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Forage soybean yield and quality response to water use

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ABSTRACT

Forages 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. Forages present an attractive alternative to grain and seed crops because of greater water use efficiency and less susceptibility to potentially devastating yield reductions due to severe water stress during critical growth stages. However, farmers need a simple tool to evaluate forage productivity under widely varying precipitation conditions. The objectives of this study were to (1) quantify the relationship between crop water use and dry matter (DM) yield for soybean (*Glycine max* L. Merrill), (2) evaluate changes in forage quality that occur as harvest date is delayed, and (3) determine the range and distribution of expected DM yields in the central Great Plains based on historical precipitation records. Forage soybean was grown under a line-source gradient irrigation system to impose a range of water availability conditions at Akron, CO. Dry matter production was linearly correlated with water use resulting in a production function slope of 21.2 kg ha^{-1} mm^{-1}. The slope was much lower than previously reported for forage production functions for triticale (*X Triticosecale* Wittmack) and millet (*Setaria italic* L. Beauv.), and only slightly lower than slopes previously reported for corn (*Zea mays* L.) and pea (*Pisum sativa* L.) forage. Forage quality was relatively stable during the last four weeks of growth, with small declines in crude protein (CP) concentration. Values of CP concentration and relative feed value indicated that forage soybean was of sufficient quality to be used for dairy feed. A standard seed variety of maturity group VII was found to be similar (in both productivity and quality) to a variety designated as a forage type. The probability of obtaining a break-even yield of at least 4256 kg ha^{-1} was 90% as determined from long-term precipitation records used with the production function. The average estimated DM yield was 5890 kg ha^{-1} and ranged from 2437 to 9432 kg ha^{-1}. Regional estimates of mean forage soybean DM yield ranged from 4770 kg ha^{-1} at Fort Morgan, CO to 6911 kg ha^{-1} at Colby, KS. Forage soybean should be considered a viable alternative crop for dryland cropping systems in the central Great Plains.

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1. Introduction

Diversifying the traditional dryland winter wheat-fallow cropping system employed in the central Great Plains of the US requires information on the production potential of alternative crops that could be grown in this region. Because of the highly variable and frequently limited nature of precipitation in this region, forage production presents an attractive alternative to grain crop production. Forage production is not as highly influenced by precipitation during critical reproductive and grain-filling periods as is grain production (Nielsen et al., 1996, 2008, 2010a). Consequently, farmers may discern less risk and be more inclined to include a forage crop in their cropping systems. A recent review of cropping systems across the Great Plains region of North America (Nielsen et al., 2005) indicated that systems utilizing forages generally had greater 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. A crop that may have potential to be grown for forage in dryland cropping systems in the central Great Plains region is soybean.

The primary use of soybean following its introduction into the US in the mid 1800s was as a forage crop (Probst and Judd, 1973). Soybean acreage for grain in the US first exceeded acreage for forage in 1941 because of growing demand for soybean oil and meal. In recent years there has been renewed interest in soybean forage production as new varieties have been bred specifically for this purpose (Devine and Hatley, 1998; Devine et al., 1998; Devine and McMurtrey, 2004).

A few studies have been reported that provide information on yield and quality of forage soybean, with yields varying widely from 1170 kg ha^{-1} in Oklahoma (MacKown et al., 2007) to 11,700 kg ha^{-1} in Iowa (Darmosarkoro et al., 2001) primarily due to varying water availability from location to location and from year to year. Wiederholt and Albrecht (2003) reported forage soybean quality

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Table 2
Soybean variety, harvest date and growth stage, water use, dry matter yield, and water use efficiency (WUE) for four water availability treatments (irrigation gradient positions) over three years at Akron, CO. Values in parentheses are one standard deviation of the mean.

