Seeding and N Fertilization Effects on Yield and Quality of Brachytic Dwarf Brown-Midrib Forage Sorghum Hybrids

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Abstract

Core Ideas

1. The relative advantage of BMR forage sorghums (efficient water usage and requires minimal inputs to grow) over corn silage (forage quality is comparable), led us to study the suitability of forage sorghums in the northeastern USA.
2. A relatively short growing window hinders the adoption of late-maturing forage sorghum hybrids in these regions. Thus, our main ideas were to evaluate the yield and forage quality of a newer early-season brachytic dwarf sorghum (AF7202) relative to a full-season hybrid (AF7401) and to evaluate the yield and forage sorghum quality response of these hybrids to two seeding rates and two N rates above currently recommended levels.

Brown midrib (BMR) forage sorghum (*Sorghum bicolor* (L.) Moench) silage is a reasonable alternative to corn (*Zea mays* L.) silage for areas with limited soil moisture. Traditional forage sorghum varieties are tall and prone to lodging, with low forage quality. Brachtyic dwarf BMR forage lines are shorter, lodging resistant and have higher forage quality. Newer, earlier hybrids have expanded the potential adaptation of forage sorghums to more northern areas. A two-year study was conducted during the 2014 and 2015 growing seasons using newly available brachytic dwarf BMR forage hybrids to determine the effects of different seeding rates and N (nitrogen) fertilization rates on forage dry matter (DM) yield and quality for two hybrids. The experimental design was split-split-plot with four replications. In each replication, main plots were two hybrids [AF7202 (early maturity) and AF7401 (late maturity)], subplots were two seeding rates (198,000 seeds ha^{-1} and 296,400 seeds ha^{-1}), and sub-subplots were two N rates (123 kg ha^{-1} and 168 kg ha^{-1}). Dry matter yield and forage-quality parameters were measured for each treatment. We observed significant differences between hybrids for all the parameters, except neutral detergent fiber digestibility (NDFD) in 2015. The early maturity hybrid, AF7202, had higher yields, higher starch content and net energy for lactation (NE_L) levels than AF7401. The dwarf hybrid, AF7401, had higher crude protein (CP) content and NDFD than AF7202. AF7202 was more responsive to the higher N rate than AF7401. Crude protein was increased as N level increased for both hybrids. Other forage quality traits were unaffected by N rates. Neither variety responded to an increase in seeding rate. This study showed that the earlier brachytic dwarf forage sorghums, such as AF7202, managed with recommended seeding rates and possibly higher N rates, have good potential for high forage yield and quality in central Pennsylvania (PA).

Introduction

Forage sorghum has become an alternative forage for dairy producers in several regions in the USA. The lower water requirement of forage sorghum (Martin 1930; Merrill et al. 2007; Miron et al. 2007; Lamm, Stone, and O'Brien 2007; Howell et al. 2008) has made it an attractive alternative not only in arid irrigated regions, such as Texas, New Mexico and California, but also in the mid-Atlantic region where corn production can be limited on shallow or coarse textured soils (Bhattarai et al. 2019). Forage sorghums can also be double-cropped following small grains harvested for forage in the mid-Atlantic USA, which can add up to 7 t ha^{-1} to the seasonal forage yield. In addition, they provide farms a late spring opportunity for manure spreading following corn planting. Forage sorghums, however, have traditionally suffered from lodging and lower feed quality than corn silage, which has limited their adoption (Bean et al. 2003; Oliver et al. 2005; Howell et al. 2008; Marsalis et al. 2009; Contreras-Govea et al. 2011).

Brown mid-rib (BMR) mutants of sorghum were identified by Porter et al. (1978) and this eventually led to commercial hybrids with improved neutral detergent fiber digestibility (NDFD) compared to conventional (non-BMR) sorghum (Grant et al. 1995; Oliver et al. 2005;

Bean and McCollum 2006), also recently the brachytic dwarf trait was incorporated into forage sorghum hybrids (Liu et al. 2016). The brachytic dwarf plant types have shorter internodes than non-brachytic plant types but maintain equal number of leaves as non-brachytic (taller) sorghum varieties do, making them less vulnerable to lodging (Liu et al. 2016). BMR is a genetic trait and shown to synthesize low lignin content in the plant body, which enhances dairy cattle digestion and thereby significantly increases the lactation potential in dairy cattle compared to non-BMR types. With the combination of brachytic dwarf and BMR traits, new more lodging-resistant hybrids with improved fiber digestibility have become commercially available (Alta Seeds 2013).

