Research Report

Effect of Amount of Irrigation Water Applied on Forage Sorghum Yield and Quality at Maricopa, AZ, 2015

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Summary

Irrigation water is a major input into production of a forage crop. The purpose of this research is to compare the yield and quality of forage sorghum grown with differing amounts of irrigation water. A linear move sprinkler system was used to apply 11 water application amounts from 23.79 to 35.52 inches over the season. Forage yield peaked at a water application amount of around 32.60 inches according to a quadratic function of yield vs water applied. Increasing irrigation amount decreased forage quality by increasing fiber components. Profit was maximized at 30.20 to 32.60 inches of applied water, which is slightly less than that for maximum yield.

Introduction

Forage sorghum is commonly grown for silage for dairy cattle in Arizona. This crop is typically planted in late June or July after small grains or silage corn. Sorghum has the advantage compared to corn in that it uses less water and fertilizer, but feeding quality of sorghum is usually less than corn. Water use of forage sorghum in Arizona and similar production areas has been published (Erie et al., 1965). Light, frequent sprinkle irrigations have been shown to increase water use efficiency of forage sorghum (Saeed and Nadi, 1998). The effect of irrigation timing on sweet sorghum has been studied in Arizona (Miller and Ottman, 2010), and this study revealed that irrigating less frequently with flood irrigation resulted in higher water use efficiency. The University of Arizona has also reported one irrigation trial with forage sorghum in recent years (Ottman, 2010). In this study, suboptimal irrigation strategies (based on flood irrigation amount per irrigation) reduced yield and profit even though water use efficiency was increased at an irrigation level suboptimal for forage yield. The purpose of this research is to compare the yield and quality of forage sorghum grown with differing amounts of irrigation water applied with a linear move sprinkler system.

Procedure

The effect of amount of irrigation water on yield and quality of forage sorghum was evaluated in a study conducted at the University of Arizona Maricopa Agricultural Center in 2015 on a Casa Grande sandy loam soil. Dual Magnum and Atrazine herbicides were applied preplant at a rates of 1.0 and 1.6 pint/acre, respectively. Nitrogen fertilizer was applied preplant at a rate of 92 lb N/acre as urea. The forage sorghum hybrid Silo 700D BMR was planted at 100,000 seeds/acre. The germination irrigation was applied on August 1, and subsequent irrigations applied every 6 days on average (Table 2). The first five irrigations were applied using the border flood method to establish the crop, and the remaining irrigations were applied with a linear move sprinkler system with differing orifice sizes in the nozzles that delivered variable rates of water.

The experimental design was a complete block with 11 irrigation levels and 2 blocks. The plots were 13.3 ft wide and 380 ft long for an area of 0.12 acres. A linear move sprinkler system was used to apply irrigation water at different rates using variable noozles that applied high amounts of water in the center of the system and progressively less water toward each end.

Yield and other measurements were taken at final harvest on November 20, and heading date was noted when it occurred. Biomass samples were taken at harvest for moisture content from a 1 m section of row. These samples were weighed wet, chopped, and a subsample removed that was weighed wet, dried at 65 C, and weighed dry for moisture content. Forage yield was calculated and adjusted to 72% moisture content. Plant height was also measured on these plants. A similar procedure was followed on November 20 for moisture content at final harvest. Yield was measured from a 13.33 ft x 309 ft swath through the middle of each plot cut with a commercial forage chopper and blown into trucks which were weighed using truck scales. Days to maturity, or black layer of the grain, and bird damage to the grain was estimated at final harvest. The forage samples from November 20 were submitted for estimation of quality parameters by near infrared spectroscopy (NIRS), and information from this analysis was used by MILK2006 (Schwab et al., 2003; Shaver et al., 2006) a feed quality calculator, to estimate TDN, NE_l, milk per ton, and milk per acre.

Results and Discussion

Irrigation amount had a large impact on yield and other plant characteristics (Table 4). Forage yield at final harvest increased with increasing irrigation amount until reaching a peak around 32.60 inches (according to a quadratic function of yield vs water applied) and decreasing slightly at the highest irrigation amount. Plant moisture content and plant height increased linearly with the amount of irrigation water applied. Lower amounts of irrigation water application delayed heading and maturity.

