Water use of pearl millet forage in response to cultural practice in the semiarid Southern Great Plains

B. Crookston[1], J. Machicek[1], B. Blaser[1], B.A. Stewart[1], M. Rhoades[1], M. Darapuneni[2]

[1]Dept of Agricultural Sciences, West Texas A&M Univ., Canyon TX, [2]Dept. of Plant and Environmental Sciences, New Mexico State Univ., Tucumcari, NM

Background

Efficient water use in semi-arid Southern Great Plains cropping systems is challenging due to uncertain precipitation and concerns of reduced irrigation because of decreasing aquifer water availability. Recent work conducted in the central Great Plains by Nielsen et. al. (2016, 2011, 2006), suggests that transitioning from traditional set grain cropping systems toward diversified forage and flexible systems can have the potential to meet producer's needs while conserving water resources. Adopting diversified flex forage cropping systems requires information on potential crops and cultural practices that optimize water use efficiency.

Pearl millet (*Pennisitum glaucum* L.), a C_4 plant typically grown in semiarid climates, has potential to be utilized in flex systems as a forage crop (Unger, 2001; Payne, 2000). Review of previous work with pearl millet forage indicated limited work involving management practices performed in the Southern Great Plains. The goal of this work was to observe and report pearl millet forage crop response to management practices so it may be used as part of a diversified cropping system in the semiarid Southern Great Plains.

Hypothesis

- Changes in cultural practice can influence soil surface evaporation and evaporative demand in the crop canopy and the crop response can be observed in forage yield, water use, and water use efficiency.

Objectives

- Evaluate pearl millet management strategies using narrow and wide row spacing, and till and no-till soil management.
- Evaluate water use and water use efficiency of these cultural practices under three irrigation levels.
- Report a water use dry matter production function for pearl millet.

Materials and Methods

Location: WTAMU Nance Ranch adjacent to Canyon, TX (1097 m above sea level).

Seed: Pearl millet forage planted at 125 seeds m^{-2} June 17, 2016 and 94 seeds m^{-2} June 1, 2017.

Figure 1. Tillage was completed using a PTO driven rotary tiller. Planting in 2016 was into native grass rangeland.

Treatment arrangement:

Split-split plot with four replications with irrigation as main plots, row spacing as subplots, and tillage as sub-subplots.

Irrigation system:

Metered surface drip from two lines 150 cm apart in each plot with emitters spaced 60 cm applying 7.5 L $hour^{-1}$.

Figure 2. Irrigation water was applied using a metered surface drip system.

Measurements:

- Soil moisture was taken using a hydraulic press at planting and at harvest to a depth of 60 cm and divided into 3 sections. Soil moisture was measure using the gravimetric method and converted to plant available soil water.
- Leaf area index was measured and calculated using an LAI-2200 Plant Canopy Analyzer.
- Above ground dry matter (DM) was collected from 0.10 m^{-2} biweekly and used to calculate plant growth rate. End of season DM collected from two 1 m^{-2} quadrats in each plot.
- Results of repeated measures are reported in thermal time, also known as growing degree days.
- Weather data in 2017 was collected using a Campbell Scientific (Logan, UT) designed weather station at the study location.
- Water use was calculated using total growing season precipitation, irrigation applied, and plant available soil water at planting, minus plant available soil water left at harvest.
- Statistical analysis: Analysis of variance was completed using Proc Mixed of the Statistical Analysis System Version 9.4 (SAS Institute, 2016). Means separation used Tukey's adjustments.

Table 1. Maximum daily average temperature, precipitation, and reference evapotranspiration (ET_o). Weather data, excluding precipitation in 2016 was taken the National Weather Service in Amarillo TX., (approx. 32km from the study location), 2017 data was collected on site.