Year	Variety	Harvest date	Harvest growth stage	Harvest DAP	Irrigation gradient position	Irrigation amount (mm)	Water use (mm)	Yield (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})
2001	Donegal (MGV)	26 September	R6	117	1	0	362 (14)	6274 (364)	17.3 (0.9)
		27 September	R6	118	2	97	461 (26)	7992 (1093)	17.3 (2.3)
		27 September	R6	118	3	161	514 (26)	8156 (741)	15.9 (1.5)
		2 October	R6	123	4	253	614 (26)	10,139 (88)	16.5 (0.4)
2004	Donegal (MGV)	30 September	Early R6	125	1	0	283 (17)	2720 (458)	9.7 (1.9)
		30 September	Early R6	125	2	33	352 (35)	4547 (282)	13.1 (2.0)
		30 September	Early R6	125	3	76	373 (9)	5324 (2087)	14.3 (5.8)
		30 September	Early R6	125	4	120	414 (30)	8714 (793)	21.1 (2.2)
2004	Dekalb H7242RR (MG VII)	30 September	R1	118	1	0	255 (52)	3935 (1205)	15.2 (2.3)
		30 September	R1	118	2	33	263 (54)	4885 (1884)	18.0 (3.7)
		30 September	R1	118	3	76	358 (20)	6804 (939)	19.1 (2.9)
		30 September	R1	118	4	120	378 (22)	6376 (1556)	16.8 (3.3)
2008	97NYCZ33 (MG III)	13 August	R1	82	1	0	208 (33)	2630 (269)	12.9 (2.3)
		13 August	R1	82	2	55	266 (25)	3265 (525)	12.4 (2.5)
		13 August	R1	82	3	140	324 (22)	3960 (336)	12.3 (1.4)
		13 August	R1	82	4	212	352 (48)	4760 (1071)	13.9 (4.3)
		27 August	R3	96	1	0	284 (43)	4957 (586)	17.7 (3.0)
		27 August	R3	96	2	55	336 (41)	4852 (446)	14.7 (3.1)
		27 August	R3	96	3	140	392 (16)	6924 (976)	17.7 (3.1)
		27 August	R3	96	4	212	420 (83)	7507 (674)	18.5 (4.5)
		3 September	R4	103	1	0	325 (34)	6543 (464)	20.4 (3.4)
		3 September	R4	103	2	55	382 (31)	6635 (1202)	17.6 (4.2)
		3 September	R4	103	3	140	444 (18)	8688 (1678)	19.5 (3.0)
		3 September	R4	103	4	212	473 (68)	8740 (1409)	18.8 (4.7)
		10 September	R5	110	1	0	351 (33)	8412 (2012)	24.4 (7.2)
		10 September	R5	110	2	75	416 (31)	6497 (487)	15.7 (1.6)
		10 September	R5	110	3	161	471 (20)	8649 (970)	18.3 (1.7)
		10 September	R5	110	4	244	496 (64)	8609 (401)	17.5 (2.0)
		17 September	R6	117	1	0	375 (31)	7967 (920)	21.4 (3.1)
		17 September	R6	117	2	75	449 (28)	8668 (945)	19.4 (2.1)
		17 September	R6	117	3	161	505 (25)	10,498 (1371)	20.8 (2.4)
		17 September	R6	117	4	244	532 (67)	9953 (1072)	18.7 (0.6)
		30 September	R7	130	1	0	413 (30)	6464 (795)	15.8 (2.8)
		30 September	R7	130	2	75	494 (25)	7212 (1089)	14.7 (2.5)
		30 September	R7	130	3	161	567 (36)	8080 (1030)	14.2 (1.0)
		30 September	R7	130	4	244	603 (48)	8646 (1289)	14.5 (3.1)

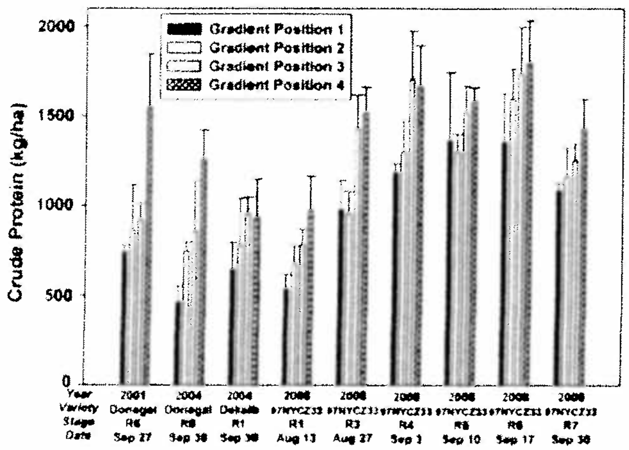

Fig. 3. Crude protein mass of forage soybean at Akron, CO. Error bar indicates one standard deviation above the mean.

