did not significantly (P = 0.05 level) affect mean PAW contents at planting, but contents tended to be greater with NT+Res, NT-ResH, and NT-ResP treatments than with the ConvT treatment (Table 2). Mean contents at planting varied among seasons. Contents were similarly low (160 to 167 mm) (6.3 to 6.6 in) in 1986, 1988, and 1990. It was low in 1986 because of field operations used to prepare the plots shortly before starting the study. In 1988 and 1990, contents at planting were low because of low precipitation during the between-crop period (Table 1). They were similarly high (207 to 216 mm) (8.1 to 8.5 in) in 1987, 1989, and 1991. The high contents in 1987 and 1989 resulted from above-average rainfall during the between-crop period. In 1991, between-crop rainfall was among the lowest, yet water content at planting was high, apparently because of a carryover of soil water from the previous crop that was irrigated three times.

Treatments did not cause significant differences in PAW depletion during the growing seasons, but depletion tended to be greater with NT+Res and NT-ResH treatments than with NT-ResP and ConvT treatments (Table 2). Mean depletion varied among growing seasons. A slight (6-mm) (0.24-in) increase in PAW occurred during the 1988-1989 season when a 127-mm (5.0 in) irrigation was applied on May 16 before the hailstorm that occurred later that day. A decrease of 151 mm (5.9 in) occurred for the 1989-1990 crop when late-season precipitation was low. Timing of late growing-season irrigation and precipitation greatly influences PAW remaining in the soil profile after harvest.

Grain and straw yield, total water use, and water use efficiency. Mean grain yield was greater with the NT+Res treatment than with NT-ResH (residue removed at harvest) and ConvT (residue incorporated) treatments (Table 3). Yields for the latter two did not differ from each other, and yield for the NT-ResP (residue removed at planting) treatment did not differ from that for the NT+Res treatment. Greater yields with the NT+Res treatment were not expected based on results from previous studies when yields of irrigated wheat declined after about 2 years with continuous no-tillage when all residues were retained on the surface on Pullman clay loam (Allen et al.; Unger 1977). Even for this study, wheat on NT+Res treatment plots for which all residues were retained on the surface was uneven in height early in some growing seasons because of differences in emergence as a result of uneven penetration of the drill openers into the residue-covered soil. These observations suggested that yields might be lower with the NT+Res treatment. However, later in the growing season, plants on all plots were relatively uniform, indicating that the wheat adjusted to earlier adverse conditions when later conditions became favorable. These results indicate that no-tillage, either with all residues retained or with some residues removed soon after harvest or at planting, is a viable option for continuous winter wheat production under limited irrigated conditions of the southern Great Plains. Even with some removal, an estimated minimum of 2.2 Mg ha^{-1} of residues remained on the surface. Such amounts provided about 70% surface cover (Gregory), which is much more than the 30% recommended for controlling erosion on highly erodible land. Hence, producers can use this practice to produce favorable crops while retaining sufficient residues on the soil surface to help meet the

Table 3. Mean grain and straw yields, total water use, and water use efficiency (WUE) for winter wheat, 1986-1992, Bushland, Texas

Factor	Treatments* NT+Res	NT-ResH	NT-ResP	ConvT	LSD†
Grain yield—Mg ha^{-1}	4.56	4.18	4.45	4.26	0.30
Straw yield—Mg ha^{-1}	9.06	8.59	9.02	8.58	NS
Total water use—mm	701	700	690	689	—
WUE for grain—kg m^{-3}	0.65	0.60	0.64	0.62	—
WUE for straw—kg m^{-3}	1.29	1.23	1.31	1.25	—

* Treatments were: NT+Res—no-tillage, all residues retained; NT-ResH—no-tillage, residues removed at harvest; NT-ResP—no-tillage, residues removed at planting; ConvT—conventional tillage.
† Protected least significant difference, 0.05 level.

residue requirements specified in their plans to control erosion on highly erodible land.

Mean yields differed among crops and ranged from 3.26 Mg ha^{-1} (2,910 lb/ac) for the 1986-1987 crop to 5.80 Mg ha^{-1} (5,170 lb/ac) for the 1991-1992 crop. The treatment x crop interaction effect was also significant (data not shown). Yield differences resulting from treatments were not significant for the 1986-1987 crop and the 1988-1989 crop was not harvested because of the hailstorm, but differences were significant in other years. Greatest yields were 4.48 Mg ha^{-1} (4,000 lb/ac) with NT-ResP in 1987-1988, 5.65 Mg ha^{-1} (5,040 lb/ac) with NT-ResP in 1989-1990, 5.15 Mg ha^{-1} (4,590 lb/ac) with NT+Res in 1990-1991, and 6.58 Mg ha^{-1} (5,870 lb/ac) with ConvT in 1991-1992. Lowest yields were 3.62 Mg ha^{-1} (3,230 lb/ac) with ConvT in 1987-1988, 4.33 Mg ha^{-1} (3,860 lb/ac) with NT-ResH in 1989-1990, 3.40 Mg ha^{-1} (3,030 lb/ac) with NTResP in 1990-1991, and 5.33 Mg ha^{-1} (4,750 lb/ac) with NT-ResP in 1991-1992. No treatment consistently resulted in the greatest or lowest yield, and there was no evidence of a yield trend with time for any treatment.

