Forage Yield Response to Water Use for Dryland Corn, Millet, and Triticale in the Central Great Plains

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ABSTRACT

Forages, with greater water use efficiency (WUE) than grain and seed crops, could be used to diversify reduced and no-till dryland cropping systems from the traditional wheat (*Triticum aestivum* L.)–fallow system in the semiarid central Great Plains. However, farmers need a simple tool to evaluate forage productivity under widely varying precipitation conditions. The objectives of this study were to (i) quantify the relationship between crop water use and dry matter (DM) yield for corn (*Zea mays* L.), foxtail millet (*Setaria italica* L. Beauv.), and winter triticale (*X Triticosecale* Wittmack); and (ii) determine the range and distribution of expected DM yields for these three crops in the central Great Plains based on historical precipitation records. The three crops were grown in a dryland no-till corn–millet–triticale sequence from 1998 through 2004 at Akron, CO. Dry matter production was linearly correlated with water use for all three crops, with regression slopes ranging from 24.2 (corn) to 33.0 kg ha^{-1} mm^{-1} (millet). Water use efficiency varied widely from year to year (0–32.2 kg ha^{-1} mm^{-1}) for the three crops, as influenced by growing season precipitation and time of year in which the crops were grown. Millet and triticale produced similar amounts of DM for a given water use, while corn produced less. Precipitation use efficiency for the millet–triticale–corn forage system was 8.7 kg ha^{-1} mm^{-1}, suggesting this as an efficient forage system for the region.

PROFITABLE agricultural operations in the semiarid central Great Plains must make efficient use of limited and highly variable precipitation. Additionally, cropping systems should be diversified, employing crop rotation systems that minimize disease, weed, and insect problems associated with monoculture. Further, those systems need to ensure that sufficient crop residues remain after harvest to protect the soil surface from wind erosion and to maximize precipitation storage efficiency during the noncrop periods. A recent review of cropping systems across the Great Plains region of North America (Nielsen et al., 2005a) indicated that systems using forages generally had greater WUE and precipitation use efficiencies (based on both mass produced per unit of precipitation received and gross value of product per unit of precipitation received) than systems that did not include forages. Three crops that may have potential to be grown for forage in dryland cropping systems in the central Great Plains region are corn, foxtail millet, and winter triticale.

Corn is often grown for silage under rainfed conditions in the Corn Belt and under irrigation in the semiarid Great Plains, but a defined DM response to water use in dryland production systems has not been reported. Many dryland farmers in the central Great Plains are reluctant to plant corn because of the high input costs and the highly variable nature of corn grain yield associated with variable precipitation during critical reproductive and grain filling growth stages (Nielsen et al., 1996, 2005b). Because corn DM production is not as highly influenced by reproductive stage precipitation as grain production, farmers may discern less risk and be more inclined to include corn for silage in their cropping systems. Haynes (1948) reported that vegetative growth of individual corn plants grown in a greenhouse study was reduced as water supply to the growing plants was restricted, but a water use/DM production function was not defined. Olson (1971) did report dryland corn DM and water use values for eastern South Dakota, but did not note a DM response to water use. The average DM production reported in that study was 8457 kg ha^{-1} for 313 mm of water use. Hattendorf et al. (1988) found irrigated corn in eastern and western Kansas produced an average of 20 075 kg ha^{-1} DM for 565 mm of water use, but no production function was reported and the water use values extended only over a very narrow range (561–584 mm). d'Andria et al. (1997) reported corn DM and water use values from southern Italy over a water range of 163 to 632 mm from which we constructed the following water use/DM production function:

$$DM = 23.0 \times (ET + 199),\ r^2 = 0.69$$

where DM is dry matter (kg ha^{-1}) and ET is evapotranspiration (mm). The large positive offset may be the result of lower calculated ET for each DM point, as they ignored all precipitation events <10 mm over a 24-h period.

We determined another production function for corn DM from combined data reported by Kasele et al. (1994) from dryland and limited irrigated corn in eastern Colorado (239 mm < ET < 294 mm) and by Howell et al. (1995) from variably irrigated corn in the Texas Panhandle (383 mm < ET < 973 mm):

$$DM = 26.2 \times (ET - 41),\ r^2 = 0.96$$

Nielsen (2004) reported an unpublished DM production function for dryland corn grown in northeastern Colorado under a variety of cropping systems from 1992 to 1997 of

$$DM = 22.4 \times (ET - 129)$$

over an ET range of 250 to 450 mm.