Crude protein concentration was higher at all six sampling dates for the '97NYCZ33-1' crop grown in 2008 compared with the crops grown in 2001 and 2004. There was a gradual decline in CP with later sampling dates (declining from about 20.4 to 16.3%) and no consistent effect of water treatment on CP.

Actual CP mass ranged from 463 kg ha^{-1} for the 2004 'Donegal' crop under dryland conditions (Gradient Position 1) to 1792 kg ha^{-1} for the 2008 '97NYCZ33-1' crop grown at Gradient Position 4 and harvested at R6 on 17 September (Fig. 3). Crude protein mass tended to increase with increasing irrigation, primarily due to increasing DM accumulation. The data collected in 2008 indicated harvesting at R6 would maximize CP mass.

Acid detergent fiber (Fig. 4) was highest (30.1–32.9%) for the 2001 'Donegal' crop and showed a tendency to increase with increasing irrigation. That tendency for increased ADF with increasing irrigation was seen in 2004 and 2008 as well. Acid detergent fiber was lower in 2004 than in 2001 and was not different between 'Donegal' and 'Dekalb' (mean values of 25.2 and 24.2, respectively) even though the two varieties were at very different growth stages. Acid detergent fiber for the 2008 '97NYCZ33-1' crop increased with plant development up to growth stage R4 and then remained fairly constant (26–27% for the Gradient 1 treatment and 30–32% for the Gradient 4 treatment) through stage R7.

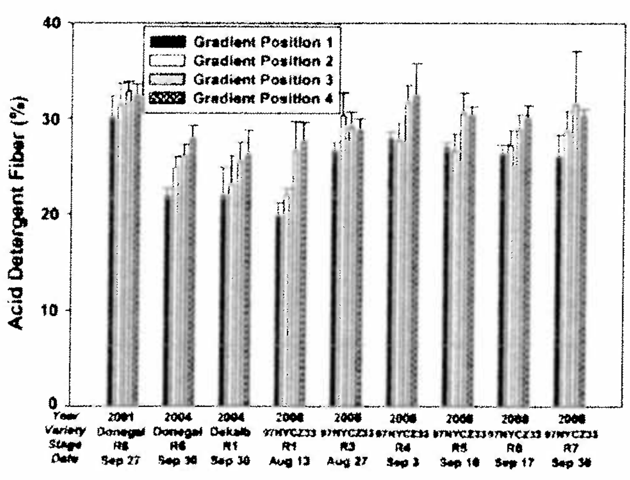

Fig. 4. Acid detergent fiber concentration of forage soybean at Akron, CO (expressed on a 100% dry matter basis). Error bar indicates one standard deviation above the mean.

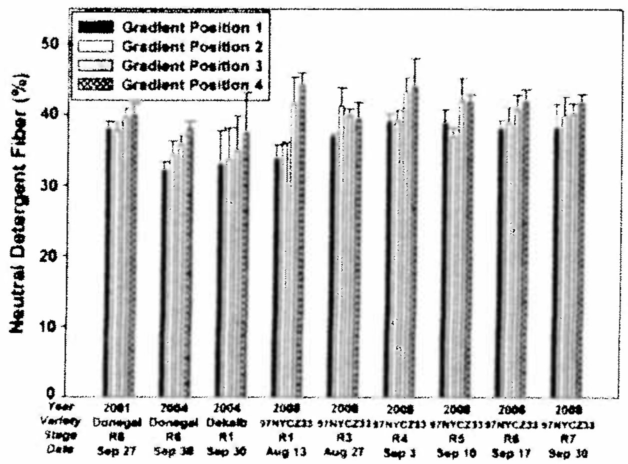

Fig. 5. Neutral detergent fiber concentration of forage soybean at Akron, CO (expressed on a 100% dry matter basis). Error bar indicates one standard deviation above the mean.

Neutral detergent fiber (Fig. 5) exhibited the same tendency as ADF to increase with increasing irrigation. As with ADF, NDF was not different between the 2004 'Donegal' and 'Dekalb' crops, but both 2004 crops exhibited somewhat lower NDF than the 2001 'Donegal' crop. Changes in NDF with growth stage in 2008 where not consistent across irrigation treatments. At the Gradient 1 position (rainfed) NDF increased up to R4 and then remained nearly constant at about 38–39%. At the other higher levels of water availability there was no clear change in NDF.

