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Lingyan Li
University of Wisconsin & Heilongjiang Bayi Agricultural University

Nancy M. Esser
University of Wisconsin- Marshfield

Robin K. Ogden
USDA Agricultural Research Service

Wayne K. Coblentz
USDA Agricultural Research Service

Matthew S. Akins
University of Wisconsin, msakins@wisc.edu

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Comparison of feeding diets diluted with sorghum-sudangrass silage or low-quality grass on nutrient intake and digestibility and growth performance of Holstein dairy heifers

Lingyan Li,[1,2] Nancy M. Esser,[3] Robin K. Ogden,[4] Wayne K. Coblentz,[4] and Matthew S. Akins[1]*
[1]Department of Dairy Science, University of Wisconsin, Madison 53706
[2]College of Animal Science and Veterinary Medicine, Heilongjiang Bayi Agricultural University, Daqing 163319, PR China
[3]Marshfield Agricultural Research Station, University of Wisconsin, Marshfield 54449
[4]USDA Agricultural Research Service, US Dairy Forage Research Center, Marshfield, WI 54449

ABSTRACT

This study was carried out to evaluate the nutrient intakes and growth of dairy heifers offered an alfalfa silage–corn silage diet (CON; 14.3% crude protein, 61.1% total digestible nutrients, 47.9% neutral detergent fiber) compared with diets containing 1 of 2 types of sorghum-sudangrass (SS) silages: conventional or photoperiod sensitive. The objective of the study was to determine the potential to use SS to control dry matter (DM) and nutrient intakes and weight gain. Both diets were similar in nutrient composition, with approximately 13% crude protein, 60 to 61% total digestible nutrients, and 55% neutral detergent fiber. Seventy-two Holstein heifers (16–18 mo at study initiation) were blocked by initial body weight (light = 422 ± 12.8 kg; medium = 455 ± 14.8 kg; heavy = 489 ± 16.7 kg) with 3 pens assigned to each weight block (8 heifers/pen; 24 heifers/block). The 3 diets were randomly allocated to the pens within each block and offered for 12 wk. Heifers offered the CON diet had greater DM, protein, and energy intakes compared with those offered the SS silage-based diets due to the greater neutral detergent fiber concentration of the SS diets. With lower DM and nutrient intakes, average daily gain was in the recommended range (0.8–1 kg/d for Holstein heifers) for heifers offered the SS silage-based diets (mean of 0.92 kg/d for both SS diets vs. 1.11 kg/d for CON). Sorting behaviors for heifers offered both SS diets were more aggressive against long, medium, and short particles compared with those of heifers offered the CON diet; however, heifers sorted large particles from photoperiod-sensitive silage more aggressively than those from conventional silage. Based on this study, SS silage-based diets can control the DM and energy intakes for heifers and maintain optimum growth rates, with harvesting at a shorter chop length likely helping to alleviate sorting issues.

Key words: dairy heifer, sorghum silage, growth performance

INTRODUCTION

Corn and sorghums [i.e., forage sorghum, sorghum-sudangrass (**SS**)] are 2 important crops grown in many regions around the world. Corn silage is one of the most important feed components for dairy cattle due to its high DM yield and energy concentration. Compared with corn, sorghums have a greater ability to extract water from deeper soil layers (Farré and Faci, 2006), allowing for better drought tolerance and adaptability to late planting as well as high biomass yields (Sanderson et al., 1992). Yield and nutritive value are 2 primary traits for plant breeders to consider for expanding the use of sorghum as a forage crop.

With the development of new varieties, sorghums have numerous traits and adaptabilities. Sorghum-sudangrass is a cross of sorghum and sudangrass with general characteristics of thin stems and leaves of moderate height. Many varieties of SS exist with different traits, including varying heights and production potentials. Remick et al. (2016) evaluated the yield and nutritive value of conventional (**CSS**) and photoperiod-sensitive (**PSS**) SS varieties in central Wisconsin. In that study, PSS and CSS had similar yields and lower NDF digestibility and TDN but greater NDF concentrations compared with corn silage; in addition, concentrations of CP were similar among PSS, CSS, and corn silage. Photoperiod-sensitive SS does not become reproductive until there is less than 12 h 20 min of daylight; this causes the forage to be higher in NDF and lower in NFC than a conventional SS that may be harvested in the soft to hard dough stage

Most previous studies comparing sorghum silage utilization with corn silage have been conducted with

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*Corresponding author: msakins@wisc.edu

lactating dairy cows. These studies found that sorghum silage had greater in vitro or in situ NDF digestion than corn silage (Oliver et al., 2004; Dann et al., 2008; Colombini et al., 2012). However, studies that focus on utilization of sorghum silages in dairy heifer diets are limited. Dairy heifers are an important part of most dairy farms and represent the future of the operation. Feeding strategies for heifers are often based on high-forage, moderate-energy rations that meet energy and nutrient requirements while preventing excess body condition gain, especially for pregnant heifers. In circumstances where producers have high-quality forages (typically for lactating cows) without a source of low- to moderate-energy forage, it can be difficult to balance rations without excess energy intake. Use of a significant proportion of corn silage or other high-quality forage with low NDF concentrations can cause issues with excess feed and energy intake and subsequent weight gain (Coblentz et al., 2015). Overconditioning before lactation can result in negative effects on mammary development and subsequent first-lactation performance as cows (Hoffman et al., 1996; Radcliff et al., 2000). Several studies have evaluated the use of forages with low nutritive value (straw, corn stover, eastern gamagrass) to dilute the energy and increase fiber content, causing lower ad libitum intakes and daily gains in the ideal range of 0.8 to 1 kg/d (Coblentz et al., 2012, 2015). However, no studies have evaluated sorghums as an option to dilute diet energy content.

