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Abstract

Forage sorghum (*Sorghum bicolor* (L.) Moench) is a highly productive annual summer forage that can be grazed, hayed or ensiled for winter feed, confined feeding, or grazed to supplement native pasture. Recently, there has been interest in growing forage sorghum for hay or grazing in place of fallow to increase residue cover as part of an integrated forage or cover crop system. The high water use efficiency and heat and drought tolerance of sorghum makes it an ideal forage crop choice for growers in the water-limited Great Plains environment. Furthermore, due to the declining saturated thickness of the Ogallala and High Plains aquifers, there is a need for more water efficient forages like sorghum compared to corn silage or alfalfa.

Despite the great potential of forage sorghum as animal feed, high nitrate content is a major concern when fed to cattle. Forage containing 3,000 ppm nitrates are generally considered safe as livestock feed, nitrate concentrations between 3,000 and 6,000 ppm may be limit fed, and concentrations > 9,000 ppm should not be fed to livestock. Ensiling reduces nitrate concentration but still requires caution when fed. Environmental stressors (including drought, frost, or cloudy weather conditions) and high manure or N fertilizer application rates can predispose forage crops to accumulate greater nitrate concentration in the aboveground biomass.

Nitrogen application generally increased DM production, but excessive N application will also increase nitrate concentration in the harvested biomass. Limited research has been conducted on forage sorghum DM production and nitrate concentration responses to N fertilizer application in the semi-arid Great Plains region. Objectives of this study were to determine optimum N rates and quantify forage sorghum hay nitrate concentration as affected by N application under rain-fed no-till conditions in the semiarid central Great Plains.

Keywords

Nitrogen fertilization, nitrogen application, grain sorghum

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Summary

Forage sorghum (*Sorghum bicolor* (L.) Moench) is an important annual forage crop but prone to high nitrate concentration, which can cause toxicity when fed to cattle. Field experiments were conducted over four site-years across western Kansas to determine the optimum nitrogen (N) rate for no-till forage sorghum biomass accumulation and also investigate the effect of N fertilization on sorghum forage nitrate content. Nitrogen fertilizer rates were 0, 25, 50, 75, 100, and 125 lb N/a arranged in a randomized complete block design with four replications. Forage sorghum responded positively to N fertilizer application in 2 of 4 site-years. Maximum DM production was 5545 lb/a and occurred with an available N rate of 114 lb N/a. However, the economic optimum N rate ranged from 76 to 89 lb/a when N fertilizer cost was $0.43/lb N and hay price ranged from $0.02 to $0.03/lb DM. Forage nitrate concentration exceeded the virtually safe limit of 3000 ppm for cattle when available N rate was beyond 55 lb/a. Because high forage nitrate content reduces the economic and feed value of forages, we recommend growers apply no more than 55 lb/a available N to forage sorghum grown under rain-fed conditions.

Introduction

Forage sorghum (*Sorghum bicolor* (L.) Moench) is a highly productive annual summer forage that can be grazed, hayed or ensiled for winter feed, confined feeding, or grazed to supplement native pasture. Recently, there has been interest in growing forage sorghum for hay or grazing in place of fallow to increase residue cover as part of an integrated forage or cover crop system. The high water use efficiency and heat and drought tolerance of sorghum makes it an ideal forage crop choice for growers in the water-limited Great Plains environment. Furthermore, due to the declining saturated thickness of the Ogallala and High Plains aquifers, there is a need for more water-efficient forages such as sorghum compared to corn silage or alfalfa.

Despite the great potential of forage sorghum as animal feed, high nitrate content is a major concern when fed to cattle. Forage containing 3,000 ppm nitrates are generally considered safe as livestock feed, nitrate concentrations between 3,000 and 6,000 ppm may be limit fed, and concentrations > 9,000 ppm should not be fed to livestock. Ensiling reduces nitrate concentration but still requires caution when fed. Environmental stressors (including drought, frost, or cloudy weather conditions) and high manure or N fertilizer application rates can predispose forage crops to accumulate greater nitrate concentration in the aboveground biomass.