All feed quality parameters calculated by MILK2006 decreased with increasing amount of irrigation water applied. Feed quality is not optimized at higher water application amounts in contrast to yield. Since forage yield is optimized at higher water application amounts, milk per acre increased with irrigation amount until reaching a peak and decreasing.

The amount of irrigation water applied resulted in changes in feed quality parameters measured by NIRS that are associated with decreased quality. For example, increased irrigation amount increased fiber components (NDF, ADF, and lignin) and decreased IVTDM and NDFD. In addition, increased irrigation amount increased fat, ADF-CP, methionine, and ash and decreased Na.

Forage yield profit was maximized at a water application amount of 30.20 and 32.60 inches even though yield was maximized at a higher amount of applied water (Table 7). Between 30.20 and 32.60 inches of applied water, the value of the marginal product (yield increase) was offset by the marginal cost of the water (cost of additional water). The assumptions of this analysis were that the cost of the irrigation water is $52/acre-ft and that the value of the forage is $25/ton including harvest cost. The highest irrigation water use efficiency or yield per inch of water applied was obtained between 28.95 and 30.20 inches of water applied. The additional yield obtained at slightly higher water application amounts (30.2 to 32.6 inches) offset increased irrigation costs. In order for profit to be maximized at peak forage yield obtained at 32.60 inches of applied water according to a quadratic function of yield vs water, water costs would have to be $45/acre-ft (and crop value at $25/ton) or crop value would have to be $29/ton (and water cost $52/acre-ft).

If we consider the value of the crop in terms of the amount of milk that can be produced per acre from the forage, the profitability of the various irrigation amounts changes. Milk increases the value of the forage by a factor of about 6 times its original value in this study and increased water costs with increased irrigation amount are not as significant for the bottom line. In terms of potential milk production, the profit is maximized between 32.60 and 32.80 inches of applied water which is slightly higher than the 30.2 to 32.6 inches of applied water where forage yield profit is maximized and similar to where forage yield itself is maximized.

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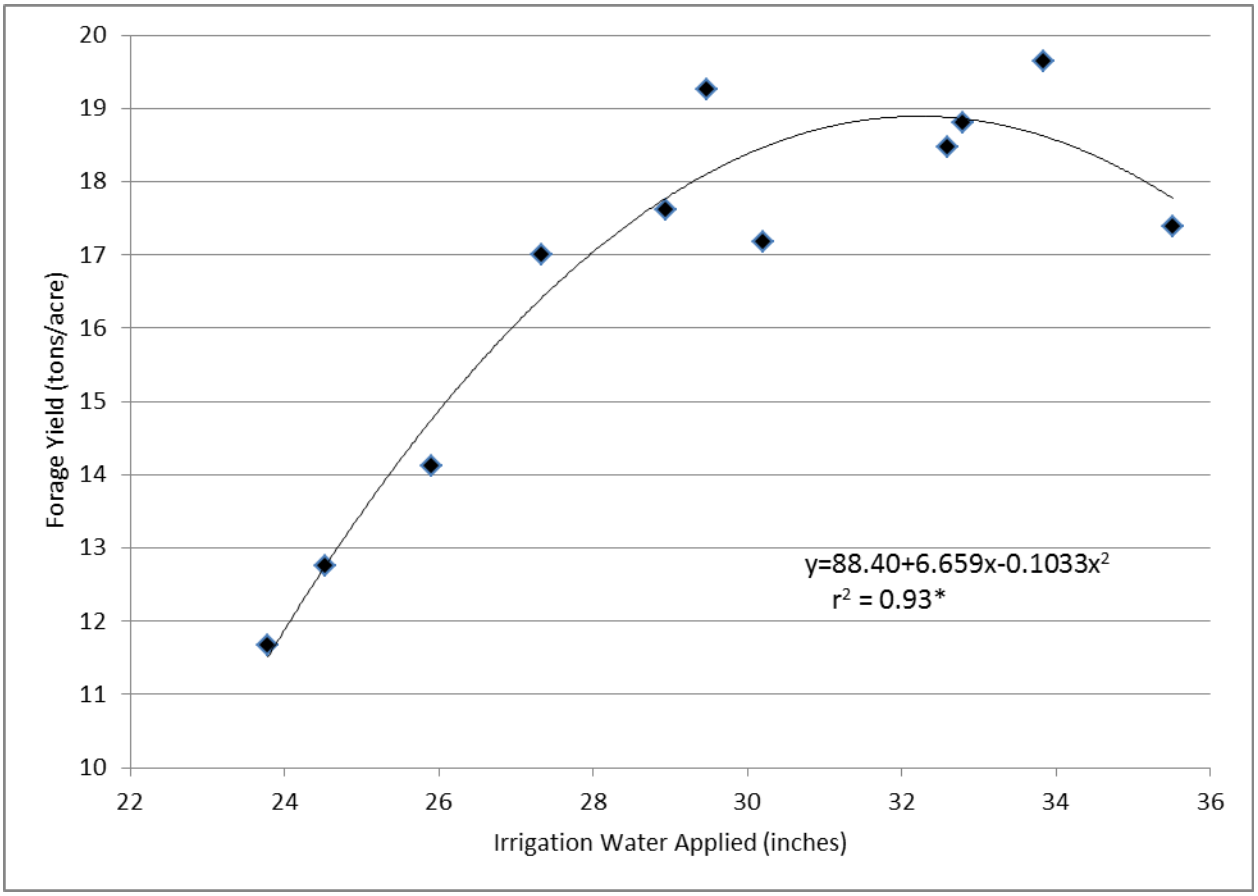

