This paper was peer-reviewed for scientific content.
Pages 277-282. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). 2001. Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Crop Residue Management Increases Dryland Grain Sorghum Yields in a Semiarid Region

Paul W. Unger and R. Louis Baumhardt*

ABSTRACT

The potential for soil erosion by wind is high under dryland (rainfed) conditions in the semiarid US southern Great Plains, but is greatly reduced when crop residues are retained on the soil surface. In early dryland studies at the USDA-ARS laboratory at Bushland, Texas, USA, most residues were plowed under. More residues were retained when stubble mulch tillage was used in later studies and most were retained when no-tillage practices were developed. Grain sorghum [*Sorghum bicolor* (L.) Moench] is a major dryland crop in the region. For 37 studies at the laboratory, preliminary analysis revealed that dryland sorghum grain yields more than tripled from 1939 to 1997. A major increase occurred in the early 1970s when using no-tillage became common. From 1939-1970, mean yield exceeded 2000 kg ha^{-1} only six times, but exceeded that amount 20 times after 1970. We determined factors responsible for the yield increase. Factors evaluated were annual precipitation, growing season rainfall, soil water content at planting, soil water use, total water use, and year of record. Analyses for the 1956-1997 period included one uniformly managed study for which the overall increase was 139%. For that study, using improved hybrids accounted for 46% of the increase; the remaining 93% was attributed to other factors, including increased soil water content at planting after 1970. Use of conservation tillage (no-tillage) became common at the laboratory at that time. Crop residue retention through use of no-tillage often increased soil water contents at planting and was primarily responsible for the yield increases. It generally also resulted in greater stover (residue) production, which, when properly managed, provided greater protection against erosion.

INTRODUCTION

The potential for soil erosion by wind is great under dryland crop production conditions in the semiarid southern US Great Plains. A major well-adapted dryland crop in the region is grain sorghum. Early grain sorghum production generally involved clean tillage, which eliminated most surface residues. Erosion control, however, is greatly enhanced when crop residues are retained on the soil surface by using practices such as stubble mulch tillage and no-tillage. When retained on the surface, crop residues also increase soil water storage. On dryland, sorghum yields are strongly influenced by soil water content at planting (Jones and Hauser, 1975) and growing season rainfall, but soil water storage, rainfall amount and distribution, climatic conditions (e.g., first freeze in fall), and crop management practices are highly variable. Hence, yields are highly variable, ranging from near or complete failures to 6000 kg ha^{-1} in the southern Great Plains (Jones and Johnson, 1991; Sow et al., 1996; Unger, 1978, 1988, 1992).

Over 30 studies have involved dryland sorghum at the USDA-ARS, Conservation and Production Research Laboratory (CPRL), Bushland, Texas, in the U.S. southern Great Plains since the CPRL was established in 1938. In early studies, tillage was used for weed control and seedbed preparation. Also, crops usually were cultivated for seasonal weed control because satisfactory herbicides were not available. Crop residue management for improving production received virtually no emphasis and grain yields generally were <2000 kg ha^{-1} in early studies.

When herbicides for controlling some weeds in sorghum became available by the early 1950s, Wiese et al. (1960, 1967) started residue management (no-tillage) research with sorghum. Use of no-tillage had little effect on yields in early studies. Residue management for sorghum production received a major boost when improved herbicides and planting equipment became available in the 1960s. As a result, extensive residue management research began at the CPRL in the late 1960s that often resulted in major yield increases for dryland grain sorghum.

Benefits of retaining crop residues on the surface for increasing sorghum yields were obvious, but other management practices undoubtedly were involved also. Hence, our objectives were to: i) document the effects that improved management practices had on dryland sorghum grain yields at the CPRL and ii) to identify factors primarily responsible for the yield increases.

MATERIALS AND METHODS

Crop Performance Data

Data are from 1939-1997 research at the CPRL, Bushland, Texas, USA, on Pullman clay loam (Torrertic Paleustoll). For this report, we used 502 treatment-years of yield data from 37 studies involving cropping systems (continuous and rotations), tillage methods (clean, stubble mulch, ridge, and no-tillage), mulch rates, plant populations and row spacings, hybrids, and non-irrigated controls from several irrigation studies.

