Evaluation of a high forage total mixed ration on the lactational performance of late lactation dairy cows[1]

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ABSTRACT: Dairy producers continuously ask questions challenging the paradigm of how much forage can be included in the ration to meet the nutrient requirements of lactating dairy cows to support milk production. The production and feeding of forages having both high dry matter digestibility (DMD) and neutral detergent fiber digestibility (NDFd) are needed to increase nutrient supply. Mid- to late-lactation lactating Holstein dairy cows were blocked by parity (10 primiparous and 10 multiparous), milk production (range 33.9 to 56.6; μ = 41.5 kg/d), and days in milk (DIM) (range 140 to 287; μ = 225 d) and randomly assigned within blocks to 1 of 2 rations based on medium forage (MF) or high forage (HF) inclusion rates. A forage blend consisting of 60% second cutting (2012) alfalfa haylage and 40% (2012) corn silage blended on a DM basis and then fed at either 60% (MF) or 80% (HF) of the ration DM. The alfalfa haylage DM (DMD = 75.7%) and NDF (NDFd = 55.7%) digestibility was above average, but corn silage (DMD = 72.9, NDFd = 52.3%, and starch = 32.1%) was average. The experimental design was a randomized completed block design with 4 continuous weeks for data collection preceded by a 1 wk covariate data collection period in which all cows were fed the MF ration. Cows were milked 3 times/d and milk weights recorded at each milking and milk samples were collected at each milking once weekly for analysis of milk composition. Rations were similar in crude protein (CP; 16.4%), starch (20.1%), acid detergent fiber (ADF; 21.8%), and NDF (34.1%) concentrations. Covariately adjusted milk production (28.1 and 24.1 kg/d for MF and HF, respectively) and 4% fat-corrected milk (FCM; 27.6 and 24.1 kg/d) were significantly reduced by feeding the HF ration compared with cows fed the MF ration, while milk fat (3.98 and 4.0%), milk protein (3.11 and 3.17%), milk lactose (4.81 and 4.77%), and milk solids-not-fat (8.87 and 8.77%) percentages were similar for cows fed both rations. Cows on the HF ration demonstrated a significant reduction in DMI and a trend for decreased body weight (BW) when compared with cows fed the MF ration. The forage nutrient digestibility was not adequate to support the milk production of mid- to late-lactation dairy cows when fed at 80% of the DM. The forage nutrient digestibility when fed at very high inclusion rate (80%) could not meet the nutrient requirements of mid- to late-lactation dairy cows.

Key words: dairy cow, forage, high forage, lactation, milk

INTRODUCTION

Mid to late lactation cows can be a significant source of cash flow on the dairy operation, even though these cows are typically viewed as "low producers". However, if cows are fed a high forage total mixed ration (TMR) having high dry matter digestibility (DMD) and neutral detergent fiber digestibility (NDFd), they can generate substantial income by reducing the feed cost to produce milk. One way to maximize income over feed costs is to use a high forage TMR to generate a more economical ration.

Forages are the cheapest nutrient sources on the farm (Casper 2008; 2012). In order for these feedstuffs to become a larger part of the TMR, they need to support the nutrient demands of lactation. Increasing forage nutrient availability increases their economic value relative to other commodities (Casper 2008; 2012). One way to increase nutrient availability is by using highly digestible forages. High digestible forages can be consumed in greater amounts than in established forage feeding systems (Llamas-Lamas and Combs, 1991). The use of highly digestible forages allows for higher inclusion rates to meet nutrient requirements of lactation (NRC, 2001), while reducing feed costs.

Cherney et al. (2004) observed that feeding a moderately high forage TMR (60 vs. 50%) could sustain milk production, while reducing TMR cost. Martinez et al. (2009) observed that DMI decreased when cows were fed a 60% high forage TMR compared with a lower forage TMR having similar ($P >$ 0.10) milk production. These observations support the theory that the nutrient requirements for milk production can be met to a certain degree with a high forage TMR to yield similar milk production and components compared with feeding a lower forage TMR.

