Optimal harvest timing for brown midrib forage sorghum yield, nutritive value, and ration performance

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ABSTRACT

Forage sorghum [*Sorghum bicolor* (L.) Moench] is a viable alternative to corn silage (*Zea mays* L.) in double cropping rotations with forage winter cereals in New York due to a later planting date and potentially earlier harvest date of forage sorghum than is typical for corn silage. Our objective was to determine whether harvest of brachytic dwarf brown midrib forage sorghum can take place before the currently recommended soft dough harvest time while maintaining dry matter (DM) yield, forage nutritive value, and total mixed ration performance. Seven trials were conducted on 2 research farms in central New York from 2014 to 2017. Forage sorghum received 1 of 2 fertilizer N rates at planting (112 and 224 kg of N/ha). Stands were harvested at boot, flower, milk, and soft dough stages. Forage samples were analyzed for nutritive value and substituted for corn silage in a typical dairy total mixed ration at varying amounts using the Cornell Net Carbohydrate and Protein System. Timing of harvest affected yield and forage nutritive value for each individual trial and across trials, and the effects were independent of N fertilizer application rate. Averaged across trials, yield ranged from 10.7 Mg of DM/ha for the boot stage to 13.5, 15.2, and 15.8 Mg of DM/ha for the flower, milk, and soft dough stages, respectively. For individual trials, yield either remained constant with harvest beyond the flower stage (4 trials), or beyond the milk stage (1 trial), whereas for 2 trials yield increased up to the soft dough stage. At the later harvest stages, DM, starch, and nonfiber carbohydrates were increased, whereas crude protein, neutral detergent fiber, and 30-h neutral

detergent fiber digestibility were decreased. Without adjusting for DM intake, substitution of corn silage by forage sorghum harvested at the soft dough stage resulted in stable predicted metabolizable energy allowable milk, whereas the reduced starch content of earlier harvested sorghum resulted in less metabolizable energy allowable milk with greater substitution of corn silage for sorghum. Forage sorghum can be harvested as early as the flower or milk stage without losing DM yield, allowing for timely planting of forage winter cereal in a double cropping rotation. However, energy supplementation in the diet is needed to make up for reduced starch concentrations with harvest of sorghum at flower and milk growth stages.

Key words: forage sorghum, ration performance, double cropping, harvest management

INTRODUCTION

Efficient home-grown forage production is critical for the long-term sustainability and profitability of the dairy industry in New York (Soberon et al., 2015). The most common forages grown in the northeast United States are corn silage and alfalfa (*Medicago sativa* L.) grass mixes, which are typically rotated every 3 to 4 years. Double cropping (harvesting 2 crops within a single growing season) of corn silage with winter cereals such as triticale (*× Triticosecale* Wittm.) and cereal rye (*Secale cereale* L.) grown for silage is becoming a popular practice in the region. The increased adoption of this practice reflects both the economic benefits of having an additional source of on-farm produced forage, and environmental benefits, such as reduced risk of soil erosion and improved uptake and recycling of nutrients between corn silage growing seasons (Ketterings et al., 2015).

It is recommended to plant winter cereals by mid-September and harvest at the flag-leaf stage for optimum forage digestibility (Cherney and Marten, 1982).

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Harvest at the flag-leaf stage typically occurs in mid to late May in New York. The growing season for corn silage can overlap with winter cereal planting in the fall and with harvest in the spring. Thus, alternative warm-season main crops that can be planted in late May or after June 1 (after harvest of the winter cereal) and can be harvested by mid-September need to be evaluated.

Forage sorghum is a warm-season annual grass that requires a minimum soil temperature of 16°C for planting (Peacock and Heinrich, 1984), which does not typically occur in New York until early June. Thus, forage sorghum could fit well in a double crop rotation with winter cereals. In addition to requiring a later planting date, forage sorghum is tolerant to adverse growing conditions including drought and high temperatures (Howell et al., 1997; Lamm et al., 2007; Merrill et al., 2007), which could result in higher yields than for corn silage in dry years.

Corn silage is typically the main forage on dairy farms in New York due to its high yield and energy content for optimized milk production. Studies elsewhere have shown that forage sorghum can have yields comparable to corn silage (Marsalis et al., 2010). Evaluations of forage sorghum yield and nutritive value compared with corn silage grown under soil and weather conditions in the Northeast are needed. In years such as 2015, 2016, and 2017 in New York, for example, with delayed corn planting because of exceptionally wet springs, and in some years, drought conditions during mid-summer (NRCC, 2016), forage sorghum would likely have competed with corn silage for both yield and nutrients.

Typically, conventional forage sorghum varieties outperformed brown midrib (**BMR**) sorghum varieties in yield (Oliver et al., 2005; Marsalis et al., 2009, 2010). For example, Marsalis et al. (2010) reported a 13% lower yield for BMR forage sorghum compared with a conventional variety (21.1 vs. 24.4 Mg of DM/ha, respectively). However, breeding improvements in the past 10 to 15 yr have resulted in new varieties of BMR forage sorghum with the brachytic dwarf trait (Oliver et al., 2005) that can compete in yield with conventional varieties. Brachytic dwarf varieties have higher leaf-to-stem ratios, increased tillering, and shortened internodes, which support greater yields and greater digestibility while also reducing the risk of lodging (Pendleton and Seif, 1961).

For more recently developed varieties, the nutritive value of BMR forage sorghum is comparable to that of corn silage for most components (Grant et al., 1995; Aydin et al., 1999; Marsalis et al., 2010) except for starch concentration, which is often lower in forage sorghum than in corn silage (Oliver et al., 2004; Harper et al., 2017), reflecting harvest at the soft-dough stage or

earlier. Thus, energy supplements might be needed for forage sorghum-based rations.

The effect of using forage sorghum as an alternative to corn silage in dairy diets has been evaluated primarily in the Midwest United States. In Nebraska, Aydin et al. (1999) observed that the primary differences between BMR sorghum-, conventional sorghum-, and corn silage-based TMR were their lignin, ADF, and NDF concentrations, as well as the amount of rolled corn and soybean meal included. Conventional and BMR sorghum TMR had less rolled corn (10.7% DM) and more soybean meal (21.5% DM) than corn silage TMR (11.4% rolled corn and 20.8% soybean meal), whereas the corn silage-based TMR had the lowest concentrations of lignin (3.3% DM), followed by BMR sorghum (5.2% DM) and conventional sorghum (6.4% DM; Aydin et al., 1999). The diet with BMR sorghum performed similarly to the diet with corn silage as the main forage and was superior to the diet based on conventional sorghum in terms of milk production and forage digestibility. Another study in Nebraska also found that cows fed a BMR sorghum-based TMR performed similarly to those fed a corn silage-based TMR while providing for more milk and milk components than cows fed a conventional sorghum-based TMR (Grant et al., 1995). Starch concentrations for these studies were not reported. However, in both of these studies, forage sorghum was harvested at the hard-dough stage, which is later than recommended for sorghum forage production in New York. A third study in Nebraska that compared 2 hybrids of BMR forage sorghum (**BMR-6** and **BMR-18**) with conventional sorghum and corn silage had findings consistent with those by Grant et al. (1995) and Aydin et al. (1999), including lower lignin in sorghum-based diets and milk production of cows similar to cows fed a corn silage-based diet (Oliver et al., 2004). A recent study in Pennsylvania showed that DMI, milk yield, and milk protein decreased whereas milk fat and ECM yield increased with partial replacement of corn silage with BMR forage sorghum harvested at the milk stage in a dairy TMR (Harper et al., 2017). The authors did not adjust the baseline diet beyond replacing 10% of the corn silage in the diet with sorghum silage. The lower starch content of the immature sorghum likely played a part in reduced milk yields. Addition of energy supplements may be needed to avoid milk yield decline.