Foxtail millet is one of the earth's oldest cultivated crops, being grown primarily for forage in the USA

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Abbreviations: DM, dry matter; ET, evapotranspiration; GSP, growing season precipitation; WUE, water use efficiency.

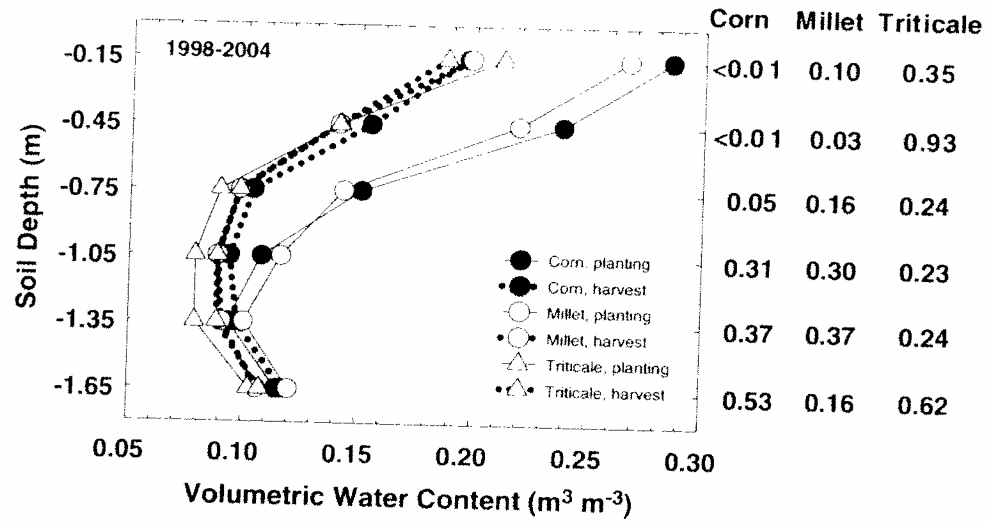

Fig. 6. Volumetric water content at planting and harvest for corn, foxtail millet, and winter triticale grown for forage at Akron, CO, 1998 to 2004. Values on right side of figure are probability (*p*) that the null hypothesis of no difference between planting and harvest volumetric water contents is true.

From the average soil water content data shown in Fig. 6, we determined average seasonal soil water use of 70 mm for corn, 66 mm for millet, and 8 mm for winter triticale. These soil water use amounts were added to the growing season precipitation record from 1965 to 2004 at Akron, CO to provide a range and distribution of water use values to use with the production functions shown in Fig. 5. The period of precipitation was 14 May to 26 August for corn, 25 June to 26 August for millet, and 24 September to June 17 for winter triticale. The calculated water use values for millet and winter triticale all fall within the range of values used to establish the production functions, except for the upper 5% of the millet values and the upper 8% of the winter triticale values. There were quite a few years in the historical precipitation record that were wetter during the corn growing season than during the data collection years of this study, such that 23% of the calculated water use values were beyond the range of the data used to establish the production function for corn. Therefore, the estimated DM histograms (Fig. 7) result from some extrapolation of the production functions beyond the water-use values used to generate them.

Estimated corn DM production ranged from 1052 to 9270 kg ha^{-1} (mean 3820 kg ha^{-1}). Dry matter production of 2000 to 4000 kg ha^{-1} would occur 43% of the time (Fig. 7). Estimated millet DM production ranged from 422 to 6465 kg ha^{-1} (mean 3283 kg ha^{-1}). Dry matter production was also most frequently estimated to occur in the 2000 to 4000 kg ha^{-1} range (53% of the time). Winter triticale DM production was estimated to occur over a broader range (527–12 623 kg ha^{-1}), and averaged greater than corn and millet (mean 5367 kg ha^{-1}). Winter triticale DM production was most frequently estimated to occur in the 4000 to 6000 kg ha^{-1} range (39% of the time). Dry matter production of at least 4000 kg ha^{-1} would be expected to occur in 45, 30, and 75% of years for corn, millet, and winter triticale, respectively. Based on this analysis, there may be less downside risk in producing a profitable forage crop with winter triticale than with corn or millet.