Relative feed value (Fig. 6) varied somewhat from year to year with mean values falling in the range of 136–208. Increasing water availability generally resulted in trends for lower RFV. There was no difference in RFV between the two varieties tested in 2004 and no consistent change in RFV with harvest date in 2008.

4. Discussion

4.1. Water use/yield production function

The production function regression slope of 21.2 kg ha^{-1} mm^{-1} was much greater than the 9.5 kg ha^{-1} mm^{-1} defined earlier from the three data points reported by Rao and Northup (2008) in Okla-

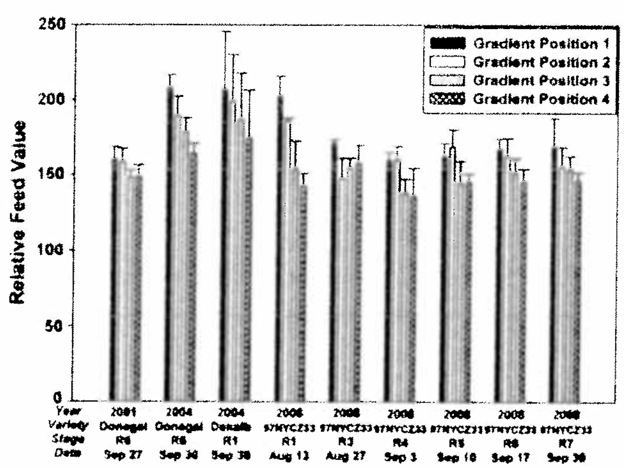

Fig. 6. Relative feed value index for forage soybean at Akron, CO. Error bar indicates one standard deviation above the mean.

4.3. Forage quality

With the exception of the 'Donegal' 2001 data, most of the CP values recorded in the current study were in the same range or slightly higher than the values Seiter et al. (2004) reported (13.9–17.9%) for forage soybean grown in New Hampshire. They also found that CP increased with growth stage from R3 to R5.5, which was not a result of the current study. Sheaffer et al. (2001) found CP ranging from 12.5 to 16.2% for three forage soybean varieties grown in Minnesota. These CP concentrations were lower than the 19.0–21.8% CP found for the standard grain variety grown in their study. They suggested that forage soybean varieties needed to be used that would reach R6 by harvest such that CP levels would be high following the formation of seed (Hintz et al., 1992). Our 2004 results did not confirm this recommendation, as both the 'Donegal' harvested at R6 and the 'Dekalb' harvested at R1 had similar CP concentrations.

The ADF values found in this study were considerably lower than the 40–42% value reported by Sheaffer et al. (2001) for forage soybean varieties grown in Wisconsin. The values of ADF reported by Seiter et al. (2004) ranged from 30.2 to 37.8% for forage soybean at R5.5. They also reported ADF to consistently increase from about 30% to about 37% as growth stage increased from R3 to R5.5.

At the most likely harvest stage of R6, NDF ranged from 38 to 42%, considerably lower than the ~50% value reported by Sheaffer et al. (2001) for forage soybean varieties grown in Wisconsin, and also lower than most of the values reported by Seiter et al. (2004) which ranged from 42 to 49% at R5.5. Seiter et al. (2004) also reported NDF to consistently increase from about 40% to about 49% as growth stage increased from R3 to R5.5. The current study did not find consistent changes in NDF with growth stage.

Heitholt et al. (2004) found that a forage soybean variety grown in Dallas, TX had RFV ranging from 120 to 163 over two years. They reported that RFV changed more between years than it did with growth stage within a given year, similar to what was found in the current study, where RFV averaged over water treatments ranged from 154 in 2001 to 192 in 2004 and the range of RFV due growth stage in 2008 was from 149 at R4 to 171 at R1. Wiederholt and Albrecht (2003) stated that soybean forage quality was similar to alfalfa forage with RFV of 150. Relative feed value in the current study was mostly greater than reported by both Heitholt et al. (2004) and Wiederholt and Albrecht (2003).

Heitholt et al. (2004) suggested that suitable hay quality for lactating dairy cattle would have CP greater than 14% and RFV greater than 150. By this standard the soybean forage produced in 2001 would not be acceptable because CP was too low, but all other forage samples collected in this study would have acceptable levels of CP and RFV very near to or exceeding 150. Both varieties grown in 2004 exceeded the RFV = 150 threshold for acceptable forage quality. Additionally, total digestible nutrients (TDN) for the forage soybean grown in this study ranged from 64.8% to 77.5% (data not shown), greater than the 60% TDN requirement noted by Poore (2011) for lactating cows.