Oliver et al. (2004) reported differences in starch and 48-h NDF digestibility (**NDFD₄₈**) concentrations among sorghum- and corn silage-based diets as well. Starch was greatest in the corn silage (19.9% DM), intermediate for BMR-6 (16.8% DM), and BMR-18 (14.5% DM) sorghum, and least in conventional sor-

ghum (10.9% DM). The NDFD₄₈ of the BMR-6 sorghum (62.4%), BMR-18 sorghum (61.0%), and corn silage (59.1%) were not different but were greater than the conventional sorghum (56.4%; Oliver et al., 2004).

In addition to variety selection, stage of maturity at harvest can affect both the yield and nutritive value of forage sorghum. A study with BMR forage sorghum in Israel reported that when the sorghum was harvested at early heading, DM and lignin concentrations were reduced compared with sorghum harvested at the soft dough stage (Miron et al., 2006). Dry matter yield, NDF, and NDFD₄₈, however, were not different between the 2 growth stages. A similar forage sorghum study in Turkey found that yield, as well as concentrations of DM and lignin, increased with maturity, whereas CP, NDF, and ADF concentrations decreased (Atis et al., 2012), leading to a recommendation to delay forage sorghum harvest until the soft dough stage when DM concentration is greater. However, although low DM concentrations can affect silage quality and increase risk of silage leachate, inoculant use (Filya, 2003) and adjustments in forage chop length can facilitate proper ensiling even if forages are relatively low in DM concentration. Mowing and wilting forage sorghum to reduce moisture have been used in the Midwest to increase forage sorghum DM (Grant et al., 1995). However, this practice has not been tested in the humid Northeast. Harvest of forage sorghum before the soft dough stage to facilitate timely planting of a winter cereal in the Northeast might be feasible, but research is needed to determine effect of timing of harvest of the sorghum on tradeoffs between forage yield and quality.

The objective of this study was to determine whether brachytic dwarf BMR forage sorghum grown in New York can be harvested before the soft dough stage to allow for an earlier winter cereal double crop planting, while maintaining yield, nutritive value, and ration performance.

MATERIALS AND METHODS

Locations and Experimental Design

Seven field trials were established at 2 locations from 2014 to 2017. Four trials were conducted at the Musgrave research farm in Aurora, New York (42.73°N, -76.66°W) in 2014 (trial 1), 2015 (trial 2), 2016 (trial 3), and 2017 (trial 4). The soil type was a Lima silt loam (fine-loamy, mixed, semiactive, mesic Oxyaquic Hapludalfs) classified as soil management group 2 (Ketterings et al., 2003). Three trials were conducted at the Pullyen-Tailby research farm in Tompkins County, New York (42.43°N, -73.67°W) in 2014 (trial 5), 2015 (trial 6), and 2017 (trial 7). The trial in 2016 at this location

failed to emerge due to a severe lack of precipitation following planting. The soil type was a mix of Hudson silt loam (fine, illitic, mesic Glossaquic Hapludalfs) and collamer silt loam (fine-silty, mixed, semiactive, mesic Glossaquic Hapludalfs), classified as soil management group 3 (Ketterings et al., 2003).

Trials were organized in a randomized complete block design with repeated measures in 4 replications. Treatments included 4 timings of harvest and 2 N rates broadcasted (surface-applied) at planting (112 and 224 kg of N/ha) as Agrotain-treated urea (Koch Agronomic Services, LLC, Wichita, KS). Harvests were repeated in the same plots across 4 wk.

Weather data were collected from an on-site weather station for the Musgrave farm, and the Cornell University weather station in Tompkins County, New York, approximately 5 km from the Pullyen-Tailby farm. Precipitation was consistent with the 30-yr average in 2014 and 2015. Precipitation was greater than normal in late spring and early summer of 2017, and lower than normal in spring and early summer in 2016 (Table 1).

Planting and Harvest

All plots were prepared with primary (chisel plow) and secondary (disc) tillage before planting. A brachytic dwarf BMR-6 forage sorghum cultivar (AF7102, Alta Seeds, Irving, TX) adapted to the northeastern United States was planted with a 4-m conventional drill at 17 kg/ha and 3 cm depth in 38 cm row spacing followed by rolling. Planting dates ranged from June 3 to July 2 (Table 2). The most economic rates of N (**MERN**) were calculated for each trial by fitting a quadratic plateau model to the yield response data (5 rates of N), as reported in Lyons et al. (2019). A fertilizer cost of \$1.54 per kg of N and forage value of \$108.86 per Mg silage were used to determine the MERN (Lyons et al., 2019). In short, for trials 1 and 6 the MERN exceeded the 224 kg of N/ha rate, whereas MERN in the 2 other Tompkins County trials (trials 5 and 7) were 157 and 150 kg of N/ha, respectively. The 3 other Cayuga County trials had MERN of 241, 229, and 262 kg of N/ha for trials 2, 3, and 4, respectively. Thus, whereas the highest of the selected N rates (224 kg of N/ha) for the assessment of timing of harvest on yield and nutritive value met or exceeded the MERN for 3 of the trials, for the other 4 trials an increased N rate could have resulted in somewhat greater yields.

Sorghum was harvested at 4 growth stages: boot (stage 5), flower (stage 6), milk (stage 6.5), and soft dough (stage 7; Vanderlip and Reeves, 1972). Trial 3 did not include a milk stage harvest due to an adjustment in protocol in 2016. In 2017 the milk stage harvest was added again. Harvest was completed by hand using

Table 1. Monthly precipitation and temperature for 7 brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017¹

Trial	County	Year	June	July	August	September	October
Total monthly precipitation (cm)							
1	Cayuga	2014	7.3	11.7	11.3	5.9	6.5
2		2015	20.3	7.1	3.5	13.2	7.2
3		2016	2.8 ²	4.8 ²	11.6 ²	9.6 ²	20.5
4		2017	9.7	18.6	3.8	6.6	15.2
		30-yr mean	10.0	8.7	8.1	10.4	8.3
5	Tompkins	2014	13.1	9.8	15.4	5.6	7.6
6		2015	16.7	12.5	3.6	10.1	5.6
7		2017	9.4	16.9	6.0	5.6	17.9
		30-yr mean	10.2	9.6	9.3	9.6	8.2
Average monthly temperature ³ (°C)							
1	Cayuga	2014	19.1	20.3	19.0	16.1	11.6
2		2015	17.8	20.4	19.8	19.2	9.9
3		2016	18.6	22.1	22.8	18.2	11.5
4		2017	17.8	20.4	19.8	19.2	9.9
		30-yr mean	19.3	21.7	20.8	16.9	10.7
5	Tompkins	2014	18.4	19.9	18.0	15.4	10.8
6		2015	17.6	19.6	19.4	18.4	9.0
7		2017	17.6	19.6	19.4	18.4	9.0
		30-yr mean	18.2	20.6	19.7	15.8	9.6

¹Data were obtained from within-county weather stations (NRCC, 2016).

