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RESPONSE OF CONSERVATION TILLAGE SORGHUM TO GROWING SEASON PRECIPITATION[1]

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ABSTRACT

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In earlier crop rotation studies in which grain sorghum (*Sorghum bicolor* (L.) Moench) followed winter wheat (*Triticum aestivum* L.) after a 10- to 11-month fallow period during which the wheat residues were managed by different tillage methods, sorghum yields increased in response to increases in soil water content at sorghum planting time. Similar results were obtained when residues were placed on the surface at the start of the fallow period. The soil water contents at planting time were positively correlated with amounts of wheat residue maintained on the soil surface during fallow.

The studies also suggested that sorghum responded positively to growing season precipitation when increasing amounts of residue remained on the soil during the growing season. The objective of this study was to evaluate this response to growing season precipitation through statistical analyses of data from five earlier tillage and residue placement studies. Regression analyses of data from the studies showed that sorghum grain yields increased with increasing amounts of surface residues at planting time. Differences in response of grain yield to precipitation were greatest in the vegetative period. For that period, grain yields increased 0.014 Mg ha^{-1} per mm of precipitation when residue amounts ranged from 0 to 0.4 Mg ha^{-1}, and 0.027 Mg ha^{-1} per mm of precipitation when residue amounts were > 3.2 Mg ha^{-1}.

Differences in response to rainfall in the heading and grain filling period were lower or negligible. High responses for the vegetative period were attributed to the residues which increased infiltration and reduced evaporation before canopy developmnet. Lower responses during heading and lack of responses during grain filling were attributed to: (1) canopy development, which minimized the effect of residues on infiltration and evaporation; (2) soil cracking, which resulted in similar infiltration with all treatments; and (3) residue decomposition, which minimized differences among residue amounts on the soil with different treatments.

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INTRODUCTION

Studies with dryland grain sorghum (*Sorghum bicolor* (L.) Moench) under clean tillage conditions in the semi-arid southern Great Plains (U.S.A.) indicate that grain yields increase 0.017 Mg ha^{-1} for each additional mm of water stored in soil at planting time above a threshold amount needed to initiate grain production (Jones and Hauser, 1975). Other studies involving an irrigated winter wheat (*Triticum aestivum* L.)-fallow-dryland grain sorghum rotation (two crops in 3 years with 10—11 months of fallow between each crop) showed that water storage during fallow after wheat was greater where conservation tillage (no-tillage or sweep plowing) maintained residues on the surface than where clean tillage (disk, moldboard and/or rotary tillage) was used to incorporate crop residues and to control weeds and volunteer wheat. The additional stored water resulted in higher grain sorghum yields (Unger and Parker, 1975; Unger and Wiese, 1979; Unger, 1984a). Water storage and subsequent sorghum yields were also increased when increasing amounts of wheat straw were placed on the soil at the start of the fallow period (Unger, 1978). When wheat straw was placed on soil after sorghum emergence on plots having different initial soil water contents, sorghum responded more to soil water content at planting than to the amount of straw applied. However, straw applied at 8 Mg ha^{-1} increased water use efficiency 19% over that with no straw on the soil surface (Unger and Jones, 1981).

The above tillage and residue placement studies clearly showed that additional water stored where crop residues were maintained on the soil surface increased sorghum yields. The greater water use efficiencies for grain production with surface residues also suggested that residues on soil during the sorghum growing season gave an additional grain yield benefit by improving the use efficiency of growing-season precipitation. The objective of this study was to show that residues on the soil surface during the growing season increase the effectiveness of growing-season precipitation for increasing sorghum yields.

MATERIALS AND METHODS

The study involved statistical analyses of data from tillage and residue placement studies conducted by Unger (1978, 1984a), Unger and Jones (1981), Unger and Parker (1975) and Unger and Wiese (1979) at the USDA Conservation and Production Research Laboratory at Bushland, Texas, on a Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) from 1972 to 1984. Data compiled were planting date, lengths of growth stages, residues on the surface at planting, soil water content at planting and at harvest, soil water use during the growing season, precipitation and sorghum grain and total dry matter yield. Although all factors were analyzed, not all factors were included in the final results that are presented.