Precipitation use efficiency for this all-forage cropping system can be calculated by taking the total production of DM by the three crop species (23 334 kg ha^{-1}) over the 7 yr of the study and dividing by the total precipitation that fell over that period (2696 mm). Doing so gives a precipitation use efficiency of 8.7 kg ha^{-1} mm^{-1}. This value is lower than precipitation use efficiency values calculated by Nielsen et al. (2005a) for data from Unger (2001) for continuous forage triticale and continuous forage wheat (about 14 kg ha^{-1} mm^{-1}) in northern Texas. This is most likely due to the corn and millet crop failures during the 2002 drought and the frequently lower WUE of corn comprising 33% of our cropping system area each year. Our precipitation use efficiency of 8.7 kg ha^{-1} mm^{-1} was greater than precipitation use efficiency for grain-based systems at this location, which ranged from 2.8 to 5.9 kg ha^{-1} mm^{-1} (Nielsen et al., 2005a) because of the lower photosynthetic energy requirements of forage production vs. grain production (Penning de Vries, 1975).

CONCLUSIONS

Corn, foxtail millet, and winter triticale DM increased linearly with water use, responding similarly to increases in water use. Because of a larger water use offset for the corn water- use/DM production function compared with millet and winter triticale production functions, corn produced less DM for a given water use than millet and winter triticale. Using the production functions determined in this study with historical precipitation records gave estimated average corn, millet, and winter triticale DM yields of 3820, 3283, and 5367 kg ha^{-1}, respectively. Winter triticale has a greater probability of achieving a DM yield of at least 4000 kg ha^{-1} than either corn or millet. Precipitation use efficiency of this corn–millet–winter triticale dryland forage system was greater than

Table 1. Planting, harvesting, and fertilizing details for corn–millet–winter triticale forage system, Akron, CO, 1998 to 2004.

Crop	Variety	Planting date	Harvest date	Seeding rate	Fertilizer kg N ha^{-1}	Fertilizer kg P ha^{-1}
1998						
Corn	DK 493BT	12 May 1998	3 Sept. 1998	39780 seeds ha^{-1}	67	7
Millet	Manta	6 July 1998	24 Aug. 1998	11 kg ha^{-1}	45	7
Triticale	Jenkins	10 Sept. 1997	26 May 1998	56 kg ha^{-1}	56	15
1999						
Corn	DK 493BT	7 May 1999	25 Aug. 1999	39780 seeds ha^{-1}	34	7
Millet	Golden German	18 June 1999	26 Aug. 1999	11 kg ha^{-1}	45	7
Triticale	Jenkins	15 Sept. 1998	21 July 1999	67 kg ha^{-1}	56	7
2000						
Corn	DKC49–92	10 May 2000	21 Aug. 2000	39780 seeds ha^{-1}	84	7
Millet	Golden German	6 June 2000	14 Aug. 2000	11 kg ha^{-1}	45	7
Triticale	Jenkins	13 Sept. 1999	7 June 2000	67 kg ha^{-1}	56	7
2001						
Corn	NK4242BT	16 May 2001	28 Aug. 2001	41020 seeds ha^{-1}	90	9
Millet	Golden German	25 June 2001	29 Aug. 2001	11 kg ha^{-1}	67	7
Triticale	Jenkins	20 Oct. 2000	8 June 2001	67 kg ha^{-1}	67	9
2002						
Corn	NK4242BT	15 May 2002	No harvest	41020 seeds ha^{-1}	67	9
Millet	Golden German	18 June 2002	No harvest	13 kg ha^{-1}	45	9
Triticale	Trical 102	19 Oct. 2001	24 June 2002	67 kg ha^{-1}	67	9
2003						
Corn	NK4242 BT	21 May 2003	28 Aug. 2003	34590 seeds ha^{-1}	67	9
Millet	Golden German	23 June 2003	27 Aug. 2003	13 kg ha^{-1}	56	9
Triticale	Trical 2700	24 Sept. 2002	12 June 2003	67 kg ha^{-1}	67	9
2004						
Corn	NK42B7	3 June 2004	14 Sept. 2004	29650 seeds ha^{-1}	67	9
Millet	Golden German	25 June 2004	1 Sept. 2004	13 kg ha^{-1}	50	7
Triticale	Trical 2700	29 Sept. 2003	28 June 2004	67 kg ha^{-1}	56	9

The specific values of lower limits used are given in Table 2. Daily precipitation was recorded as the average of measurements made at two diagonally opposite corners of the 7.8-ha plot area.

