Effects of Nitrogen Fertilization on Forage Sorghum Nutrient Composition

Nathaniel Lawton

Virginia Tech

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Mark Reiter, Chair

Gonzalo Ferreira

W. Hunter Frame

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Abstract

Whole plant nutrient composition was investigated as forage sorghum (*Sorghum bicolor* (L) Moench) nitrogen (N) fertilization regimes were changed for Virginia production systems. Five N rates were applied to forage sorghum plots using a randomized complete block design with four replications. The N rates where 23.5, 53.5, 83.5, 113.5 and 143.5 lb N acre^{-1}. Total digestible nutrients (TDN), crude protein (CP), neutral detergent fiber (NDF) and acid detergent fiber (ADF) concentrations were analyzed from two harvests, 40 days post emergence and 45 days after first cutting, using near infrared spectroscopy. No significance for TDN, CP, ADF or NDF across N rates was found for either cutting. Means for TDN were 57.0% and 59.0% for the first and second cutting and means for CP concentrations where 9.0% and 10.4 %, respectively. Plant height and normal difference vegetative index readings were taken twice for each harvest period and were not significant across N rates. Dairy manure had been applied in previous years which could have led to higher plant available N rates. Lower than average rainfall may have limited growth for the second growth period.

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Introduction:

Forage sorghum (*Sorghum bicolor* (L) Moench) has potential to fulfill a niche within forage production in Virginia. When replacing corn silage in dairy cattle total mixed ration, sorghum silage can give comparable milk yields (Barnard & Tao, 2015; Yang, Ferreira, Corl & Campbell, 2019; Sánchez-Duarte et al., 2019). Forage sorghum research on a loam soil in Spain (Farre & Faci, 2006) and in Egypt, (Hasan, Rabei, Nada, & Abogadallah, 2017) have shown similar yields and greater drought tolerance for forage sorghum when compared to corn. This gives sorghum attention as a potential crop to diversify cropping cycles in Virginia by replacing corn in silage acres.

Current research is lacking on how forage sorghum nutrient composition changes under different nitrogen (N) fertilization rates, particularly in climates and soils found in Virginia. A number of studies found increased sorghum dry matter (DM) yield with increased N rates (Maughen et al., 2012; Haankuku, Epplin, & Kakani, 2014; Turgut et al., 2007). Forage sorghum nutrient composition has been documented under different N fertilization regimes, but mostly investigating crude protein (CP) concentrations (Marsalisa, Angadia & Contreras-Goveab, 2009; Damien et al., 2017). Two studies investigated digestibility differences across N rates in addition to CP concentrations, though in different climate conditions than Virginia (Restellatto et al., 2013; Belanger et. al., 2017).

This study investigated the relationship between N fertilization rates and total digestible nutrients (TDN), acid detergent fiber (ADF), neutral detergent fiber (NDF), and CP concentrations. Plant height and normalized difference vegetative index (NDVI) readings were performed bi-weekly during the growing season and analyzed across N rates to find correlations.

Literature Review:

Modern cattle production, both beef and dairy, relies on large quantities of harvested forage to meet animal energy requirements. Corn chopped for silage is used to meet cattle's forage needs. In 2017, Virginia's agricultural census reported 1,482,888 total head of cattle with 87,322 being milk cows (National Agricultural Statistics Service, 2017). In total, 99,224 corn acres were chopped for silage to feed animals in 2017 (National Agricultural Statistics Service, 2017). Forage quality is a large factor in how economically a farmer can produce milk or meat.

Forage sorghum has received interest in the United States as an alternative to corn for silage. In Egypt, compared to corn, sorghum had greater water use efficiency and drought tolerance; the latter measured as DM yield in drought stressed plots versus sufficiently watered plots (Hasan, Rabei, Nada, & Abogadallah, 2017). In northeast Spanish loam soils, Farre and Faci (2006) found that sorghum produced greater DM yields under water limited irrigation than corn did. This enables forage sorghum to yield better than corn under conditions in which water may be limited. In Virginia, forage sorghum can be used in situations where drought conditions are expected, soils drain excessively, or a short season crop is needed.