Nitrogen application generally increased DM production, but excessive N application will also increase nitrate concentration in the harvested biomass. Limited research has been conducted on forage sorghum DM production and nitrate concentration responses to N fertilizer application in the semi-arid Great Plains region. Objectives of this study were to determine optimum N rates and quantify forage sorghum hay nitrate concentration as affected by N application under rain-fed no-till conditions in the semi-arid central Great Plains.

Procedures

Treatments were six N fertilizer rates (0, 25, 50, 75, 100, and 125 lb N/a) applied prior to planting, conducted over four site-years near Garden City and Jetmore, KS. At each site-year, the N fertilizer rates were arranged in a randomized complete block design with four replications. Individual plot sizes were 10-ft wide × 30-ft long. All plots at each site-year received a blanket application of P and S fertilizers prior to seeding based on recommendations from soil tests conducted at the Kansas State University Department of Agronomy Soil Testing Laboratory. Seasonal precipitation was recorded for all site-years from nearby weather stations (Table 1). Weed control at each site-year was accomplished with a pre-plant burn down using appropriate herbicides. Forage sorghum at each site-year was planted the first week in June depending on weather and soil conditions.

The plots were harvested at heading which is when most producers harvest to optimize both forage hay biomass production and nutritive value. Due to limited moisture availability to generate regrowth, forage was harvested only once in August at heading. During each harvest, a 3-ft wide × 30-ft long forage strip was harvested from each plot to a 5-inch stubble height using a Carter small plot forage harvester (Carter Manufacturing Company, Inc., Grand Haven, MI). Forage plots were intentionally harvested at a higher stubble height to match Kansas State University recommendations to retain soil residue cover and avoid the lowest portions of the plant which are normally greater in nitrate concentration. Fresh weights of samples were recorded, sub-samples were weighed, and oven dried at 50°C for at least 48 hours in a forced-air oven for DM determination. Oven-dried samples were ground to pass through a 1-mm mesh screen in a Wiley Mill (Thomas Scientific, Swedesboro, NJ), sequentially. The ground samples were then analyzed for N concentration by dry combustion using a LECO CN analyzer (LECO Corporation, St. Joseph, MI). In addition, forage samples were extracted with 2 M KCl and nitrate concentration determined colorimetrically by cadmium reduction. The amount of N removed was computed by multiplying N concentration by forage DM biomass accumulation. Nitrogen use efficiency (NUE; lb DM/ lb N uptake) was also computed.

Statistical analysis with the Proc Mixed procedure in SAS version 9.4 (Cary, NC) was used to examine sorghum DM production, CP, nitrate concentration, and NUE as a function of N application. Site-year and N rates were considered fixed effects, and block nested within site-year as random. Mean comparisons were done using Tukey's Honest Significant Difference (HSD) test. Interaction and treatment effects were considered significant when F test P values were ≤ 0.05. Regression analyses were conducted to determine the relationship between DM production, nitrate concentration and available N (soil plus fertilizer application rate) using data from site-years with a response to N application. A quadratic response model was used to describe DM response to N fertilizer application rate, and the agronomic maximum N rate (N_{max}, lb N/a) was determined by equating the first derivative of the quadratic function to zero. Similarly, the economic optimum N rates (EONR, lb N/a) were calculated by setting the first derivative of the quadratic response curve of the relationship between DM production and available N rate equal to the price ratio of the N fertilizer cost and the price of sorghum hay. The EONR rates were then computed for fertilizer price range of $300 to $800/ton of urea fertilizer, and hay value of $40 to $120/ton DM.

Results

Forage Biomass Production

Site-year × N rate interaction had an effect on forage DM accumulation (Table 2). This occurred because sorghum DM showed no significant response to N application in 2013 and 2014 at Garden City and Jetmore, KS, respectively. This was mostly due to greater residual NO_3-N at Garden City and possibly greater N mineralization from soil organic matter decomposition from previous alfalfa crop at the Jetmore site. In site-years when DM yield responded positively to N fertilizer application, forage DM produced with 50 lb N/a was similar to that obtained with greater N rates. Across site-years, average DM production was least in 2012 at Garden City and the most in 2014 at Jetmore. This corresponds well with the growing season precipitation measured at each of the study sites (Table 1).