The initial introductions of brachytic dwarf, BMR forage sorghums were late-maturity hybrids, such as AF7401. This limited the adoption of forage sorghums in some shorter-season environments with drought prone soils and they were at risk for frost damage in the fall and had limited double-cropping potential. Eventually, newer shorter-season, brachytic BMR hybrids, such as AF7202, became available as an option for some of these regions, such as Pennsylvania and New York (Alta Seeds 2013), but the yield and forage-quality potential of these early-maturing hybrids were not well established.

In some trials, yields from the BMR varieties have not been as high as those of the taller forage sorghum varieties (Bean and McCollum 2006). A possible way to overcome these lower yields of BMR genotypes, especially with their reduced potential for lodging, could be through more intensive management, such as the use of higher N rates and/or seeding rates. Current N fertilization recommendations for forage sorghum in Pennsylvania are 141 kg ha^{-1} to achieve a yield of 11.8 t ha^{-1} (Beegle 2016). Seed industry recommendations have been approximately 110 kg ha^{-1} to 132 kg ha^{-1} for forage sorghums in this region (Kings Agriseeds 2017).

Previous research on N rates on forage sorghum is quite limited. Bean et al. (2003) reported that high amounts of N application did not significantly increase the yields but might increase the incidence of lodging. Marsalis et al. (2010) found no benefit from increasing N rates on conventional or BMR forage sorghums from 106 to 140 kg ha^{-1}. Buxton, Anderson, and Hallam (1999) observed no yield gain by increasing N rates above the recommended levels. In some trials, the highest dry matter yields of forage sorghum were obtained at 125 kg N ha^{-1} (Beyaert and Roy 2005). Moreover, Ketterings et al. (2007) reported that optimum N level was between 125 and 145 kg N ha^{-1} for BMR-sorghum sudangrass in the northeastern USA.

Jahanzad et al. (2013) studied the response of forage sorghum yield and quality in varied seeding and water regimes and showed that increased seeding rates could positively influence forage dry matter yield. The recommended seeding rate for forage sorghum hybrids from industry is 198,000 seeds ha^{-1} (Kings Agriseeds 2017). According to Sanderson et al. (1994), forage sorghum growers generally think that high plant densities improve the forage quality by producing thinner stems and more number of leaves. However, Caravetta, Cherney, and Johnson (1990a) showed decreased tillering, stem diameter, height and leaf-stem ratio with increasing plant density. Moreover, Caravetta, Cherney, and Johnson (1990b) also demonstrated that higher plant densities decreased the forage quality but increased the forage dry matter yield. Previous work with grain sorghum has shown no advantage of using high plant densities as far as aboveground biomass and grain production are concerned (Staggenborg et al. 1999; Berenguer and Faci 2001). Thus, the present study was conducted to understand the role of nitrogen and seeding rates on forage sorghum yield and quality in higher altitude conditions. The specific objectives of this study were 1) to evaluate the yield and forage quality of a newer early-season brachytic dwarf sorghum relative to a full-season hybrid, and 2) to evaluate the yield and forage sorghum quality response of these hybrids to two seeding rates and two N rates above currently recommended levels.

Materials and methods

Experiment location, weather and methodology

Field experiments were conducted in 2014 and 2015 at the Russell E. Larson Research Farm of the Pennsylvania State University (40° 43` N, 77° 56` W, 372 m elevation). Sorghum was planted using no-till techniques in the first week of June during both years of the study. Seasonal precipitation totaled 623 mm in 2014 and 553 mm in 2015 (Table 1). No supplemental irrigation was applied. The experimental design was a split-split-plot with four replications. In each replication, main plots were two varieties, subplots were two seeding rates, and sub-subplots were two N rates. Individual subplots consisted of four 6 m long rows, with a row spacing of 76 cm. The two forage sorghum hybrids were AF7202 and AF7401. AF7202 is a semi-dwarf early-maturity hybrid and AF7401 is a dwarf, medium-maturity hybrid. Both hybrids carry the brown midrib 6 (*bmr-6*) gene. The two seeding rates evaluated were 198,000 (recommended) and 296,400 (high) seeds ha^{-1}. The two N rates were 123 (recommended) and 168 (high) kg ha^{-1}. Basal N rates consisted of a pre-emergence, broadcast application of 112 kg ha^{-1} as UAN, along with 11 kg ha^{-1} N as a starter. A second side-dress N application of 45 kg ha^{-1} N as UAN dribbled between the rows at 45 DAP (days after planting) was used for the higher rate N treatment.