Compared with corn silage, sorghum-type silages usually have lower energy and greater fiber concentrations, which makes them an excellent potential forage source for heifer rations to control energy intake and growth. The objectives of this research were to (1) compare intakes and growth of dairy heifers fed diets (based on alfalfa silage and corn silage) diluted with either SS silage or a low-quality grass hay and (2) determine whether SS silage type (CSS or PSS) has an effect on intakes and growth of dairy heifers. We hypothesized that heifers offered diets with higher NDF content using SS silage would have lower DMI and more optimal growth and that SS type would have minimal effects on intakes and growth.

MATERIALS AND METHODS

SS Forage Management

Conventional SS (‘AS5201’; Alta Seed, Irving, TX) and PSS (‘Mega Green’; Walter Moss Seed, Jacksboro, TX) varieties of SS were seeded at a rate of 44.8 kg/ha on July 4, 2017, at the Marshfield Agricultural Research Station (Stratford, WI). The seeded areas of AS5201 and Mega Green were 2.43 and 1.78 ha, respectively. Sorghum-sudangrasses were planted with a no-till drill (model 1206T; Great Plains, Salina, KS) configured with 38.1-cm row spacings. Dairy manure was applied before planting at a rate of 85,700 L/ha of liquid manure and 57,700 kg/ha of solid manure, thereby providing 105 kg of N, 111 kg of P, and 220 kg of K/ha according to soil nutrient recommendations based on soil samples, previous crop grown, and expected yield of 15 tons of DM/ha using a direct single cut in late fall based on previous plot research at the location. Yields of both CSS and PSS (Remick et al., 2016) in previous plot research at the location were similar, and current soil nutrient recommendations do not differentiate between CSS and PSS; thus, nutrient requirements were assumed to be similar for both SS types. Due to the later planting date, the CSS was not anticipated to reach a suitable maturity for harvest before frost; thus, forage was harvested earlier using a cut and wilt method rather than direct harvest. Forage was cut and conditioned using a pull-type disc mower with intermeshing steel conditioner rollers (R113PT; MacDon, Winnipeg, MB, Canada) on September 22, 2017, and allowed to wilt for 3 d before harvesting as precision-chopped silage on September 25 using a pull-type forage harvester (model F-41, Dion-AG, Boisbrian, QC, Canada). Empty and filled wagons of harvested forage were weighed to determine forage yields, with samples taken at each wagonload for DM content. Dry matter content was determined by drying forage to a constant weight at 55°C. Yields for AS5201 and Mega Green were 6.92 and 5.93 tons of DM/ha, respectively. Chopped forage was stored in a silage bag until the feeding study began during February 2018.

Animals, Feeds, and Management

The procedures for animal handling in this experiment were approved by the Research Animal Resources Committee of the University of Wisconsin–Madison (RARC no. A005195-A01). Seventy-two bred or pregnant Holstein heifers (16–18 mo of age) at the University of Wisconsin Marshfield Agricultural Research Station (Stratford, WI) were blocked by initial BW (light = 422 ± 12.8 kg; medium = 455 ± 14.8 kg; heavy = 489 ± 16.7 kg) and assigned to 1 of 3 pens within each weight block (8 heifers/pen; 24 heifers/block) to minimize size variation within pens. Three diets were randomly allocated to the pens in each block as a randomized complete block experimental design. Ingredient and nutrient composition of diets and forages are shown in Table 1. The 3 diets offered included (DM basis) (1) 16.8% corn silage, 56.3% alfalfa silage, and 25.8% chopped grass hay (control; **CON**); (2) 48% CSS, 5% corn silage, and 46% alfalfa silage (CSS treatment); and (3)

48% PSS, 5% corn silage, and 46% alfalfa silage (PSS treatment). The chopped grass hay was primarily reed canary grass harvested after heading from waterways separating cropping fields. The hay was processed to pass through a 10-cm screen in a Haybuster model 1100 tub grinder (DuraTech Industries International Inc., Jamestown, ND). The SS silage and chopped hay were used to dilute the diet energy to obtain similar energy contents for the diets. All the diets were balanced to achieve similar protein concentrations (overall mean = 13.4% CP) and energy densities (overall mean = 60.5% TDN), and diets were rebalanced weekly to attempt to maintain similar energy and CP by adjusting diet ingredient inclusion rates using weekly forage sample analysis conducted by the University of Wisconsin Soil and Forage Analysis Laboratory (Marshfield, WI). Diets were balanced to obtain target growth rates of 0.9 to 1.0 kg/d. Diets were offered for 12 wk as a TMR once per day between 0900 and 1000 h and then pushed up at least twice per day for the heifers to easily reach the TMR. Orts were collected at 0830 h each day. Eight head-locking feeding gates, set to allow free access at all times, were located in each pen. Fresh water was available without restriction at all times.