4.4. DM production estimates

The production function defined in this study can be used with the historical precipitation record to estimate the distribution of expected DM production if used with some estimate of soil water use by forage soybean. Volumetric water content profiles (Fig. 7) taken at planting and harvest indicated significant extraction of soil water in the 0–135 cm soil layer in most years and water availability conditions. More soil water was extracted in 2001 (161 mm averaged over all four water treatments) than in 2004 (101 mm averaged over water treatments and varieties) and 2008 (137 mm averaged over water treatments). The average soil water extraction over all water treatments, varieties, and years was 125 mm.

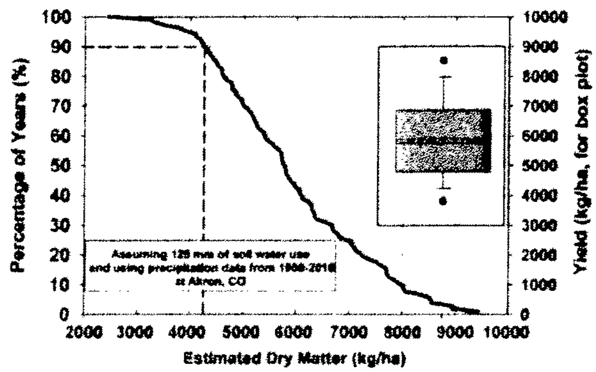

Fig. 8. Probability distribution of predicted forage soybean dry matter yields based on 103 years of precipitation data at Akron, CO. Inset box plot indicates the mean (interior dashed line), median (interior solid line), 5% (lower dot), 10% (lower whisker), 25% (bottom of box), 75% (top of box), 90% (upper whisker), and 95% (upper dot) yields.

This estimate of soil water use was added to the growing season (28 May to 23 September) precipitation record from 1908 to 2010 at Akron, CO to provide a range and distribution of water use values to use with the production function shown in Fig. 1. The 103 calculated water use values ranged from 187 to 516 mm and all but one of the values fell within the range of values used to establish the production function.

Estimated soybean DM production ranged from 2437 to 9432 kg ha^{-1} (mean 5890 kg ha^{-1} see Fig. 8, inset). The 4-year average forage soybean yield reported by Rao and Northup (2009) in Oklahoma was 5579 kg ha^{-1} (range 2746–10,011 kg ha^{-1}) with an average growing season precipitation of 324 mm (100 mm more than the 103-year average precipitation at Akron), but grown immediately following a winter wheat crop in a double cropping situation. Fifty percent of the estimated DM values fell between 4800 (25th percentile) and 6850 kg ha^{-1} (75th percentile). Dry matter production of at least 4256 kg ha^{-1} (the forage yield threshold identified by Nielsen et al., 2010b as a break-even yield for forages) would be expected to occur 90% of the time (Fig. 8).

The slope and intercept of the relationship between water use and yield (Fig. 1) may shift somewhat with changes in latitude and longitude due primarily to changes in vapor pressure deficit, temperature, and evaporation (Tanner and Sinclair, 1983). As such, the production function defined in the current study should be validated at other locations. Nevertheless, the climate of the west-central Great Plains is sufficiently uniform that the production function can probably be applied to get an initial idea regarding the productivity potential of forage soybean in other areas of a limited region varying primarily in precipitation due to the rain shadow effect of the Rocky Mountains. Annual precipitation here increases from west to east at a rate of about 63 mm every 100 km (Martin, 2007), with the gradient increasing as distance to the mountains on the west side of the region decreases. We applied the production function to seven additional locations within 220 km of Akron by using the long-term average precipitation for June, July, August, and September along with the measured mean soil water extraction of 125 mm to generate expected mean forage soybean DM yields for the region (Fig. 9). Predicted mean yield ranged from 4770 kg ha^{-1} at Fort Morgan, CO to 6911 kg ha^{-1} at Colby, KS. The mean yields at all of the locations were greater than the 4256 kg ha^{-1} break-even yield for forages specified by Nielsen et al. (2010b).

Nielsen and Vigil (2010) measured a 10-year average soil water increase at Akron, CO of 38 mm over the period of 1 October to 30