²2 to 7 d of missing data.

³The average monthly temperature is determined from calculated daily averages [(maximum daily temperature – minimum daily temperature)/2].

a 10-cm cutting height and a 1.5 m × 4 row harvest area, or approximately 1.5 m² (1.5 × 1.5 m), per plot. Given inconsistent stands in some of the trials, gaps between individual plants in a row greater than approximately 30 cm were recorded and area harvested was adjusted accordingly (Lyons et al., 2019).

Soil and Forage Sampling and Analysis

Before fertilization, 2 soil cores (0–20 cm depth) were taken in each plot and composited by replication (Table 3). Soil composites were dried at 50°C and ground to pass a 2-mm screen. Samples were submitted for both baseline fertility analysis (Analytical Laboratory and Maine Soil Testing Service, Orono, ME; Table 3) and Morgan extracted NO₃-N (Nutrient Management Spear Program Laboratory, Ithaca, NY). Soil pH was

measured in a 1:1 (wt/vol) water extract, and soil OM was determined by loss-on-ignition through exposure to 500°C for 2 h (Storer, 1984). The Cornell Morgan soil test was used to extract P, K, Mg, Ca, Mn, and Zn by shaking dried samples in a 1:5 (vol/vol) ratio Morgan solution (1 M sodium acetate buffered at pH 4.8; Morgan, 1941) for 15 min. The extracts were filtered through a Whatman No. 2 equivalent filter paper following procedures outlined in NEC-1012 (Northeast Coordinating Committee for Soil Testing, 2011). The filtered extracts were analyzed for K, Mg, Ca, Mn, and Zn using an inductively coupled plasma atomic emission spectrometer (ICP-AES, JY70 Type II, Jobin Yvon, Edison, NJ). Phosphorus was determined colorimetrically using the ammonium molybdate-ascorbic acid method (Knudsen and Beegle, 1988) with a Lachat QuikChem 8000 flow injection analyzer (Lachat

Table 2. Planting and harvest dates for 7 brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017¹

Trial	County	Year	Planting	Growth stage at harvest			
				Boot	Flower	Milk	Soft dough
1	Cayuga	2014	June 20	Sep. 18	Sep. 23	Oct. 2	Oct. 9
2		2015	July 2	Sep. 3	Sep. 18	Oct. 16	Oct. 30
3		2016	June 3	Aug. 15	Aug. 23	NA ²	Sep. 20
4		2017	June 12	Aug. 24	Sep. 1	Sep. 26	Oct. 5
5	Tompkins	2014	June 21	Sep. 15	Sep. 22	Oct. 1	Oct. 6
6		2015	June 12	Aug. 27	Sep. 17	Oct. 1	Oct. 14
7		2017	June 9	Aug. 22	Aug. 30	Sep. 19	Oct. 2

¹Sorghum was hand-harvested at 4 different growth stages (boot, flower, milk, and soft dough).

²NA = not available.

Table 3. Baseline soil fertility status for 7 brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017¹

Trial	County	Year	pH	SOM ² (g/kg)	Morgan-P ³ (mg/kg)	Morgan-K ³ (mg/kg)	Morgan-Mg ³ (mg/kg)
1	Cayuga	2014	7.7	22	5.2 (H)	59 (H)	282 (VH)
2		2015	7.5	24	7.1 (H)	58 (H)	225 (VH)
3		2016	8.0	24	5.3 (H)	51 (H)	305 (VH)
4		2017	7.9	23	5.3 (H)	70 (H)	337 (VH)
5	Tompkins	2014	5.9	27	18.7 (H)	288 (VH)	137 (VH)
6		2015	5.6	20	17.0 (H)	150 (VH)	90 (H)
7		2017	6.1	25	19.2 (H)	162 (VH)	168 (VH)

¹Values are averages of four 0- to 20-cm core soil composites within each field.

²Soil organic matter (SOM) determined by loss-on-ignition (Storer, 1984).

³Morgan extraction (Morgan, 1941): low, medium, high (H), and very high (VH) according to Cornell Cooperative Extension (2018).

Instruments, Milwaukee, WI). The Morgan extraction (Morgan, 1941) was used to extract soil NO₃-N followed by determination of NO₃-N in solution with a discrete analyzer (EasyChem Plus, Chinchilla Scientific LLC, Oak Brook, IL). Soil pH for all trials ranged from 5.9 to 8.0. Although a soil pH of 6.0 is often recommended for sorghum, it will grow at a pH as low as 5.5 (Teutsch, 2009), and thus soil pH was unlikely to significantly affect performance. Soil OM ranged from 20 to 27 g/kg. Soil test P, K, and Mg were classified as high or very high, and Mn was normal for all trials according to Cornell Cooperative Extension (2018).

Plants were coarsely ground using a leaf shredder-chipper (MacKissic Inc., Parker Ford, PA), subsampled, placed in sealed plastic bags, and kept cold until reaching the laboratory for drying. Forage subsamples were dried in a forced-air oven at approximately 55°C until stable weights were reached and DM concentrations were determined. Dried samples were ground with a Wiley mill (Thomas Scientific, Swedesboro, NJ) to pass a 1-mm screen and submitted to Cumberland Valley Analytical (Waynesboro, PA) for analysis with a Foss 5000 NIR. Total forage N was multiplied by 6.25 to determine CP concentration following method 46–10.01 (AACC International, 1999).

Diet Simulation

The Cornell Net Carbohydrate and Protein System v. 6.55 (Van Amburgh et al., 2015) was used to evaluate the effect of corn silage substitution by forage sorghum in a typical dairy TMR on predicted ME and MP allowable milk. The control diet was a corn silage-based TMR (Table 4). The BMR forage sorghum was substituted for 0, 25, 50, 75, and 100% of corn silage in the diet to demonstrate the effect of ration changes on ME and MP allowable milk. No adjustments for DMI were considered in this evaluation, although changes in NDF digestibility could affect feed intake (Kendall et al., 2009).