The objective was to evaluate the lactational performance of mid-to late-lactation dairy cows when fed a highly digestible forage at a very high inclusion rate. The hypothesis was that feeding a highly digestible forage to mid- to late-lactation dairy cows would achieve similar milk production to those cows fed a lower inclusion rate of forage, i.e., more grain.

MATERIALS AND METHODS

Animals and Diets

The experiment was performed at the Dairy Research and Training Facility (DRTF) at South Dakota State University (SDSU) from November 2, 2012 through December 6, 2012 and all procedures were approved by the SDSU Institutional Animal Care and Use Committee. Twenty lactating Holstein dairy cows, (10 primiparous and 10 multiparous), in mid-late-lactation were blocked by milk yield (41.5 ± 5.9 kg/d), DIM (225 ± 49.5 DIM), lactation number, and randomly assigned to 1 of 2 treatments differing in the inclusion rate of an alfalfa haylage/ corn silage blend incorporated into the TMR.

The experimental design was a randomized completed block design with 4 continuous wk for data collection preceded by 2 wk for training to feed boxes and covariate data collection period in which all cows were fed the MF ration to measure individual feed intake. Rations were balanced for CP and starch for a 635 kg cow producing 36 kg/d of milk (NRC,

Table 1. Ingredient composition (% of Mix) of Medium Forage (MF) and High Forage (HF) grain mixes and total mixed rations fed

	TMR	
Ingredients, grain mixes	MF	HF
Ground Corn	38.60	56.35
Soyhulls	37.05	21.80
Distillers Grain w Solubles	19.00	11.15
48 SBM	1.11	2.21
Urea	0.25	0.49
Magnesium Oxide	0.09	0.18
Sodium Bicarbonate	0.67	1.33
Dicalcium phosphate, 18.5 P, 21.0 Ca	0.67	1.33
Monosodium Phosphate	0.05	0.10
MonoAmmonium Phosphate	0.22	0.44
Dynamate	0.70	1.40
Salt	1.10	2.20
Selenium Yeast, 0.2%	0.04	0.07
Dairy Premium, VTM[1]	0.48	0.95
Ingredients, TMR, % DM basis		
Grain Mix	40	20
second cut Alfalfa haylage, 2012	36	48
Corn silage, 2012	24	32

[1]Contains, Yeast Culture, Rice Hulls, Magnesium Mica, Manganese Sulfate, Zinc Sulfate, Vitamin E Supplement, Active Dry Yeast, Copper Sulfate, Dried *Aspergillus* oryzae Fermentation Extract, Zinc Proteinate, Iron Sulfate, Mineral Oil, Manganese Proteinate, Choline Chloride, Copper Proteinate, Vitamin A Supplement, d-Calcium Pantothenate, Thiamine Mononitrate, Iron Proteinate, Niacin, Cobalt Carbonate, Zinc Polysaccharide Complex, Zinc Amino Acid Complex, Copper Amino Acid Complex, Manganese Amino Acid Complex, Cobalt Glucohepatonate, Vitamin B_{12} Supplement, Iron Polysaccharide Complex, Manganese Polysaccharide Complex, Copper Polysaccharide Complex, Cobalt Proteinate, Riboflavin Supplement, Biotin, Calcium Iodate, Vitamin D_3 Supplement, Pyridoxine Hydrochloride, and Folic Acid. Source: Agri-King, Inc., Fulton, IL.

2001). Forages were 60% second cutting alfalfa haylage (2012 crop year) and 40% corn silage (2012 crop year) blended on a DM basis and then fed at either 60% (Medium Forage: MF) or 80% (High Forage: HF) of the ration DM. The second cutting alfalfa haylage was harvested at the highest quality possible, and stored in an Ag Bag (Ag-Bag Systems, ST. Nazianz, WI) for approximately 6 mo prior to the experiment. Corn silage was from the 2012 crop season, harvested and ensiled in a concrete bunker silo at the DRTF for approximately 3 mo, prior to the start of the experiment. Forage nutrient digestibility was confirmed by sending forage samples to a commercial testing laboratory (Analab, Inc., Fulton, IL) for nutrient digestibility measurements and then data used for balancing rations. The ingredient composition of grain mixes are given in Table 1.

