Effects of feeding wheat straw or orchardgrass at ad libitum or restricted intake during the dry period on postpartum performance and lipid metabolism¹

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ABSTRACT

The objectives of this study were to investigate the effects of forage source [wheat straw (WS) or orchardgrass hay (OG)] and total amount of diet dry matter fed [ad libitum or restricted to 70% of predicted dry matter intake (DMI)] prepartum on postpartum performance. The study design was a 2 × 2 factorial design with 10 cows per treatment. Treatments were WS total mixed ration (TMR) ad libitum, OG TMR ad libitum, WS TMR restricted, and OG TMR restricted. The WS TMR (dry matter basis) contained 30% WS, 20.7% corn silage, 10.0% alfalfa hay, 18.2% ground corn, 16.8% soybean meal, and 4.3% molasses mineral mix (14.7% CP, 1.5 Mcal/kg of net energy for lactation, 37.0% neutral detergent fiber). The OG TMR contained 30% OG, 46.2% corn silage, 10.0% alfalfa hay, 9.5% soybean meal, and 4.3% molasses (14.2% CP, 1.5 Mcal/kg of net energy for lactation, 41.0% neutral detergent fiber). Cows received 1 lactation diet after calving (17.7% CP, 1.6 Mcal/kg of net energy for lactation, 27.3% neutral detergent fiber). Total diet DMI prepartum was higher for ad libitum than for restricted as designed, but forage source had no effect on DMI. Total tract apparent digestibilities of DM and NDF were greater for OG than for WS. Postpartum DMI expressed as a percentage of body weight for the first week of lactation was higher for ad libitum than for restricted diets. Postpartum DMI during the first 30 d of lactation was higher for OG than for WS, but no effect was observed for the amount fed prepartum. Milk yield during the first week of lactation was higher for OG than for WS; however, during the first 30 d, 3.5% fat-corrected milk yield and yield of milk fat were highest for OG TMR restricted and WS TMR ad libitum. Prepartum treatments had a limited effect on pre- and postpartum lipid metabolism;

however, cows fed WS TMR ad libitum had the highest postpartum β -hydroxybutyrate. Eating behavior was observed by 10-min video scans of 24-h video surveillance for 5 d pre- and postpartum. Prepartum eating time and eating bouts tended to be greater by WS than for OG, and postpartum eating time per kilogram of neutral detergent fiber intake tended to be greater for WS than for OG. Results indicate that forage source and amount of DM fed prepartum affected postpartum performance and tended to alter the behavior of cows in tie-stall barns.

Key words: forage, ad libitum, restricted, transition cow

INTRODUCTION

Nutrition and management strategies to prevent the decrease in DMI before calving are not clearly defined. Maintaining DMI in periparturient dairy cattle is important to minimize the disruption in energy balance, which is known to affect lipid mobilization and the performance of dairy cattle after parturition. Minimizing the extent and duration of the negative energy balance will help reduce lipid mobilization, which is linked to liver lipid accumulation (Hammon et al., 2009; McCarthy et al., 2010) and impaired immune function (Wathes et al., 2009). The concept of prepartum limit feeding has received some interest from researchers. Grum et al. (1996) was the first to report that a lower energy intake prepartum (with lower DMI because of fat supplementation) was associated with a lower liver lipid accumulation without a significant detriment to milk production. Subsequently, Douglas et al. (2006) limit-fed cows prepartum and observed higher DMI and NE_L intake during the first 21 d postpartum compared with cows fed ad libitum. The authors concluded that the amount of prepartum energy intake had an effect on metabolism because lower prepartum energy intake resulted in improvements in key metabolic indicators. Other researchers have demonstrated that limit feeding prepartum to maintain a consistent energy balance (Kunz et al., 1985; Holcomb et al., 2001) or a slightly

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negative energy balance prepartum (Holtenius et al., 2003) results in higher postpartum DMI. More recently, Dann et al. (2006) demonstrated that cows with a lower energy balance [either limit fed or using wheat straw (WS) to dilute the dietary energy density] during the far-off dry period had higher postpartum DMI and a higher energy balance and lower serum NEFA and BHBA during the first 10 DIM.