Month	Avg. max daily temp.			Precipitation			ET_o†	
	°C			mm			mm	
	2016‡	2017	avg.§	2016	2017	avg.	2016	2017
June	35	32	31	28	103	80	114	332
July	36	32	33	61	79	72	300	327
Aug	31	28	32	113	127	74	197	243
Sept	29		28	15		49	161	
Total				217	309	275	772	902
Percent of normal				79%	137%			

†ET_o= ASCE reference evapotranspiration (ET) for a well-watered grass crop, calculated using Ref-ET (Allen, 2016).

‡Growing Season= 2016 June 17 - Sept. 30; 2017 June 1 - Aug 30

§ Averages for temperature and precipitation are 1981 - 2010 averages for Amarillo TX.

Figure 3. Pearl millet as seen in Aug. 2016.

Figure 4. Nitrogen deficiency was observed in 2017 no-till treatment.

Table 2. Pearl millet dry matter (DM), growing season water use (WU), and calculated water use efficiency (WUE). Growing season water use was calculated using total growing season precipitation, irrigation, and plant available soil water (PAW) at planting, minus PAW left at harvest. WUE is calculated using DM divided by WU. Row widths had no effect on DM, WU, and WUE.

Treatment	DM†		WU		WUE	
	kg ha^{-1}		mm		kg ha^{-1} mm^{-1}	
	2016	2017	2016	2017	2016	2017
Irrigation level						
High	2213a***	3450a**	436a***	602a**	5.06	5.75
Moderate	1704ab	2615ab	385b	469b	4.4	5.57
Limited	1219b	2213b	310c	366c	3.9	6.04
Tillage						
No-till	1283***	2301**	378	479	3.35***	4.87**
Till	2141	3218	376	479	5.57	6.7
SEM	243	369	1.9	4.1	0.76	0.76

† DM= dry matter; WU=total water used; WUE=water use efficiency.

** Significant at the 0.01 probability level.

*** Significant at the 0.001 probability level.

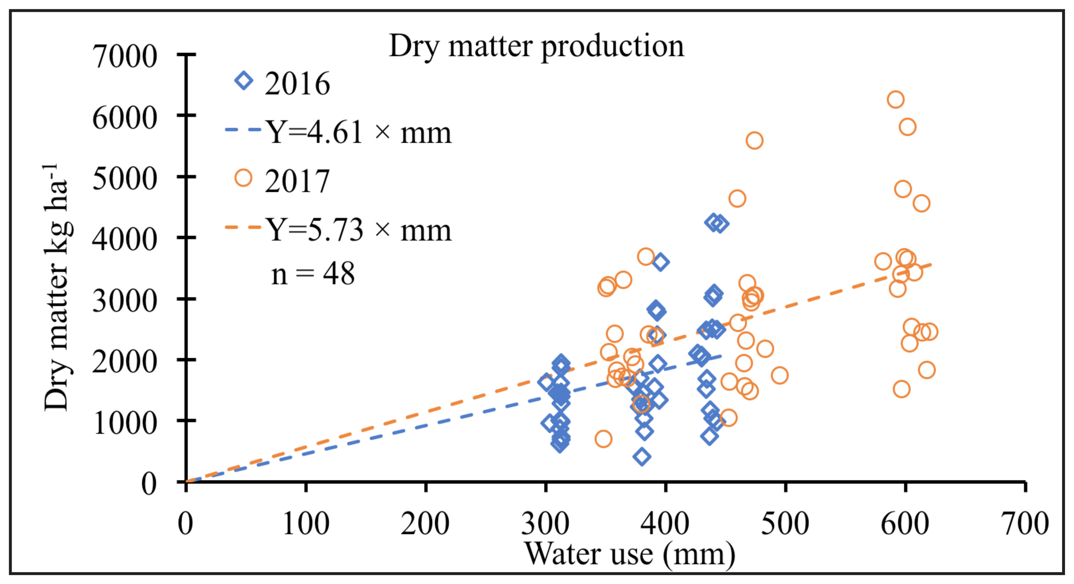

Figure 5. Pearl millet forage linear regression of dry matter (DM) and water use (WU) for 2016 and 2017. Regression calculations generated low r^2 values, 0.21 and 0.17, in 2016 and 2017 respectively.