Cows were fed a TMR once daily at 1000 h using a Calan Data Ranger (American Calan Inc., Northwood, NH). Cows were fed for 10% refusals and refusals were collected and weighed the day before the next feeding.

The forage component, 60% alfalfa haylage: 40% corn silage DM basis was premixed in a Patz 420 vertical mixer (Patz Corporation, Pound, WI). This forage mix was then weighed into the Calan Data Ranger and the appropriate experimental concentrate mix was added and allowed to mix for 5 min prior to feeding. Prior to the experiment starting, wk 1 was for cow training on using the Calan doors, while wk 2 was for data collection for use as a covariate in statistical analysis followed by 4 wk of data collection. Cows were fed the MF ration during this training and covariate period. Bedding, milking, cow monitoring, and manure scrapping followed normal DRTF procedures. Administration of 14-d slow release recombinant bST (Prosilc, Elanco, Greenfield, IN) was continued as a normal herd management practice. Cows were milked 3 times a day at: 0700, 1400, and 2100 h and milk weights were recorded electronically (DeLaval-ALPRO, Kansas City, MO) at each individual milking.

Sampling

Dry matter concentration of individual forages were determined per wk and feed sheets were adjusted accordingly. Individual samples of corn silage, alfalfa silage, concentrate mixes and TMR were collected once per wk throughout the trial and stored at –20°C. Milk samples were collected once per wk at each milking throughout the study. Milk samples were composited by d on a weighted basis proportional to that day's individual milk yields. Samples were sent to Dairy Herd Improvement Association Heart of American (Manhattan, KS) for compositional and quality analysis using AOAC (2006) appropriate methods. Protein, fat, and lactose were analyzed using near infrared spectroscopy (Bentley 2000 infrared Milk Analyzer, Bentley Instruments, Chaska, MN). Milk urea nitrogen (MUN) concentration was determined using a chemical method based on a modified Berthelot reaction (Chaney and Marbach, 1962; Chemspec 150 analyzer, Bentley Instruments). Somatic cell count (SCC) was determined with a flow cytometer laser (Somacount 500, Bentley Instruments). The calculation of 4% fat-corrected milk (FCM) was via the equation as described in the NRC (2001).

Once a wk at 1300 h, body weight (BW) and body condition score (BCS) were taken. The BCS were recorded at the same time as BW. Body condition score was evaluated independently by 3 trained graduate students using a scale of 1 to 5, where 1 is emaciated and 5 is obese (Wildman et al., 1982).

During wk 3 and 4 of the study, approximately 2 to 4 h after feeding, three 10-mL blood samples were collected from the tail vein. Blood samples were collected into 3 separate vacutainers (Becton Dickinson Vacutainer Systems, Rutherford, NJ); 2 vacutainer tubes contained

K$_2$–EDTA (Becton Dickinson Vacutainer Systems), and 1 vacutainer tube contained sodium fluoride (Becton Dickinson Vacutainer Systems). Blood samples were collected and immediately stored on ice, then transported to the lab and centrifuged (2000 × g) for 20 min to separate plasma, which was stored at –20°C.

Laboratory Analysis

At the completion of the study, individual forages, concentrate mixes and TMR samples were thawed and DM was determined for wk samples by drying in a 55°C oven for 48 h (Despatch style V-23, Despatch Oven Co., Minneapolis, MN) to a constant weight before grinding (AOAC, 2006). Samples were then ground via a Wiley Mill (Model 3, Arthur H. Thomas Co., Philadelphia, PA) to pass through a 2-mm screen and then further ground through a 1-mm screen using an ultracentrifuge mill (Brinkman Instruments Co., Westbury, NY). The samples were then composited by study periods of covariate, wk 1 and 2, and wk 3 and 4 for 3 individual samples of the individual forage components, concentrate mixes, and TMR. Samples were sent to AnaLab (Fulton, IL) for nutrient analysis. Samples were analyzed using the following AOAC (2006) methods: DM, ADF, NDF, CP, ash, ether extract (fat), and lignin. The remaining nutrient parameters were measured via the following methods: soluble protein (Krishnamoorthy et al., 1982), starch (Glucose Reagent Set, AMRESCO, Solon, OH and Alpkem Corporation, 1990), in vitro dry matter digestibility [IVDMD; 24 h ruminal and 24 h enzymatic digestion using the Kansas State Buffer (Marten and Barnes, 1980)], neutral detergent fiber digestibility (Van Soest et al., 1991), incubated for 30 h using the Kansas State Buffer (Marten and Barnes, 1980), lactic acid (El Rossi, 1996), acetic acid (Cancalon and Bryan, 1993).

