Long-term Dryland Grain Sorghum and Winter Wheat Production Using Stubble-mulch and No-tillage Residue Management

R. L. Baumhardt[1] P. W. Unger

Conservation and Production Research Laboratory, USDA-Agricultural Research Service, U.S.A

B. A. Stewart

Dryland Agriculture Institute, Division of Agriculture, West Texas A&M University, U.S.A

Abstract Fallow using stubble-mulch (sub-surface sweep plow) or no-tillage (chemical weed control) residue management is an effective method of increasing stored plant available water in the soil profile. As a result, dryland crop yields are increased for the wheat-sorghum-fallow (WSF) rotation thmt produces two crops in three years. Our objective was to document the impact of residue management practices in the semiarid (400-600 mm precipitation) U.S.A. southern Great Plains on dryland water use and yields of grain sorghum [*Sorghum bicolor* (L.) Moench] and winter wheat (*Triticum aestivum* L.) during a long-term study. Wheat and sorghum were grown in rotation with an intervening fallow on six contour-farmed terraced watersheds so that each phmse of the rotation appeared every year. For both tillage systems, we compared grain yields and harvest index for each crop, and plant available soil water content after planting and harvesting (to determine seasonal water use). Long-term average grain yields with no-tillage exceeded 4.00 Mg hm^2 for sorghum and 1.90 Mg hm^2 for wheat compared to ~3.20 Mg hm^2 for sorghum and 1.80 Mg hm^2 for wheat with stubble-mulch tillage. Use of no-tillage after wheat increased soil water storage more than 30 mm when compared with plots where stubble mulch tillage was used, resulting in an average sorghum yield increase of 17 kg mm^2 available soil water at planting. For the WSF rotation, no-tillage residue management conserved water and increased yield of dryland grain sorghum in semiarid U.S.A. southern Great Plains.

Keywords Water conservation Fallow management Dryland

Introduction

The High Plains (>1000 m above mean sea level) portion of the southern Great Plains has a semiarid continental climate chmracterized by high winds that promote evaporation, and erratic rain with amounts ranging from 400 to 600 mm annually. For example, the mean annual precipitation at Bushland (Fig. 1.) is ~490 mm or, 25% of the 2.3 m annual pan evaporation (Dugas and Ainsworth, 1983). Sixty-five percent of the precipitation at Bushland falls as rain during the May-August (summer) growing season; however, water stored in the soil is needed to stabilize and increase yields of summer crops. The importance of soil water storage was shown in two separate studies, where the reported grain sorghum yield increase per millimeter water ranged from 17kg /hm^2 (Jones and Hmuser, 1975) to 19 kg/hm^2 (Baumhmrdt et al., 1985). Therefore, most dryland cropping systems in the southern Great Plains involve fallow periods between crops to store precipitation as soil water for a subsequent crop.

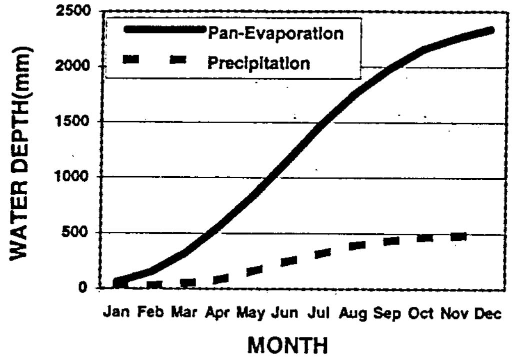

Fig. 1 Long-term monthly cummulative precipitation and pan-evaporation at Bushland, TX, USA

Early agriculture in the drier, western portion of the Great Plains was based primarily on one winter wheat crop in 2 years. This wheat-fallow system, generally, has been replaced in the southern and central Great Plains with a wheat-sorghum-fallow (WSF) rotation. The WSF rotation results in two crops in 3 years with an 11-month fallow (noncropped) period preceding each crop (Fig.2.). Using long-term Bushland, TX, data, Stewart and Burnett (1987) showed that evaporation during fallow (between crops) for the WSF rotation was 48% of total precipitation compared to 61% with wheat-fallow systems. Soil water storage with the WSF rotation is also affected by fallow period residue management.