Observations recorded

The days to 50% flowering and plant height were recorded before harvest. All the observations were recorded from the middle two rows in each plot. The 50% flowering was recorded when 50% of the plants had flowered in a plot. Plant height was recorded from the ground level to the top of the inflorescence on three randomly selected plants in each plot. Plant stands were recorded by counting plants when they were approximately 20 cm tall. Plant stand counts were recorded in 2015 but not in 2014.

Harvesting and sample collection

The middle two rows were harvested at 90-95 days after planting at the soft-dough stage using a research forage harvester (Wintersteiger, Salt Lake City, UT) that finely chopped the plant material and recorded the fresh weight from each plot with the sensors attached to the harvester. Two sets of 900 g of sub-samples were collected in each plot to determine dry matter and to assess forage quality. The lab test sub-samples were immediately transferred to a cold storage unit to freeze and preserve the sample quality. The dry weight for each treatment was determined by weighing the fresh sub-samples at harvest and then again after a week of drying at 35°C.

Forage quality analysis

The forage-quality analysis was performed by Cumberland Valley Analytical Services (Waynesboro, PA) using near infrared reflectance (NIR) spectroscopy to predict the levels of neutral detergent fiber (NDF), crude protein (CP), lignin, starch, ethanol-soluble carbohydrates (ESC), total digestible nutrients (TDN), net energy for lactation (NE_L) and other parameters relevant to forage quality. The NDFD was determined via wet chemistry analysis using a 30-hour incubation.

Statistical analysis

All the agronomic, yield and quality parameters were analyzed using the split-split-plot analysis of variance program in the 14th edition of GENSTAT software of Rothamsted

Experimental Station (Payne et al. 2011). PROC MIXED (SAS 2008) was used to generate Type 3 fixed effects for selected variables and mean separation was done using Tukey's test to differentiate the means by ranking for main effects and interaction terms (Steel and Torrie 1981).

Results and discussion

Plant growth was generally good in both years of the study. Precipitation was near normal, except in July and September of 2014 and August of 2015. Mean temperatures were near normal, except in September 2014. In both seasons, all treatments reached the soft-dough harvest maturity before occurrence of a killing frost in the fall.

Flowering dates were influenced by hybrids and seeding rates in both years. The early-maturity hybrid AF7202 flowered 7 days earlier in 2014 and 9 days earlier in 2015 than AF7401. The effect of seeding rate on flowering date was significant in both years. On average, higher seeding rates caused flowering to occur 2 days earlier (data not shown), but this was not consistent across hybrids. In 2014, lower N rate caused flowering dates to be earlier, but this was not consistent across hybrids and seeding rates. In 2015, significant hybrids by nitrogen rates interaction was observed; lower N rate delayed flowering by 2 days in AF7202, whereas the higher N rate delayed flowering in AF7401 by one day (data not shown).

Plant height was impacted primarily by the hybrids, with AF7202 averaging 105 and 110 cm in height in 2014 and 2015, respectively, compared with 81 and 78 cm for AF7401 in 2014 and 2015, respectively. This difference in height was expected because AF7202 is an early-season, semi-dwarf hybrid, whereas AF7401 is a full-season dwarf hybrid (Alta Seeds 2013). In 2014, hybrids by seeding rates interaction for plant height was significant. This occurred because of the good emergence of the hybrids.

Forage dry matter yield

Forage dry matter yields averaged across all treatments were 13.2 and 13.6 t ha^{-1} in 2014 and 2015, respectively, demonstrating that forage sorghum will exhibit a good yield potential in this region (Table 3). Significant differences were observed between hybrids for both years for forage dry matter yield (Tables 2 and 3). The dry matter yield of AF7202 was higher than that of AF7401 in both years (Table 3) and averaged across both years, the AF7202 yield was 1.9 t ha^{-1} higher than that of AF7401. The higher yield of AF7202 could be attributed to its being taller and its ability to mature under more favourable and warmer conditions. The late-maturity hybrid, AF7401, reached the soft-dough stage each year just prior to frost and matured during the cool days of late September.