The wide range of treatments along with variable precipitation resulted in highly variable yields within and

*Paul W. Unger and R. Louis Baumhardt, USDA-ARS, Conservation and Production Research Laboratory, P. O. Drawer 10, Bushland, TX 79012. *Corresponding author: pwunger@tcac.net.

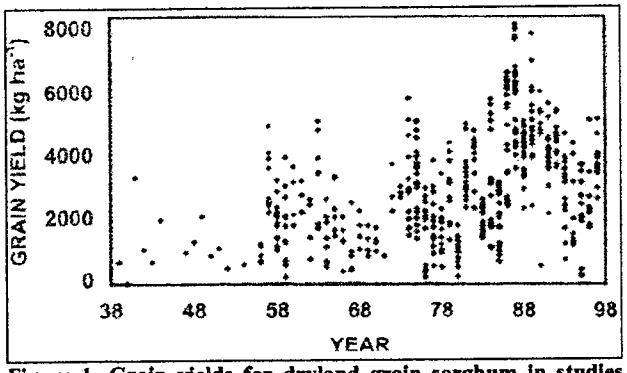

Figure 1. Grain yields for dryland grain sorghum in studies conducted at the USDA-Agricultural Research Service, Conservation and Production Research Laboratory, Bushland, Texas, 1939 to 1997.

among years. Year of record (YEAR) has no biological effect on sorghum, but grain yields more than tripled from 1939-1997 (Fig. 1). To reduce scatter and potential for bias because more data were available for some years than others, we calculated annual avg. yields (AVYLD, kg ha^{-1}) and used them for the analyses. Minimum and maximum yields (MINYLD and MAXYLD, kg ha^{-1}) also tended to increase and were evaluated, when available, after 1956.

Possible reasons for yield increases include use of improved cultivars, pest control (weeds and insects) methods, and management practices. To evaluate these, we included data on annual (ANPRCP, mm) and growing season (GSPRCP, mm) precipitation, soil water content at planting (SWPLNT, mm), growing season soil water use [SWUSE, mm (content at planting minus content at harvest)], and growing season evapotranspiration [GSET, mm (GSET = SWUSE + GSPRCP)] from studies for which this information was available. When not available, we estimated GSPRCP (June-October) from CPRL records or other studies conducted at the same time; also SWPLNT and SWUSE from other studies conducted under similar conditions in the same years. No studies involved fertilizer use because dryland sorghum has not responded to fertilizer on Pullman soil, except in a few cases where increased amounts of water were available.

ANALYTICAL METHODS

We used Pearson correlation (Haan, 1977; SAS Inst. Inc., 1988) procedures to identify relationships among the different variables. Preliminary analyses helped identify factors correlated with yields or that duplicated information (were intercorrelated). Correlations were computed first for the entire 1939-1997 data set and then for the more complete 1956-1997 data set. Results were similar in both cases; hence, we used the more complete 1956-1997 data set in subsequent analyses. We also analyzed one subset of data for the 1970-1997 period to determine the impact of improved residue management practices on yield and water use parameters.

We used regression models to identify factors related to yields. These models excluded intercorrelated and included yield affecting factors previously identified in the correlation analyses. Models were developed in a step-wise manner; i.e., factors correlated with yield were introduced and retained if they increased the coefficient of determination (R^2 value, $P = 0.05$). Differences between observed and model-predicted yields were further analyzed to identify conditions when the model failed.