Blood plasma was analyzed for glucose using an assay kit (Liquid Glucose Oxidase Reagent Set) from Pointe Scientific (Pointe Scientific, Inc., Canton, MI). Blood plasma was analyzed for β-Hydroxybutyrate using an assay kit (β-Hydroxybutyrate Reagent Set) from Pointe Scientific (Pointe Scientific, Inc.). Plasma samples were analyzed for plasma urea nitrogen (PUN) using an assay kit [Stanbio Urea Nitrogen (BUN) Procedure No. 0580] from Stanbio (Stanbio Laboratory, Boerne, TX).

Statistical Analysis

Statistical analysis of all data were subjected to least squares ANOVA using the PROC MIXED procedure of SAS (SAS Inst. Inc., Cary, NC, Version 9.3) for a randomized complete block design (Steel and Torrie, 1980). Data collected during the pre-treatment wk was

Table 2. Nutrient composition (% of DM) of medium forage (MF) and high forage (HF) grain mixes, corn silage (CS), and alfalfa haylage (AH) and the total mixed rations (TMR)

Nutrient	Grain mix		Forages		TMR Calculated		TMR, Analyzed	
	MF	HF	CS	AH	MF[1]	HF[2]	MF	HF
DM, %	89.8	89.3	36.9	44.7	60.9	51.1	53.2	49.2
CP	13.7	13.5	8.0	26.1	16.8	17.8	17.3	17.3
SP, % of CP	20.4	27.2	58.0	65.4	45.6	55.4	55.4	58.0
ADF	24.2	15.7	20.5	25.5	23.8	21.9	24.2	22.0
NDF	36.9	21.6	35.9	32.9	35.2	31.6	33.6	30.5
Lignin	–	–	1.7	5.8	–	–	4.0	4.0
Fat	5.1	4.6	2.7	2.6	3.61	3.02	3.0	3.4
NFC	40.9	54.1	49.9	32.8	40.1	42.5	39.7	42.2
Starch	20.3	34.7	35.9	–	16.7	18.4	–	–
IVDMD	–	–	72.9	75.7	–	–	–	–
NDFd, % of NDF	–	–	52.9	64.9	–	–	–	–
Lactic acid	–	–	7.0	5.2	–	–	–	–
Acetic acid	–	–	2.2	0.6	–	–	–	–

[1]Calculated as 40% grain mix, 36% alfalfa haylage, and 24% corn silage on a DM basis.

[2]Calculated as 20% grain mix, 48% alfalfa haylage, and 32% corn silage on a DM basis.

used as a covariate to adjust all cows to a similar starting point. Fixed effects were block, parity, treatment, week, and all interactions. The statistical model used was: $Y_{ijkl} = \mu + B_i + T_j + TM_k + (T_j \times TM_k) + Cov_l + e_{ijkl}$, where Y_{ijkl} = dependent variable, μ = overall mean, B_i = Block effect, T_j = treatment, TM_k = time, and $(T_i \times TM_k)$ = treatment by time interactions, where time = wk, Cov_l = covariate, and e_{ijkl} = random error. Week was analyzed as a repeated measure using an autoregressive covariance structure and cow was specified as a random effect. Data were tested for heterogeneity of variances and statistical significance was declared at $P \leq 0.05$ or < 0.01 and trends were declared at $0.05 < P < 0.10$.