Statistical Analysis

For both locations, initial analyses with PROC MIXED of SAS with the Tukey adjustment for multiple comparisons (SAS Institute, 1999) showed a significant interaction between growth stage and year for all nutritive value parameters. For yield, a significant interaction was observed between growth stage and year for the Tompkins County trials, and a significant effect of year for the Cayuga County trials. Because of this, trials were analyzed individually (by location and year) using PROC MIXED of SAS v. 9.4 with the Tukey adjustment for multiple comparisons (SAS Institute, 1999). If the interaction between N rate and timing of harvest was not significant, main effects were determined and presented. Significance is defined as $P \leq 0.05$.

RESULTS AND DISCUSSION

Nitrogen Rate, Yield, and Forage Nutritive Value

No interaction was observed between timing of harvest and N rate for yield ($P \geq 0.1991$; Table 5). Yield at the higher N rate and soft dough stage of harvest ranged from 14.1 Mg of DM/ha (trial 5) to 19.5 Mg of DM/ha (trial 7). As mentioned, yields for 4 of the trials would have been somewhat greater with a higher N application, as MERN for these 4 sites exceeded 224 kg of N/ha. These yields are similar to or greater than those reported by Miron et al. (2005) for irrigated BMR forage sorghum harvested at soft dough stage in Israel (averaging 15.3 Mg of DM/ha) and the yields of a nonirrigated study in Nebraska that ranged from 9.7 to 13.5 Mg of DM/ha when harvested at the hard dough stage (Oliver et al., 2004). Another irrigated study in New Mexico reported BMR forage sorghum yields of 21.1 Mg of DM/ha when harvested at the soft dough stage (Marsalis et al., 2010). Irrigation is not often used in New York due to typically high amounts of rainfall in the Northeast, which could explain yield differences between drier years in New York and yields in the ir-

Table 4. Cornell Net Carbohydrate and Protein System (CNCPS) input parameters for a typical dairy TMR¹

Item	Value
Animal input	
Milk production (kg/d)	40
Mature weight (kg)	750
Age (mo)	42
Days since calving	120
Inputted DMI (kg of DM/d)	26.0
Predicted DMI (kg of DM/d)	23.1
Diet input ² (% of diet)	
Corn silage (300 g/kg of DM, 410 g/kg of NDF), BMR sorghum, ³ or both	38.5
Alfalfa silage (200 g/kg of CP, 400 g/kg of NDF, 170 g/kg of LNDF ⁴)	17.3
Corn grain (ground fine)	17.3
Soybean meal	5.8
Soybean hulls	5.8
Cottonseed (fuzzy)	3.8
Soy Plus ⁵	3.8
Citrus pulp (dry)	1.9
Corn gluten feed (dry)	1.9
Blood meal	0.8
Mineral-vitamin mixture	2.7
Trace mineral premix	0.4

¹Brown midrib (BMR) forage sorghum sample analyses from 7 trials in New York from 2014 to 2017 were substituted for different percentages of corn silage in the diet.

²All diet inputs except for BMR sorghum are derived from the CNCPS library.

³Control diet contains corn silage only. Treatment diets substitute BMR forage sorghum for 0, 50, and 100% of corn silage.

⁴LNDF = g of lignin/kg of NDF.

⁵Dairy Nutrition Plus, Landus Cooperative, Ames, Iowa.

Table 5. Effect (*P*-values) of timing of harvest and N rate and their interaction (Int.) on yield, DM, and forage nutritive value parameters¹

Trial	Timing	N rate	Int.	Timing	N rate	Int.	Timing	N rate	Int.
	Yield			aNDFom			Starch		
1	<0.0001	0.0035	0.9742	<0.0001	0.8414	0.2619	<0.0001	0.0551	0.8027
2	<0.0001	0.0014	0.4080	0.0023	0.5332	0.3135	<0.0001	0.0029	0.0011
3	<0.0001	0.5151	0.7563	<0.0001	0.7235	0.2509	<0.0001	0.7729	0.9148
4	0.0014	0.1391	0.3807	<0.0001	0.0708	0.4218	<0.0001	0.7626	0.6640
5	0.0166	0.1685	0.1991	0.0170	0.7063	0.5441	<0.0001	0.6028	0.9752
6	0.0002	0.0182	0.6278	<0.0001	0.4857	0.8849	<0.0001	0.5780	0.7971
7	<0.0001	0.9060	0.9438	<0.0001	0.1396	0.4142	<0.0001	0.9313	0.5522
Trial	DM			ADF			TDN		
	Timing	N rate	Int.	Timing	N rate	Int.	Timing	N rate	Int.
1	0.0001	0.0010	0.6643	<0.0001	0.3671	0.3732	0.0008	0.0400	0.8861
2	<0.0001	0.0031	0.5745	<0.0001	<0.0001	0.3772	<0.0001	<0.0001	0.4400
3	0.0002	0.7830	0.7128	<0.0001	0.2103	0.2918	<0.0001	0.0459	0.3707
4	<0.0001	0.4612	0.4477	<0.0001	0.0078	0.7567	0.0012	0.0015	0.9526
5	<0.0001	0.0002	0.5116	0.0014	0.2878	0.5134	<0.0001	0.0499	0.3022
6	0.0019	0.1919	0.8716	<0.0001	0.0892	0.8040	<0.0001	0.2077	0.7806
7	<0.0001	0.5198	0.3029	<0.0001	0.0767	0.4672	0.0017	0.0928	0.4660
Trial	CP			NDFD ₃₀			NFC		
	Timing	N rate	Int.	Timing	N rate	Int.	Timing	N rate	Int.
1	0.0317	0.0011	0.7879	<0.0001	0.5369	0.6977	<0.0001	0.1416	0.2614
2	<0.0001	<0.0001	0.6732	<0.0001	0.0257	0.0586	<0.0001	0.1543	0.9275
3	<0.0001	0.0149	0.3442	<0.0001	0.6147	0.9766	<0.0001	0.8415	0.8299
4	<0.0001	0.0043	0.9973	<0.0001	0.2580	0.7540	<0.0001	0.4232	0.7405
5	0.1358	<0.0001	0.7519	<0.0001	0.0790	0.9514	0.0068	0.1268	0.4195
6	<0.0001	0.0085	0.7277	<0.0001	0.9809	0.5300	<0.0001	0.6602	0.5118
7	<0.0001	0.0003	0.1981	<0.0001	0.6693	0.5764	<0.0001	0.9198	0.3131

¹aNDFom = neutral detergent fiber (OM basis with amylase); NDFD₃₀ = neutral detergent fiber digestibility (30 h).

rigated, drier climate of New Mexico as described by Marsalis et al. (2010).

The effect of fertilizer N rate (112 vs. 224 kg of N/ha) on yield and forage nutritive value varied among trials (Table 5). Nitrogen rate had a main effect on yield for 3 trials (trials 1, 2, and 6) and on DM for 3 trials (trials 1, 2, and 5), consistent with the fact that for these trials the MERN was greater than the 224 kg of N/ha rate (Lyons et al., 2019). For these trials, the 112 kg of N/ha rate resulted in lower DM yield and greater DM at harvest (Table 5). Most sorghum research has been conducted in dryland or irrigated cropping systems (Leikam et al., 2003; Westfall and Davis, 2005; Marsalis et al., 2010), and literature on N management of forage sorghum is scant. Thus, research across climates and soil resources is needed to allow for a direct comparison of N needs with values reported in the literature. Although forage nitrate-N was not measured, it should be considered when feeding sorghum as nitrate toxicity is a potential issue for this crop (Adams et al., 1992). However, nitrate-N is usually reduced during the ensiling process as much of it is converted to nitrogen dioxide (Undersander et al., 1999).