Growth Performance

Heifers were weighed using a chute (Real Tuff, Clearbrook, MN) equipped with an electronic scale (Tru-Test Inc., Mineral Wells, TX) before the morning feeding for 3 consecutive days at the beginning and end of the experiment. Body condition score was assessed by 2 trained evaluators following the method described by Wildman et al. (1982) using 0.5-unit increments to best describe body condition. In addition, body measurements, including hip height, hip width, and heart girth, were taken at the beginning and end of the trial.

Laboratory Analysis for Feed and Orts Samples

Daily TMR and orts from each pen were weighed and sampled every day. Samples were kept at −20°C and then thawed at room temperature and composited for each week of study. Ingredients were sampled once weekly and stored at −20°C until later analysis. The weekly composites of TMR and orts and weekly individual dietary ingredients were dried to constant weight in a forced-air oven at 55°C to determine DM concentration (Undersander et al., 1993; method 2.2.1.1). A temperature of 55°C was used to minimize volatilization of silage acids during drying. Samples of TMR and ingredients were then ground through a 1-mm screen using a Thomas-Wiley model 4 mill (Thomas Scientific, Swedesboro, NJ) and stored in sealed plastic sample bags. Samples of TMR and ingredients were analyzed by the University of Wisconsin Soil and Forage Laboratory (Marshfield, WI) to determine laboratory DM (NFTA, 2001), CP (method 988.05; AOAC International, 1998), ether extract (method 920.29; AOAC, 1990), and ash by combustion in a muffle furnace at 500°C for 6 h. Concentrations of NDF, ADF, and ADL were analyzed using the methods of Goering and Van Soest (1970); NDF was measured using heat-stable amylase and sodium sulfite. Concentrations of ADF and ADL were determined without preliminary digestion in neutral detergent. In vitro 48-h digestion of NDF (**NDFD**) in buffered rumen fluid was performed using procedures described in detail by Kruse et al. (2010) and Coblentz et al. (2012). Concentrations of Ca, K, and Mg were determined by atomic absorption spectroscopy, and concentration of P was determined by colorimetric methodology (Schulte et al., 1987). Total digestible nutrients, ME, NE_G, and NE_M of experimental diets were calculated via the summative equations (NRC, 2001) with 48-h NDFD serving as a digestibility coefficient for NDF to estimate truly digestible fiber.

Nutrient Digestibility

Fecal grab samples were collected over 2 consecutive days (0800 and 1200 h on d 1 and 1600 and 2000 h on d 2) during wk 5 and 10. Sample times were based on a previous study using a similar sampling schedule (Su et al., 2017). Previous research at the facility has shown similar digestibility between total pen collections and sampling at a single time point (Coblentz et al., 2013). Heifers were restrained using head-locking feed gates before the collection time points. Fecal samples were collected from all heifers in a pen using a clean plastic sleeve and lubricant, composited by pen at each time point, and then stored at −20°C until later analysis. Fecal samples were dried to constant weight under forced air at 55°C and ground through a 1-mm screen. Dried and ground fecal samples from each time point were then composited by week for each pen. The TMR and orts composite samples from wk 5 and 10 as well as ground fecal composites were weighed (0.5 g) in triplicate into F57 fiber bags (Ankom Technology Corp., Macedon, NY) for measurement of indigestible NDF. Fiber bags were incubated in situ for 240 h within the rumen of 1 nonlactating Holstein cow offered a diet of alfalfa silage, corn silage, and chopped grass hay (14.7% CP, 46.9% NDF, and 67% TDN). Bags removed from the rumen were rinsed thoroughly with clean water until the rinse water was clear, dried at 55°C for 48 h, and then analyzed for indigestible NDF with heat-stable amylase and sodium sulfite included in the NDF solution (Ankom200 fiber analyzer; Ankom

Table 1. Feed and nutrient composition of diets and nutrient composition of individual ingredients

Item	Diet[1]			Nutrient composition (DM basis)				
	Control	CSS	PSS	Conventional SS silage	Photoperiod-sensitive SS silage	Corn silage	Chopped grass hay[2]	Alfalfa silage
Ingredient,[3] % of DM								
Conventional SS silage	0	48.0	0					
Photoperiod-sensitive SS silage	0	0	48.0					
Corn silage	16.8	5.0	5.0					
Chopped hay	25.8	0	0					
Alfalfa silage	56.3	46.0	46.0					
Urea	1.0	1.0	1.0					
Nutrient composition (DM basis unless otherwise stated)								
DM, % as fed	48.8	40.1	39.0	42.1	40.7	40.9	94.1	50.0
OM,%	91.2	90.7	90.3	92.2	92.0	96.6	92.8	90.9
CP, %	14.3	12.8	13.1	6.82	6.98	6.45	8.42	13.7
NDF, %	47.9	55.4	55.2	62.9	58.7	35.6	61.9	48.6
NDFD,[4] % of NDF	54.2	61.2	58.6	49.2	45.6	43.4	36.6	49.7
ADF, %	34.2	35.8	35.2	40.8	39.0	23.3	43.7	35.9
ADL, %	4.72	3.81	4.10	3.83	3.76	2.49	6.67	6.18
Ether extract, %	2.29	2.19	2.17	1.24	1.33	3.11	2.30	2.43
Ash, %	8.84	9.29	9.73	7.84	7.99	3.38	7.21	9.08
P, %	0.30	0.31	0.30	0.26	0.27	0.22	0.26	0.36
Ca, %	0.52	0.48	0.50	0.23	0.25	0.28	0.34	0.50
K, %	1.91	2.17	2.20	2.27	2.48	1.03	1.71	2.54
Mg, %	0.23	0.29	0.30	0.30	0.32	0.08	0.18	0.25
Energy estimate[5]								
TDN, %	61.1	61.1	59.3	53.7	53.5	71.8	48.2	60.3
ME, Mcal/kg	2.37	2.35	2.29	1.94	1.94	2.75	2.34	1.87
NE_M, Mcal/kg	1.50	1.47	1.42	1.10	1.09	1.82	1.46	1.03
NE_G, Mcal/kg	0.90	0.88	0.83	0.54	0.54	1.19	0.87	0.47