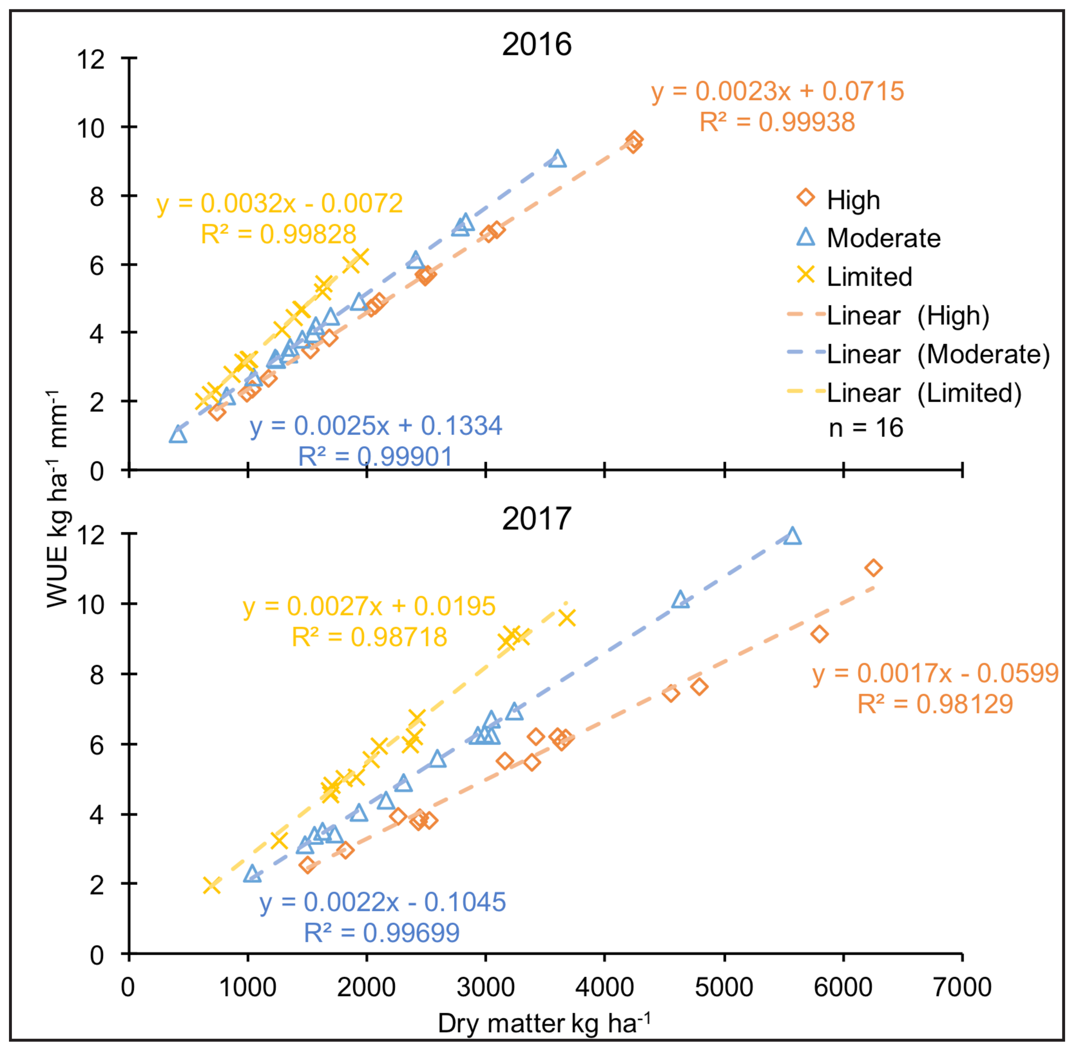

Figure 6. Linear regression of pearl millet forage water use efficiency (WUE) and dry matter (DM) production by irrigation level for 2016 and 2017. Regression slopes illustrate the relationships among irrigation level, WUE, and DM produced.