Reasons for the improvements in postpartum DMI from limiting energy intake prepartum by restricted feeding remain unclear. The published data suggest that higher DMI postpartum reduces lipid mobilization and prevents the suppression of DMI by NEFA (Overton and Waldron, 2004). Limit-fed cows therefore have lower energy intake and are potentially at lower risk for excessive lipid mobilization compared with ad libitum-fed cows, which often consume energy in excess of requirements (Dann et al., 2006; Winkelman et al., 2008). Limit feeding also prevents BCS gain during the dry period (Dann et al., 2006), reduces feed costs, and reduces the amount of nutrients excreted into the environment (Hoffman et al., 2007; Zanton and Heinrichs, 2007). Perhaps restricted-fed cows have less rumen fill and a greater appetite drive immediately postpartum compared with ad libitum-fed cows. The effect of prepartum rumen fill on feed intake would likely be only transient unless limit feeding had carryover effects on postpartum feeding behavior. The digestibility of limit-fed diets and mean retention time in the rumen are likely also important factors contributing to DMI in the first week postpartum. Sheep fed in restricted amounts spent more time ruminating per gram of DMI (Galvani et al., 2010), and cattle fed in restricted amounts increased the chewing rate when eating and ruminating (Dias et al., 2011). To our knowledge, no studies have examined the effect of prepartum restricted feeding on postpartum feeding behavior.

In addition to restricted feeding, we wanted to compare the effect of feeding 2 dry forages that varied greatly in physical and chemical properties, WS or orchardgrass hay (OG), to determine the effect of forage type on periparturient performance. Wheat straw tends to be lower in potassium than grasses, which accumulate potassium within plant tissues. Minerals from forages are thought to be readily digestible and contribute to the DCAD. A positive DCAD increases the risk for hypocalcemia and related periparturient disorders (Lean et al., 2006). Additionally, the rate of digestion is likely an important factor in the selection of forages for dry cow diets. Wheat straw has a slower ruminal disappearance rate compared with OG, resulting in greater rumen fill that maintains a more stable rumen fiber mat, reducing the risk for displaced abomasum after

freshening (Douglas et al., 2006; Janovick et al., 2011), but perhaps also limits feed intake in the first days after parturition. The amount and rate of digestion of NDF on the periparturient dairy cow is unknown. The rate and extent of NDF digestion affects ruminants by altering DMI, microbial ecology, VFA production, and rumination behavior and influencing the rate of passage through the gastrointestinal tract.

The objectives of this study were to determine whether limit feeding during the dry period would prevent the decline in intake at parturition, and to determine whether the forage source would alter prepartum energy intake, postpartum performance, and metabolism. We hypothesized that limit feeding would result in more consistent DMI through parturition and that OG would result in greater prepartum energy intake compared with WS.

MATERIALS AND METHODS

Animals and Treatments

All procedures involving animals were approved before the onset of the experiment by the University of Minnesota Institutional Animal Care and Use Committee (No. 0706A09601). The experiment began in September 2008 and ended in March 2009. Holstein and Holstein crosses with Jersey, Montbéliard, and Swedish Red dairy cattle ($n = 40$) entering their second or later lactation were selected from the University of Minnesota Dairy Teaching and Research Center. Treatments were balanced for BW at dry off, parity, breed, and previous-lactation 305-d mature-equivalent milk yield. At the day of dry off (45 d before expected calving) cows were assigned to 1 of 4 treatments: (1) WS ad libitum (AWS), (2) OG ad libitum (AOG), (3) WS restricted (RWS), and (4) OG restricted (ROG). The restricted diets were fed at 70% of NRC (2001)-predicted DMI for dry cows. Dietary treatments are described in Tables 1 and 2. Prepartum diets fed ad libitum (A-fed) were formulated for 13.6 kg/d of DMI and those fed restricted were formulated for 9.5 kg/d of DMI. To ensure the nutrient requirements were met for restricted-fed (R-fed) cows, the diets were formulated to supply greater than 100% of nutrient requirements for multiparous dry cows averaging 635 kg at 270 d of gestation when fed ad libitum. All nutrient requirements were met except for MP, which was calculated as 106 ± 6.0 g/d less than required for R-fed cows; however, requirements for the amino acids lysine and methionine were met. Wheat straw and OG were chopped in a vertical mixer to reduce particle size to a uniform consistency between forages. Cows were fed a common lactation diet (Table

Table 1. Ingredient and nutrient composition (n = 5) of dietary treatments for cows fed a TMR with 30% wheat straw in ad libitum (AWS) or restricted (RWS) amounts or 30% orchardgrass hay in ad libitum (AOG) or restricted (ROG) amounts prepartum