Most data were summarized in the above publications. However, for this study, data for individual treatments, replications and years were obtained from the original records for each study, resulting in a set with 399 observations. Residue amounts were either weighed or estimated by comparison with standard photographs (Duley, 1958). Soil water contents were determined to a 1.8-m depth, yields were determined from 4- or 6-m^2 areas per plot, and precipitation was measured at or near plot areas with 200-mm diameter (U.S. Weather Bureau standard) rain gauges.

Linear regression of grain dry matter or total dry matter yields on precipitation for the vegetative, heading, grain filling or total growing season periods was analyzed for the complete data set and for residue levels of 0—0.4, 0.5—3.2 and > 3.2 Mg ha^{-1}. The 0—0.4 Mg ha^{-1} residue level was essentially a bare surface condition with <10% of the surface covered with residues. Such condition resulted from moldboard, disk or rotary tillage, or when no residues were placed on the surface. Increasing surface coverage occurred in the 0.5—3.2 Mg ha^{-1} range due to sweep tillage, no-tillage and/or residue placement. Full coverage occurred at about 3.2 Mg ha^{-1}. At >3.2 Mg ha^{-1}, the surface remained covered with residues during most of the growing season. Such amounts resulted from no-tillage or residue placement. The regression coefficients resulting from the linear regression analyses indicated the yield responses to precipitation as a result of residue on the surface at planting time. For the analyses, the sorghum growing season was divided into different periods which were affected by planting date. The approximate lengths of the periods are shown in Table I.

TABLE I

Estimated lengths of growth periods for a medium maturity grain sorghum as affected by planting dates (B.A. Stewart, Bushland, Texas, unpublished data, 1984)

Planting date	Growth periods		
	Vegetative[a]	Heading	Grain filling
		days	
25 May	47	33	31
10 June	43	33	31
25 June	40	33	31

[a]Includes period from planting to floral initiation.

RESULTS AND DISCUSSION

Sorghum grain yields varied widely for a given level of growing-season precipitation (Fig. 1), undoubtedly because of differences in initial soil water contents and precipitation distribution, but presumably also because

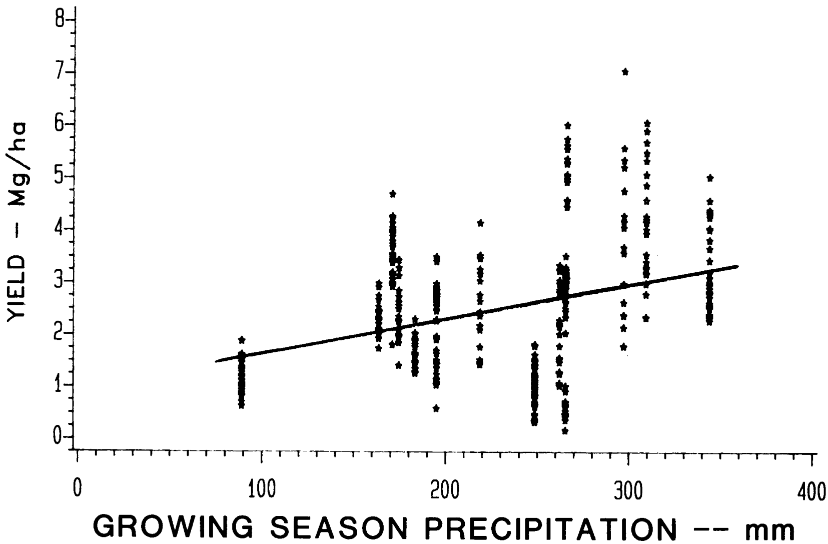

Fig. 1. Sorghum grain yield as affected by growing season precipitation at Bushland, Texas, 1972—1984 (see Table II for equation (No. 1) represented by regression line).