Stubble-mulch tillage (SM) and no-tillage (NT) crop residue management are effective means of retaining residues that increase infiltration (Baumhardt et al., 1993) and reduce evaporation; thus, conserving precipitation for dryland crop production (Steiner, 1994; Jones & Pophmm, 1997). The NT residue management system, however, results in significantly greater profile soil water contents compared to SM (Jones et al., 1994) because of better evaporation control. Several short-term studies have reported that reduced water

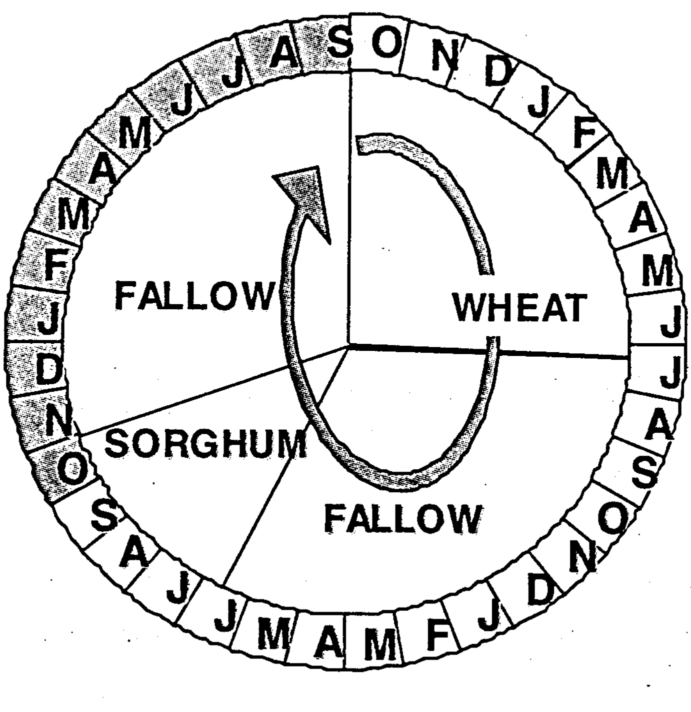

Fig. 2. The WSF crop rotation diagramed as a three year cycle beginning in October (top) with wheat establishment. Wheat is harvested 10-months later in July when the soil is fallowed until June of the second year (11-months). Grain sorghum is then grown using soil water stored during fallow to augment rainfall. After sorghum harvest in November of the third year the soil is again fallowed for 10-months when wheat is planted and the cycle repeated.

losses to evaporation increased both soil water storage and crop yield; however, reports from long-term studies with direct comparisons of residue management and fallow practice effects on yield were not found. The objective of this report is to document the impact of residue management practices in the semiarid U.S.A. southern Great Plains on dryland water use and yields of grain sorghum and winter wheat during a long-term study.

Materials and Methods

The research was conducted at the USDA-Agricultural Research Service, Conservation and Production Research Laboratory, Bushland, Texas, USA (35° 11' N lat., 102° 5' W long.), on six contour-farmed graded-terraced watersheds Hmuser et al. (1962). These watersheds range in area from 2.3 to 4.1 hm^2 and have a gently sloping (1%-2%) Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll). They were cropped in a WSF rotation, with each phase of the rotation present every year. Weeds were controlled on all water sheds from 1955 until 1984 using SM tillage sweep plows such as the 4.6m wide Richmrdson[1] (Sunflower Man. Co., Inc., Beloit, Kansas, USA) that had one 1.5 and two 1.8m wide overlapping V-shaped blades and an attached mulch treader. Beginning in 1984, the watersheds were divided into two groups that received either NT or continued SM residue management On the NT watersheds, weeds were chemically controlled during fallow (Table 1), resulting in no soil disturbance, except for seeding the crops.

Winter wheat, e.g., 'TAM 107' (Foundation Seed, College Station, TX) was sown on all wheat plots in late September or early October at a 40 kg/ hm^2 rate to achieve a 2.5 x 10^6 plants hm^2 population. Normally, a high-clearance grain drill with hoe openers and press wheels was used with a 0.2 to 0.3m row spacing. Control of flixweed [*Descurainia sophia* (L.) Webb ex Prantl] in growing wheat required 0.6 kg a.i. hm^2 2,4-D applied in late February during some years. Grain sorghum, e.g., Dekalb hybrid 'DK41Y' (DeKalb, IL) was seeded during early to mid-June in rows 0.75 to 1.0m apart at 50,000 to 80,000 seed hm^2, using unit planters such as 'Max-Emerge™' (John Deere, East Moline, IL). Growing season weed control consisted of cultivation or, when available, 1.7 kg a.i. hm^2 propazine applied pre-emergence after sorghum planting.

