Water Use Efficiency of Forage Sorghum Grown with Sub-optimal Irrigation, 2009

Michael J. Ottman

Summary

A forage sorghum irrigation study was conducted at Maricopa, AZ to determine water use and if sub-optimal irrigation increases water use efficiency and profitability. Sorghum was planted on July 10 with a row spacing of 40 inches and irrigated three times with a total of 8.7 inches of water to establish the crop. Variable amounts of irrigation water were applied commencing on Aug 12 based on 25, 50, 75, and 100% of estimated crop water use (evapotranspiration, ET). The plots were 53.3 ft wide (16 rows) and 40 ft long. ET was estimated from soil water measurements using a neutron probe. The total amount of water applied was 15.5, 19.8, 23.7, and 27.8 inches for the 25, 50, 75, and 100% ET treatments, respectively. The forage was harvested on Oct 28 near the soft dough stage. Forage yields adjusted to 70% moisture were 11.3, 16.4, 21.5, and 23.1 tons/acre for the 25, 50, 75, and 100% ET treatments, respectively. Yield produced per inch of water used by the crop (WUE_{ET}, water use efficiency of water used in ET) increased with water application. Yield produced per inch of water applied to the crop (WUE_{irr}, water use efficiency of irrigation water applied plus rainfall) also increased with water application, but then decreased from the 75 to 100% ET treatments. Nevertheless, sub-optimal irrigation strategies are not economical using the results from this study assuming a water cost of $45 per acre-foot and a sorghum silage value of $20 per ton. For sub-optimal irrigation strategies to be economical, water costs would have to increase, sorghum silage value would have to decrease, or the differences in the irrigation efficiencies of the strategies being compared would have to be greater than measured in the present study.

Introduction

Water use of forage sorghum in Arizona and similar production areas has been published (Erie et al., 1965). However, this work has come under criticism since deep drainage of soil water apparently was not accounted for and the water use estimates may therefore be too high. Light, frequent irrigations have been shown to increase WUE of forage sorghum (Saeed and Nadi, 1998), but light irrigations are not possible with flood irrigation. In a simulation study with grain sorghum, it was found that WUE was increased by irrigating fewer acres with more water with complementary dryland areas rather than more acres with less water (Baumhardt et al., 2007). The effect of irrigation timing on sweet sorghum was studied by us recently (Miller and Ottman, 2010), and this study revealed that irrigating less frequently resulted in higher water use efficiency. However, the stress imposed by our irrigation treatments were not severe enough to decrease forage yield, so in the proposed study, we intend to introduce more severe stress than the previous study.

The objectives of this study are to determine: 1) forage sorghum water use, and 2) if sub-optimal irrigation of forage sorghum increases water use efficiency and potential profitability.

Materials and Methods

A forage sorghum irrigation experiment was established at the Maricopa Agricultural Center in Maricopa, AZ on a Casa Grande sandy clay loam soil. The previous crop was hesperaloe, a succulent crop grown for fiber. Atrazine was applied preplant for weed control. The forage sorghum hybrid Richardson Seeds 'Silo 700D' was planted on flat ground 7 July 2009 at a seeding rate of 96,000 seeds per acre in 40 inch row spacing. Urea was applied at planting and on 7 Aug 09 at a rate of 100 lbs N/acre each application.

A germination irrigation was applied on 7 July 2009 and two more irrigations were applied to establish the crop before differential irrigations were initiated (Table 1). Plots were established by creating basins surrounded by earthen berms so each plot could be irrigated individually with polypipe fitted with gates. Each plot was 53.3 ft wide (16 rows) and 40 ft long. Irrigation treatments were based on target ET levels of 25, 50, 75, and 100% after establishment. ET was calculated from soil water depletion measured before and after each irrigation with a neutron probe in 0.2 m increments to a depth of 3.0 m.

The center 5 feet of 2 rows in the plots were hand harvested on 28 Oct 2009 to obtain forage yield. The plants were sampled for moisture determination and the yield was adjusted to 70% moisture content.

The experimental design was a randomized complete block with 4 blocks. The data was statistically analyzed using the MIXED procedure in SAS.

Results and Discussion

Irrigation water application increased most measures of crop growth and development (Table 2). Water application increased sorghum forage yield in a linear fashion with some diminishing returns at the highest rate. Forage yield adjusted to 70% moisture content increased from about 11 to 23 tons/acre with an increase in water application from 15.5 to 27.9 inches. Forage moisture content at harvest increased with water application. Forage protein content at harvest decreased substantially with an increase in water application from 8.58 to 4.75%. Water application increased plant height substantially. The density of stems at harvest was not affected by water application. The plants did not produce productive tillers to any extent, and the number of stems at harvest was roughly 8% less than 3 weeks after planting (data not presented).

At harvest, the leaf area index (LAI) was less than 3, for 25 and 50% ET treatments, and greater than 5, for 75 and 100% ET treatments. The difference in LAI among the irrigation treatments can be attributed to less area of brown and green leaves in the lower irrigation treatments but also to premature senescence of the lower leaves in these treatments. The final leaf number increased with water application, and the 25% ET treatment had 3-4 fewer leaves than the other treatments. This can be partially explained by the fact that the 25% treatment had not bloomed by harvest on 10/28, and since cold weather had set in by that time, the chances of ever reaching bloom for this treatment were remote. An increase in water application hastened maturity and the date of 50% bloom.