of differences in residues on the soil surface, which influenced the effectiveness of growing-season precipitation for grain production. This assumption was verified by showing that the regression of grain yield on growing-season precipitation increased with increasing amounts of surface residues. Results of these analyses are given in Table II, and the relationships are illustrated in Fig. 2. For the relationships between grain yield and growing-season precipitation, regression coefficients (*b* or slope values) increased with increasing amounts of surface residues. All three regression coefficients (Eqns. 2, 3 and 4 in Table II) were different from zero at the 0.0001 probability level. Differences between regression coefficients for Eqns. 2 and 3, Eqns. 3 and 4 and Eqns. 2 and 4 were significant at 0.20, 0.50, and 0.20 probability levels, respectively. The responses of total drymatter yield to growing-season precipitation were significant at $P = 0.0001$, but the regression coefficient for residues > 3.2 Mg ha^{-1} was slightly less than for residues ranging from 0.5 to 3.2 Mg ha^{-1} (Table II). Again, all regression coefficients (Eqns. 18, 19 and 20 in Table II) were different from zero at the 0.0001 probability level. In this case, the regression coefficient for Eqn. 18 was different from that for Eqn. 19 at a 0.025 probability level, while the difference between those for Eqns. 19 and 20 was significant at only the 0.50 level. Although the differences between regression coefficients generally were not significant at high levels, the results show definite trends toward increased grain and total dry matter yields in response to growing-season precipitation when increasing amounts of residue were on the soil surface at planting time.

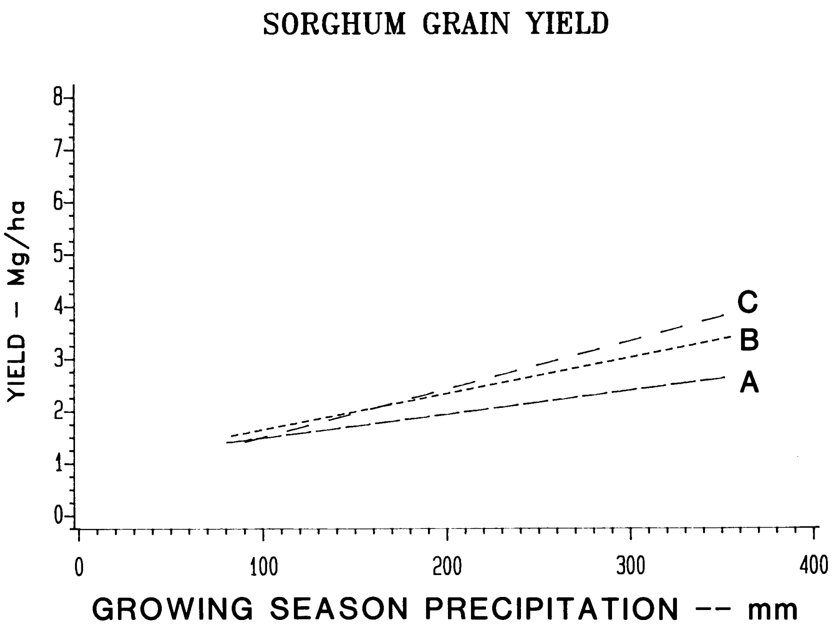

Fig. 2. Sorghum grain yield at three levels of surface residue (A: 0—0.4 Mg ha^{-1}; B: 0.5—3.2 Mg ha^{-1}; C: > 3.2 Mg ha^{-1}) as affected by growing season precipitation at Bushland, Texas, 1972—1984 (see Table II for equations (Nos. 2, 3 and 4 for A, B and C, respectively) represented by the regression lines).

The effect of surface residues on increasing the grain yield response to precipitation was highest for vegetative-period precipitation (Table II). For that period, the regression coefficients were different from zero at the 0.0001 probability level and from each other at the 0.10 (Eqn. 6 vs. 7, and Eqn. 7 vs. 8) or higher (Eqn. 6 vs. 8) probability levels. For vegetative-period precipitation, yields increased about 0.014 Mg ha^{-1} per mm when residues ranged from 0 to 0.4 Mg ha^{-1} and about 0.027 Mg ha^{-1} per mm when residues were > 3.2 Mg ha^{-1}. For heading-period precipitation, the regression coefficients differed significantly from zero, but differences between the coefficients were significant at probability levels of 0.20 (Eqn. 10 vs. 12) or lower (Eqn. 11 vs. 12), or not significant (Eqn. 10 vs. 11). In this case, the yield responses per mm of precipitation varied from 0.013 to 0.019 Mg ha^{-1} at the different residue levels. For grain-filling-period precipitation, the regression coefficients were negative and statistically different from the zero, but the coefficient of determination (r^2) was low, indicating that the response to grain-filling-period precipitation as affected by surface residues was minor with respect to influencing grain yields (Table II). Another possible reason for negative responses to grain-filling-period precipitation was the assumption that the growing season progressed according to the periods indicated in Table I. Dryland sorghum has the ability to adjust to prevailing climatic conditions (mostly rainfall) by either reducing