Total DM produced over the two site-years (2012 growing season at Garden City and Jetmore) that responded to N fertilizer rate were combined and modelled with a quadratic response model. The model showed a maximum DM production of 5545 lb/a that occurred with available N rate (soil plus fertilizer N) of 114 lb/a (Figure 1). However, the EONR ranged from 37 to 105 lb N/a available N depending on N fertilizer and sorghum hay price (Table 3). At lower sorghum hay prices, N fertilizer price had a significant effect on EONR that a grower should apply. For instance, at $0.02 to $0.03/lb hay price, the EONR varied greatly with a change in N fertilizer price. However, when sorghum hay price was set at $0.06/lb DM, little change in EONR was observed with change in fertilizer price (Table 3). Using a current local urea fertilizer price of $0.43/lb N (Midland Marketing, personal communication) and hay value of $0.02 to $0.03/lb DM, the EONR ranged from 76 to 89 lb N/a (Table 3).

Forage Nitrate Concentration

Forage nitrate concentration differed with site-year and N fertilizer application rate. Averaged across N rates, nitrate concentration was most at Jetmore in 2014 and least at Garden City in 2012 (Table 2). The observed differences in forage nitrates correspond well with initial residual soil profile N concentration measured at each site-year. Residual soil test N in 2012 at Garden City was 23 lb, and 123 lb/a at this same site in 2013 (Table 2). The significantly greater soil nitrates mostly contributed to greater forage nitrate concentrations in 2013 at this site. Greater forage nitrate concentration at Jetmore in 2012 could be due to relatively warmer temperatures in summer of 2012 at this site (Table 1) that resulted in high nitrate accumulation. Using the forage nitrate data at Jetmore only, nitrate concentration responded linearly to available N rate. The regression analysis showed a 35.7 ppm increase in forage nitrate concentration with each lb of available N (Figure 2). In general, available N amounts beyond 55 lb/a resulted in forage nitrate concentration exceeding the virtually safe limit of 3000 ppm for cattle consumption. This finding suggests supplementing 50 to 60 lb N/a (residual soil nitrate plus fertilizer) will produced adequate forage biomass and also reduce nitrate concentration in the harvested feed.

Nitrogen Uptake and Nitrogen Use Efficiency

Site-year × N rate interaction had an effect on N uptake. Increasing N fertilizer application increased N uptake only in 2012 at Garden City and Jetmore but not in 2013 or 2014 growing seasons. This is possibly due to greater available N in 2013 at Garden City and 2014 at Jetmore. In general, N uptake was most in 2014 at Jetmore and the least in 2012 at Garden City, mostly due to differences in DM produced (Table 2).

Nitrogen use efficiency computed as DM produced per unit of N uptake was not affected by N application rate except at Jetmore in 2012. Applying N fertilizer decreased NUE from 81 lb DM/lb N with no N to 62 lb DM/lb N at the highest N rate of 125 lb N/a (Table 2). In general, NUE was most at Garden City in 2012 and least at this same site in the 2013 growing season (Table 2). This observation could be explained by the greater DM response to N fertilizer application in 2012 compared to 2013 when there was no response to N due to greater residual soil N.

Table 1. Total monthly precipitation at the study locations in southwest Kansas

	Garden City		30-year	Jetmore		30-year
Month	2012	2013	average	2012	2014	average
			Precipitation, in.			
January	0.01	0.41	0.45	0.01	0.43	0.67
February	0.56	0.82	0.55	1.29	0.78	0.74
March	1.93	0.12	1.42	1.99	0.15	2.07
April	2.43	0.47	1.75	2.30	0.71	1.91
May	0.15	0.81	2.91	1.18	0.78	3.25
June	1.11	2.49	3.35	0.89	8.86	3.06
July	2.32	1.95	2.86	2.58	4.32	3.14
August	1.89	5.26	2.52	6.09	2.30	2.30
Total	10.4	12.33	15.81	16.33	18.33	17.14