Data obtained included triplicate soil core samples for determining gravimetric soil water content to a depth of 1.8 m in 0.3m increments from each plot at crop planting and harvest. Triplicate crop biomass and grain yield data were measured using hand samples from $2m^2$ areas in each plot. Grain yields were corrected to 0.13 kg/kg water content. The response of crop yield components and water use factors to treatments were compared using paired two-tailed t-tests (SAS Inst., 1988).

[1] The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA – Agricultural Research Service. Mention of a pesticide does not constitute a recommendation for use nor does it imply registration under FIFRA as amended.

Table 1 Chemical weed control applications for the NT, no-tillage, system used at Bushland, TX, with the 3-y wheat-sorghum-fallow rotation

WSF Rotation Sequence Stage	Chemical Application
	3.36 kg a.i. $(hm^2)^{-1}$ atrazine†
Fallow wheat harvest (July-Y1)	0.84 kg a.i. $(hm^2)^{-1}$ 2,4-D‡
Before sorghum planting (June-Y2)	0.56 kg a.i. $(hm^2)^{-1}$ glyphosate§
Seasonal weed control in sorghum (June – Y2)	1.68 kg a.i. $(hm^2)^{-1}$ propazine¶
	0.023 kg a.i. $(hm^2)^{-1}$ chlorosulfuron#
Mid-fallow sorghum (Feb.-Y3)	0.37 kg a.i. $(hm^2)^{-1}$ 2,4-D
Before wheat planting (Oct.-Y3)	0.56 kg a.i. $(hm^2)^{-1}$ glyphosate
	0.56 kg a.i. $(hm^2)^{-1}$ glyphosate
Any weed control during fallow periods	0.37 kg a.i. $(hm^2)^{-1}$ 2,4-D

† atrazine = [6-chloro-N-ethyl-N'-(1-methylethyl)2,3,5-triazine-2,4-diamine]

‡ 2,4-D = [(2,4-dichlorophenoxy) acetic acid]

§ glyphosate = [N-(phosphonomethyl) glycine]

¶ propazine = [6-chloro-N,N'-bis (1-methylethyl)2,3,5-triazine-2,4-diamine]

#chlorosulfuron=[2-chloro-N[[(4-methoxy-6-methyl2,3,5-triazin-2-yl)amino]carbonyl] benzenesulfanomide]

Results and Discussion

Mean yield of wheat grown during the period 1958 through 1999 with SM residue management was 1.38 Mg/hm^2 grain and 2.44 Mg/hm^2 straw. During this period, there were two crop failures due to hailstorm damage. Generally, wheat grain yields increased during the study from 1.0 Mg/hm^2 before 1970 to about 2.0 Mg/hm^2 for the last 10 years (data not shown). No corresponding increase in soil water storage or crop use with SM was measured; therefore, much of the yield increase may be due to improved wheat cultivars.

Mean sorghum yield during the period 1958 through 1999 with SM management was 2.48 Mg/hm^2 grain and 3.7 Mg/hm^2 stover. Sorghum grain yields increased during the study from 1.96 Mg hm^2 before 1970 when chemical weed control methods were being developed to about 3.20Mg/hm^2 for the last 10 years (data not shown). Unger and Baumhmrdt (1999) attributed sorghum grain yield increases to improved water management (61% of total) and the development of improved cultivars (39% of overall total). Because no increase in soil water storage or crop use with SM was measured during the corresponding periods, we attributed the yield increase to improved cultivars.

Beginning in 1984, wheat grain and straw yields with SM or NT residue management were compared (Table 2.). No significant yield differences were measured, but the soil water available at planting and the growing season water use was significantly greater with NT than with SM. While NT increased water storage during fallow and growing season water use by ~ 30 mm, that difference did not translate into a significant yield increase. Better soil water conditions with NT promote early vegetative growth and water use in wheat that is often countered during the long growing season by later water stress conditions at grain fill. As a result, wheat yield response to the additional water stored with NT is lost and the water use efficiency is similar to SM conditions.