TABLE II

Sorghum yield response to precipitation with different amounts of wheat residue on the soil surface at sorghum planting time

Variables: Dependent	Variables: Independent	Residue level ($Mg\ ha^{-1}$)	Obs.[a] No.	Eqn.[b] No.	Equation	Coefficient of determination (r^2): Value	Coefficient of determination (r^2): Significance level
Grain yield ($Mg\ ha^{-1}$)	Growing season precipitation (mm)	0—8.0	399	1	y = 0.941 + 0.0066x	0.116	0.0001
		0—0.4	117	2	y = 1.041 + 0.0045x	0.145	0.0001
		0.5—3.2	156	3	y = 0.961 + 0.0069x	0.145	0.0001
		3.2	126	4	y = 0.586 + 0.0092x	0.078	0.0015
	Vegetative period precipitation (mm)	0—0.8	399	5	y = 1.032 + 0.0203x	0.307	0.0001
		0—0.4	117	6	y = 1.050 + 0.0144x	0.357	0.0001
		0.5—3.2	156	7	y = 1.103 + 0.0199x	0.273	0.0001
		3.2	126	8	y = 0.866 + 0.0271x	0.370	0.0001
	Heading period precipitation (mm)	0—8.0	399	9	y = 1.166 + 0.0151x	0.182	0.0001
		0—4.0	117	10	y = 0.871 + 0.0134x	0.297	0.0001
		0.5—3.2	156	11	y = 1.207 + 0.0151x	0.235	0.0001
		3.2	126	12	y = 1.178 + 0.0195x	0.148	0.0001
	Grain filling precipitation (mm)	0—8.0	399	13	y = 2.800 - 0.0049x	0.047	0.0001
		0—0.4	117	14	y = 2.295 - 0.0046x	0.068	0.0045
		0.5—3.2	156	15	y = 2.838 - 0.0040x	0.033	0.0239
		3.2	126	16	y = 3.390 - 0.0079x	0.101	0.0003

Total dry-matter yield (Mg ha^{-1})	Growing season precipitation (mm)	0—8.0	399	17	$y = 0.664 + 0.0243x$	0.293	0.0001
		0—0.4	117	18	$y = 1.422 + 0.0197x$	0.372	0.0001
		0.5—3.2	156	19	$y = -0.352 + 0.0289x$	0.363	0.0001
		3.2	126	20	$y = 0.727 + 0.0245x$	0.148	0.0001
	Vegetative period precipitation (mm)	0—8.0	399	21	$y = 3.583 + 0.0372x$	0.194	0.0001
		0—0.4	117	22	$y = 3.295 + 0.0354x$	0.288	0.0001
		0.5—3.2	156	23	$y = 4.046 + 0.0318x$	0.099	0.0001
		3.2	126	24	$y = 3.449 + 0.0434x$	0.253	0.0001
	Heading period precipitation (mm)	0—8.0	399	25	$y = 1.940 + 0.0501x$	0.373	0.0001
		0—4.0	117	26	$y = 1.396 + 0.0502x$	0.558	0.0005
		0.5—3.2	156	27	$y = 1.343 + 0.0565x$	0.459	0.0001
		3.2	126	28	$y = 3.159 + 0.0413x$	0.176	0.0001
	Grain filling period precipitation (mm)	0—8.0	399	29	$y = 6.295 - 0.0016x$	0.001	0.5304
		0—0.4	117	30	$y = 5.693 - 0.0009x$	0.001	0.8418
		0.5—3.2	156	31	$y = 6.066 - 0.0045x$	0.006	0.3468
		3.2	126	32	$y = 7.228 - 0.0095x$	0.038	0.0278

[a] Observations.
[b] Equations.

translocation into the grain producing structures during drought periods or by increasing tillering or regrowth during favorable periods, thus possibly resulting in different lengths of the periods. These possibilities were not considered in the statistical analyses. It is doubtful that grain-filling-period precipitation actually decreased grain yields. For total dry matter yields, regression coefficients varied with increasing residue levels for vegetative- and heading-period precipitation, and were mostly negative and nonsignificant for grain-filling-period precipitation.