Table 2. Forage sorghum biomass production, nitrogen (N) uptake and forage nitrate responses to N fertilizer over four site-years in southwest Kansas

N rate	Soil NO_3	Biomass	Forage NO_3	N uptake	NUE[§]
---------------------- lb/a ----------------------			ppm	lb/a	lb/lb
Garden City 2012					
0	23	1884 b[†]	156 a	23 b	83 a
25	23	3295 ab	164 a	36 ab	93 a
50	23	4606 a	170 a	43 ab	109 a
75	23	5160 a	258 a	55 a	98 a
100	23	4480 a	399 a	51 ab	92 a
125	23	5263 a	337 a	60 b	90 a
HSD[‡]		2035	ns[¶]	30.2	ns
P-value		0.0004	0.06	0.01	0.11
Garden City 2013					
0	123	3492 a	3694 a	60 a	59 a
25	123	4120 a	3703 a	69 a	59 a
50	123	4403 a	4062 a	80 a	55 a
75	123	4477 a	3954 a	75 a	59 a
100	123	4601 a	4019 a	78 a	59 a
125	123	4476 a	3530 a	79 a	56 a
HSD		ns	ns	ns	ns
P-value		0.32	0.85	0.18	0.19

continued

Table 2. Forage sorghum biomass production, nitrogen (N) uptake and forage nitrate responses to N fertilizer over four site-years in southwest Kansas

N rate	Soil NO_3	Biomass	Forage NO_3	N uptake	NUE[§]
---------------------- lb/a ----------------------			ppm	lb/a	lb/lb
Jetmore 2012					
0	12	3504 b	556 b	43 b	81 ab
25	12	4914 ab	615 b	61 bc	83 a
50	12	5035 ab	3885 a	75 ab	68 abc
75	12	6741 a	4402 a	95 a	70 abc
100	12	6225 a	5009 a	97 a	64 bc
125	12	5940 ab	5777 a	97 a	62 c
HSD		2685	2423	30	18
P-value		0.02	<0.0001	0.006	0.004
Jetmore 2014					
0	23	8385 a	2294 b	89 a	96 a
25	23	8383 a	3330 ab	95 a	91 a
50	23	8471 a	5111 ab	98 a	88 a
75	23	7663 a	7408 a	83 a	95 a
100	23	7091 a	5536 ab	81 a	89 a
125	23	8894 a	4562 ab	107 a	84 a
HSD		ns	4304	ns	ns
P-value		0.25	0.016	0.39	0.9

[†]Means followed by same lower case letter (s) within a site-year are not significantly different using Tukey's Honest Significant Difference (HSD) test.
[‡]HSD is minimum difference between two treatments used to declare they are significantly different using Tukey's Honest Significant Difference Test.
[§]NUE = Nitrogen use efficiency.
[¶]NS = not significant.

Table 3. Economic optimum nitrogen (N) rates (EONR, lb/a) as a function of N fertilizer price and forage sorghum hay value

N price/forage value ($/lb DM)	0.02	0.03	0.04	0.05	0.06
$/lb N			EONR (lb/a)		
0.33	85	95	100	103	105
0.43	76	89	95	99	102
0.54	66	82	90	95	98
0.65	56	76	85	91	95
0.76	47	69	80	87	92
0.87	37	63	76	83	89