No interactions were observed between harvest timing and N rate for CP. For all trials, the 112 kg of N/ha N rate resulted in lower CP concentrations than the 224 kg of N/ha rate. On average for the soft dough

stage, CP ranged from 75 to 85 g/kg for the 112 and 224 kg of N/ha rates, respectively. This range is similar to BMR sorghum CP found in other studies, which ranged from 63 to 97 g/kg (Grant et al., 1995; Aydin et al., 1999; Oliver et al., 2004; Miron et al., 2005, 2006; Marsalis et al., 2010).

There was an interaction between time of harvest and N rate for starch content for 1 trial (trial 2). For this trial, a greater increase occurred in starch content from the boot to the soft dough stage for the 224 kg of N/ha treatment (70 to 174 g/kg, respectively) than for the 112 kg of N/ha treatment (78 to 131 g/kg, respectively). For all other trials, N rate had no effect on starch concentrations; starch content ranged from 94 to 230 g/kg when harvested at the soft dough stage.

No interaction was observed between N rate and timing of harvest for any of the other forage quality parameters (Table 5). The effect of N rate on forage quality indicators was inconsistent among trials. The 224 kg of N/ha rate had decreased ADF content for trials 2 (287 vs. 301 g/kg) and 4 (275 vs. 292 g/kg), decreased NDFD₃₀ for trial 2 (645 vs. 653 g/kg), and increased TDN content for trials 1 (667 vs. 663 g/kg), 2 (699 vs. 690 g/kg), 3 (693 vs. 688 g/kg), 4 (704 vs. 693 g/kg), and 5 (672 vs. 667 g/kg). The same quality parameters were not affected by N rate for the other trials and N rate did not affect aNDFom or NFC at any of the sites

Table 6. Dry matter yield, DM, and CP for 7 brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017¹

Trial	Boot	Flower	Milk	Soft dough	SE	P-value ²
Yield (Mg of DM/ha)						
1	10.9 ^b	13.7 ^a	14.3 ^a	15.7 ^a	0.6	0.0001
2	9.9 ^b	16.2 ^a	18.1 ^a	18.1 ^a	0.6	<0.0001
3	8.1 ^c	10.1 ^b	NA ³	16.3 ^a	0.5	<0.0001
4	11.1 ^b	12.4 ^b	14.8 ^a	12.4 ^b	0.6	0.0002
5	10.9 ^b	12.1 ^{ab}	12.9 ^{ab}	14.1 ^a	0.7	0.0220
6	10.1 ^b	13.9 ^a	14.3 ^a	14.7 ^a	0.7	0.0004
7	13.9 ^c	15.9 ^b	16.5 ^b	19.5 ^a	0.5	<0.0001
DM (g/kg)						
1	221 ^c	259 ^{ab}	244 ^b	270 ^a	3.0	<0.0001
2	215 ^c	266 ^b	290 ^a	302 ^a	4.0	<0.0001
3	201 ^b	208 ^b	NA	293 ^a	7.0	<0.0001
4	203 ^c	241 ^b	274 ^a	291 ^a	4.0	<0.0001
5	221 ^c	258 ^a	243 ^b	238 ^b	2.0	0.0015
6	238 ^b	284 ^a	272 ^{ab}	303 ^a	7.5	<0.0001
7	190 ^d	217 ^c	241 ^b	267 ^a	5.0	<0.0001
CP (g/kg of DM)						
1	91 ^a	80 ^a	85 ^a	75 ^a	3.6	0.0780
2	102 ^a	94 ^b	76 ^c	77 ^c	1.9	<0.0001
3	129 ^a	117 ^b	NA	91 ^c	1.4	<0.0001
4	99 ^a	87 ^{ab}	76 ^{bc}	68 ^c	3.4	<0.0001
5	76 ^a	80 ^a	80 ^a	86 ^a	2.8	0.3777
6	116 ^a	96 ^b	85 ^b	83 ^b	3.8	<0.0001
7	118 ^a	105 ^b	90 ^c	84 ^d	1.4	<0.0001

^{a-d}Different lowercase letters among growth stages within trial represent significant differences ($P \leq 0.05$).

¹Harvest took place at 4 growth stages, and 2 rates of N (112 and 224 kg of N/ha) were applied at planting.

²Overall P-value for growth stage at harvest.

³NA = not available.

either. Findings for NDF content and NDF digestibility are consistent with Marsalis et al. (2010) who reported that NDF content and NDF digestibility were not affected by N rate when 2 N rates were applied (196 and 230 kg of N/ha). However, it is not known what the MERN was for these specific trials in comparison to the 2 rates of N used in the current study.

Harvest Timing and Yield

Timing of harvest affected yield for all trials (Table 6 and Figure 1). For 4 of the trials, DM yield did not increase past the flower stage (trials 1, 2, 5, and 6).

For trial 4, DM yield was maximized at the milk stage, whereas sorghum in trials 3 and 7 continued to increase in DM yield until the soft dough stage. Dry matter yield across trials averaged 10.7, 13.5, 15.2, and 15.8 Mg of DM/ha for the boot, flower, milk, and soft dough stages, respectively. A study in Turkey observed a similar increase in forage sorghum DM yield with maturity, ranging from 10.3 Mg of DM/ha at the panicle emergence stage (between boot and flowering) to 21.1 Mg of DM/ha at the soft dough stage (Atis et al., 2012). The study by Atis et al. (2012) showed a greater increase in DM with maturity most likely reflecting the drier climate in Turkey compared with New York.

Figure 1. Summary of yield and forage nutritive value as affected by growth stage at harvest for 7 brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017. Neutral detergent fiber was analyzed on an OM basis with amylase. Values are the means of all 7 trials. Error bars represent SEM. aNDFom = neutral detergent fiber (OM basis with amylase); NDFD₃₀ = neutral detergent fiber digestibility (30 h).

Two studies comparing forage sorghum yield, DM, and forage quality at different growth stages stated that DM was much lower at the early growth stages compared with soft dough, resulting in the recommendation to delay harvest until the soft dough stage (Miron et al., 2006; Atis et al., 2012). In our study, DM increased with later harvests when averaged across trials (Table 6), but individual trials differed in their response. For 3 trials (trials 1, 5, and 6), DM concentration did not increase beyond the flower stage. For 2 trials (trials 2 and 4), DM increased until the milk stage, whereas for 2 trials (trials 3 and 7), DM was maximized at the soft dough stage. On average across all trials, DM was 213, 249, 258, and 280 g/kg for the boot, flower, milk, and soft dough stages, respectively. Given the lower DM content of these forages, management strategies such as use of bacterial inoculants could aid the ensiling process (Filya, 2003).