There were no significant differences attributable to the main effects of seeding rates and N rates for forage dry matter yield in either year. In 2014, a significant hybrid × N rate interaction as well as a seeding rate × N rate interaction occurred (Table 2). The yield of the AF7202 hybrid was increased in 2014 with the higher N rate, whereas that of AF7401 was not (Table 3). The seeding rate × N interaction occurred because yields tended to increase with more N but not at the low seeding rate (data not shown). This was likely because both hybrids tillered well at both seeding rates. In 2015, no differences attributable to N or seeding rate were observed. Our results are similar to those of Marsalis et al. (2009) and Marsalis, Angadi, and Contreras-Govea (2010). Bean et al. (2003) and Carmi et al. (2006) also reported no effect of increasing either seeding rate or N rate above the recommended levels on forage sorghum dry matter yield.

Crude protein

We observed significant differences attributable to hybrids for crude protein in both years, and significant differences between years, with 78 g kg^{-1} in 2014 and 85 g kg^{-1} in 2015 (Tables 2 and 4). The hybrid AF7401 had higher crude protein in both years, with 81 g kg^{-1} in 2014 and 90 g kg^{-1} in 2015; whereas AF7202 had only 75 g kg^{-1} crude protein in 2014 and 81 g kg^{-1} in 2015 (Table 4). On average, the crude protein of AF7401 was 8 g kg^{-1} higher than that of AF7202. N rate increased crude protein content in 2014 but not in 2015 (Table 4). This may be attributable to differences in the plant population stand. In the year 2015, there was a less than ideal plant stand because of poor emergence (data not shown). Individual plants likely had less competition for N, which improved crude protein content and reduced response to additional N. Generally, increasing N rates has resulted in increased amount of crude protein (Oliver et al. 2005; Miron et al. 2007). Seeding rate did influence the crude protein values across years (Table 4). A significant seeding rate × N rate interaction effect was also observed for crude protein for both years (data not shown). When increasing from the low to high seeding rate, with increasing N rate, the crude protein content was also improved in 2014. However, the high seeding rate with high N rate had a negative influence on crude protein content in 2015. The same trend was also observed by Cox and Cherney (2001) in corn, where they showed reduced crude protein in high plant populations (116,000 plants ha^{-1} vs. 80,000 plants ha^{-1}) at several different N levels, with consistent results across different environments. So, recommended seeding rate (80000 plants ha^{-1}) is enough to achieve the desirable crude protein level in forage sorghum.

Starch

Starch content was primarily affected by hybrid and this was significant in both years. The hybrid AF7202 accumulated more starch than AF7401 in both years (Table 5). Averaged across both years, the starch concentration of AF7202 was 295 or 49 g kg^{-1} higher than that of AF7401, which averaged 246 g kg^{-1}. This was because of the earliness of AF7202 (approximately 7 to 9 days earlier than AF7401; data not shown). This led to good grain fill in AF7202 compared to AF7401. N rate did not influence starch content in either year of the study (Tables 2 and 5). Significant seeding rate × N rate, and hybrid × N rate interactions occurred in 2014 but not in 2015 (Table 2). This resulted because starch content increased in AF7401 in each year with additional N, but this did not occur with AF7202.

Neutral detergent fiber digestibility

Neutral detergent fiber digestibility (NDFD) was only affected by hybrid in 2014 (Table 2), when AF7401 had a 19 g kg^{-1} advantage over AF7202 (Table 6). Although not significant, there was a trend for slightly higher NDFD levels in AF7401 in 2015 as well. Averaged across both years, the difference between NDFD of AF7401 and AF 7202 was 12 g kg^{-1}, which may not be biologically significant in animal nutrition. Neither seeding rate, nor N rate had significant effects on NDFD in either year (Tables 2 and 6). Larger differences in NDFD were evident between years, as in 2015, when NDFD averaged 521 g kg^{-1}, whereas in 2014, NDFD averaged 464 g kg^{-1} (Table 6). Carmi et al. (2006) reported that increasing the seeding rate from 200,000 to 260,000 plants ha^{-1} increased the NDFD with an additional irrigation. The higher NDFD in the BMR-forage sorghums may contribute to higher milk yield compared to conventional sorghum (Bean and McCollum 2006; Marsalis et al. 2009). Based on the current study, the recommended seeding rate (198000 plants ha^{-1}) and N rate (123 kg ha^{-1}) should be sufficient to achieve the optimum NDFD levels in BMR-forage sorghums for silage.