RESULTS AND DISCUSSION

Year Effects on Grain Yields and Water Variables

Preliminary correlations among AVYLD, YEAR, ANPRCP, and GSET were calculated for the 1939-1997 period. AVYLD increased and was correlated ($P = 0.01$) with YEAR ($r = 0.63$). Although this correlation has no biological basis, it illustrates that yields increased with years, which was our first objective. Based on this relationship, mean yields increased 348% (from 840 to 3760 kg ha^{-1}) from 1939 to 1997. Both ANPRCP and GSPRCP describe climatic factors and should be independent of year of observation. These variables were inter-correlated ($r=0.74$) and contained similar information about precipitation, but were not correlated with YEAR. GSPRCP averaged 270 mm, ranging from 76 mm in 1940 to 503 mm in 1960. ANPRCP averaged 475 mm, ranging from 240 mm in 1970 to 828 mm in 1941. These highly variable amounts contributed to the large year-to-year yield differences during the period of record.

Beginning in 1956, more complete information became available, including ranges in annual yields that allowed us to establish a data set containing annual MINYLD and MAXYLD. Information also became more complete for

Table 1. Correlation coefficients, r, for dryland grain sorghum production factors† from 1956 to 1997, Bushland, TX.

	MINYLD	MAXYLD	YEAR	ANPRCP	GSPRCP	SWPLNT	SWUSE	GSET
AVYLD	0.778***	0.929***	0.529***	0.371*	0.375*	0.583***	0.109	0.434**
MINYLD		0.594***	0.304	0.422**	0.339*	0.485**	0.223	0.478**
MAXYLD			0.561***	0.382*	0.424**	0.472**	-0.021	0.405**
YEAR				0.051	0.182	0.579***	0.181	0.227
ANPRCP					0.766***	-0.021	-0.410**	0.667***
GSPRCP						0.037	-0.439**	0.874***
SWPLT							0.523***	0.285
SWUSE								0.001

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Factors are: AVYLD, average yield, kg ha^{-1}; MINYLD, minimum yield, kg ha^{-1}; MAXYLD, maximum yield, kg ha^{-1}; YEAR, production year; ANPRCP, annual precipitation, mm; GSPRCP, growing season rainfall, mm; SWUSE, soil water use, mm; and GSET, total water use, mm.

SWPLNT, SWUSE, and GSET. Correlation coefficients for all factors for 1956-1997 are shown in Table 1. For 1956-1997, increases were 139% (1600-3830 kg ha^{-1}) for AVYLD, 91% (1040-1990 kg ha^{-1}) for MINYLD, and 127% (2500-5680 kg ha^{-1}) for MAXYLD. MINYLD included several crop failures because of drought or freeze damage before crop maturity. MAXYLD included results from irrigated winter wheat (*Triticum aestivum* L.)-dryland sorghum rotation studies (Unger, 1984; Unger and Wiese, 1979). Annual AVYLD, MINYLD, and MAXYLD were interrelated (r = 0.59 to 0.93), with AVYLD and MAXYLD correlated with YEAR (r = 0.53 and 0.56, respectively).

Use of improved cultivars or their response to improved management practices may partly explain the yield increases. Information on cultivars used was not available for all studies, but a 1956-1997 study on conservation bench terraces (CBTs) where stubble mulch tillage was used involved changes in hybrids while other practices remained constant. For the CBT system, runoff from the upslope (non-leveled) portion of watershed is captured on the level benches (Hauser, 1968; Zingg and Hauser, 1959). Sorghum yielded more on the benches than in all other studies in 7 of the first 20 years (1956-1977), indicating that growing sorghum on CBT benches was a good practice in the early years. We, therefore, analyzed data from that study to determine the effect changes in hybrids had on yield increases through the years. Yields averaged 2240 kg ha^{-1} for early hybrids (1956-1977), with yields >3000 kg ha^{-1} in 6 of 20 years. Yields averaged 3260 kg ha^{-1} with improved hybrids (1978-1997; no yield in 1990), an increase of 46%, with yields >3000 kg ha^{-1} in 12 of 19 years. A single-step yield increase occurred because the hybrid used through 1977 was replaced in later years with hybrids for which yields were similar, based on another study (Unger, 1994). If the assumption is valid that use of improved hybrids increased yields 46%, the remaining increase of 93% must be attributed to improved management practices, mainly the use of tillage methods that retained more crop residues on the soil surface, which increased soil water contents and use of that water for crop growth and yield.