Fig. 1. Forage yield (72% moisture basis) as affected by amount or irrigation water applied.

Table 1. Amount of irrigation water applied at each date of irrigation for each of the 11 levels of total water application for study of the effect of irrigation amount on forage sorghum conducted at Maricopa, AZ in 2015 . The irrigations up to 9/4 were applied using the surface flood method and irrigations afterward were applied using a linear move sprinkler system with variable orifice sizes.

	Date of irrigation																
Total	8/1	8/3	8/12	8/28	9/4	9/11	9/14	9/15	9/24	9/25	9/28	9/29	10/1	10/6	10/12	10/13	11/6
---------- inches ----------																	
23.79	5.90	4.00	2.20	4.40	5.00	0.14	0.14	0.21	0.14	0.21	0.21	0.29	0.14	0.14	0.21	0.21	0.21
24.53	5.90	4.00	2.20	4.40	5.00	0.19	0.19	0.28	0.19	0.28	0.28	0.38	0.19	0.19	0.28	0.28	0.28
25.91	5.90	4.00	2.20	4.40	5.00	0.28	0.28	0.41	0.28	0.41	0.41	0.55	0.28	0.28	0.41	0.41	0.41
27.34	5.90	4.00	2.20	4.40	5.00	0.36	0.36	0.55	0.36	0.55	0.55	0.73	0.36	0.36	0.55	0.55	0.55
28.95	5.90	4.00	2.20	4.40	5.00	0.47	0.47	0.70	0.47	0.70	0.70	0.93	0.47	0.47	0.70	0.70	0.70
29.48	5.90	4.00	2.20	4.40	5.00	0.50	0.50	0.75	0.50	0.75	0.75	1.00	0.50	0.50	0.75	0.75	0.75
30.20	5.90	4.00	2.20	4.40	5.00	0.54	0.54	0.82	0.54	0.82	0.82	1.09	0.54	0.54	0.82	0.82	0.82
32.60	5.90	4.00	2.20	4.40	5.00	0.69	0.69	1.04	0.69	1.04	1.04	1.39	0.69	0.69	1.04	1.04	1.04
32.80	5.90	4.00	2.20	4.40	5.00	0.71	0.71	1.06	0.71	1.06	1.06	1.41	0.71	0.71	1.06	1.06	1.06
33.84	5.90	4.00	2.20	4.40	5.00	0.77	0.77	1.16	0.77	1.16	1.16	1.54	0.77	0.77	1.16	1.16	1.16
35.52	5.90	4.00	2.20	4.40	5.00	0.88	0.88	1.31	0.88	1.31	1.31	1.75	0.88	0.88	1.31	1.31	1.31

Table 2. Precipitation (PPT) for a sorghum irrigation study conducted at Maricopa, AZ in 2015. Total precipitation received over the growing season was 2.84 inches.