[1]Control = alfalfa silage–corn silage diet offered for ad libitum intake; CSS = alfalfa silage–sorghum silage diet containing 48.0% conventional sorghum-sudangrass (SS) silage offered for ad libitum intake; PSS = alfalfa silage–SS silage diet containing 48.0% photoperiod-sensitive SS silage offered for ad libitum intake.

[2]Chopped grass hay was primarily reed canary grass processed through a 10-cm screen of a tub grinder.

[3]Mineral package contained 70.7% calcium carbonate, 15.1% salt, 5.04% magnesium oxide, 2.12% sulfur, 1.62% selenium 1600, 1.56% vitamin A, 0.91% manganese sulfate 32%, 0.68% vitamin E 50%, 0.65% copper sulfate, 0.50% vitamin D, 0.50% mineral oil, 0.33% iodine mix 7.3%, 0.23% thiamin mononitrate 99%, and 0.025% cobalt carbonate. Mineral package was blended into the total diet at a rate of 122 g/heifer per day and delivered as a TMR.

[4]NDF digestibility determined following a 48-h digestion in buffered rumen fluid.

[5]Calculated according to NRC (2001).

Technology Corp.). Original NDF concentrations of the TMR, orts, and fecal samples from wk 5 and 10 were determined using the same NDF method as described for indigestible NDF. Ash of TMR, orts, and fecal samples were determined by combustion in a muffle furnace at 500°C for 6 h, and N was determined using a rapid combustion procedure (AOAC International, 1998; method 990.63; TruMac CN, Leco Corp., St. Joseph, MI). Organic matter content was calculated as 100% − ash (%) on a DM basis. The concentration of indigestible NDF after a 240-h in situ incubation was used as an internal marker to estimate fecal output of DM, OM, NDF, and N. Nutrient intake was calculated by subtracting the nutrient amount in the orts from the nutrient amount fed. Digestibilities of DM, OM, NDF, and apparent N were determined on a whole-pen basis as 100 − (fecal nutrient output/nutrient intake × 100). Similar procedures have been used to assess total-tract digestibility of diets within individual lactating cows (Lee and Hristov, 2013) and diets on a whole-pen basis for Holstein heifers (Coblentz et al., 2015). All calculations of nutrient digestibility were based on the DMI and orts collected during wk 5 and 10 for each pen.

Feed Bunk Sampling and Evaluation of Particle Size Distribution

Feed bunk samples were collected over a 4-d period in wk 4 and 9 to evaluate feed sorting by the heifers. Feed bunk sampling times were at 1400, 1700, 2000, and 2300 h after TMR was offered between 0900 and 1000 h daily. Feed bunks were sampled only once per day for each pen to minimize disruption of eating and sorting behaviors. Sampling times were randomized for each pen across the 4-d period so that each sampling time was represented on 1 d of the 4-d sampling period. A scoop shovel was used to collect feed samples from each pen within the width of the shovel from the feed alley to the concrete curb. Two samples from each feed bunk were taken with 1 random shovel sample on each half of the feed bunk. The 2 feed samples/pen were mixed thoroughly in a large plastic 70-L tub. Then, a subsample (~1,000 g) was collected and sealed in a freezer bag and frozen (−20°C) until evaluation of particle size distribution. The TMR and ort composites during each feed sorting evaluation week were then evaluated for particle size distribution.

The TMR, bunk, and orts samples were assessed for particle size distribution using the Penn State Particle Separator, containing 3 screens (19, 8, and 4 mm) and a bottom pan. Feed particles were separated into 4 fractions: large (>19 mm), medium (<19 and >8 mm), short (<8 and >4 mm), and fine (<4 mm; Heinrichs, 2013). Sorting factors were calculated as the proportion of each particle fraction in the feed bunk divided by the proportion in the original TMR diet (Coblentz et al., 2015) because it was impractical to weigh, mix, and sample the TMR remaining in the feed bunk, as is often done for individual animal feeding studies. Therefore, values equal to 1.0 indicate no sorting, whereas values >1.0 indicate that particles were less desirable and sorted against and values <1.0 indicate that particles were preferred by heifers.

Statistical Analysis

All the data were analyzed by PROC MIXED of SAS version 9.4 (SAS Institute Inc., 2012) using a randomized complete block design with 3 blocks based on initial heifer BW. In all cases, the experimental unit was the pen rather than the individual heifer, thereby permitting 8 total degrees of freedom for the statistical analysis. Analysis for digestibility and particle size distribution data included a repeated statement for sampling week. Dietary treatments and BW-based blocks were considered fixed variables. Pen within treatment was considered the random effect. The statistical model used for growth and intake measures was

$$Y_{ij} = \mu + D_i + B_j + D(P)_i + \varepsilon_{ij},$$

where Y_{ij} is the observed variable, μ is the overall mean, D_i is the fixed effect of diet treatment (i = 1 to 3), B_j is the fixed effect of weight block (j = 1 to 3), $D(P)_i$ is the random effect of pen with treatment (i = 1 to 3), and ε_{ij} denotes the residual error.