The 139% yield increase for 1956-1997 was for a single uniformly managed study. The overall increase of 348% from 1939-1997 included the 1956-1997 study discussed above and the other 36 studies conducted at the laboratory, with some being conducted at the same time as the 1956-1997 study. The other 209% yield increase (348 - 139 = 209) did not necessarily all occur from 1939 to 1956, but was attributable partially to improved practices through the years. Major increases, however, did occur before 1956. These resulted from such factors as a change from open pollinated to hybrid cultivars; using improved weed control practices, including herbicides; and a change from using mainly clean tillage to using stubble mulch tillage.

AVYLD, MINYLD, and MAXYLD from 1956-1997 were correlated with SWPLNT and GSET, but not with SWUSE (Table 1). These findings suggest practices that increase GSET, or at least increase SWPLNT, will increase sorghum yields. Mean SWPLNT increased with YEAR during the 1956-1997 period (r = 0.58), but growing season SWUSE and GSET did not increase, which suggests greater use of GSPRCP contributed to the yield increases with time. This occurred when more crop residues remained on the soil surface. Greater use of GSPRCP with more surface residues resulted mainly from less evaporation and, to some extent, less runoff.

Increases in SWPLNT for 1956-1997 became evident in the early 1970s. Analyses for the 1970-1997 period showed that SWPLNT and YEAR were not correlated (Table 2), i.e., after 1970, SWPLNT did not increase annually. Research before 1970 involved mainly clean or stubble mulch tillage. Yields where herbicides were used for dryland crops generally were poor during that period (Wiese et al., 1960, 1967). When improved herbicides became available in the early 1970s, a major shift to no-tillage crop production occurred. Retaining crop residues on the soil surface with no-tillage and improved herbicidal weed control are largely responsible for the increased water conservation achieved since the early 1970s.

Table 2. Correlation coefficients, r, for dryland grain sorghum production factors† after improved residue management practices were typically used from 1970 to 1997, Bushland, TX.

	MINYLD	MAXYLD	YEAR	ANPRCP	GSPRCP	SWPLNT	SWUSE	GSET
AVYLD	0.730***	0.926***	0.461*	0.426*	0.294	0.519**	0.060	0.385*
MINYLD		0.544**	0.203	0.467*	0.235	0.473*	0.271	0.435*
MAXYLD			0.515**	0.477*	0.387*	0.368	-0.119	0.392*
YEAR				0.233	0.160	0.354	0.058	0.235
ANPRCP					0.782***	0.070	-0.356	0.686***
GSPRCP						-0.122	-0.484**	0.868***
SWPLT							0.492**	0.139
SWUSE								0.008

*, **, ***Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

†Factors are: AVYLD, average yield, kg ha^{-1}; MINYLD, minimum yield, kg ha^{-1}; MAXYLD, maximum yield, kg ha^{-1}; YEAR, production year; ANPRCP, annual precipitation, mm; GSPRCP, growing season rainfall, mm; SWUSE, soil water use, mm; and GSET, total water use, mm.

Water Variable Effects on Grain Yield

Sorghum AVYLD, MINYLD, and MAXYLD increased from 1956-1997 due to using improved water conservation practices. We, therefore, used correlation analyses to clarify relationships between yields and water variables after adoption of improved practices. AVYLD was correlated with SWPLNT after improved water conservation practices were factored out by analyzing yields after 1970. Some dependencies between MINYLD and ANPRCP (r = 0.42) and between MAXYLD and GSPRCP (r = 0.42) were also eliminated. Our data suggest that use of improved soil water conservation techniques reduced the high GSPRCP impact on peak yields.

These results show the importance of increased SWPLNT for achieving favorable yields. Increases in SWPLNT for 1956-1997 resulted mainly from using no-tillage after 1970 or from applying a crop residue mulch. Grain yield was correlated with GSET (r = 0.41 to 0.48) for the post-1970 period when no-tillage was widely used. Yield increases with increased GSET without use of no-tillage were attributed to the combined effect of GSPRCP and SWUSE, even though yield was not related to SWUSE. The lack of yield response to SWUSE, even though differences in SWPLNT occurred, suggests that soil water contents remained greater during the growing season when more water was present at planting, as when more crop residues remained on the surface with no-tillage management. This further suggests GSPRCP was used more effectively for grain production under such conditions than when less residues were present.