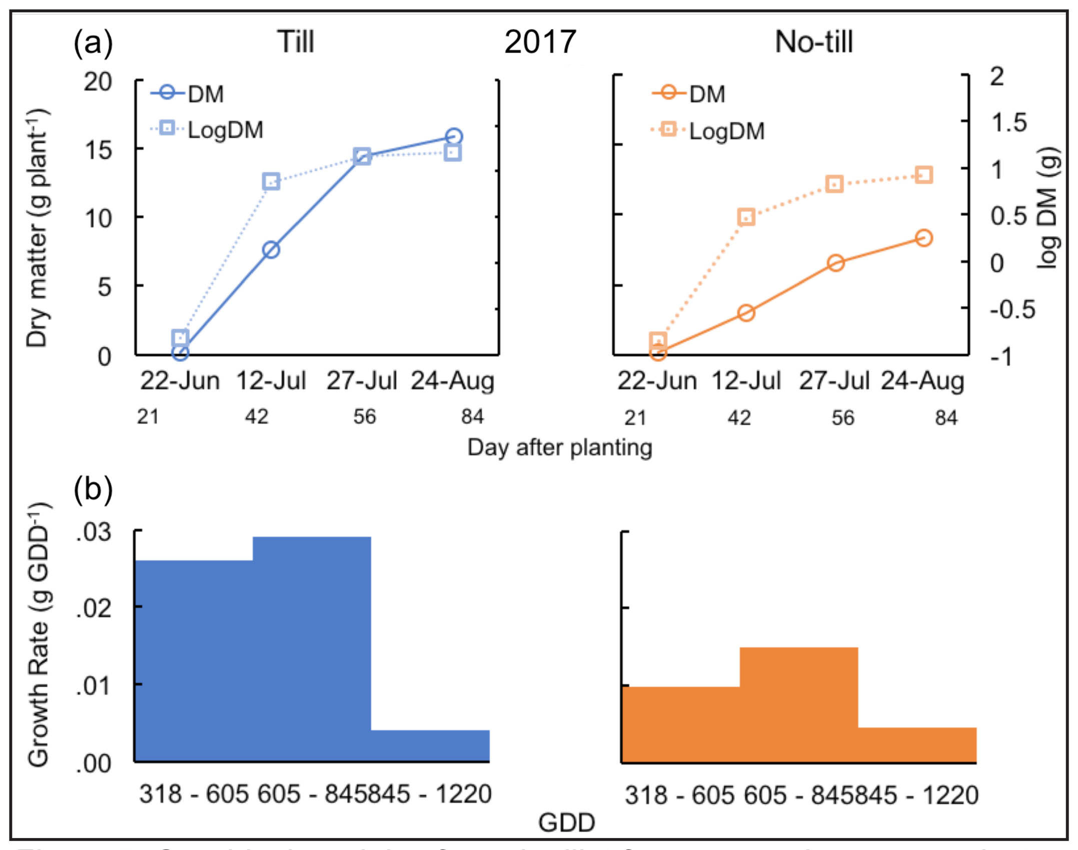

Figure 7. Graphical models of pearl millet forage growth on a per-plant basis for till and no-till in 2017. They depict DM accumulation over time (a), and the growth rate (b) at specified growing degree day (GDD) intervals which correspond to sampling dates in days after planting. The log of DM in (a) renders a sigmoid curve used to analyze crop development from seedling to maturity.