The statistical model used for digestibility and diet particle size sorting indexes was

$$Y_{ijk} = \mu + D_i + B_j + D(P)_i + T_k + (D \times T)_{ik} + \varepsilon_{ijk},$$

where Y_{ijk} is the observed variable, μ is the overall mean, D_i is the fixed effect of diet treatment (i = 1 to 3), B_j is the fixed effect of weight block (j = 1 to 3), $D(P)_i$ is the random effect of pen with treatment (i = 1 to 3), T_k is the fixed effect of sampling week (k = 1 to 2 for digestibility data) or time (k = 1 to 5 for sorting index data), $(D \times T)_{ik}$ is the fixed effect of the interaction of diet treatment and sampling time, and ε_{ijk} denotes the residual error. Analysis for digestibility and diet particle sorting indices included a repeated statement for sampling time using the first-order autoregressive covariance structure, which provided the best fit according to Sawa's Bayesian information criterion.

Logical contrasts used to test the effects of dietary treatment included (1) CON versus SS silage diets (CSS and PSS) and (2) a comparison of SS silage treatments (CSS vs. PSS). Significance was declared for $P < 0.05$, and trends were reported at $0.05 < P < 0.10$.

RESULTS AND DISCUSSION

Diet Formulation

Diet and forage nutrient composition are shown in Table 1. The CSS and PSS silages had greater NDF and NDFD but lower energy density than the corn silage used in the study, which allowed for replacement of corn silage and the dry grass hay. The CON diet had numerically greater concentrations of CP (14.3% vs. 13.0% for SS diets) but lower NDF, NDFD, and ADF compared with the SS silage diets. Energy densities of the diets were similar and ranged between 59.3 and 61.1% TDN.

DMI and Nutrient Intake

Dry matter and nutrient intakes are shown in Table 2. Heifers offered CON diets had greater DMI than the SS silage treatments ($P < 0.01$) due to greater NDF concentrations within the SS diets. Previous research by Hoffman et al. (2008) revealed that daily ad libitum DMI for dairy heifers was controlled by NDF at approximately 1.0% of their BW. In the present study, intakes of NDF as a percentage of average BW during the study were consistent with this standard (1.04, 1.04, and 1.01% for CON, CSS, and PSS, respectively), with daily intakes of NDF not being different among the diets ($P \geq 0.21$). Quigley et al. (1986) reported that when dietary NDF concentration exceeded 42% of DM, DMI was negatively correlated with NDF concentration for dairy heifers due to a greater fill effect concomitant with increases in dietary NDF concentration. The NDF was lower in the CON diet (47.9% NDF) than in the SS silage diets (55.4 and 55.2% NDF for CSS and PSS, respectively), which likely caused heifers offered CON to have greater DMI compared with those offered SS silage diets. Aydin et al. (1999) and Miron et al. (2007) also reported that cows consumed less DM when offered diets in which sorghum silage replaced corn silage. Use of higher fiber forages in several other studies has also led to reduced ad libitum intake and controlled growth (Greter et al., 2008; Coblentz et al., 2015; Su et al., 2017). These included the use of warm season perennials (eastern gamagrass), straw, corn stover, or alfalfa stemlage and demonstrate that various forages can be used for this purpose in dairy heifer diets. Use of precision feeding (also known as limit feeding) is another option to control nutrient intakes and heifer growth, with use of sorghum forages working well with this feeding strategy (Pino and Heinrichs, 2017).

We also found that intakes of OM, CP, fat, minerals, and energy were significantly greater for the heifers offered CON than the SS silage diets ($P \leq 0.03$). Differences between CON and SS silage diets were largely driven by DMI because concentrations of these nutrients generally varied minimally among diets. Nutrient intake did not differ between the 2 SS silage diets, but

Table 2. Nutrient and energy intakes for heifers fed diets containing sorghum-sudangrass (SS) silages

	Diet[1]				Contrast[2] (P-value)	
Item	Control	CSS	PSS	SEM	1	2
Nutrient intake						
DM, kg/d	10.90	9.27	9.01	0.14	<0.01	0.26
OM, g/d	9.95	8.43	8.16	0.13	<0.01	0.21
CP, kg/d	1.51	1.17	1.16	0.02	<0.01	0.92
NDF, kg/d	5.22	5.16	5.01	0.07	0.21	0.22
NDF, % of BW	1.04	1.04	1.01	0.01	0.58	0.13
Fat, kg/d	0.25	0.21	0.20	0.002	<0.01	0.07
P, g/d	32.4	28.4	26.7	0.43	<0.01	0.05
Ca, g/d	57.0	44.3	44.6	0.77	<0.01	0.80
K, g/d	207.6	197.2	194.6	2.84	0.03	0.54
Mg, g/d	24.8	26.1	26.3	0.35	0.03	0.75
Energy intake[3]						
TDN, kg/d	6.68	5.71	5.38	0.09	<0.01	0.05
ME, Mcal/d	25.9	22.0	20.8	0.34	<0.01	0.02
NE_M, Mcal/d	16.4	13.8	12.9	0.21	<0.01	0.04
NE_G, Mcal/d	9.89	8.34	7.64	0.13	<0.01	0.02

[1]Control = alfalfa silage–corn silage diet offered for ad libitum intake; CSS = alfalfa silage–sorghum silage diet containing 48.0% conventional SS silage offered for ad libitum intake; PSS = alfalfa silage–SS silage diet containing 48.0% photoperiod-sensitive SS silage offered for ad libitum intake.