Harvest Timing and Forage Nutritive Value

For 1 trial CP was not affected by harvest timings (trial 5; $P = 0.3777$; Table 6). All other trials decreased in CP with maturity or showed a similar trend (trial 1;

$P = 0.0780$). On average across all trials, CP was 104, 94, 82, and 81 g/kg of DM at the boot, flower, milk, and soft dough stages, respectively. These results are consistent with findings by Miron et al. (2006), which showed a decrease in CP from 79 g/kg of DM at early heading to 73 g/kg of DM at the soft dough stage of BMR sorghum. Atis et al. (2012) also reported a decrease in CP with increasing maturity, ranging from 83 g/kg at panicle emergence to 77 g/kg at the soft dough stage.

Later harvest timings resulted in decreased aNDFom, ADF, and NDFD₃₀ for all trials (Table 7). For aNDFom, trials 1 and 6 were lowest for sorghum harvested at the soft dough stage, trials 2, 4, and 7 decreased in aNDFom until the milk stage, and trials 3 and 5 decreased in aNDFom until the flower stage. On average, aNDFom decreased from 547 g/kg of DM at the boot stage to 458 g/kg of DM at the soft dough stage, a decrease of 38 g/kg of DM from the boot to the flower stage, 27 g/kg of DM from the flower to the milk stage, and 25 g/kg of DM from the milk to the soft dough stage, whereas starch content increased. This NDF decrease was also observed in the studies by Miron et al. (2006) and Atis et al. (2012), who documented an aver-

Table 7. Forage fiber characteristics for 7 brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017¹

Trial	Boot	Flower	Milk	Soft dough	SE	P-value ²
aNDFom ³ (g/kg of DM)						
1	556 ^a	536 ^b	531 ^b	476 ^c	6.3	<0.0001
2	523 ^a	514 ^{ab}	456 ^{bc}	446 ^c	1.6	0.0019
3	563 ^a	455 ^b	NA ⁴	444 ^b	1.6	<0.0001
4	544 ^a	501 ^b	473 ^c	459 ^c	6.6	<0.0001
5	560 ^a	529 ^b	525 ^b	531 ^{ab}	7.6	0.0118
6	513 ^a	516 ^a	487 ^b	397 ^c	1.1	<0.0001
7	570 ^a	516 ^b	458 ^c	452 ^c	6.1	<0.0001
ADF (g/kg of DM)						
1	322 ^a	318 ^a	312 ^a	286 ^b	4.0	<0.0001
2	37 ^a	308 ^a	269 ^c	292 ^b	2.9	<0.0001
3	312 ^b	324 ^a	NA	260 ^c	2.8	<0.0001
4	304 ^a	283 ^b	277 ^b	272 ^b	4.0	<0.0001
5	329 ^a	306 ^b	308 ^b	307 ^b	4.0	0.0010
6	286 ^{ab}	295 ^a	272 ^{bc}	265 ^c	3.9	<0.0001
7	313 ^a	286 ^b	265 ^c	264 ^c	3.3	<0.0001
NDFD ₃₀ ³ (% of NDF)						
1	70 ^a	71 ^a	66 ^b	67 ^b	0.425	<0.0001
2	71 ^a	68 ^b	61 ^c	59 ^d	0.378	<0.0001
3	71 ^a	70 ^a	NA	58 ^b	0.474	<0.0001
4	70 ^a	67 ^b	62 ^c	59 ^d	0.255	<0.0001
5	69 ^a	68 ^a	67 ^b	66 ^b	0.315	<0.0001
6	70 ^a	66 ^b	59 ^c	56 ^d	0.501	<0.0001
7	69 ^a	67 ^b	63 ^c	60 ^d	0.364	<0.0001

^{a-d}Different lowercase letters among growth stages within year and location represent significant differences ($P \leq 0.05$).

¹Two rates of N (112 and 224 kg of N/ha) were applied at planting. Harvest took place at 4 growth stages.

²Overall P -value for harvest timing.

³aNDFom = neutral detergent fiber (OM basis with amylase); NDFD₃₀ = neutral detergent fiber digestibility (30 h).

⁴NA = not available.

age decrease with maturity of 73 g/kg. In our study, ADF decreased by 11 g/kg of DM per growth stage. The maximum NDFD₃₀ occurred at the boot and flower stages for trials 1, 3, and 5, and at the boot stage for trials 2, 4, 6, and 7. On average, NDFD₃₀ decreased from 698 g/kg of NDF at the boot stage to 606 g/kg of NDF at the soft dough stage, an average decrease of 31 g/kg of NDF per growth stage.

Starch was maximized at more mature growth stages (Table 8), and on average increased by 16 g/kg of DM from the boot to the flower stage, 47 g/kg of DM from the flower to the milk stage, and 43 g/kg of DM from the milk to the soft dough stage. For 5 of the trials, the highest starch concentrations were obtained at the soft dough stage, whereas sorghum did not increase in starch beyond the milk stage for trial 2 and the flower stage for trial 5. Thus, in most cases, harvesting before the soft dough stage resulted in lower starch concentrations. These findings are consistent with a study by Miron et al. (2006) where the authors concluded that with increasing BMR forage sorghum maturity, whole plant water-soluble carbohydrate concentrations decreased from 280 g/kg of DM at the early heading stage to 138 g/kg of DM at the soft dough stage. This was attributed to an increase in starch with grain maturation reflecting a conversion of water-soluble carbohydrate to

starch (Miron et al., 2006). The response of starch to timing of harvest was also reflected in NFC, with most trials having the highest NFC concentration at the milk or soft dough stages (Table 8).

Whereas TDN was affected by growth stage at harvest, for 3 trials there was no difference in TDN between the boot and soft dough stages (trials 4, 5, and 7; 688 g of TDN/kg of DM average), 3 had the highest TDN at the soft dough stage (trials 1, 3, and 6; 700 g of TDN/kg of DM average), and 1 had maximum TDN at the milk stage (trial 2; 708 g of TDN/kg of DM). On average, TDN changed by 3 g/kg of DM among growth stages. The TDN range in the current study is similar to BMR forage sorghum variety trials conducted in Texas (soft dough harvest), ranging from 563 to 713 g of TDN/kg of DM (Miller and Stroup, 2003).