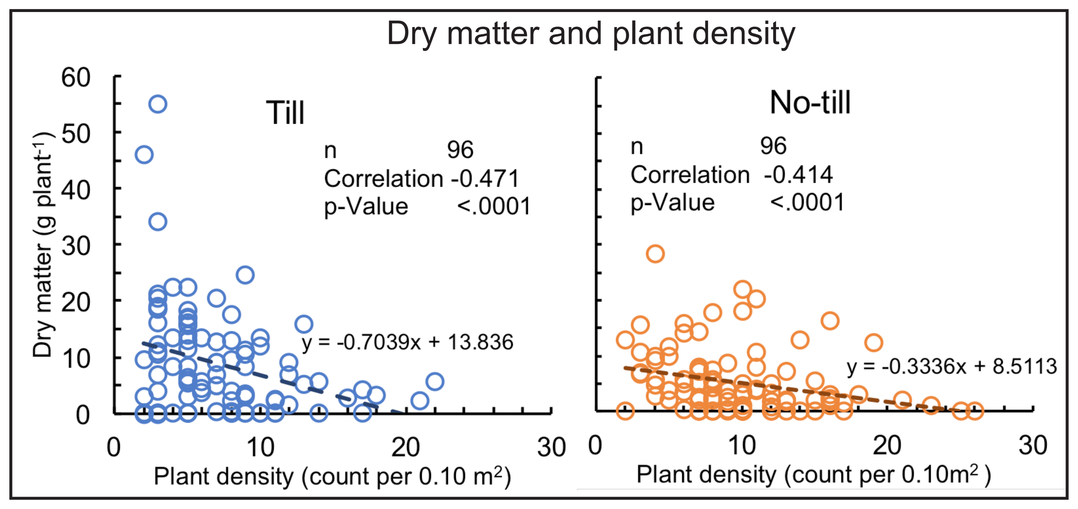

Figure 8. Crop community dynamics in pearl millet are represented by correlation and regression of DM production and plant density for till and no-till treatments in 2017.

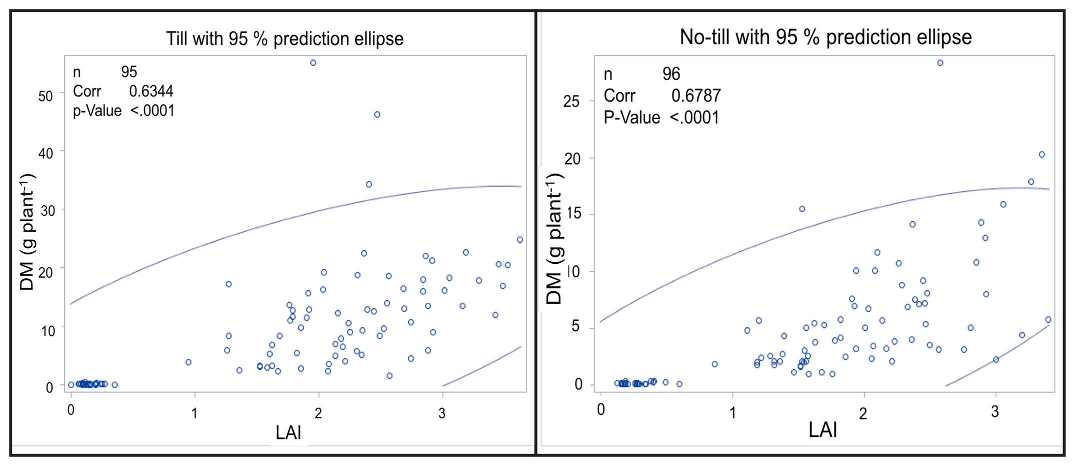

Figure 9. Photosynthetic assimilate production is illustrated in the relationships between crop canopy leaf area index (LAI) development and pearl millet DM per plant as measure throughout the growing season in 2017.

Results

Weather

- Growing season precipitation in 2017 was 137%, of normal whereas 2016 was only 79% (Table 1).

Irrigation and Row Spacing Effect

- Row spacing did not influence pearl millet DM yield in 2016 or 2017.
- Irrigation caused more pearl millet DM production. At harvest, DM was 2213, 1704, and 1,219 kg ha^{-1} ($p<0.001$) for high (H), moderate (M), and limited (L) irrigation, respectively, in 2016; and 3450, 2615, 2213 kg ha^{-1} ($p<0.01$) for H, M, and L, respectively, in 2017 (Table 2).