RESULTS

Feed Analysis

The ration that was initially formulated for the design of the experiment was formulated using first cutting (2012 crop year) alfalfa. However, at the onset of the trial, it was necessary to switch to the second cutting (2012 crop year) alfalfa instead of first cutting because of accessibility to the stored forages. This resulted in some differences between the formulated and the analyzed ration. The formulated ration was expected to be approximately 16.4% CP, 41.5% SP, 34.1% NDF, 21.8% ADF, and 20% starch. A 1% unit increase in CP was observed in the analyzed rations versus the formulated rations (Table 2). The level of soluble protein (SP) was substantially higher in the analyzed TMR in comparison to the formulated ration. Finally,

the amount of NDF was also lower in the analyzed ration in comparison to the formulated ration. These differences were due to switching from first to second cutting (2012 crop year) alfalfa haylage.

Milk Production and Components

A significant decrease ($P < 0.01$) in production of milk and 4% FCM was observed in cows fed the HF TMR compared to cows fed the MF TMR (Table 3). The decline in milk production for cows fed the HF ration occurred during the first wk of the study after the abrupt change over from the covariate (MF) ration (Fig. 1). No significant differences between forage amounts were observed for fat ($P = 0.89$), protein ($P = 0.29$), lactose ($P = 0.41$), SNF ($P = 0.20$), and SCC concentrations ($P = 0.96$) as would be expected because of feeding a higher forage TMR. The MUN concentrations were greater ($P < 0.01$) for cows fed the HF rations compared to cows fed the MF rations due to the greater TMR SP concentrations in the HF ration.

Dry Matter Intake, Body Weight, and Feed Efficiency

Feeding lactating dairy cows a HF TMR resulted in lower ($P < 0.04$) DMI compared to cows fed the MF TMR (Table 3). Cows fed the MF TMR tended to gain DMI with experimental wk, while cows fed the HF TMR dropped in DMI from the covariate period and did not increase DMI until the final wk of the study (Fig. 2). When FE was compared between treatments using Milk/DMI,

Table 3. Milk production, milk composition, milk quality, dry matter intake (DMI), body weight (BW), body weight change (BWc), and body condition score (BCS), and body condition score change (BCSc) when lactating dairy cows were fed a medium forage (MF) or high forage (HF) ration

| Measurement | TMR | | SEM | $P <$ |
	MF	HF		
Milk, kg/d	28.1	24.1	0.56	0.01
4% FCM[1], kg/d	27.6	24.1	0.50	0.01
Fat, %	3.98	4.00	0.11	0.85
Protein, %	3.11	3.17	0.04	0.29
Lactose, %	4.81	4.77	0.03	0.41
SNF,%	8.87	8.77	0.05	0.20
MUN[2], mg/dL	12.1	13.1	0.25	0.01
SCC[3], x1000 CFU/ml	189.0	176.9	159.0	0.96
DMI, kg/d	21.9	18.8	.59	0.04
FE[4], Milk/DMI	1.29	1.30	0.06	0.69
FE[4], FCM/DMI	1.25	1.30	0.44	0.70
BW, kg	685.9	673.2	4.91	0.09
BW change, kg	4.8	–14.7	6.47	0.05
DMI/BWT, %	3.15	2.82	0.08	0.01
BCS[5], 1–5 scale	3.37	3.05	0.04	0.01
BCS change, kg/d	–0.15	–0.23	0.12	0.62

[1]FCM = 0.4 * Milk, kg/d) + (15* (Milk Fat/100) * Milk, kg/d, (NRC, 2001).

[2]Milk Urea Nitrogen.

[3]Somatic Cell Count.

[4]Feed Efficiency.

[5]Body Condition Score.

as well as, 4% FCM/DMI, no significant ($P = 0.69$) differences were detected in FE between treatments (Table 3).