August	PPT	September	PPT	October	PPT	November	PPT
	inches		inches		inches		
7-Aug	0.12	3-Sep	0.02	4-Oct	0.15	4-Nov	0.07
9-Aug	0.46	13-Sep	0.01	6-Oct	0.08	5-Nov	0.01
11-Aug	0.07			16-Oct	0.21	15-Nov	0.05
25-Aug	0.15			17-Oct	0.06	16-Nov	0.01
				18-Oct	0.96		
				20-Oct	0.29		
				21-Oct	0.01		
				29-Oct	0.09		
				30-Oct	0.02		
SUM	0.80	SUM	0.03	SUM	1.87	SUM	0.14

Table 3. Yield and other plant characteristics of forage sorghum harvested on November 20, 2015 and sampled on October 24, 2015 as affected by irrigation amount for a study conducted at Maricopa, AZ in 2015.

Irrigation amount	November 20 Yield	Moisture	Height	Days to maturity	Bird damage	October 24 Yield	Moisture	Heading
inches	T/A	%	inches		rating	T/A	%	
23.79	11.7	74.4	68.0	24	0	11.9	74.4	27-Oct
24.53	12.8	76.6	75.5	24	0	15.4	76.6	27-Oct
25.91	14.1	76.9	72.0	21	0	13.7	76.9	25-Oct
27.34	17.0	76.6	88.0	18	0	13.3	76.6	25-Oct
28.95	17.6	77.7	90.0	18	0	20.2	77.7	25-Oct
29.48	19.3	78.8	88.0	18	0	19.3	78.8	25-Oct
30.20	17.2	79.6	87.5	15	0	15.5	79.6	25-Oct
32.60	18.5	78.5	92.5	15	0	20.6	78.5	25-Oct
32.80	18.8	79.1	94.5	15	3	22.0	79.1	25-Oct
33.84	19.6	78.5	90.5	15	3	18.7	78.5	25-Oct
35.52	17.4	80.3	92.5	15	3	16.5	80.3	25-Oct
Avg	16.6	77.9	85.4	18	1	17.0	77.9	25-Oct
$LSD_{.05}$	4.6	2.8	15.5	3	ns	ns	2.8	1.3
Linear	**	**	**	**	ns	*	**	**
Quadratic	*	ns	ns	**	ns	ns	ns	**
Cubic	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	12	2	8	11	280	24	2	0

Table 4. Feed quality parameters (abbreviations in Table 6) calculated by MILK2006 for forage sorghum harvested on November 20, 2015 as affected by irrigation amount for a study conducted at Maricopa, AZ in 2015.

Irrigation amount	TDN	NE_l	Milk per ton	Milk per acre
inches	%	Mcal/lb	lb/T	lb/A
23.79	62.7	0.590	2,587	8,433
24.53	63.5	0.594	2,621	9,369
25.91	62.9	0.588	2,580	10,202
27.34	61.3	0.573	2,473	11,750
28.95	62.6	0.587	2,568	12,698
29.48	62.6	0.585	2,563	13,809
30.20	61.3	0.568	2,452	11,790
32.60	62.1	0.582	2,532	13,097
32.80	61.1	0.570	2,454	12,926
33.84	60.6	0.564	2,418	13,294
35.52	60.5	0.565	2,417	11,782
Avg	61.9	0.579	2,515	11,741
$LSD_{.05}$	ns	ns	ns	3,076
Linear	**	**	**	**
Quadratic	ns	ns	ns	**
Cubic	ns	ns	ns	ns
CV (%)	1	2	2	12

Table 5. Feed quality parameters (abbreviations in Table 6) measured by NIRS for forage sorghum harvested on November 20 as affected by irrigation amount in a study conducted at Maricopa, AZ in 2015.

Irrigation amount	NDF	ADF	Protein	Fat	SIP	ADF-CP	NDF-CP	UIP	Lignin	Starch	NFC
inches	%	%	%	%	%	%	%	%	%	%	%
23.79	52.1	32.2	9.06	2.18	44.0	0.491	1.83	31.5	8.21	15.8	30.3
24.53	52.6	32.6	8.64	2.10	40.6	0.485	1.89	30.6	8.22	16.1	30.3
25.91	53.4	33.0	9.14	2.18	41.3	0.503	1.84	31.3	8.34	15.9	31.7
27.34	52.2	33.5	7.61	2.24	41.2	0.582	1.92	29.5	7.84	16.2	30.3
28.95	52.5	33.6	7.63	2.16	41.0	0.527	1.95	31.1	7.99	15.9	28.6
29.48	52.9	33.3	8.20	2.02	39.4	0.566	1.94	31.3	8.34	16.1	32.4
30.20	56.0	35.7	9.05	2.41	44.6	0.597	1.89	30.0	8.64	14.4	30.2
32.60	54.1	35.5	7.06	2.30	45.5	0.629	1.82	31.2	8.36	15.8	34.6
32.80	55.4	36.4	7.48	2.42	45.4	0.642	1.82	31.5	8.55	15.1	36.2
33.84	55.4	36.6	7.82	2.43	45.9	0.656	1.81	31.1	8.65	15.1	30.7
35.52	55.9	36.5	8.47	2.46	43.6	0.686	1.80	30.9	8.75	14.7	27.4
Avg	53.9	34.4	8.20	2.26	42.9	0.579	1.86	30.9	8.36	15.5	31.2
$LSD_{.05}$	ns	2.4	ns	ns	ns	0.109	ns	ns	ns	ns	ns
Linear	**	**	ns	*	ns	**	ns	ns	*	ns	ns
Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cubic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	2	3	13	7	10	8	5	3	3	7	10