Water use, or evapotranspiration (ET), increased with water application from 14.7 to 23.7 inches. Irrigation efficiency decreased as more water was applied either due to movement of water past the active rooting zone or more water unused and remaining in the soil profile at harvest. Water use efficiency is defined as the tons for crop yield produced per unit of water used by or applied to the crop. The water use efficiency of water used in ET (WUE_{ET}) increased with the amount of water used by the crop. The water use efficiency of water applied (WUE_{irr}) also increased with the amount of water applied to the crop, but then decreased at the highest water application amount. The loss in WUE_{irr} with the 100% ET treatment could be explained by losses of water from the root zone or a larger amount of water remaining in the root zone at harvest compared to the other treatments.

Whether or not irrigating at 100% ET is the most economical strategy depends on the relative prices of water and sorghum silage. If we assume water costs $45/acre-foot and sorghum silage is worth $20/ton, then the yield increase in our study of 1.6 T/acre is worth $32/acre (1.6 T/acre x $20/T = $32/acre) and pays for the $15 cost of the additional 4.1 inches of water (4.1 inches/12 inches/ft x $45/acre-ft = $15). So, water costs would have to double or sorghum silage prices reduce by half in order for reducing irrigation to 75% ET to be economical. This cost analysis is based on the results of the present study where the difference in irrigation efficiency between the two treatments being compared is relatively small (4%). The likelihood of reduced irrigation strategies being more economical than full irrigation depends not only on the relative costs of water, value of the forage, and expected yield, but also on the differences in water application amounts that might be expected.

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References

Baumhardt, R. L., J. A. Tolk, T. A. Howell, and W. D. Rosenthal. 2007. Sorghum management practices suited to varying irrigation stategies: A simulation Analysis. Agronomy Journal 99:665-672.

Erie, L. J., O. F. French, and K. Harris. 1965. Consumptive use of water by crops in Arizona. Technical Bulletin 169. Univ. Ariz. Ag. Exp. Stn., Tucson.

Saeed, I. A. M., and A. H. El-Nadi. 1998. Forage sorghum yield and water efficiency under variable irrigation. Irrig. Sci. 18:67-71.

Miller, A. N., and M. J. Ottman. 2010. Irrigation Frequency Effects on Growth and Yield in Sweet Sorghum. Agronomy Journal 102:60-70.

Table 1. Irrigation Schedule for a forage sorghum irrigation study conducted in 2009 at Maricopa, AZ on a sandy clay loam soil. Irrigation water was applied at a constant amount until the crop was established before initiating differential irrigation treatments on 8/12. The irrigation treatments after establishment were based on the amount of water required to meet evapotranspiration (ET) requirements of the crop watered at 100% ET.

		Irrigation amount (after establishment)			
Irrigation Date	Growth Stage	25% ET	50% ET	75% ET	100% ET
		------------------------------------- inches -------------------------------------			
Establishment irrigations					
07/07	Planting	3.98	3.98	3.98	3.98
07/15	2-leaf	2.03	2.03	2.03	2.03
07/30	6-leaf	2.65	2.65	2.65	2.65
Sum		8.66	8.66	8.66	8.66
Variable irrigations					
08/12	10-leaf	0.62	1.24	1.70	2.19
08/25	14- leaf	0.99	1.69	2.44	3.23
09/04	17- leaf	1.11	1.91	2.76	3.55
09/17	21-leaf	1.60	2.93	4.03	5.32
10/01	Boot	0.99	1.80	2.55	3.34
Sum		5.30	9.57	13.47	17.63
Rainfall	---	1.52	1.52	1.52	1.52
TOTAL	---	15.48	19.75	23.65	27.81

Table 2. Water application effect on forage sorghum growth and development including on forage yield adjusted to 70% moisture, moisture, protein, height, stem density and green leaf area index (LAI) at harvest, final leaf number, and 50% bloom date.

Water applied after establishment	Forage Yield	Forage Moisture	Forage Protein	Plant Height	Stem Density	Green LAI	Leaf Number	50% Bloom
% ET	T/A	%	%	in	stems/A			
25	11.3	68.3	8.58	61.5	77,200	2.45	20.2	--
50	16.4	70.0	6.69	66.5	81,700	2.98	23.8	10/14
75	21.5	71.1	6.27	83.8	85,100	5.05	23.7	10/10
100	23.1	71.3	4.75	83.5	82,200	5.57	24.7	10/07
Average	18.1	70.2	6.57	73.8	81,500	4.01	23.1	10/10
CV (%)	8.0	3.0	18.4	6.1	11.4	28.2	11.7	0
Linear	**	+	**	**	ns	**	+	--
Quadratic	*	ns	ns	ns	ns	ns	ns	--

Table 3. Water application effect on water used by the crop in evapotranspiration (ET) and various calculated efficiencies including irrigation efficiency (water used/water applied), and water use efficiency of water applied in irrigation and rainfall (WUE_{irr}, forage yield/water applied), and water use efficiency of water used in ET (WUE_{ET}, forage yield/water used in ET).

Water applied after establishment	Total Water Applied	Water Use (ET)	Irrigation Efficiency	Water applied WUE_{irr}	Water used WUE_{ET}
% ET	in	in	%	T/A/in	T/A/in
25	15.5	14.7	95.3	0.73	0.78
50	19.8	18.0	90.8	0.83	0.92
75	23.7	21.1	89.4	0.91	1.02
100	27.8	23.7	85.2	0.83	0.98
Average	21.7	19.4	90.2	0.82	0.92
CV (%)	1.4	4.1	5.7	8.6	11.1
Linear	**	**	**	*	*
Quadratic	ns	ns	ns	*	ns