Cows fed the HF TMR tended ($P < 0.09$) to have lower BW and lost significantly ($P < 0.05$) more BW than cows fed the MF TMR. Cows fed the MF TMR demonstrated a greater ($P < 0.01$) DMI/BW than cows fed the HF TMR. These observed responses in DMI and BW resulted in cows fed the HF TMR being lower in BCS when compared to cows fed the MF TMR (Fig. 3). There was a significant difference in BCS between treatments, how-
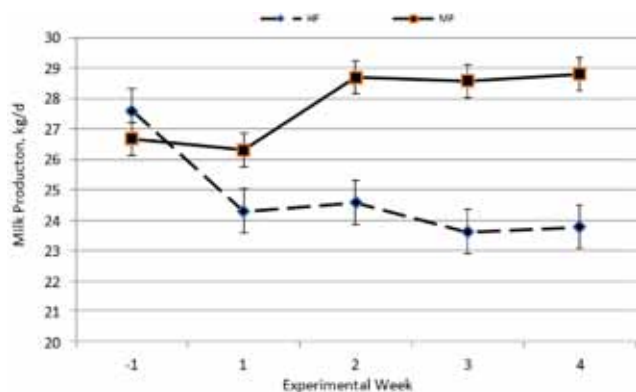

Figure 1. Milk Production (kg/d) by cows fed a Medium Forage (MF) or a High Forage (HF) ration.
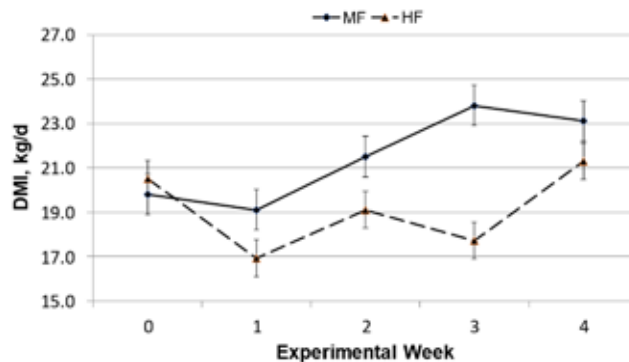

Figure 2. Dry matter intake (DMI) by cows fed a Medium Forage (MF) or High Forage (HF) ration.

ever cows fed the HF TMR had numerically ($P > 0.10$) higher losses of BCS (BCSc) than cows fed the MF TMR

Blood Parameters

Concentrations of plasma glucose and βHBA were similar ($P \geq 0.10$) for cows fed both TMR (Table 4). However, cows fed the MF TMR had significantly lower ($P < 0.05$) PUN when compared to cows fed the HF TMR. The higher PUN for cows fed the HF TMR would correlate with the higher MUN observed for these cows (Table 4).

DISCUSSION

While the literature contains an abundance of forage to concentrate ratio studies, a paucity of studies exist pushing for maximum forage inclusion rates. Dairy producers strive to produce large amounts of highly digestible forage and desire to know with confidence the amount of forage to include in the ration of a given nutrient digestibility. This information is not found in the literature. The production of highly nutrient digestible forages (> 80% IVDMD) was a priority when designing this experiment to test the hypothesis of maintaining similar milk yield and DMI on an exceptionally high inclusion rate of the forage blend in the ration. The corn silage digestibility of DM and NDFd was slightly better than the reported averages by Casper (2012), while the alfalfa haylage was much higher than reported averages, for both IVDMD

Table 4. Blood Parameters of cows fed Medium Forage (MF) or High Forage (HF) total mixed rations (TMR)

| Measurement | TMR | | SEM | $P <$ |
	MF	HF		
Glucose, mM	51.4	50.5	2.4	0.74
βHBA[1], mg/dl	73.5	73.5	6.46	1.00
PUN[2], mg/dl	16.4	20.8	1.78	0.05

[1]Beta hydroxyl butyrate.

[2]Plasma urea nitrogen.

and NDFd (Table 3), thereby achieving an objective of this study. The calculation of digestible NDF (DNDF) on a DM basis [DNDF = NDF × (NDFd/100)] indicates that the alfalfa haylage contained approximately 2% units greater digestible fiber than corn silage (19.0 and 21.4% DNDF of DM for corn silage and alfalfa haylage, respectively). Casper and Mertens (2007) reported that the greatest factor affecting energy and nutrient availability was digestible fiber (DNDF) based on the analysis of the Energy Metabolism Unit database.