Table 5 (con'd). Feed quality parameters (abbreviations in Table 6) measured by NIRS for forage sorghum harvested on November 20 as affected by irrigation amount in a study conducted at Maricopa, AZ in 2015.

Irrigation amount	Soluble carbs	Simple sugars	IVTDM D24	IVTDM D30	IVTDM D48	NDFD 24	NDFD 30	NDFD 48	Lysine	Methi-onine	Lactic acid
inches	%	%	%	%	%	%	%	%	%	%	%
23.79	6.28	5.07	68.0	73.4	76.9	45.6	52.7	60.2	0.255	0.138	2.95
24.53	5.38	4.14	68.8	74.2	77.7	47.6	54.7	62.2	0.244	0.134	2.72
25.91	5.11	4.24	68.3	73.7	77.2	47.1	54.2	61.7	0.254	0.135	2.94
27.34	6.99	4.92	68.2	73.7	77.2	45.8	52.9	60.4	0.235	0.133	2.47
28.95	6.05	4.33	68.2	73.7	77.2	46.1	53.1	60.7	0.238	0.129	2.30
29.48	6.03	4.63	68.9	74.3	77.8	46.9	54.0	61.5	0.247	0.132	2.75
30.20	5.85	4.45	67.1	72.5	76.0	46.6	53.7	61.2	0.265	0.143	2.46
32.60	7.43	5.07	67.5	73.0	76.4	45.8	52.9	60.4	0.250	0.139	2.57
32.80	7.20	4.75	67.0	72.5	75.9	45.9	53.0	60.5	0.266	0.143	2.59
33.84	5.74	4.29	66.7	72.2	75.7	45.6	52.6	60.2	0.264	0.143	2.80
35.52	6.19	4.18	66.5	71.9	75.4	45.1	52.1	59.7	0.275	0.145	2.50
Avg	6.20	4.55	67.7	73.2	76.7	46.2	53.3	60.8	0.254	0.137	2.64
$LSD_{.05}$	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Linear	ns	ns	**	**	**	*	*	*	ns	*	ns
Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cubic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	11	9	1	1	1	2	1	1	7	5	8

Table 5 (con'd). Feed quality parameters measured by NIRS for forage sorghum harvested on November 20 as affected by irrigation amount in a study conducted at Maricopa, AZ in 2015.

Irrigation amount	Ash	Ca	P	Mg	S	K	Na	Cl	Fe	Mn	Cu	Zn
inches	%	%	%	%	%	%	%	%	ppm	ppm	ppm	ppm
23.79	8.44	0.378	0.217	0.123	0.102	1.65	0.024	1.29	14	74.1	7.27	36.0
24.53	8.48	0.340	0.214	0.075	0.098	1.58	0.022	1.27	17	69.2	7.39	36.5
25.91	8.60	0.356	0.225	0.092	0.101	1.63	0.022	1.31	52	71.8	7.34	36.4
27.34	8.14	0.314	0.184	0.070	0.086	1.55	0.019	1.15	70	71.3	7.16	35.7
28.95	8.21	0.324	0.196	0.063	0.095	1.72	0.022	1.19	28	72.3	7.06	35.9
29.48	8.78	0.346	0.205	0.091	0.101	1.76	0.022	1.36	31	72.1	7.12	36.4
30.20	9.41	0.356	0.235	0.072	0.100	1.63	0.020	1.30	63	75.5	7.62	36.5
32.60	8.72	0.313	0.186	0.047	0.087	1.59	0.020	1.10	55	71.6	7.23	36.2
32.80	9.39	0.319	0.202	0.027	0.089	1.61	0.019	1.19	35	71.4	7.47	36.4
33.84	9.72	0.325	0.212	0.041	0.093	1.59	0.017	1.16	69	73.7	7.73	36.4
35.52	9.40	0.350	0.226	0.093	0.100	1.70	0.018	1.28	21	74.1	7.69	36.3
Avg	8.84	0.338	0.209	0.072	0.096	1.64	0.020	1.24	41	72.5	7.37	36.2
$LSD_{.05}$	ns	ns	ns	ns	ns	0.10	ns	ns	ns	ns	ns	0.4
Linear	**	ns	ns	ns	ns	ns	**	ns	ns	ns	ns	ns
Quadratic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Cubic	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	7	7	13	44	7	3	9	7	62	6	6	0