Optimum timing of harvest for forage nutritive value is dependent on the specific quality parameter that is most desired. Early harvest resulted in greater fiber digestibility and CP concentrations, whereas harvest at soft dough resulted in greater starch, DM, and NFC concentrations. To optimize yield and allow for timely planting of a winter cereal, harvest at the flower or milk stage is recommended, recognizing that the lower DM content at these stages compared with soft dough

Table 8. Forage starch, TDN, and NFC on a DM basis for 7 brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017¹

Trial	Boot	Flower	Milk	Soft dough	SE	<i>P</i> -value ²
Starch (g/kg of DM)						
1	66 ^c	81 ^b	79 ^b	116 ^a	2.43	<0.0001
2	74 ^b	90 ^b	153 ^a	152 ^a	6.03	<0.0001
3	41 ^b	48 ^b	NA ³	229 ^a	6.43	<0.0001
4	66 ^d	90 ^c	144 ^b	194 ^a	4.16	<0.0001
5	73 ^b	92 ^a	93 ^a	94 ^a	2.77	<0.0001
6	85 ^c	96 ^c	186 ^b	230 ^a	7.59	<0.0001
7	59 ^d	82 ^c	125 ^b	193 ^a	4.85	<0.0001
TDN (g/kg of DM)						
1	665 ^b	661 ^b	661 ^b	673 ^a	1.97	0.0008
2	687 ^c	688 ^c	708 ^a	697 ^b	1.83	<0.0001
3	680 ^b	677 ^b	NA	715 ^a	2.09	<0.0001
4	696 ^b	706 ^a	691 ^b	693 ^b	2.74	0.0022
5	659 ^c	682 ^a	671 ^b	666 ^{bc}	2.59	<0.0001
6	698 ^{bc}	691 ^c	704 ^b	714 ^a	2.12	<0.0001
7	692 ^b	706 ^a	695 ^b	696 ^b	2.32	0.0018
NFC (g/kg of DM)						
1	308 ^c	337 ^b	343 ^b	400 ^a	6.50	<0.0001
2	317 ^c	335 ^c	434 ^b	398 ^a	5.91	<0.0001
3	265 ^b	270 ^b	NA	424 ^a	6.76	<0.0001
4	324 ^c	379 ^b	410 ^a	431 ^a	5.16	<0.0001
5	310 ^b	346 ^a	343 ^a	343 ^a	7.78	0.0073
6	320 ^b	341 ^b	400 ^a	422 ^a	6.74	<0.0001
7	278 ^c	348 ^b	407 ^a	425 ^a	6.11	<0.0001

^{a-d}Different lowercase letters among growth stages within year and location represent significant differences ($P \leq 0.05$).

¹Two rates of N (112 and 224 kg of N/ha) were applied at planting. Harvest took place at 4 growth stages.

²Overall *P*-value for harvest timing.

³NA = not available.

requires management practices to facilitate proper silage fermentation. Reduced starch concentrations at the flower or milk stages can be addressed through diet adjustments.

Harvest Timing, Dietary Inclusion, and ME and MP Predictions

Studies on the effect of forage sorghum growth stage at harvest on milk performance in dairy cows are scant. A feeding trial replacing BMR forage sorghum with corn silage in Nebraska concluded that cows fed diets with BMR forage sorghum (BMR-6) resulted in similar milk production (34.1 kg/d) to those cows fed diets with corn silage (33.8 kg/d; Oliver et al., 2004). Another study in Pennsylvania found that diets that included forage sorghum had less DMI (26.0 kg/d) and milk yield (38.7 kg/d), and similar ECM yield (35.1 kg/d) compared with a corn silage-only diet (26.7 kg of DMI/d, 39.6 kg of milk/d, and 36.9 kg of ECM/d), although the differences were small (Harper et al., 2017). Sorghum in these studies was harvested at a single growth stage (hard dough in Oliver et al., 2004; milk in Harper et al.,

2017), so comparisons among growth stages at harvest cannot be made based on these studies.

In our study, the effect of substitution of corn silage by forage sorghum on milk yield predictions varied depending on the growth stage at which sorghum was harvested. For 5 trials (trials 1, 3, 4, 6, and 7), there was an interaction between growth stage and percent sorghum substitution on ME allowable milk (Table 9, Figure 2). For trials 1, 4, and 6, inclusion of sorghum forage harvested at boot, flower, and milk stages resulted in less ME allowable milk as the percent substitution in the TMR increased, whereas with harvest at the soft dough stage, the effect of substitution on ME was consistent. For trials 3 and 7, the soft dough and milk harvests remained fairly stable in ME allowable milk, whereas the boot and flower harvests decreased with increasing sorghum addition to the ration. For trial 2, ME allowable milk was affected by main effects of both growth stage and percent substitution; the milk and soft dough stages had greater ME allowable milk than the boot and flower stages across substitutions, and greater sorghum substitution resulted in lower ME allowable milk across growth stages. For trial 5, substitution of

Table 9. Predicted ME allowable milk as affected by forage sorghum growth stage at harvest and percent substitution for corn silage in a typical dairy TMR

Trial	Substitution ¹ (%)	Predicted ME allowable milk (kg)				P-value		
		Boot	Flower	Milk	Soft dough	Growth stage	Percent substitution	Interaction
All	0	41.9	41.9	41.9	41.9			
1	25	41.1	41.0	41.2	41.5	<0.0001	<0.0001	0.0001
	50	40.3	40.1	40.4	41.0			
	75	39.4	39.2	39.6	40.5			
	100	38.6	38.3	38.9	40.1			
2	25	41.5	41.6	41.8	41.9	<0.0001	0.0018	0.2161
	50	41.1	41.3	41.8	41.9			
	75	40.7	41.0	41.7	41.9			
	100	40.3	40.7	41.6	41.9			
3	25	41.2	41.6	NA ²	41.9	<0.0001	<0.0001	0.0044
	50	40.6	41.2	NA	41.9			
	75	39.9	40.9	NA	41.9			
	100	39.2	40.5	NA	41.8			
4	25	41.4	41.5	41.5	41.7	<0.0001	<0.0001	0.0124
	50	40.8	41.1	41.0	41.6			
	75	40.2	40.7	40.6	41.5			
	100	39.7	40.3	40.2	41.3			
5	25	41.2	41.4	41.3	41.2	0.0013	<0.0001	0.6639
	50	40.5	40.8	40.7	40.6			
	75	39.9	40.2	40.1	39.9			
	100	39.2	39.7	39.5	39.2			
6	25	41.4	41.5	41.6	41.9	<0.0001	<0.0001	<0.0001
	50	40.8	41.0	41.4	41.9			
	75	40.3	40.5	41.2	41.9			
	100	39.7	40.1	40.9	41.9			
7	25	41.3	41.6	41.7	41.7	<0.0001	<0.0001	<0.0001
	50	40.8	41.3	41.5	41.5			
	75	40.2	41.1	41.2	41.3			
	100	39.6	40.8	41.0	41.1			

¹Percent forage sorghum substitution for corn silage.

²NA = not available.