As an ensiled feed for dairy cattle, forage sorghums with the brown midrib (BMR) trait are comparable to corn silage in milk yield (Bernard and Tao, 2015; Yang et al., 2019; Sánchez-Duarte et al., 2019). Dairy producers are able to use sorghum silage as replacement for corn silage and still get similar milk yields (Bernard and Tao, 2015; Yang et al., 2019; Sánchez-Duarte et al., 2019). These studies show that forage sorghum silage can be used in rations as a replacement for corn silage without decreasing the amount of milk produced per cow, and thus the amount of milk shipped for the dairy producer.

As a macro nutrient used by plants, N plays a major role in plant life cycle, meaning N management is a determining factor in crop production. Management of N has been researched in many types of sorghum. Maughen et al. (2012) studied how N fertilization rates related to DM yield in biomass sorghum at three locations in Illinois, all silt loam soils. Yield increased as N rates increased, up to 134 lb N acre-1. At 134 lb N acre^{-1}, the first and second cutting yields were 6.2 ton DM/acre and 2.4 ton DM/acre, respectively (Maughen et al., 2012). The optimum economic yield response was 89 lb N acre^{-1}, in a study in Oklahoma, yielding 7.5 ton DM/acre and 6.6 ton DM/acre for two biomass sorghum varieties (Haankuku et al., 2014). A study conducted in Turkey on sweet sorghum found optimal N rate to be 89 lb N acre^{-1} with a 10.8 ton DM/acre yield (Turgut et al., 2007).

Management of N is also a determining factor in forage sorghum yields. In the first year, a study in Brazil on oxisol soil found an increase in yield and CP concentrations up to the highest N rates applied, 178 lb N acre^{-1}, yielding 11.4 ton DM/acre for forage sorghum grown during the second half of summer with one cutting (Damien et al., 2017). Second year yields were 4.7 ton DM/acre and no correlation between N rates and yield or CP concentrations was found, but a drought and a different hybrid planted were cited as limiting factors (Damien et al., 2017). In another study in Brazil with multiple cuttings (6 first year cuts and 4 for the second), Restelatto et al. (2013) found increased DM yield up to 256 lb N acre^{-1} (5.1 ton DM/acre) in the first year and 220 lb N acre^{-1} (2.3 ton DM/acre) in the second. Due to the higher number of cuts and a longer growing season, six months the first year and 4 months the second, N rates recommended were much higher than more temperate climates that have a shorter growing season and fewer cuttings. The rates in the studies above exceed those recommended by the Virginia Nutrient

Management Standards and Criteria handbook which recommends not exceeding 130 lb N acre^{-1} for forage sorghum.

Crop yield does not give an indication of feed value. Cattle production, especially dairy, requires high feed value forages. Feed value is commonly measured using CP, ADF, NDF, TDN, and digestibility. The Brazilian multi-cut forage sorghum study mentioned earlier by Restellatto et al., (2013) found that N rate increased CP concentrations to 15% at the highest N rate applied, 311 lb N acre^{-1}, but maximum in-vitro digestibility was at 185 lb N acre^{-1}. Recommended rate under tropical summer conditions and soils was 185-190 lbs N/acre for optimum CP and digestibility (Restelatto et al., 2013). However, no difference in NDF and ADF across N rates was found (Restelatto et al., 2013). In Quebec on a sandy loam, sweet sorghum digestibility and NDF decreased as N rates increased from 0 lb N acre^{-1} to 108 lb N acre^{-1} but the opposite was true for plant N concentrations (Belanger et. al., 2017). Marsalisa et al. (2009) found that CP did not change across N rates when using BMR forage sorghum, though only two N rates were used, 95 and 125 lbs N/acre which are considered normal and high N fertilization rates on a semi-aridic clay loam under irrigation in New Mexico. A study in Brazil on forage sorghum found that CP increased with N fertilization up to the highest N rate, 196 lbs N/acre, with 11.1% CP concentrations (Damien et al., 2017).

Given the information in these studies, there is a gap in knowledge based on Virginia's soil, climate and rainfall patterns. Forage sorghum's feed quality response to N rate is known in summer conditions in Brazil, both single cut (Damien et al., 2017) and multiple cuttings (Restelatto et al., 2013). Forage sorghum was tested in New Mexico under irrigated conditions but with limited variability of N rates (Marsalisa et al., 2009). Prior to the initiation of this study, the response of forage sorghum to N rate under conditions similar to Virginia's soil, cropping system and rainfall patterns was unknown.