[2]1 = control versus sorghum silage diets (mean of CSS and PSS); 2 = CSS versus PSS.

[3]Energy calculations based on NRC (2001).

Table 3. Nutrient digestibilities for heifers fed diets containing sorghum-sudangrass (SS) silages

	Diet[1]				Contrast[2] (P-value)	
Item	Control	CSS	PSS	SEM	1	2
Nutrient intake,[3] kg/d						
DM	10.9	8.56	9.22	0.19	<0.01	0.07
OM	10.3	8.22	8.79	0.18	<0.01	0.09
NDF	6.00	5.10	5.30	0.11	<0.01	0.27
N	0.26	0.19	0.21	0.004	<0.01	0.06
Fecal output,[4] kg/d						
DM	4.42	3.93	3.78	0.10	<0.01	0.05
OM	3.89	2.99	3.35	0.09	<0.01	0.05
NDF	2.64	2.09	2.30	0.05	<0.01	0.04
Apparent N	0.08	0.06	0.07	0.002	<0.01	0.12
Digestibility, %						
DM	58.6	60.4	59.1	0.45	0.09	0.10
OM	60.6	62.9	60.9	0.48	0.01	<0.01
NDF	54.6	58.5	55.2	0.94	0.07	0.04
Apparent N	68.4	67.8	67.0	0.70	0.16	0.30

[1]Control = alfalfa silage–corn silage diet offered for ad libitum intake; CSS = alfalfa silage–sorghum silage diet containing 48.0% conventional SS silage offered for ad libitum intake; PSS = alfalfa silage–SS silage diet containing 48.0% photoperiod-sensitive SS silage offered for ad libitum intake.

[2]1 = control versus sorghum silage diets (mean of CSS and PSS); 2 = CSS versus PSS.

[3]Based on wk 5 and 10 of the trial only. All calculations were based on collective DMI and orts for the entire week of analysis and then reported on a daily per-heifer basis.

[4]Fecal output was determined using indigestible NDF following a 240-h ruminal incubation in situ as an internal marker.

energy (TDN, ME, NE_M, and NE_G) intakes were greater for CSS compared with PSS ($P \leq 0.05$). Calculated energy intake was likely greater for CSS due to slightly greater NDF digestibility of the conventional SS silage.

Nutrient Digestibility

Nutrient intake, fecal excretion, and digestibility data are presented in Table 3. During the digestibility sampling periods, heifers offered CON had higher intakes of DM, OM, NDF, and N than those offered SS diets ($P \leq 0.01$). Fecal output of DM, OM, NDF, and apparent N of the heifers offered CON also were greater than those of heifers offered the SS diets ($P \leq 0.01$). Within the SS silage diets, fecal output of NDF was greater for PSS than for CSS ($P = 0.04$), with fecal DM and OM tending to be greater for PSS ($P = 0.05$). Digestibility of OM was greater for CON compared with SS silage treatments ($P = 0.01$). This was expected with lower NDF and greater NFC within the CON diet. Digestibilities of OM and NDF were greater for CSS than for PSS within the SS diets ($P \leq 0.04$). Previous studies also found that the digestibility of OM was greater for lactating dairy cows fed diets containing corn silage compared with those fed sorghum silage (Dann et al., 2008; Harper et al., 2017). However, Colombini et al. (2012) found that digestibility of OM was not different between corn silage and whole-plant grain sorghum silage diets for dairy cows. The greater NDF digestibility for the conventional SS silage likely explains the greater OM digestibility for the CSS treatment. The in vitro NDF digestibilities (Table 1) of the diets agree closely with the total-tract NDF digestibilities for the diet, with the CON diet being the lowest, PSS being moderate, and CSS having the greatest NDF digestibility. Similar results for dairy cows have been published by Colombini et al. (2012). However, some studies found that the digestibility of NDF for corn silage was greater than that for forage sorghum silage (Grant et al., 1995; Aydin et al., 1999; Oliver et al., 2004).