The ration change from first cutting alfalfa to second cutting reduced the DMD of the ration and increased the CP and SP. in the post-experiment analyzed rations when compared to the initial formulated rations. This increase in CP supply could have contributed to the higher PUN and MUN, but were within recommended concentrations (Ferguson, 2000) for cows fed the HF ration. The lower content of NDF in the HF ration may have still reduced the amount of energy available to the cow, because of a decrease in digestible NDF when forage NDF replaced NDF from soyhulls. The NDF in soyhulls has been reported (Ipharraguerre and Clark, 2003) to be as high as 90%, which would increase the amount of digestible fiber in the MF compared to the HF ration due to less digestible fiber alfalfa replacing digestible fiber soyhulls. Dado and Allen (1996) using similar NDF rations differing in NDFd resulted in the greater NDFd ration supporting increased DMI and milk production.

This study observed lower DMI in the HF ration in comparison to the cows fed the MF ration. Increasing the forage to concentrate ratio generally results in decreased feed intake (Allen, 2000). However, Aguerre et al. (2011) increase the forage inclusion rate from 47 to 68% and observed similar DMI for lactating dairy cows. However, Broderick (2003) reported a decrease in DMI as forage inclusion rate went from 50.1 to 74.7%. The difference in the DM and NDF digestibility of the forages between these 2 studies can explain the differences in results. If the forages are highly digestibility (Aguerre et al., 2011; Ruiz et al., 1995), then the forages can be a greater percentage of the ration and maintain DMI and milk production. Oba and Allen (1999) in their summary stated that enhanced NDF digestibility of forage improves DMI and milk production of dairy cows, while Dado and Allen (1996) using similar NDF rations differing in NDFd resulted in the greater NDFd ration supporting increased DMI and milk production.

The calculated NDF intake as a % of BW was 1.07 and 0.85% for cows fed MF and HF, respectively. The intake of forage digestible NDF (DMI × Forage NDF/100 × NDFD/100 × ration forage inclusion/100) as a percentage of BW was 0.26% and 0.31%, while the intake of indigestible forage NDF {DMI × Forage NDF/100 × [(100-NDFD)/100] × ration forage inclusion/100} as a
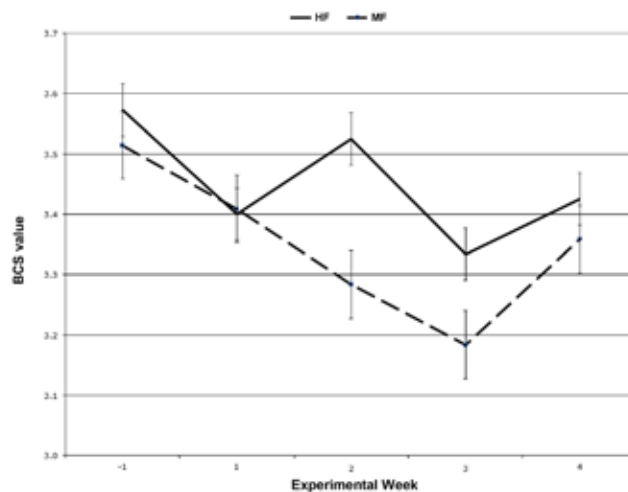

Figure 3. Body condition score (BCS) of cows fed a Medium Forage (MF) or High Forage (HF) ration.

percentage of BW was 0.39% and 0.45%. Casper (2017) reported that preliminary research suggested the maximum intake of indigestible NDF was ~0.45% of BW that will determine the maximum amount of NDF that a dairy cow can consume. Thus, the cows fed the HF ration were consuming more digestible fiber, but the amount of indigestible fiber was limiting intake for these cows compared with the cows fed the MF ration. Thus, the reduction in DMI may be due to too much indigestible fiber, which reduced milk production for cows fed the HF ration compared with the cows fed the MF ration. Results from this study are in contrast to work by Martinez et al. (2009) and Broderick (2003) in which they observed that a 60% or greater HF ration demonstrated no significant differences in DMI in comparison to cows fed a 50% MF ration. Martinez et al. (2009) also observed a numerical increase in NDF digestibility in their high forage ration, while Broderick (2003) observed a linear decrease in DMD with increasing forage inclusion rates. The researchers theorized that this promoted higher ruminal, rather than intestinal NDF digestion, reduced passage rate of fiber, which allowed for more microbial degradation. The current study's HF ration of 80% forage pushed beyond the previously observed positive results with 60% forage and demonstrated that the limiting factor in the 80% HF TMR was DMI, implying that the forage quality and digestibility of the consumed ration was not sufficient, i.e., > 80% IVDMD.