Methods:

A field experiment was initiated in summer 2019 with five treatments and four replications per treatment. This experiment was conducted in a production field located in Montgomery county, Virginia (located at 37.194956 ^{o}N, -80.587966 ^{o}W). The soil type was Guernsey silt loam (Fine, mixed, superactive, mesic Aquic Hapludalfs) (Natural Resources Conservation Service, 2003), and has been in no-till production for more than 10 years. The previous crop was triticale and crimson clover planted in October 2018 and chopped for silage before sorghum planting. The previous summer crop was Sudan grass, also chopped for silage. Soil samples were collected at four inches of depth and submitted to Virginia Tech Soil Testing laboratory. The recommended phosphorus and potassium rates given by the lab for a yield of 20 ton/acre were used. The five N rates were based on those used in other temperate sorghum research and evenly incremented. After sorghum planting on June 12, plots were flagged and fertilizer was spread. The variety used was SS2010, a sorghum x sudangrass cross with the BMR trait, used for silage and recovers quickly from cutting (Prairie Creek Seed, 2018).

Plots were 20 feet by 10 feet and treatment level was assigned by a randomized complete block design. Seed was planted with a grain drill on 7.5-inch rows and one inch deep with a population of 245,000 seeds/acre. All fertilizer was pre-weighed and spread by hand on June 18. Sixty pounds K_2O per acre and sixty pounds P_2O_5 per acre were supplied through potassium chloride and di-ammonium phosphate applications. The N was supplied from di-ammonium phosphate and granular urea using the fertilization rates given in Table 1. Due to the fertilizer sources available, there was no true 0-N control since di-ammonium phosphate was used; therefore, the lowest N rate was 23.5 lbs. N/acre (Table 1).

Table 1. N, P, and K Fertilization Rates by Treatment Level

Treatment	Nitrogen	Phosphorus	Potassium
	lb N acre^{-1}	lb $P_2 0_5$ acre^{-1}	lb K_2O acre^{-1}
1	23.5	60.0	60.0
2	53.5	60.0	60.0
3	83.5	60.0	60.0
4	113.5	60.0	60.0
5	143.5	60.0	60.0

Normalized difference vegetative index and plant height were measured on July 9 and July 23. NDVI and plant height were measured again at 18 days and 32 days post cutting, on August 27 and September 10. The NDVI values were obtained with a Trimble Green Seeker hand held device (Trimble Inc., Sunnyvale, CA). Plant height was obtained by measuring from the ground to the upper most leaf tip on 10 plants randomly located in each plot. The measurement dates for plant height were the same as NDVI.

Prior to the field being mowed on August 7 and September 23, three feet of one row from the center of each plot was hand collected. Hand collection occurred on August 5 and September 21. Samples were dried in an air dryer at a constant temperature (140 ^{o}F) and ground in a Wiley mill with a 1 mm screen (Thomas Scientific. Swedesboro, NJ) before analyzing with near infrared spectroscopy (NIR). The TDN values were obtained using the equation TDN = 81.088 + (CP * 0.36) - (ADF * 0.77), which originated from the Virginia Tech forage testing laboratory. One-way analysis of variance (ANOVA) was used to compare TDN's across N rates. An ANOVA was also used for NDVI, plant height, CP concentrations, ADF and NDF. The difference was tested to a 0.05 significance level. All statistical calculations were done using JMP (SAS Institute Inc. Cary, NC).

Results:

Average TDN for each N rate is presented in Table 2. Rate of N had no significant effect on TDN, the *p* values for first and second cutting were, 0.6636 and 0.3741, respectively. There was not a significant effect on CP by N rates, with *p* values 0.7058 and 0.3239 for first and second cuttings.