Net energy for lactation

The only variable that affected net energy for lactation (NE_L) in this study was hybrid and this was significant in both years (Table 2). In both years, AF7202 had a slightly higher NE_L, which was likely attributable to the higher starch content in this variety. The NE_L is calculated from the acid detergent fiber content, which is inversely related to starch content. Seeding rate and N rate had no impact on NE_L (Tables 2 and 7). The higher NE_L was also likely because of the earliness of AF7202, which facilitated the accumulation of more starch in the Pennsylvania environments.

Conclusions

This study has demonstrated that the development of an earlier semi-dwarf BMR forage sorghum hybrid, such as AF7202, can have a positive impact on the potential of the crop in the northeastern USA, where the growing season can be marginal for some of the longer-season forage sorghum hybrids, such as AF7401. The earlier hybrid (AF7202) had higher yields, higher starch content and NE_L. There was some indication that, in northeastern USA environments, AF7202 might be more responsive to N; so, this should be evaluated further. Seeding rate recommendations appear to be adequate for both hybrids as both appear to tiller well when emergence is less than satisfactory. Of the factors evaluated in this study, the improved genetics of AF7202 had the largest impact on forage sorghum yield and quality. Future development of earlier BMR forage sorghum varieties and hybrids could focus on continuing to improve the NDFD of the early-maturing hybrids, such as AF7202, to match or be higher than that of late-maturing hybrids, such as AF7401.

Declaration of Interest

The authors declare that there is no conflict of interest.

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References

Alta Seeds. 2013. "Sorghums forage and grain." In, edited by Alta Seeds, 201 East John Carpenter Freeway, Irving, Texas. http://altaseeds.advantaus.com.

Bean, B., T. McCollum, M. Rowland, and K. McCuistion. 2003. "Seeding and nitrogen rate effect on forage yield, lodging, and nutrient composition of two brown midrib forage sorghums." http://agrilife.org/amarillo/files/2010/11/Seedingnitrogenrate2003.pdf.

Bean, B., and T. McCollum. 2006. "Summary of six years of forage sorghum variety trials." http://amarillo.tamu.edu/files/2010/11/SixYearForageSorghumSummary.pdf.

Beegle, D.B. 2016. *Soil fertility management*. Vol. 1, *The Agronomy Guide*. Cooperative Extension, The Pennsylvania State University, University Park, PA.

Berenguer, M.J., and J.M. Faci. 2001. "Sorghum (Sorghum bicolor (L.) Moench) yield compensation processes under different plant densities and variable water supply." *European Journal of Agronomy* 15:43-55.

Beyaert, R. P., and R.C. Roy. 2005. "Influence of nitrogen fertilization on multi-cut forage sorghum–sudangrass yield and nitrogen use." *Agronomy Journal* 97 (6). doi: 10.2134/agronj2005.0079.

Buxton, D.R., I.C. Anderson, and A. Hallam. 1999. "Performance of sweet and forage sorghum grown continuously, double-cropped with winter rye, or in rotation with soybean and maize." *Agronomy Journal* 91:93-101.

Bhattarai, B., S. Singh, C.P. West, and R. Saini. 2019. "Forage potential of pearl millet and forage sorghum alternatives to corn under the water limiting conditions of the Texas High Plains: A Review." *Crop Forage and Turfgrass Management* 5(1):1-12.

Caravetta, G.J., J.H. Cherney, and K.D. Johnson. 1990a. "Within-row spacing influences on diverse sorghum genotypes: I. Morphology." *Agronomy Journal* 82:206-10.

Caravetta, G.J., J.H. Cherney, and K.D. Johnson. 1990b. "Within-row spacing influences on diverse sorghum genotypes: II. Dry matter yield and forage quality." *Agronomy Journal* 82:210-5.

Carmi, A., Y. Aharoni, M. Edelstein, N. Umiel, A. Hagiladi, E. Yosef, M. Nikbachat, A. Zenou, and J. Miron. 2006. "Effects of irrigation and plant density on yield, composition and in vitro digestibility of a new forage sorghum variety, Tal, at two maturity stages." *Animal Feed Science and Technology* 131 (1-2):121-33. doi: 10.1016/j.anifeedsci.2006.02.005.