Table 2 Mean (± standard deviation) wheat and grain sorghum yield and soil water storage and use with SM, stubble mulch, and NT, no-tillage, residue management systems at Bushland, TX, 1984-1999. Means with * or ** are different at P=0.05 or 0.01 by an unpaired t-test

	Wheat			Sorghum		
Yield (Mg/hm²)	SM	NT		SM	NT	
Grain	1.83 ± 1.08	1.86 ± 0.97		3.23 ± 1.40	4.00 ± 1.30	**
Straw/Stover	3.44 ± 1.75	3.59 ± 1.74		4.79 ± 2.68	5.13 ± 2.55	
Water (mm)						
Used	362 ± 109	387 ± 125	*	349 ± 65	368 ± 72	**
At Planting	172 ± 33	200 ± 30	**	179 ± 37	212 ± 37	**

The 1984 through 1999 mean sorghum grain and stover yields with NT were significantly greater than with SM residue management (Table 2.). Compared to SM, the NT residue management increased mean soil water at planting and growing season water use significantly, but storm runoff during the growing season was unaffected.

Mean sorghum grain yield for NT and SM residue management is plotted in Fig 3 for 1984 through 1999. Yields typically increased as the evapotranspiration increased, which corresponded to years with the greatest precipitation. Because of increased soil water storage with NT compared to SM residue management, observed yields were typically greater with NT.

Years with similar NT and SM grain yields

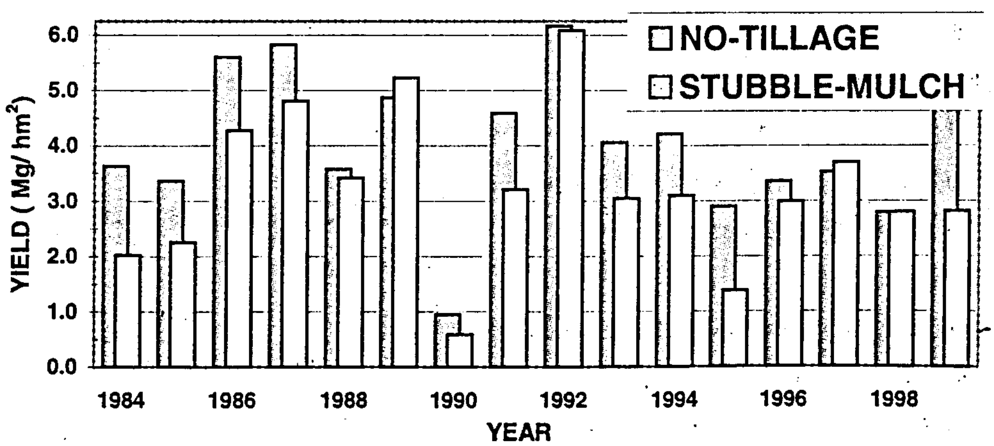

Fig. 3 Mean sorghum grain yield for stubble-mulch and no - tillage residue managemen from 1984 to 1999

illustrate the complex relation between crop growth and water use. To produce grain during years with limited rain, sorghum relied heavily on stored soil water, which was often depleted before yield benefits with NT could be obtained. In contrast, when rain was adequate, i.e., more than

75% of the total water use, sorghum relied on soil water to augment the water needed to optimize grain production. Increased soil water with NT, therefore, benefited grain yields during most years.

Summary and Conclusions

In this long-term study (~40 years), mean yield of wheat and grain sorghum grown during the last 10 years increased by ~50% over the yields measured during the initial 1958 through 1970 period. Water storage, crop use, and grain yield for sorghum were significantly increased with NT compared to SM residue management. Wheat did not achieve yield benefits with NT residue management, possibly because the additional water was consumed during the longer growing season before grain production. Our data show that for the WSF rotation, no-tillage residue management conserved water and increased yield of dryland grain sorghum in the semiarid U.S.A. southern Great Plains.

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[1] R. L. Baumhardt, Male, Professor , Soil Scientist

Address: Conservation and Production Research Laboratory USDA-Agricultural Research Service, P. O. Drawer 10, Bushland, TX, USA, 79012

Tel: 806-356-5766