Figure 2. Predicted ME allowable milk for 7 brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017. Harvest took place at 4 growth stages. Sorghum was substituted for different percentages of corn silage in a typical dairy TMR. A significant interaction ($P \leq 0.05$) was observed between growth stage and percent substitution for all trials except for trials 2 (B) and 5 (E). Error bars represent SEM.

forage sorghum for corn silage resulted in decreased ME allowable milk independent of the growth stage at which the sorghum was harvested. On average across trials, predicted ME allowable milk decreased from 41.9 kg/d (corn silage only) to 39.5, 40.1, 40.3, and 41.1 kg/d (sorghum only) for the boot, flower, milk, and soft dough growth stages, respectively. Although the aNDFom content of the forage sorghum was significantly higher than the aNDFom content of the corn silage, a couple of conditions must be recognized. First, the corn silage without the dilution of starch would be approximately 70 to 74% aNDFom because the plant is a grass at full maturity, so when evaluating the fiber components, the corn silage fiber is much more mature than the sorghum forage. This level of maturity leads to greater indigestibility primarily through increased lignification and cross-linking between the lignin and carbohydrates in the hemicellulose (Raffrenato et al., 2017). The forage sorghum is a BMR with lower lignin and lower capacity to cross-link, and it was grown in cooler weather conditions; thus, the NDFD₃₀ is higher despite the apparent higher aNDFom content, which

would allow for similar milk yield between the forages due to the higher sorghum digestibility.

The predicted MP allowable milk results were more variable among trials than the ME allowable milk results. For 3 trials there was an interaction between growth stage at harvest and percent sorghum substitution (trials 1, 4, and 7; Table 10, Figure 3). For trial 1, sorghum harvested at the boot, flower, milk, and soft dough stages had decreased predicted MP allowable milk with increased percent sorghum in the ration. The predicted MP allowable milk decreased the least with increasing sorghum substitution when sorghum was harvested at the soft dough stage, followed by greater decreases with substitutions when forage harvested at the flower, milk, or boot stages was used. This was likely due to less starch in the diet for microbial growth. When the forage sorghum was harvested at the soft dough stage in trial 4, the diet resulted in increased MP allowable milk with greater sorghum substitutions in the diet, whereas diets with forage sorghum harvested at the boot, flower, and milk growth stages had decreased predicted MP allowable milk. For trial 7,

Table 10. Predicted MP allowable milk as affected by forage sorghum growth stage at harvest and percent substitution for corn silage in a typical dairy TMR

Trial	Substitution ¹ (%)	Predicted MP allowable milk (kg)				P-value		
		Boot	Flower	Milk	Soft dough	Growth stage	Percent substitution	Interaction
All	0	43.0	43.0	43.0	43.0			
1	25	42.4	42.2	42.3	42.7	<0.0001	<0.0001	0.0337
	50	41.8	41.4	41.6	42.4			
	75	41.3	40.6	40.8	42.0			
	100	40.7	39.9	40.1	41.7			
2	25	43.1	43.1	43.2	43.3	0.2342	0.3400	0.9987
	50	43.1	43.2	43.3	43.6			
	75	43.1	43.3	43.4	43.9			
	100	43.2	43.4	43.5	44.2			
3	25	43.0	43.4	NA ²	43.3	0.0053	0.1035	0.6719
	50	42.9	43.7	NA	43.6			
	75	42.9	44.0	NA	43.8			
	100	42.9	44.4	NA	44.1			
4	25	42.8	42.8	42.8	43.2	<0.0001	0.0007	0.0265
	50	42.5	42.5	42/5	43.3			
	75	42.3	42.3	42.3	43.4			
	100	42.0	42.0	42.0	43.6			
5	25	42.4	42.6	42.6	42.5	0.0046	<0.0001	0.7985
	50	41.8	42.2	42.1	42.0			
	75	41.2	41.7	41.7	41.5			
	100	40.6	41.3	41.2	41.0			
6	25	43.1	43.3	43.3	43.6	<0.0001	<0.0001	0.0811
	50	43.3	43.5	43.5	44.2			
	75	43.4	43.8	43.7	44.8			
	100	43.6	44.0	43.9	45.4			
7	25	42.8	43.2	43.2	43.1	<0.0001	0.5969	0.0005
	50	42.6	43.3	43.3	43.2			
	75	42.4	43.5	43.4	43.2			
	100	42.3	43.6	43.5	43.3			

¹Percent forage sorghum substitution for corn silage.

²NA = not available.

Figure 3. Predicted MP allowable milk for 7 brown midrib (BMR) forage sorghum trials in New York from 2014 to 2017. Harvest took place at 4 growth stages. Sorghum was substituted for different percentages of corn silage in a typical dairy TMR. A significant interaction ($P \leq 0.05$) was observed between growth stage and percent substitution for trials 1 (A), 4 (D), and 7 (G). Error bars represent SEM.

forage sorghum harvested at the flower, milk, and soft dough growth stages led to an increase in predicted MP allowable milk with increasing substitution for corn silage, whereas forage sorghum harvested at the boot stage resulted in a decrease in predicted MP allowable milk with increasing substitution. No differences were observed in MP allowable milk among forage sorghum growth stages at harvest or percent substitutions for corn silage in trial 2. Sorghum growth stage at harvest had a main effect on predicted MP allowable milk for trial 3, where the boot stage had lower predicted MP allowable milk than the flower, milk, or soft dough stages. Trials 5 and 6 had main effects of both percent sorghum substitution and growth stage at harvest on predicted MP allowable milk. For trial 5, MP allowable milk decreased with increased sorghum substitution in the diet; the boot stage had the greatest predicted MP allowable milk decrease followed by the soft dough, milk, and flower growth stages. For trial 6, MP allowable milk increased with greater sorghum substitution in the diet, with soft dough increasing the most followed by the flower, milk, and boot growth stages. Across all trials, MP allowable milk was 43 kg/d with only corn silage in the diet, and 42, 43, 42, and 43 kg/d for boot, flower, milk, and soft dough with only sorghum in the diet. Based on these results, if forage sorghum harvested at the flower or milk growth stage is to be substituted for corn silage in a dairy TMR, protein might be sufficient but additional energy supplementation will be needed to promote microbial growth to support the AA requirements of the cow.

CONCLUSIONS

Brachytic dwarf BMR forage sorghum is a potential alternative to corn silage in double cropping rotations with winter cereals grown for forage in New York. Forage sorghum can be harvested as early as the flower stage without affecting total DM yield. Harvest before the soft dough stage results in increased NDFD₃₀, aNDFom, ADF, and CP concentrations, and decreased NFC, starch, and DM concentrations of the harvested forage. Direct substitution of corn silage with sorghum silage in a dairy TMR is possible based on model simulations. However, energy supplements are needed if sorghum is harvested before the soft dough stage, primarily due to a lower starch concentrations of sorghum harvested at or before the soft-dough growth stage, compared with corn silage harvested after physiological maturity. Additional forage in the diet may also be necessary if including sorghum in a TMR due to changes in fiber digestibility among growth stages at harvest. Adjustments in chop length and additives may be necessary to ensure proper ensiling of direct-chopped forage at

flower, milk, and soft dough stage, due to the increased moisture content of the forage at harvest, compared with corn silage. Future work assessing milk performance in feeding trials, the economics of growing, processing, and feeding of forage sorghum, and how to best handle the low DM content of early harvested forage sorghum in the northeast United States is needed.

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