Growth Performance

Effects of different SS silage diets on growth performance of heifers are presented in Table 4. The initial BW, hip height, hip width, heart girth, and BCS of heifers were not different among dietary treatments ($P > 0.10$). At the conclusion of the study, there were no differences among diets for hip height, hip width, or BCS. However, final BW and heart girth were greater for heifers offered CON compared with SS silage diets ($P \leq 0.03$). Heart girth usually has the strongest correlation with BW compared with other body dimensions (Davis et al., 1961; Heinrichs et al., 2007), which agrees with the measurements in this study. Average daily gain (1.11, 0.89, and 0.94 kg/d for CON, SS, and PSS, respectively) was close to targets (0.8–1.0 kg/d) recommended for Holstein heifers (Hoffman, 1997; NRC, 2001). Heifers offered the CON diet had greater total BW gain (94.0 vs. 78.1 kg; $P = 0.02$), ADG (1.11 vs. 0.92 kg/d; $P = 0.02$), and hip width increase (3.18 vs. 2.15 cm; $P = 0.03$) compared with those fed SS silage diets. There were no differences in growth measures between heifers offered the CSS or PSS diets. The greater gains for heifers offered CON can be explained by the heifers having greater nutrient intakes than those offered the SS silage diets. In a previous study evaluating diets (14% CP, 50–53% NDF, and 59–60% TDN) diluted with high-fiber forages (eastern gamagrass, wheat straw, or corn fodder) compared with a corn silage–alfalfa silage diet (14% CP, 43% NDF, and 67% TDN), heifers offered diets with high-fiber dilutant forages had reduced nutrient intakes and more optimal gains (Coblentz et al., 2015). In addition, the use of ad libitum-fed diets with high-fiber forages allows heifers to express more natural eating behaviors (Greter et al., 2008) while still controlling intakes and gain. Feed efficiency was similar across diets ($P > 0.12$), with a mean of 10 kg of DM/kg of gain. This was expected because the diets were balanced closely for energy and protein concentration, with differences in NDF concentration causing greater intake and gains for CON but not improved feed conversion to gain.

When comparing the NRC (2001) model estimates of intakes and gain with the study results using the diet and forage composition and a mean BW of 495 kg, the model overestimated the intakes for the SS diets, with an estimate of 12.2 kg of DMI and resulting 1.17 kg of energy allowable gain and 1.41 kg of MP allowable gain. Using the mean intake for the SS diets (9.1 kg of DM), the model estimated 0.58 kg of energy allowable gain and 0.91 kg of MP allowable gains, which underestimated energy allowable gains; however, protein allowable gains were similar to actual gains for the SS treatments (0.89–0.94 kg/d). For the control diet, the model estimated 12.1 kg of DMI and resulting 1.40 kg of energy allowable gain and 1.52 kg of MP allowable gain. When using the actual intakes for the control diet (10.9 kg of DM), the model was close to actual gains (1.11 kg/d), with an estimated 1.15 kg of energy allowable gain and 1.31 kg of MP gain. It appears that with the use of higher fiber diets, model estimates of intake and energy requirement and supply calculations may need to be revised to better estimate intakes and predicted growth.

Diet Particle Size Distributions and Sorting Index

Diet particle size distribution and sorting index are reported in Table 5. Initially, CSS and PSS had numerically greater percentages of large particles retained on the 19-mm screen compared with CON (20.0, 18.1, and 16.1% of particles >19 mm in TMR for PSS, CSS, and CON, respectively). The percentage of sorghum-silage TMR retained on the 19-mm screen was similar to values reported by Dann et al. (2008) and Colombini et

Table 4. Growth performance for heifers fed diets containing sorghum-sudangrass (SS) silages

	Diet[1]				Contrast[2] (P-value)	
Item	Control	CSS	PSS	SEM	1	2
Initial						
BW, kg	455	457	455	2.56	0.78	0.51
Hip height, cm	140	139	140	0.65	0.41	0.51
Hip width, cm	48.4	49.2	49.5	0.32	0.07	0.46
Heart girth, cm	182	180	181	0.79	0.28	0.53
BCS	3.11	3.05	3.00	0.04	0.19	0.47
Final						
BW, kg	549	533	535	3.63	0.03	0.79
Hip height, cm	145	143	143	0.78	0.16	1.00
Hip width, cm	51.6	51.5	51.4	0.13	0.63	0.62
Heart girth, cm	193	189	189	0.55	0.01	0.61
BCS	3.42	3.35	3.34	0.07	0.42	0.90
Growth						
BW gain, kg	94.0	76.0	80.1	3.45	0.02	0.45
ADG, kg/d	1.11	0.89	0.94	0.04	0.02	0.46
Hip height, cm	4.19	4.05	2.95	0.73	0.48	0.34
Hip width, cm	3.18	2.38	1.91	0.24	0.03	0.23
Heart girth, cm	10.6	8.20	7.89	1.15	0.15	0.86
BCS	0.32	0.31	0.34	0.06	0.95	0.73
Feed efficiency (DMI/ADG)	9.93	10.43	9.62	0.29	0.80	0.12

[1]Control = alfalfa silage–corn silage diet offered for ad libitum intake; CSS = alfalfa silage–sorghum silage diet containing 48.0% conventional SS silage offered for ad libitum intake; PSS = alfalfa silage–SS silage diet containing 48.0% photoperiod-sensitive SS silage offered for ad libitum intake.

[2]1 = control versus sorghum silage diets (mean of CSS and PSS); 2 = CSS versus PSS.

al. (2012) for diets of dairy cows, with 45 and 28% sorghum-silage (DM basis), respectively. However, Aydin et al. (1999) found a lower percentage of large particles (2.3–5.2%) with the diet containing 65% sorghum-silage (DM basis). Oliver et al. (2004) observed a wide range in percentage of particles >19 mm (14.7–35.2%) of sorghum silage diets of dairy cows (40% of diet DM), and these may have been affected by the forage harvesting management, especially theoretical length of cut. The dietary treatments had similar proportions of medium (between 8 and 19 mm) and short (between 4 and 8 mm) particles in the original TMR, whereas the proportion of fine particles (<4 mm) in the original CON was numerically greater than in the SS silages.