The NDF and ADF values were not significantly different when analyzed across N rates, and are presented in table 3. The *p* values were 0.6519 for ADF and 0.3769 for NDF on the first cutting. The second cutting *p* values were 0.4239 for ADF and 0.1687 for NDF. Yield was not significantly affected by N rate for the first cutting on either dry matter yield ($p = 0.4591$) or wet yield ($p = 0.4725$; Table 4). Second cutting yield was limited by low water and only the wet yield is reported. The second cutting yield was not significantly effected by N rate. The means for wet yield were 9.5 ton/acre and 2.2 ton/acre for the first and second cuttings, respectively.

Table 2. Average total digestible nutrients (TDN) and Crude Protein (CP) by N rate for two cutting forage sorghum. No significant difference across the N rates.

N Rate	**Sampling Date**			
	Aug. 5	Sep. 21	Aug. 5	Sep. 21
lb N acre^{-1}	TDN	TDN	CP	CP
	-----------------------------------%---			
23.5	57.4	58.4	9.2	10.0
53.5	57.6	58.8	9.4	9.9
83.5	55.8	59.0	7.8	10.3
113.5	56.0	60.5	8.4	12.0
143.5	58.5	58.5	10.3	9.9
Mean	**57.1**	**59.0**	**9.0**	**10.4**

Table 3. Forage sorghum Acid Detergent Fiber (ADF) and Neutral Detergent Fiber (NDF) Values by N rate for first (August 5) and second (September 21) cuttings. No significant difference found.

N Rate	Aug. 5 ADF	Sep. 21 ADF	Aug. 5 NDF	Sep. 21 NDF
lb N acre^{-1}	ADF		NDF	
	------------------------------%------------------------------			
23.5	35.0	34.1	56.3	60.3
53.5	34.9	33.6	55.6	57.1
83.5	36.5	33.6	55.2	60.2
113.5	36.6	32.3	54.6	57.5
143.5	34.2	33.9	54.2	57.6
Mean	**35.4**	**33.5**	**55.2**	**58.5**

Table 4. Yield in wet weight, % dry matter and dry matter yield by N rate for first cutting. Wet yield for the second cuttings of forage sorghum. No significance was found.

N Rate	First Cutting (8/5/19)			Second Cutting (9/21/19)
Lb N acre^{-1}	Wet Yield	Dry Matter	Dry Matter Yield	Wet Yield
	ton/acre	%	ton/acre	ton/acre
23.5	6.4	22.5	1.4	1.8
53.5	7.9	22.9	1.8	2.3
83.5	11.0	24.3	2.7	1.4
113.5	11.9	26.8	3.2	1.4
143.5	10.4	22.3	2.3	4.2
Mean	**9.5**	**23.76**	**2.3**	**2.2**

Plant height and NDVI values for each data collection are presented in Table 5. Plant height was not significantly different for any N rate. Plant height at 14 days post emergence and 18 days after cutting are comparable. However, plant height at 28 days post emergence and 32 days after cutting differ, with a greater average plant height at 28 days post emergence. For July

9, August 27 and September 10 there was not a significant difference in NDVI values across N rates. The July 23 NDVI reading did show a significant difference with $p = 0.0059$, with higher N rate correlating to higher NDVI reading.

Table 5. Plant height and NDVI for the 4 measurement dates. July 9 and July 23 are 14 and 28 days post emergence and Aug. 27 and Sep. 10 are 18 days and 32 days after the first harvest. * means significant to p < 0.05. All other data not significant.

N Rate	**Plant Height**			
	July 9	July 23	Aug. 27	Sep. 10
lb N acre^{-1}	Inches			
23.5	20.5	35.9	20.7	27.3
53.5	19.9	36.8	19.8	27.1
83.5	21.5	39.1	20.0	27.2
113.5	21.3	40.4	21.6	28.7
143.5	20.1	39.3	21.9	28.7
Mean	**20.7**	**38.3**	**20.8**	**27.8**
	NDVI			
	July 9	July 23*	Aug. 27	Sep. 10
23.5	0.70	0.73	0.64	0.54
53.5	0.69	0.75	0.63	0.54
83.5	0.70	0.77	0.63	0.51
113.5	0.70	0.77	0.65	0.54
143.5	0.68	0.77	0.68	0.57
Mean	**0.69**	**0.76**	**0.65**	**0.54**

Discussion:

Overall, TDN was not found to be significantly impacted by N fertility, as studies have seen in other forage grasses harvested for silage. In a study on corn silage in Minnesota, Sheaffer, Halgerson, and Jung (2006) found that N fertilization did not affect nutrient composition and digestibility other than CP. A study in Wisconsin on oat forages found CP increased but TDN decreased for increasing N rates (Coblentz et al., 2017). Nakano et al. (2011) found that N fertilization level did not affect TDN in forage rice in a study in southern Japan.