Multiple Factor Effects on Grain Yield

Sorghum AVYLD, MINYLD, and MAXYLD were predicted using a regression model containing the more highly correlated factors. We determined partitioned and combined effects of SWPLNT, ANPRCP, YEAR, and SWUSE on yield (Table 3). No parameter was most critical for predicting yields. SWPLNT and ANPRCP appeared in all models, accounting for variations of 51% for AVYLD,

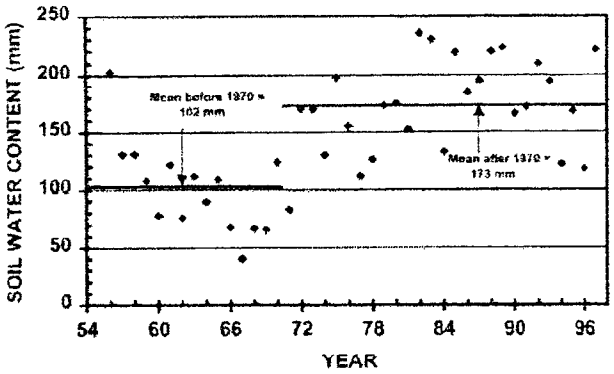

Figure 2. Average annual plant available soil water content (volumetric basis) at planting time for dryland grain sorghum in studies conducted at the USDA-Agricultural Research Service, Conservation and Production Research Laboratory, Bushland, Texas, 1956 to 1997.

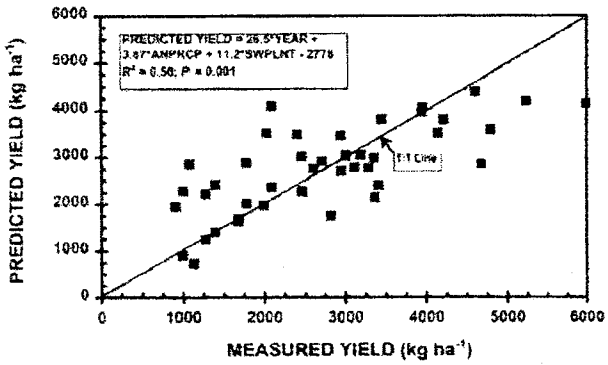

Figure 3. Predicted average grain yield as a function of measured average yields for dryland grain sorghum in studies conducted at the USDA-Agricultural Research Service, Conservation and Production Research Laboratory, Bushland, Texas, 1956 to 1997. The line represents the 1:1 ratio between measured and predicted yields.

Table 3. Parameter estimates for multiple regression of the average, minimum, and maximum grain sorghum yields (kg ha^{-1}) for the years 1956 to 1997 on production factors of year (YEAR), annual precipitation (ANPRCP, mm), soil water content at planting (SWPLNT, mm), and soil water use (SWUSE, mm). Parameter estimates are kg ha^{-1}, except that the yield INTERCEPT is in kg ha^{-1} and the YEAR is unitless.

	Average yield			Minimum yield			Maximum yield		
	Parameter estimate	Model R^2		Parameter estimate	Model R^2		Parameter estimate	Model R^2	
Factor		Partial	Total		Partial	Total		Partial	Total
SWPLNT	11.2±3.2	0.38	0.38	6.4±2.6	0.24	0.24	8.6±4.5	0.05	0.05
ANPRCP	3.9±1.2	0.13	0.51	4.4±1.1	0.18	0.42	5.2±1.7	0.11	0.16
YEAR	26.5±13.7	0.05	0.56	–	--	--	55.2±19.3	0.34	0.50
SWUSE	–	--	--	5.2±3.3	0.03	0.45	--	--	–
INTERCEPT	-2777.8±1027.1	–	--	-1932.8±661.6	--	–	-3842.9±1446.6	–	–

42% for MINYLD, and 16% for MAXYLD. SWPLNT and ANPRCP quantify conditions critical for crop establishment and growth. YEAR appeared in the AVYLD and MAXYLD models, but SWUSE replaced it in the MINYLD model. MINYLD conditions reflect limited season length or available water; thus, SWUSE would be more important.