The current study observed a significant decrease in body weight change (BWc) and BCS in cows fed the HF TMR compared with cows fed the MF TMR. To meet the nutrient requirements for milk production, cows fed the HF ration mobilized more body tissue, lost BW, and lost BCS. However, there was only a trend in the difference between BW between cows fed both TMR. This observation aligns with Martinez et al. (2009) where they ob-

served no effect on BW between treatments with changing the level of forage inclusion in the ration.

Feeding lactating dairy cows the HF ration compared with cows fed the MF ration reduced milk production in the current study. Martinez et al. (2009) maintained milk production on a 60% HF ration, while Aguerre et al. (2011) maintained milk production on a 68% forage ration. The 20% additional increase in the forage amounts in the HF ration in this study resulted in a decrease in milk production. The observations in this study lead to the hypothesis that the nutrient digestibility of the forage was the limiting factor for DMI and consequently, milk production. Feeding lactating dairy cows the HF ration in the current study resulted in no significant differences in milk protein, lactose, SNF, and MUN. The lack of significant differences in milk components was also observed by Martinez et al. (2009). This data support the conclusion that feeding a HF ration to lactating dairy cows can maintain milk components when compared with cows fed a MF ration.

Martinez et al. (2009) and Aguerre et al. (2011) not only reported no significant differences in milk production at the high forage level, Martinez et al. observed an improved FE, i.e., DMI converted to milk. This is in contrast to the current study, where no significant differences in FE between the 2 rations were observed. This was expected because of the reduction in milk production for cows fed the HF ration compared with cows fed the MF ration. However, the experiment conducted by Martinez et al. (2009) worked with early lactation cows compared with the current study, which was conducted using mid- to late-lactation cows. Late lactation cows will have a much lower FE in comparison to early lactation cows because of converting DMI to BW and body condition gain. This difference in relative position along the lactation curve may explain the differences observed in FE between studies.

Feed Costs (FC) were calculated using feed costs from the July 2014 period. There was a FC savings of $0.58/cow per d when cows were fed the HF ration compared with cows fed the MF ration. However, the FC savings would not offset the lost in milk income of $2.32/cow per d observed in this experiment. While the goal is to reduce FC and the cost to produce 100 kg milk by feeding a higher forage ration, it cannot be at the loss of income and profitability. Further work is needed to properly define the amount of forage that can be fed at specific levels of digestibility that is profitable for the dairy producer.

Though the current study did not analyze individual animal nutrient digestibility (i.e., collect fecal grab samples) during the trial, the forage nutrient digestibility was analyzed before the initiation of the trial using in vitro laboratory measurements. Laboratory methods of measuring nutrient digestibility are routinely applied to the formulation of rations for meeting the nutrient requirements of lactating dairy cows. Although, forages of even higher digestibility are commonly produced (Casper, 2012). These data support the theory that though the forage nutrient digestibility was higher than average in this study, but the ruminal nutrient digestibility and kinetics were not able to energetically meet the nutrient demands of the cows fed the HF ration in regards to BWc, BW, and milk production when compared with cows fed the MF ration.

Conclusions

This study supports the theory that although the forage quality was above average (i.e., high), but still insufficient in nutrient digestibility to support milk production when fed at 80% of the ration DM to mid- and late-lactation dairy cows. The theory that an 80% forage ration can be fed to maintain milk composition compared with cows fed 60% forage was not supported by this study. Much higher forage quality is needed (> 80% DMD) than what was fed in this study to potentially maintain milk production at an 80% forage inclusion rate.

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