Table 6. Abbreviations for various phrases used to define feed quality.

Abbreviation	Phrase
ADF	Acid detergent fiber
ADF-CP	Acid detergent fiber crude protein
IVTDMD24	*In vitro* dry matter digestibility after incubation for 24 hours
IVTDMD30	*In vitro* dry matter digestibility after incubation for 30 hours
IVTDMD48	*In vitro* dry matter digestibility after incubation for 48 hours
NDF	Neutral detergent fiber
NDF-CP	Neutral detergent fiber crude protein
NDFD24	Neutral detergent fiber digestibility after incubation for 24 hours
NDFD30	Neutral detergent fiber digestibility after incubation for 30 hours
NDFD48	Neutral detergent fiber digestibility after incubation for 48 hours
NE_l	Net energy for lactation
NFC	Non-fibrous carbohydrate
SIP	Soluble intake protein
TDN	Total digestible nutrients
UIP	Undegradable intake protein
VFA	Volatile fatty acids

Table 7. Economic analysis of forage yield per acre (predicted by a quadratic function) as affected by water application amount. The assumptions are water cost of $52/acre-ft, crop value of $25/ton at 68% moisture which includes harvest cost of $7/ton, and that no other production cost changes as water cost increases.

Water applied	Water cost	Predicted yield at 72% moisture	Yield per inch water applied	Crop value	Return over water cost	Value of marginal product	Marginal cost of water	Marginal return
in	$/A	T/A	T/in	$/A	$/A	$/A	$/A	$/A
23.79	103	11.5	0.49	252	149	---	---	---
24.53	106	12.8	0.52	279	173	27	3	24
25.91	112	14.8	0.57	323	211	44	6	38
27.34	118	16.4	0.60	359	241	36	6	30
28.95	125	17.8	0.61	389	264	30	7	23
29.48	128	18.1	0.61	396	268	7	2	5
30.20	131	18.5	0.61	404	273	8	3	5
32.60	141	18.9	0.58	413	272	9	10	-1
32.80	142	18.9	0.57	412	270	0	1	-1
33.84	147	18.6	0.55	407	261	-5	5	-10
35.52	154	17.8	0.50	389	235	-19	7	-26

Table 8. Economic analysis of milk per acre (predicted by a quadratic function) as affected by water application amount. The assumptions are water cost of $52/acre-ft, milk price of $19.22/cwt which is the 5-year average for Arizona from 2011-15, and that no other cost changes as water cost increases.

Water applied	Water cost	Predicted milk per acre	Milk per inch water applied	Milk value	Return over water cost	Value of marginal product	Marginal cost of water	Marginal return
in	$/A	T/A	lb/in	$/A	$/A	$/A	$/A	$/A
23.79	103	8382	352	1,611	1,508	---	---	---
24.53	106	9234	376	1,775	1,669	164	3	161
25.91	112	10598	409	2,037	1,925	262	6	256
27.34	118	11704	428	2,250	2,131	213	6	206
28.95	125	12574	434	2,417	2,291	167	7	160
29.48	128	12774	433	2,455	2,327	38	2	36
30.20	131	12976	430	2,494	2,363	39	3	36
32.60	141	13075	401	2,513	2,372	19	10	9
32.80	142	13044	398	2,507	2,365	-6	1	-7
33.84	147	12781	378	2,457	2,310	-51	5	-55
35.52	154	12006	338	2,308	2,154	-149	7	-156