Multiple regressions of AVYLD on YEAR, SWPLNT, and ANPRCP may reveal more than regressions using yield limits. Predicted average yield is plotted as a function of measured average yield in Fig. 3. Yields predicted by the regression model were acceptable, considering the various data sources. We identified SWPLNT as being most important for increasing yields. Favorable SWPLNT due to improved management practices affect sorghum establishment and early growth. ANPRCP, which was intercorrelated with GSPRCP and GSET, quantified the water available for crop growth and grain production. Increases in ANPRCP, therefore, resulted in increased yield. The yearly yield increase of 26 kg ha^{-1} was the final component added to the regression model. Over the 40-year period, these average annual yield increases amounted to 1040 kg ha^{-1}, an amount similar to the increase attributable to improved cultivars.

CONCLUSIONS

Sorghum grain yields have more than tripled in studies at the USDA-ARS, CPRL, Bushland, Texas, from 1939-1997. Based on analyses to determine factors primarily related to the yield increases with time (years), we conclude:

1. Yield increased at an annual average of 50 kg ha^{-1} from 1939-1997. For 1956-1997 when other factors could be partitioned out, the annual increase was 26 kg ha^{-1}.
2. Annual and growing season precipitation were related to yields, but not to years of observation, showing that annual yield increases were independent of precipitation.
3. Growing season soil water use was not related to grain yield nor year of observation. Growing season evapotranspiration was related to yields, but not to year of observation.
4. Based on the 1956-1997 uniformly managed study, introduction of improved hybrids increased yields 46% (1020 kg ha^{-1}). An additional yield increase of 93% resulted from other factors in that study.
5. Soil water content at planting was the dominant factor contributing to yield increases with time. Most increases in soil water content at planting occurred after the early 1970s, when improved herbicides became available and using conservation tillage (crop residue retention on the soil surface) received major emphasis at the laboratory.
6. Associated with the grain yield increases resulting from greater soil water contents at planting was greater stover (residue) production. When properly managed, the greater amounts of residue reduced the potential for soil erosion by wind.

REFERENCES

(Note: References followed by an asterisk contain data used in this report.)

Bond, J.J. and T.J. Army. 1960. Narrow row planting dryland grain sorghum. Soil and Water 9:22-23.*

Bond, J.J., T.J. Army and O.R. Lehman. 1964. Row spacing, plant populations and moisture supply as factors in dryland grain sorghum production. Agron. J. 56:3-6.*

Haan, C.T. 1977. Statistical methods in hydrology. Iowa State Univ. Press, Ames, IA. 378 pp.

Hauser, V.L. 1968. Conservation bench terraces in Texas. Trans. ASAE 11:385-386, 392.*

Jensen, M.E. and W.H. Sletten. 1965. Evapotranspiration and soil moisture - fertilizer interrelations with irrigated grain sorghum in the southern Great Plains. Conserv. Res. Rpt. 5, USDA-ARS, Washington, DC.*

Jones, O.R. 1981. Land forming effects on dryland sorghum production in the Southern Great Plains. Soil Sci. Soc. Am. J. 45:606-611.*

Jones, O.R. and R.N. Clark. 1987. Effects of furrow dikes on water conservation and dryland crop yields. Soil Sci. Soc. Am. J. 51:1307-1314.*

Jones, O.R. and V.L. Hauser. 1975. Runoff utilization for grain sorghum. pp. 277-283. *In* G.W. Frazier (ed.) Proc. Water Harvesting Symp., 1975. U.S. Dept. Agric., ARS W-22.