In this study, CP, yield and plant height, were not affected by N fertilization rates, which contrasts with most studies. Restelatto et al. (2013) and Damien et al. & (2017) found that yield and CP increased with increasing N fertilization rates. Increased CP was found with increased N fertilization rates in corn and oats by Sheaffer et al., (2006) and Coblentz et al., (2017) respectively. The ADF and NDF values did not change across N rates in this study which agrees with what Restelatto et al. (2013) and Marsalisa et al. (2009) found.

A limiting factor was the potential of N coming from other sources. The previous winter crop contained crimson clover, which is a legume. Clover forms a symbiotic relationship with bacteria that can fix atmospheric N. This can lead to increased soil N levels as clover residue breaks down. Using recommendations from Virginia Nutrient Management Standards and Criteria for residual N following a clover crop with <25% stand there was 40 lb N acre^{-1} residual N (Commonwealth of Virginia, 2014). The field also had a history of manure application. In spring 2017 and 2018 10 ton/acre of solid dairy manure was applied. In June 2018 10,000 gallons/acre liquid dairy manure was applied. Using values from Virginia Nutrient Management Standards and Criteria for total kjeldahl nitrogen (TKN) and coefficient for residual availability from previous applications, available N can be calculated (Commonwealth of Virginia, 2014). The formula for that is TKN x amount manure applied x coefficient. The TKN values are 7.22 for solid dairy manure and 19.22 for liquid dairy manure. The coefficient for an application two years ago is 0.05 and 0.12 for the previous year application. This calculates to be 7.7 lb N acre^{-1} available from solid manure applied in 2017, 23.1 lb N acre^{-1} from liquid manure applied in 2018, and 8.7 lb N acre^{-1} from solid manure applied in 2018, with a total of 39.5 lb N acre^{-1}. Adding the two nitrogen sources together equals about 80 lb N acre^{-1}. Haankuku et al. (2014), found that their study's first year was influenced by previous field management. A similar circumstance may have affected this study.

Rainfall for the period between August 7 and September 21, the second growing period was below average. Accumulated rainfall for that time period was 2.13 inches, while the 15 year average was 4.12 inches (Climate Corporation, 2020). This compares with 9.35 inches accumulated rainfall for first growing period, from planting on June 6 to the first harvest on August 7 (Climate Corporation, 2020). This was above the 7.15 inches 15 year average (Climate Corporation, 2020). Lower soil water may have been a limiting factor in plant growth and limited the response to N rate. This could also explain the shorter average plant height for the second growing period after first cutting.

The one data set where significance was found is the second NDVI reading on July 23. This is not surprising given the N uptake curve for sorghum, generated by Cavalcante et al. (2018; Figure 1). The first measurement was 14 days post emergence (July 9), at which point the plant's N need was low, approximately 10 lb N acre^{-1}. By the reading at 28 days post emergence (July 23), N needed by the plant would have risen to around 67 lb N acre^{-1}. Greener plants expressed by higher NDVI values explains why in the first reading there was not a difference across N rates, but there was one on the second reading. For the first measurement plant N needs were being met by N that was already in the soil. By July 23, the plants were needing more N than could be supplied by the soil, and N fertilizer rate became the limiting factor.