Contreras-Govea, F., M. Marsalis, S. Angadi, G. Smith, L. M. Lauriault, and D. VanLeeuwen. 2011. "Fermentability and nutritive value of corn and forage sorghum silage when in mixture with lablab bean." *Crop Science* 51 (3). doi: 10.2135/cropsci2010.05.0282.

Cox, W.J., and D.J.R. Cherney. 2001. "Row spacing, plant density, and nitrogen effects on corn Silage." *Agronomy Journal* 93 (3):597-602.

Grant, R. J., S.G. Haddad, K.J. Moore, and J.F. Pedersen. 1995. "Brown midrib sorghum silage for midlactation dairy cows." *Journal of Dairy Science* 78:1970-80.

Howell, T.A. , S.R. Evett, J.A. Tolk, K.S. Copeland, P.D. Colaizzi, and P. Gowda. 2008. "Evapotranspiration of corn and forage sorghum for silage." *World environmental and water resources congress* 10 (1):1-10.

Jahanzad, E., M. Jorat, H. Moghadam, A. Sadeghpour, M. R. Chaichi, and M. Dashtaki. 2013. "Response of a new and a commonly grown forage sorghum cultivar to limited irrigation and planting density." *Agricultural Water Management* 117:62-9. doi: 10.1016/j.agwat.2012.11.001.

Ketterings, Q. M., J. H. Cherney, G. Godwin, T. F. Kilcer, P. Barney, and S. Beer. 2007. "Nitrogen management of brown midrib sorghum × sudangrass in the northeastern USA." *Agronomy Journal* 99 (5). doi: 10.2134/agronj2006.0350.

Kings Agriseeds. 2017. "Product information guide " In *Product information guide*, edited by Kings Agriseeds, 1828 Freedom Rd, Lancaster, PA. http://www.kingsagriseeds.com.

Lamm, F.R., L.R. Stone, and D.M. O'Brien. 2007. "Crop production and economics in northwest kansas as related to irrigation capacity." *Applied Engineering in Agriculture* 23 (6):737-45.

Liu, C., Q. Ketterings, K. Czymmek, T. Kilcer, J. Cherney, M. Hunter, K. O' Neil, and S. Lyons. 2016. "Guidance for growing BMR brachytic dwarf forage sorghum." *Cornell University Cooperative Extension Agronomy Fact Sheet Series* 92:1-2.

Marsalis, M. A., S. V. Angadi, and F. E. Contreras-Govea. 2010. "Dry matter yield and nutritive value of corn, forage sorghum, and BMR forage sorghum at different plant populations and nitrogen rates." *Field Crops Research* 116 (1-2):52-7. doi: 10.1016/j.fcr.2009.11.009.

Marsalis, M.A., S. V. Angadi, F.E. Contreras-Govea, and R.E. Kirksey. 2009. "Harvest timing and by product addition effects on corn and forage sorghum silage grown under water stress." *Agricultural Experiment Station Bulletin* 799.

Martin, J. H. 1930. "The comparative drought resistance of sorghums." *Agronomy Journal* 22:993-1003.

Merrill, S. D., D. L. Tanaka, J. M. Krupinsky, M. A. Liebig, and J. D. Hanson. 2007. "Soil water depletion and recharge under ten crop species and applications to the principles of dynamic cropping systems." *Agronomy Journal* 99 (4):931-8. doi: 10.2134/agronj2006.0134.

Miron, J., E. Zuckerman, G. Adin, R. Solomon, E. Shoshani, M. Nikbachat, and E. Yosef. 2007. "Comparison of two forage sorghum varieties with corn and the effect of feeding their silages on eating behavior and lactation performance of dairy cows." *Animal Feed Science and Technology* 139 (1-2):23-39. doi: 10.1016/j.anifeedsci.2007.01.011.

Oliver, A. L., J. F. Pedersen, R. J. Grant, and T. J. Klopfenstein. 2005. "Comparative effects of the sorghum bmr-6 and bmr-12 genes: I. Forage sorghum yield and quality." *Crop Science* 45 (6). doi: 10.2135/cropsci2004.0644.

Payne, R.W., D.A. Murray, S.A. Harding, D.B. Baird, and D.M. Soutar. 2011. "An introduction to GenStat for windows (14th Edition)." *VSN International, Hemel Hempstead, UK*.