Water use and water use efficiency

- Irrigation level determined total water use (WU) ($p<0.001$, in 2016 and 2017; Table 2).
- Pearl millet forage water use efficiency (WUE = DM ÷ WU) was not improved from change in row spacing or irrigation (Table 2).
- WUE was influenced by tillage level. No-till was consistently lower ($p<0.001$); 60% in 2016 and 72% in 2017 (Table 2).

Pearl millet dry matter production function

- Linear regression of pearl millet forage DM and WU for 2016 and 2017 generated low r^2 values, 0.21 and 0.17, respectively, due to the highly variable (CV = 44) DM production. Calculated production functions are presented from the origin (B.A. Stewart, personal communication, 2017): y = 4.61 x (mm), and y = 5.73 x (mm) for 2016 and 2017, respectively (Fig. 5).
- WUE and DM production relationships at each irrigation level demonstrate that greater DM production is dependent on increased water level (Fig. 6).

Tillage Effect

- Pearl millet population was influenced by tillage in both years (data not shown). In 2016, no-till was 37% of the till population ($p<0.01$); 2017 till population was 35% of no-till. No-till planting in 2016 was into herbicide killed native perennial grass. In 2017 a heavy rain caused significant runoff in till treatment following sowing; 2017 was planted into wheat stubble.
- N deficiency was observed in no-till treatment during 2017 (Fig.4). Reduced tillage affects plant available N supply due to changes in N cycling and losses through microbial and residue interactions (Malhi et al. 2001).
- In 2016, no-till and till produced 2141 and 1283 kg ha^{-1} DM ($p<.0001$), and 3218 and 2301 kg ha^{-1} ($p<0.01$) in 2017 for till and no-till, respectively (Table 2).
- Pearl millet crop growth was influenced by tillage and time ($p<0.01$). Avg. max DM was 15.86 and 8.3 g $plant^{-1}$ and growth rate was 0.03 and 0.01 g GDD, in till and no-till, respectively (Fig. 7).
- Crop community dynamics (Fig. 8) in pearl millet DM production and plant density for till and no-till treatments in 2017 are correlated (r = -0.471, -0.414).
- Correlation (r = 0.6344 and 0.6787) between leaf area index (LAI) and pearl millet DM per plant explain photosynthetic assimilate production in till and no-till (Fig. 9).

Conclusion

- No-till had poor establishment in native perennial grass. However, pearl millet no-till in wheat residue prevented washout observed in till treatment following heavy rain 2 d after planting.
- Dry matter was observed to be influenced by irrigation and tillage effects more than row spcing.
- Water use efficiency was lower than expected; forage sorghum has reached 31 kg ha^{-1} mm^{-1} WUE (Unger, 2001).

Acknowledgements

Special thanks to WTAMU Dryland Ag Institute and B.A. Stewart for financial support.

References

- Malhi, S.S. et al. (2001). Nitrogen fertilization management for no-till cereal production in the Canadian Great Plains: a review. Soil and Tillage Research, 60, 101 – 122.
- Muchow, R. (1989). Comparative Productivty of Maize, Sorghum, and Pearl Millet in a Semi-Arid Tropical Envi. II: Effect of Water Deficits. Field Crops Research, 20, 207-219.
- Neilsen, D. et al. (2006). Forage Response to Water Use for Dryland Corn, Millet, and Triticale in the Central Great Plains. Agron. J., 98 , 992-998.
- Nielsen, D. et al. (2011). Evaluating Decision Rules for Dryland Rotation Crop Selection. Field Crops Research, 120, 254-261.
- Nielsen, D. et al. (2016). Evaluating Potential Dryland Cropping Systems Adapted to Climate Change in the Central Great Plains. Agron. J., 108:2391-2405.
- Payne, W. (2000). Optimizing Crop Water Use in Sparse Stands of Pearl Millet. Agron. J., 92, 808-814.
- Unger, P. (2001). Alternative and Opportunity Crops and Related Soil Conditions in the Southern Great Plains. Agronomy Journal, 93, 216-226.