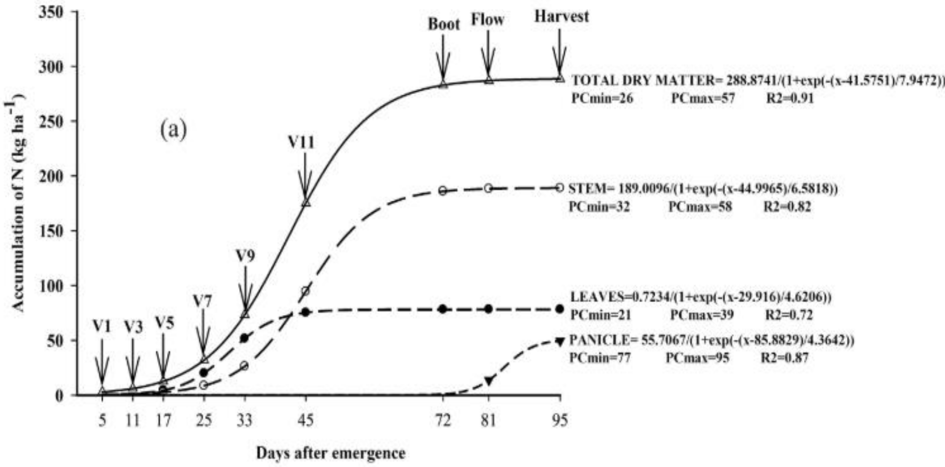

Figure 1. Nitrogen Uptake Curve for Sorghum. N uptake by the plants at 14 days post emergence would be ~ 9 lb N acre^{-1} and ~43 lb N acre^{-1} at 28 days after emergence. For the second cutting N uptake would be ~ 17 lb N acre^{-1} at 18 days after cutting and ~ 67 lb N acre^{-1} for 32 after cutting (Cavalcante et al., 2018)

Conclusion:

No significant effect on TDN, CP, ADF and NDF was found. This aligns with research on forage sorghum in tropical environments (Restelatto et al., 2013; Damien et al., 2017), and on other sorghum types (Belanger, 2017; Marsalisa et al. 2009). Two limiting factors were previous manure applications and low rainfall, which could have changed plant response to N rates. Future research should focus on additional site years, cropping system histories, manure applications and/or forage sorghum hybrids. As we continue to adapt Virginia cropping systems to thrive with climate change, alternative crops could play an important role in agricultural systems.

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Appendix A: Soil Test Results

Lab ID: 19-31789 2019-06-10 MONTGOMERY / 121

Virginia Cooperative Extension

Soil Test Report

Questions? Contact:
Montgomery County Office
755 Roanoke Street, Suite 1G
Christiansburg, VA 24073
540-382-5790

Virginia Tech Soil Testing Laboratory
145 Smyth Hall (0465)
185 Ag Quad Ln
Blacksburg, VA 24061
www.soiltest.vt.edu

SEE NOTES:
1
at www.soiltest.vt.edu under Report Notes

OWNER LAWTON NATHANIEL

COPY FOR

SAMPLE HISTORY

Sample ID	Field ID	LAST CROP Name	LAST CROP Yield	LAST LIME APPLICATION Months Prev.	LAST LIME APPLICATION Tons/Acre	SOIL INFORMATION SMU-1 %	SMU-2 %	SMU-3 %	Yield Estimate	Productivity Group
CFTD3		Sm Gr + Winter Ann Legume - Hay, Gr (36)				30C 52	19B 48		20.0	Ia

LAB TEST RESULTS (see Note 1)

Analysis	P (lb/A)	K (lb/A)	Ca (lb/A)	Mg (lb/A)	Zn (ppm)	Mn (ppm)	Cu (ppm)	Fe (ppm)	B (ppm)	S.Salts (ppm)
Result	28	115	1847	425	2.7	8.1	0.5	7.3	0.5	
Rating	M	M	H	VH	SUFF	SUFF	SUFF	SUFF	SUFF	

Analysis	Soil pH	Buffer Index	Est.-CEC (meq/100g)	Acidity (%)	Base Sat. (%)	Ca Sat. (%)	Mg Sat. (%)	K Sat. (%)	Organic Matter (%)
Result	7.0	6.60	6.5	0.0	100.0	70.8	26.9	2.3	

FERTILIZER AND LIMESTONE RECOMMENDATIONS

Crop: Sorghum (Silage) (22)

Lime, TONS/AC Amount	Lime, TONS/AC Type	Fertilizer, lb/A N	Fertilizer, lb/A P205	Fertilizer, lb/A K20
0		140	60	60

991. "Explanation of Soil Tests, Note 1" and other referenced notes are viewable at www.soiltest.vt.edu under Report Notes.