Item	Treatment ¹		SEM
	AWS, RWS	AOG, ROG	
Ingredient			
Wheat straw, chopped, % of DM	30.0	0.0	
Orchardgrass, chopped, % of DM	0.0	30.0	
Corn silage, processed, % of DM	20.7	46.2	
Alfalfa hay, chopped, % of DM	10.0	10.0	
Shelled corn, ground, % of DM	18.2	0.0	
Soybean meal, 48%, % of DM	16.8	9.5	
Vitamin-mineral mix, ² % of DM	4.3	4.3	
Particles retained, % as fed			
>19.0 mm	14.7	15.8	
19.0 to 8.0 mm	37.1	41.5	
<8.0 mm	48.2	42.7	
Nutrient composition			
DM, %	66.1	50.6	27.7
CP, %	14.7	14.2	0.5
RUP, % of CP	31.4	29.8	0.5
RDP,% of CP	68.6	70.1	0.5
Soluble protein, % of CP	29.1	39.5	0.5
MP, g/d	1,384	1,279	27.7
NE _L , Mcal/kg	1.51	1.50	<0.1
ADF, %	21.4	22.8	0.6
NDF, %	37.0	41.0	<0.1
Sugar, %	3.8	3.6	0.6
Starch, %	14.6	7.0	<0.1
Fat, %	2.2	2.5	0.2
Ash, %	6.9	8.1	<0.1
Calcium, %	0.54	0.62	<0.1
Phosphorous, %	0.35	0.37	<0.1
Magnesium, %	0.24	0.29	<0.1
Potassium, %	1.4	1.8	<0.1
Sulfur, %	0.16	0.17	2.0
DCAD1, ³ mEq/100 g	21.0	30.2	2.0
DCAD2, ⁴ mEq/100 g	21.6	31.7	2.0

¹AWS = ad libitum-fed TMR with 30% wheat straw; AOG = ad libitum-fed TMR with 30% orchardgrass hay; RWS = restricted to 70% of predicted ad libitum DMI of TMR with 30% wheat straw; ROG = restricted to 70% of predicted ad libitum DMI of TMR with 30% orchardgrass hay.

²DM, 66.0%; CP, 18.2%; fat, 7.3%; calcium, 4.5%; phosphorus, 2.1%; magnesium, 0.6%; chlorine, 6.5%; potassium, 2.9%; sodium, 3.7%; sulfur, 0.6%; cobalt, 16.5 mg/kg; copper, 206.1 mg/kg; iodine, 27.3 mg/kg; iron, 1,317.7 mg/kg; manganese, 901.5 mg/kg; selenium, 9.3 mg/kg; zinc, 1,545.5 mg/kg.

³DCAD1: (Na + K) - (Cl + S).

⁴DCAD2: [(Na + K + 0.38 Ca + 0.30 Mg) - (Cl + 0.60 S + 0.50 P)] (Horst and Goff, 1997).

3) after calving, and measurements were made through 30 d postpartum.

Animals and Housing

At dry off, cow BW averaged 677.0 ± 40 kg, parity averaged 2.8 ± 0.4 , and previous lactation 305-d mature-equivalent milk yield averaged $10,949 \pm 490$

kg (Table 4). Dry period length averaged 40.7 ± 2.2 d (Table 4). Cows were housed in individual tie-stalls with rubber-filled mattresses bedded with sawdust in a mechanically ventilated barn. Cows were moved to a calving area once calving appeared imminent, and they were returned to their tie-stalls within 2 h after calving. Lactating cows were milked twice daily (0100 and 1300 h) in a milking parlor. Cows were fed once daily during the dry period (1200 h) and twice daily after calving at 0400 and 1100 h.

Sampling and Nutrient Intake

Individual cow diet amounts offered and refused were measured daily from dry off to 30 DIM. Dry matter intake was calculated by correcting as-fed amounts offered minus amounts refused and corrected for DM using the weekly diet DM for each treatment. The diet nutrient profile was determined by analyzing composite samples of individual ingredients on a monthly basis. Samples of the forages, grain, and protein mixture, and TMR were obtained weekly throughout the experiment. Dry matter was determined by drying at 60°C until reaching a static weight, and all samples were ground through a 1-mm screen in a Wiley mill. Amounts of corn silage in the TMR were adjusted weekly based on changes

Table 2. Least squares means of monthly averages (n = 5) of the nutrient composition and particle size (n = 16) of wheat straw (WS) and orchardgrass hay (OG)