Across sampling times, no differences in sorting were observed between treatments until 2300 h, or 13 to 14 h after feeding. Heifers of all treatment groups had aggressive sorting against the large particles and a preference for medium, short, and fine particles across all sampling times. At 2300 h, discriminatory sorting of CON was less for large particles ($P < 0.01$) and preferential sorting was less for medium and short particles ($P < 0.01$) compared with both SS silage treatments. Heifers offered PSS had stronger sorting behaviors against large particles and preference for medium, short, and fine particles at 2300 h compared with CSS. At collection of orts, the SS silage diets had a 3 to 4 times greater proportion of large particles and 50 to 70% less fine, short, and medium particles than the original TMR. Between 2000 h and orts collection, sorting seemed to be more aggressive because the remaining TMR was a greater proportion of large particles. The orts remain-

Table 5. Particle distribution and sorting index of TMR by heifers fed diets containing sorghum-sudangrass (SS)

Sorting factor[1,2]	Initial TMR, % of DM (±SD)	Sampling time, h 1400	1700	2000	2300	Orts[3]
Large particles (>19 mm, upper sieve)						
Control	16.1 ± 0.68	1.26	1.33	1.64	1.55	1.86
CSS	18.1 ± 0.78	1.16	1.23	2.08	2.43	3.94
PSS	20.0 ± 0.88	1.11	1.51	1.88	3.05	3.09
SEM[4]				0.20		
Contrast[5] ($P > F$)						
1		0.60	0.86	0.20	<0.01	<0.01
2		0.86	0.35	0.50	0.05	0.01
Medium particles (>8 mm, middle sieve)						
Control	49.9 ± 2.14	0.90	0.90	0.87	0.94	0.86
CSS	49.2 ± 2.07	0.96	0.98	0.86	0.81	0.58
PSS	48.6 ± 1.99	0.96	0.84	0.78	0.51	0.49
SEM				0.05		
Contrast[5] ($P > F$)						
1		0.38	0.91	0.42	<0.01	<0.01
2		1.00	0.07	0.28	<0.01	0.18
Short particles (>4 mm, lower sieve)						
Control	18.8 ± 0.62	1.05	1.00	0.86	0.90	0.80
CSS	18.7 ± 0.94	1.08	1.03	0.88	0.80	0.50
PSS	18.6 ± 1.26	1.03	0.99	0.83	0.47	0.51
SEM				0.05		
Contrast[5] ($P > F$)						
1		0.82	0.98	0.86	<0.01	<0.01
2		0.43	0.58	0.43	<0.01	0.92
Fine particles (<4 mm, bottom pan)						
Control	15.2 ± 0.85	0.88	0.85	0.68	0.58	0.52
CSS	13.9 ± 0.35	0.90	0.84	0.63	0.58	0.34
PSS	12.7 ± 0.15	0.97	0.81	0.69	0.37	0.38
SEM				0.05		
Contrast[5] ($P > F$)						
1		0.35	0.65	0.71	0.11	0.02
2		0.36	0.61	0.36	0.01	0.49

[1]Control = alfalfa silage–corn silage diet offered for ad libitum intake; CSS = alfalfa silage–sorghum silage diet containing 48.0% conventional SS silage offered for ad libitum intake; PSS = alfalfa silage–SS silage diet containing 48.0% photoperiod-sensitive SS silage offered for ad libitum intake.

[2]Sorting factor calculated as concentration of large, medium, short, and fine particles (% as fed) divided by the corresponding concentration in the original TMR. Particle size designations were determined with the Penn State Particle Separator, which has 19-, 8-, and 4-mm screens and a bottom pan that retain large, medium, short, and fine particles, respectively.

[3]Orts gathered at approximately 0830 h each morning.

[4]SEM for the treatment × time interaction for each particle size.

[5]1 = control versus sorghum silage diets (mean of SS and PSS); 2 = SS versus PSS.

ing for the SS diets contained a considerable proportion of unchopped long particles (approximately 10–20 cm) that the heifers refused to consume. Greter et al. (2008) indicated that heifers more actively sorted against long forage particles when ad libitum diets contained low-energy forages. In the present study, the SS silages were lower in energy and had greater NDF content than the corn silage and alfalfa silage, so the heifers fed SS diets were more likely to sort for medium, short, and fine particles compared with CON. The SS silages also had long particles (approximately 10–20 cm based on visual assessment; silage particle size distribution not determined) that were easily sorted against and unpalatable to the heifers. Harvesting using the cut, wilt, and then harvest method makes it difficult for uniform chopping of long-stem forages with a hay-crop forage harvester because the stems enter the forage harvester at various angles, causing more variation in particle sizes. Adjustment of the forage harvester for a shorter chop length or direct harvesting of the forage at 30 to 35% DM using a multidirectional harvesting head would allow for a more uniform silage particle size distribution and reduced sorting.

CONCLUSIONS

Results from this research indicated that greater NDF concentrations within SS silage diets resulted in decreased DM and energy intakes of the heifers. Body weight gains were closer to the optimal range recommended for Holstein heifers fed SS diets compared with the CON diet. Furthermore, we conclude that SS silage-based diets can control the nutrient intake and growth rates with minimal differences between the CSS and PSS varieties; however, SS silage harvest management and length of cut should be managed to minimize sorting.

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