Mean straw yields did not differ as a result of treatments, but tended to be greater with the NT+Res and NT-ResP treatments than with other treatments (Table 3). Straw yields differed among crops, and ranged from 6.6 Mg ha^{-1} (5,900 lb/ac) for the 19861987 crop to 12.1 Mg ha^{-1} (10,800 lb/ac) for the 1987-1988 crop. The effect of the large amount of residues from the 1987-1988 crop on yields of the subsequent crop could not be determined because the 1988-1989 crop was destroyed by hail.

Differences in mean total water use among treatments (Table 3) were small because differences in soil water depletion during the growing season were small and all plots were irrigated uniformly and were assumed to have received the same amount of precipitation. In addition, yield differences among treatments were relatively small (Table 3). Hence, differences in water use efficiencies (WUEs) based on grain or straw yield per unit of water used (m^3) were relatively small also. For grain production, mean WUEs ranged from 0.60 kg m^{-3} for the NT-ResH treatment to 0.65 kg m^{-3} for the NT+Res treatment. These WUEs compared favorably with those reported by Schneider et al. for wheat receiving less than full irrigation. Their WUEs ranged from 0.62 to 0.70 kg m^{-3}. Mean WUEs for straw production ranged from 1.23 kg m^{-3} for the NT-ResH treatment to 1.31 kg m^{-3} for the NT-ResP treatment.

Conclusions

Soil water storage during between-crop periods differed as a result of treatments imposed and among periods, but storage was more closely related to water contents at the start of the periods than to surface residue amounts resulting from the treatments. As a result, mean soil water contents were similar at planting with all treatments. Treatments did not affect soil water depletion during the growing season and mean total water use by wheat differed only slightly among treatments. Early wheat growth was erratic when all residues were retained on the surface, as indicated by the uneven height of the crop on NT+Res treatment plots early in some growing seasons. However, wheat on all plots was relatively uniform later in the growing seasons, and mean grain yields were greater with no-tillage than with conventional tillage. Mean straw yields were not affected by treatments. Differences in water use efficiency for grain and straw production among treatments were small. Use of no-tillage for continuous winter wheat production under limited-irrigation conditions, even where some residues are removed immediately after harvest or shortly before planting, is a practice that producers can use on highly-erodible land in the southern Great Plains to help meet the surface residue requirements specified in their conservation plans.

REFERENCES CITED

Allen, R.R., J.T. Musick, and A.F. Wiese. 1976. Limited tillage of furrow irrigated winter wheat. Transactions of the American Society of Agricultural Engineers 19:234-236, 241.

Gregory, J.M. 1982. Soil cover prediction with various amounts and types of crop residue. Transactions of the American Society of Agricultural Engineers 25:1333-1337.

Musick, J.T. 1970. Effect of antecedent soil water on preseason rainfall storage in a slowly permeable irrigated soil. Journal of Soil and Water Conservation 25:99-101.

Musick, J.T. 1985. Strategies and techniques for water conservation with limited and full irrigation in the southern Great Plains. In: Proceedings, Workshop on Planning and Management of Water Conservation Systems in the Great Plains States, October 1985, Lincoln, NE. U.S. Department of Agriculture—Soil Conservation Service, Lincoln, NE. pp. 144-187.

Musick, J.T., A.F. Wiese, and R.R. Allen. 1977. Management of bed-furrow irrigated soil with limited- and no-tillage systems. Transactions of the American Society of Agricultural Engineers 20:666-672.

Musick, J.T., D.A. Dusek, and A.C. Mathers. 1984. Irrigation water management of winter wheat. Paper No. 84-2094. American Society of Agricultural Engineers, St. Joseph, MI.

Schneider, A.D. 1968. Irrigation of winter wheat with limited water. Proceedings, Texas A&M University-Soil Conservation Service Conservation Workshop, July 1968, College Station, TX. 7 pp.

Schneider, A.D., J.T. Musick, and D.A. Dusek. 1969. Efficient wheat irrigation with limited water. Transactions of the American Society of Agricultural Engineers 12:23-26.

SAS Institute. 1985. SAS user's guide. Statistics. Version 5 ed., SAS Institute, Cary, NC.

Schertz, D.L., and J.L. Bushnell. 1993. USDA crop residue management action plan. Journal of Soil and Water Conservation 48:175-177.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd ed. McGraw-Hill Book Co., New York.

Unger, P.W. 1977. Tillage effects on winter wheat production where the irrigated and dryland crops are alternated. Agronomy Journal 69:944-950.

Unger, P.W. 1984. Tillage and residue effects on wheat, sorghum, and sunflower grown in rotation. Soil Science Society of America Journal 48:885-891.

Unger, P.W., L.J. Fulton, and O.R. Jones. 1990. Land-leveling effects on soil texture, organic matter content, and aggregate stability. Journal of Soil and Water Conservation 45:412-415.

Unger, P.W., and A.F. Wiese. 1979. Managing irrigated winter wheat residues for water storage and subsequent dryland grain sorghum production. Soil Science Society of America Journal 43:582-588.