Jones, O.R. and G.L. Johnson. 1991. Row width and plant density effects on Texas High Plains sorghum. J. Prod. Agric. 4:613-619.*

Jones, O.R. and G.L. Johnson. 1997. Evaluation of a short season - high density production strategy for dryland sorghum. Rpt. No. 97-01. USDA-ARS, Conserv. and Prod. Res. Lab., Bushland, TX.*

Jones, O.R. and T.W. Popham. 1997. Cropping and tillage systems for dryland grain production in the Southern High Plains. Agron. J. 89:222-232.*

Laryea, K.B. and P.W. Unger. 1995. Grassland converted to cropland: Soil conditions and sorghum yield. Soil Tillage Res. 33:29-45.*

Musick, J.T. and D.A. Dusek. 1971. Grain sorghum response to number, timing, and size of irrigations in the Southern High Plains. Trans. ASAE 14:401-404, 410.*

Musick, J.T. and D.A. Dusek. 1972. Irrigation of grain sorghum and winter wheat in alternating double-bed strips. J. Soil Water Conserv. 27:17-20.*

Musick, J.T., W.H. Sletten, and D.A. Dusek. 1971. Preseason irrigation of grain sorghum in the Southern High Plains. Trans. ASAE 14:93-97.*

SAS Inst. Inc. 1988. SAS/STAT Users Guide, Release 6.03 Edition. SAS Inst. Inc., Cary, NC.

Sow, A.A., L.R. Hossner, P.W. Unger and B.A. Stewart. 1996. Effects of furrow diking and tillage on water storage, plant water use efficiency and yield of sorghum. African Crop Sci. J. 4:433-440.*

Steiner, J.L. 1986. Dryland grain sorghum water use, light interception, and growth responses to planting geometry. Agron. J. 78:720-726.*

Stewart, B.A., J.T. Musick and D.A. Dusek. 1983. Yield and water use efficiency of grain sorghum in a limited irrigation - dryland farming system. Agron. J. 75:629-634.*

Unger, P.W. 1972. Dryland winter wheat and grain sorghum cropping systems – Northern High Plains of Texas. Bull. B-1126, Texas Agric. Exp. Stn., College Station, TX.*

Unger, P.W. 1978. Straw-mulch rate effect on soil water

storage and sorghum yield. Soil Sci. Soc. Am. J. 42:486-491.*

Unger, P.W. 1984. Tillage and residue effects on wheat, sorghum, and sunflower grown in rotation. Soil Sci. Soc. Am. J. 48:885-891.*

Unger, P.W. 1988. Grain and forage sorghum production with no-tillage on dryland. Agron. J. 80:193-197.*

Unger, P.W. 1991. Ontogeny and water use of no-tillage sorghum cultivars on dryland. Agron. J. 83:961-968.*

Unger, P.W. 1992. Ridge height and furrow blocking effects on water use and grain yields. Soil Sci. Soc. Am. J. 56:1609-1614.*

Unger, P.W. 1994. Residue management for winter wheat and grain sorghum production with limited irrigation. Soil Sci. Soc. Am. J. 58:537-542.*

Unger, P.W. 1994. Tillage effects on dryland wheat and sorghum production in the southern Great Plains. Agron. J. 86:310-314.*

Unger, P.W. and J.J. Parker. 1975. No-till dryland grain sorghum after irrigated wheat with intervening fallow. Prog. Rpt. PR-3330C, Texas Agric. Exp. Stn., College Station, TX.*

Unger, P.W. and A.F. Wiese. 1979. Managing irrigated winter wheat residues for water storage and subsequent dryland grain sorghum production. Soil Sci. Soc. Am. J. 43:582-588.*

Wiese, A.F., J.J. Bond and T.J. Army. 1960. Chemical fallow in the Southern Great Plains. Weeds 8:284-290.*

Wiese, A.F., E. Burnett and J.E. Box, Jr. 1967. Chemical fallow in dryland cropping sequences. Agron. J. 59:175-177.*

Zingg, A.W. and V.L. Hauser. 1959. Terrace benching to save potential runoff for semiarid land. Agron. J. 51:289-292.*