The increasing responses of grain yields with increasing amounts of surface residues to growing-season and especially to vegetative-period precipitation when plant canopies are not fully developed are attributed to the effects of surface residues on increasing water infiltration and reducing soil water evaporation. Surface residues enhance infiltration by intercepting raindrops, thus minimizing soil aggregate dispersion and surface sealing, and by reducing water flow across the soil surface.

The effect of surface residues on runoff has been extensively investigated. Unger (1984b) showed that soil protected by surface residues (no-tillage treatment) had a physical condition more conducive to water infiltration than soil on which residues were incorporated. On the same soil (Pullman clay loam), infiltration of simulated rainfall was greater when the surface was protected with residues than when it was bare (Benyamini and Unger, 1984). Also on the same soil, runoff from rainfall and/or irrigation was less with no-tillage than with clean tillage (Allen et al., 1975; Allen et al., 1980). Other examples of less runoff with surface residues than with bare soil can be found in reports by Griffith et al. (1977), Harrold and Edwards (1972), Ketcheson (1977), Mannering and Meyer (1963) and others.

In contrast to the increasing response of grain and total dry matter yields to vegetative-period precipitation with increasing amounts of surface residues, the lower or lack of responses to heading- and grain-filling-period precipitation with increasing amounts of surface residues are attributed to plant canopies present at the heading- and grain-filling growth stages. These canopies minimized the effect of surface residues by intercepting precipitation and thus enhancing infiltration, and by reducing evaporation. Other factors that minimized the effect of residues at the heading- and grain-filling stages were soil cracking and residue decomposition. The studies were conducted on a cracking soil, and extensive cracking due to soil drying often occurred by the time heading and grain filling occurred. When cracking occurred, runoff from precipitation and subsequent evaporation apparently were similar, regardless of the amount of surface residues present. Also, residue decomposition by the time of heading and grain filling minimized the differences in residue amounts present on the surface.

As with runoff, the influence of surface residues on soil water evaporation has been extensively investigated. Under laboratory conditions, Bond and Willis (1969, 1970, 1971), Unger (1976) and Unger and Parker (1976) showed that evaporation decreased with increasing amounts of surface residues. Under field conditions, evaporation was less with surface residues than with bare soil (Phillips, 1974; Smika, 1983). In other cases, greater water conservation with conservation tillage than with clean tillage has been attributed to lower evaporation (Greb et al., 1967; Unger et al., 1971; Musick et al., 1977; Unger, 1978, 1984a; Greb, 1979; Unger and Wiese, 1979).

CONCLUSIONS

Analyses of data from tillage and residue placement studies conducted on Pullman clay loam soil at Bushland, Texas, from 1972 to 1984, for which surface residues at sorghum planting time ranged from 0 to 8.0 Mg ha^{-1} showed that response to growing-season precipitation for grain production increased with increasing amounts of surface residues. For total dry matter production, the response was variable. Sorghum responded most to increasing residue amounts when precipitation occurred during the vegetative growth period. During that period, plant canopy development was incomplete and residues reduced runoff and soil water evaporation. During heading periods, plant canopies had developed, which minimized the effects of residues for reducing runoff and soil water evaporation, and, therefore, lowered the differences in response to precipitation. Responses to grain-filling-period precipitation were significant and negative, but small, again presumably due to canopy development. Other factors that contributed to the lower responses to surface residues for precipitation during heading- and grain-filling periods were soil cracking due to water extraction by plants and to residue decomposition. Cracking enhanced water infiltration and reduced evaporation (by storing water deeply in the soil) and, consequently, provided more water for use by plants. Decomposition during the growing season minimized residue amount differences among treatments near the end of the growing season.

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