Dry matter, water use, and WUE were evaluated for crop species differences by analysis of variance, with years considered as a random variable (Gomez and Gomez, 1984). The relationships between crop water use and DM yield were analyzed by linear regression. Statistical analysis was performed using Statistix 8 software (Analytical Software, 2003). Both linear and quadratic regression models were tested. Linear regression slopes and intercepts were compared for significant differences using the Statistix 8 Comparison of Regression Lines procedure.

RESULTS AND DISCUSSION

Precipitation was highly variable from year to year, and from growing season to growing season within a year for the three crops (Table 3), resulting in a significant year by crop interaction effect for water use ($p < 0.01$), DM ($p < 0.01$), and WUE ($p < 0.01$). Consequently, the data are presented and discussed by year.

Corn water use ranged from 146 (2002) to 316 mm (2001), averaging 256 mm (SE = 25 mm) (Fig. 1). Millet water use ranged from 70 (2002) to 266 mm (2003), averaging 186 mm (SE = 28 mm). Winter triticale water use ranged from 86 (2000) to 330 mm (2003), averaging 205 mm (SE = 36 mm). Differences in water use between crops were significant in 6 of 7 yr ($p < 0.05$), with corn having the greatest water use in 5 of those 6 yr.

Table 2. Lower limits of volumetric soil water used to calculate available soil water for foxtail millet, winter triticale, and corn on a Weld silt loam, Akron, CO.

Soil depth	Foxtail millet	Winter triticale	Corn
m		m^3 m^{-3}	
0.0–0.3	0.100	0.090	0.110
0.3–0.6	0.129	0.120	0.135
0.6–0.9	0.087	0.072	0.087
0.9–1.2	0.067	0.061	0.074
1.2–1.5	0.086	0.082	0.079
1.5–1.8	0.119	0.111	0.101

Corn DM ranged from 0 (2002) to 6132 kg ha^{-1} (2001), averaging 2930 kg ha^{-1} (SE = 767 kg ha^{-1}) (Fig. 2). Millet DM ranged from 0 (2002) to 5638 kg ha^{-1} (2003), averaging 3155 kg ha^{-1} (SE = 844 kg ha^{-1}). This was 28% lower than the 3-yr average foxtail millet DM of 4382 kg ha^{-1} reported by Weichenthal et al. (1998) for the Nebraska panhandle, but only 9% lower than the 3-yr average of 3479 kg ha^{-1} reported by Peterson et al. (2001) for an opportunity cropping system in northeastern Colorado. Persistent dry conditions in 2002 resulted in withering and failure to produce any harvestable corn or millet forage. Winter triticale DM ranged from 731 (2000) to 10 632 kg ha^{-1} (2003), averaging 3916 kg ha^{-1} (SE = 1322 kg ha^{-1}). This value is nearly the same as the 3-yr average triticale DM yield of 3913 kg ha^{-1} reported by Peterson et al. (2001) measured in a triticale–corn–forage soybean rotation in northeast Colorado. Dry weight of all three crops in the current study was greatly affected by growing season precipitation. For example, the maximum winter triticale DM was observed in 2003 when growing season precipitation was 143% of normal. At the other extreme, no corn DM was harvested in 2002 when growing season precipitation was only 56% of normal. The average DM was not significantly different ($p < 0.05$) in 4 of 7 yr among the three crops.

Corn WUE ranged from 0.0 to 19.4 kg ha^{-1} mm^{-1}, averaging 10.5 kg ha^{-1} mm^{-1} (SE = 2.5 kg ha^{-1} mm^{-1}) (Fig. 3). This is approximately the same as the 9.3 kg ha^{-1} mm^{-1} of rainfed corn in northern Texas reported by Howell et al. (1995). Millet WUE ranged from 0.0 to 22.0 kg ha^{-1} mm^{-1}, averaging 14.3 kg ha^{-1} mm^{-1} (SE =