Porter, K. S., J. D. Axtell, V. L. Lechtenberg, and V. F. Colenbrander. 1978. "Phenotype, fiber composition, and in vitro dry matter disappearance of chemically induced brown midrib (bmr) mutants of sorghum." *Crop Science* 18:205-8.

Sanderson, M.A. , G. Ali, M.A. Hussey, and F. Miller. 1994. "Plant density effects on forage quality and morphology of four sorghum cultivars." *Proceedings of American Forage Grassland Council* 3:237-41.

SAS. 2008. "The SAS system for windows." *SAS Institute, Cary, NC.* Release 9.2.

Staggenborg, S.A., D.L. Fjell, D.L. Devlin, W.B. Gordon, and B.H. Marsh. 1999. "Grain sorghum response to row spacings and seeding rates in Kansas." *Journal of Production Agriculture* 12 (3):390-5.

Steel, R.G.D. , and J.H. Torrie. 1981. *Principles and procedures of statistics: A biometrical approach*. Edited by R.G.D. Steel and J.H. Torrie. Vol. 2: McGraw-Hill, New York.

Table 1. Monthly rainfall and mean temperature during the growing seasons of 2014 and 2015 at Rock Springs, PA.

	Rainfall (mm)		Minimum temperature (^0C)		Maximum temperature (^0C)		Mean temperature (^0C)	
	2014	2015	2014	2015	2014	2015	2014	2015
June	123	166	14	14	25	24	19	19
July	80	158	15	15	26	27	20	21
August	120	51	13	13	24	26	19	19
September	34	75	11	12	22	25	16	18

Table 2. Analysis of variance for flowering, plant height, dry matter (DM) yield, crude protein (CP), starch, neutral detergent fiber digestibility (NDFD), and net energy for lactation (NE_L) for the summer 2014 and 2015 with two varieties, two seeding rates (SR), and two N rates (NR).

Source	d.f.	Flowering (days)	Plant height (cm)	DM yield ($t\ ha^{-1}$)	CP ($g\ kg^{-1}$)	Starch ($g\ kg^{-1}$)	NDFD ($g\ kg^{-1}$)	NE_L ($Mcal\ kg^{-1}$)
2014								
Variety (Var)	12	***	***	***	*	**	*	***
Seeding rate (SR)	3	***	***	NS	NS	**	NS	NS
Nitrogen rate (NR)	6	***	NS	NS	***	NS	NS	NS
SR × NR	6	**	NS	*	*	*	NS	NS
Var × SR	12	NS	**	NS	NS	NS	NS	NS
Var × NR	12	NS	NS	**	NS	*	NS	NS
Var × SR × NR	12	*	NS	NS	NS	NS	NS	NS
2015								
Variety (Var)	12	**	***	***	***	***	NS	***
Seeding rate (SR)	3	*	NS	NS	NS	NS	NS	NS
Nitrogen rate (NR)	6	NS	NS	NS	NS	NS	NS	NS
SR × NR	6	NS	NS	NS	**	NS	NS	NS
Var × SR	12	*	NS	NS	NS	NS	NS	NS
Var × NR	12	*	NS	NS	NS	NS	NS	NS
Var × SR × NR	12	NS	NS	NS	NS	NS	NS	NS

*significant at p = 0.05.

**significant at p = 0.01.

***significant at p = 0.001.

NS, non-significant at p = 0.05.

Table 3. Total seasonal dry matter (DM) yield (t ha^{-1}) of sorghum forage varieties at two seeding rates (SR) and two N rates (NR) for two cropping seasons at Rock Springs, PA.

Forage dry matter yield (t ha^{-1})	2014			2015		
	Cultivar			Cultivar		
	AF7401	AF7202	Means	AF7401	AF7202	Means
Variety	12.3B†	14.1A†	13.2***	12.6B†	14.6A†	13.6***
LSD	0.6			0.6		
N rate (kg ha^{-1})						
123	12.6	13.7	13.1a‡	12.9	14.7	13.8a‡
168	12.0	14.6	13.3a‡	12.3	14.5	13.4a‡
LSD	0.5			0.5		
Seeding rate (ha^{-1})						
198000	12.3	14.1	13.2a‡	12.1	14.3	13.2a‡
296400	12.3	14.1	13.2a‡	13.1	14.9	14.0a‡
LSD	0.4			0.8		

†Means in a row with the same uppercase letter are not significantly different from each other at p = 0.05.