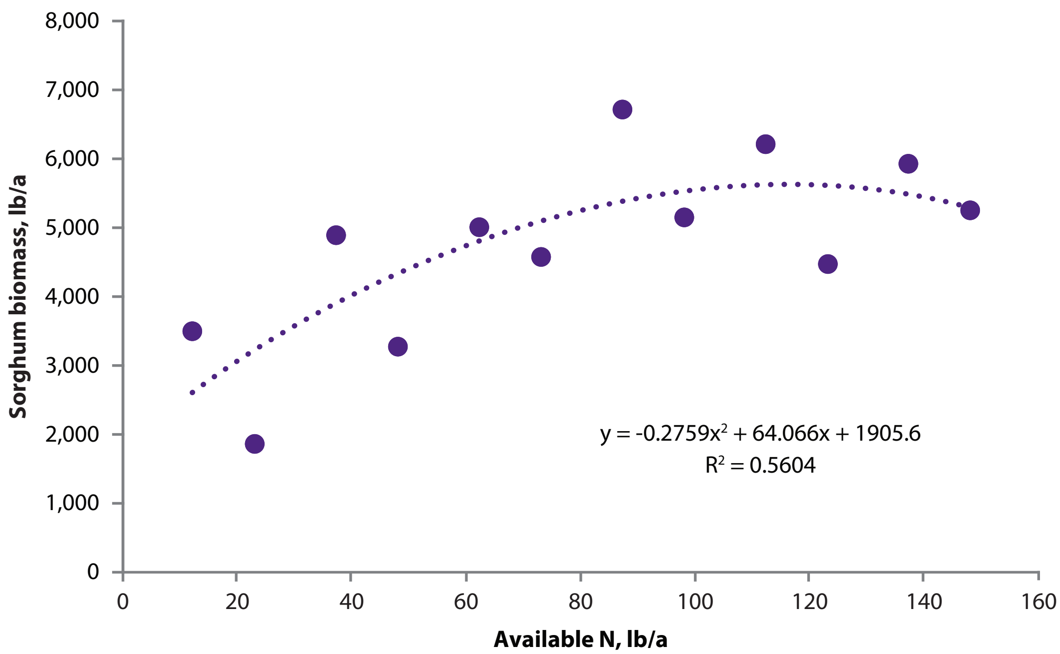

Figure 1. Forage sorghum biomass response to available N (soil plus fertilizer N) over two site-years (Garden City and Jetmore in 2012 growing season) in southwest Kansas.

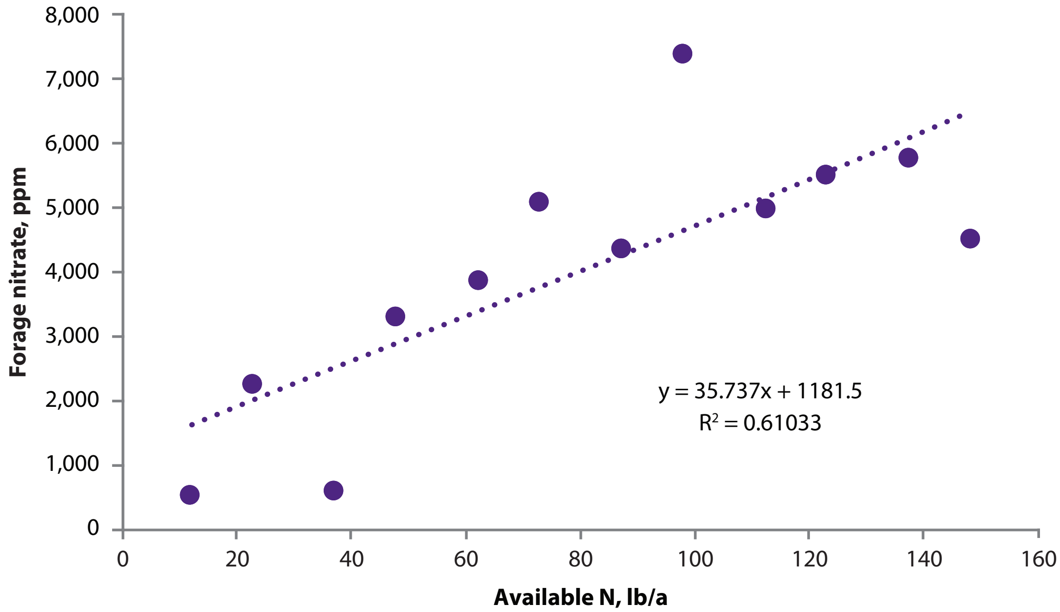

Figure 2. Response of forage sorghum biomass nitrate concentration to available N at Jetmore, KS, in 2012 and 2014 growing seasons.