‡ Means in a column with the same lowercase letter are not significantly different from each other at p = 0.05.

***significant at p = 0.001.

Table 4. Crude protein content (g kg^{-1}) of sorghum forage varieties at two seeding rates (SR) and two N rates (NR) for two cropping seasons at Rock Springs, PA.

Crude protein (g kg^{-1})	2014			2015		
	Cultivar			Cultivar		
	AF7401	AF7202	Means	AF7401	AF7202	Means
Variety	81A†	75B†	78*	90A†	81B†	85***
LSD	5			2		
N rate (kg ha^{-1})						
123	75	78	73b‡***	90	81	86a‡NS
168	87	80	84a‡***	90	81	85a‡NS
LSD	4			2		
Seeding rate (ha^{-1})						
198000	80	72	76a‡	92	81	86a‡
296400	82	78	80a‡	89	81	85a‡
LSD	6			3		

†Means in a row with the same uppercase letter are not significantly different from each other at p = 0.05.

‡ Means in a column with the same lowercase letter are not significantly different from each other at p = 0.05.

*significant at p = 0.05. ***significant at p = 0.001. NS, non-significant at p = 0.05.

Table 5. Starch content (g kg-1) of sorghum forage varieties at two seeding rates (SR) and two N rates (NR) for two cropping seasons at Rock Springs, PA.

Starch (g kg-1)	2014			2015		
	Cultivar			Cultivar		
	AF7401	AF7202	Means	AF7401	AF7202	Means
Variety	218B†	273A†	245**	273B†	317A†	295***
LSD	22			7		
N rate (kg ha-1)						
123	204	276	251a‡	268	322	295a‡
168	232	270	240a‡	278	312	295a‡
LSD	17			13		
Seeding rate (ha-1)						
198000	228	284	256a‡	264	315	290a‡
296400	208	262	235a‡	282	319	300a‡
LSD	11			20		

†Means in a row with the same uppercase letter are not significantly different from each other at p = 0.05.
‡ Means in a column with the same lowercase letter are not significantly different from each other at p = 0.05.
**significant at p = 0.01. ***significant at p = 0.001.

Table 6. NDFD (g kg-1) of sorghum forage varieties at two seeding rates (SR) and two N rates (NR) for two cropping seasons at Rock Springs, PA.

NDFD (g kg-1)	2014			2015		
	Cultivar			Cultivar		
	AF7401	AF7202	Means	AF7401	AF7202	Means
Variety	473A†	454B†	464*	523A†	519A†	521NS
LSD	21			21		
N rate (kg ha-1)						
123	467	455	461a‡	526	517	521a‡
168	480	453	466a‡	520	522	521a‡
LSD	16			14		
Seeding rate (ha-1)						
198000	466	458	462a‡	527	518	518a‡
296400	480	450	465a‡	519	521	524a‡
LSD	26			19		

†Means in a row with the same uppercase letter are not significantly different from each other at p = 0.05.

‡ Means in a column with the same lowercase letter are not significantly different from each other at p = 0.05. *significant at p = 0.05. NS, non-significant at p = 0.05.

Table 7. NE_L (Mcal kg^{-1}) of sorghum forage varieties at two seeding rates (SR) and two N rates (NR) for two cropping seasons at Rock Springs, PA.

NE_L (Mcal kg^{-1})	2014			2015		
	Cultivar			Cultivar		
	AF7401	AF7202	Means	AF7401	AF7202	Means
Variety	1.55B†	1.56A†	1.56***	1.54B†	1.55A†	1.55***
LSD	0.02			0.01		
N rate (kg ha^{-1})						
123	1.55	1.56	1.55a‡	1.54	1.56	1.55a‡
168	1.55	1.57	1.56a‡	1.54	1.55	1.55a‡
LSD	0.01			0.01		
Seeding rate (ha^{-1})						
198000	1.55	1.56	1.55a‡	1.54	1.55	1.55a‡
296400	1.54	1.56	1.55a‡	1.54	1.55	1.55a‡
LSD	0.01			0.01		

†Means in a row with the same uppercase letter are not significantly different from each other at p = 0.05.

‡ Means in a column with the same lowercase letter are not significantly different from each other at p = 0.05.

***significant at p = 0.001.