Nutrient ¹	Treatment		SEM
	WS	OG	
DM, %	90.4	87.5	0.9
CP, % of DM	2.5	14.4	0.3
ADICP, % of CP	33.3	7.0	2.8
NDICP, % of CP	53.9	50.3	5.9
ADF, % of DM	43.7	23.6	4.3
NDF, % of DM	73.8	58.6	0.2
Sugar, % of DM	3.1	6.0	0.5
Starch, % of DM	0.3	0.7	0.1
Fat, % of DM	1.3	2.8	0.1
Ash, % of DM	8.9	12.0	0.4
Calcium, % of DM	0.2	0.4	0.04
Phosphorous, % of DM	0.1	0.4	0.01
Magnesium, % of DM	0.1	0.3	0.02
Potassium, % of DM	1.6	3.1	0.07
Sulfur, % of DM	0.1	0.2	<0.01
Sodium, % of DM	<0.1	<0.1	<0.01
Chloride, % of DM	0.4	0.2	<0.01
Particles retained, % as fed			
>19.0 mm	32.3	13.9	2.2
19.0 to 8.0 mm	44.8	40.7	1.0
<8.0 mm	22.9	45.4	2.0

¹ADICP = acid detergent-insoluble CP; NDICP = neutral detergent-insoluble CP.

Table 3. Ingredient and nutrient composition of the lactation diet for cows fed prepartum diets manipulated for forage and energy intake

Item	Lactation diet	SEM
Ingredient, % of DM		
Corn silage, processed	42.4	
Alfalfa hay, chopped	14.2	
Shelled corn, ground	14.2	
Soybean meal, 48% CP	10.9	
Protein mix ¹	13.9	
Molasses vitamin-mineral mix ²	3.5	
Energy Booster 100 ³	0.9	
Nutrient		
DM, %	52.7	0.31
CP, % of DM	17.3	0.18
ADF, % of DM	14.8	0.34
NDF, % of DM	26.7	0.45
Sugar, % of DM	3.3	0.2
Starch, % of DM	23.6	0.5
Fat, % of DM	3.7	0.07
Calcium, % of DM	0.8	<0.1
Phosphorous, % of DM	0.4	<0.1
Magnesium, % of DM	0.3	<0.1
Potassium, % of DM	1.5	<0.1
Sulfur, % of DM	0.2	<0.1
Sodium, % of DM	0.7	<0.1
Chloride, % of DM	0.4	<0.1
Particle size retained, % as fed		
>19.0 mm	12.1	1.2
19.0 to 8.0 mm	35.4	0.7
<8.0 mm	52.5	1.6

¹Corn distillers grains with solubles, expeller soybean meal, canola meal, sodium bicarbonate, salt, calcium carbonate, magnesium oxide, potassium carbonate, dicalcium phosphate, and yeast culture; DM, 89.7%; CP, 32.3%; NDF, 18.3%; ADF, 7.0%; starch, 2.3%; fat, 4.3%; ash, 23.6%; acid detergent-insoluble CP (% of DM), 2.1%; neutral detergent-insoluble CP (% of DM), 3.5%; calcium, 2.1%; phosphorus, 0.7%.

²Dry matter, 66.0%; CP, 18.2%; fat, 7.3%; calcium, 4.5%; phosphorus, 2.1%; magnesium, 0.6%; chlorine, 6.5%; potassium, 2.9%; sodium, 3.7%; sulfur, 0.6%; cobalt, 16.5 mg/kg; copper, 206.1 mg/kg; iodine, 27.3 mg/kg; iron, 1,317.7 mg/kg; manganese, 901.5 mg/kg; selenium, 9.3 mg/kg; zinc, 1,545.5 mg/kg.

³Milk Specialties Global (Carpentersville, IL).

in DM content. Dry matter contents of the TMR were used in calculating DMI for the corresponding week.

Dried, ground ingredient samples were analyzed at Dairyland Laboratories (St. Cloud, MN) using wet chemistry methods. Ash content was determined by AOAC method 942.05 (AOAC International, 1995). Crude protein was determined by AOAC method 990.03 (AOAC International, 1995). Amylase-treated NDF was determined by methods described by Van Soest et al. (1991). Acid detergent fiber was determined by AOAC method 973.18 (AOAC International, 1995). Lignin was determined by AOAC method 973.18 (AOAC International, 1995). Ether extract was determined by AOAC method 920.39 (AOAC International, 1995). Sugar was determined by measuring total ethanol-soluble carbohydrates (Hall et al., 1999). Starch was determined by an enzymatic method described by Knudsen (1997).

Default model chemical compositions of dietary ingredients were adjusted to reflect the average monthly composite analysis (Dairyland Laboratories). Monthly averages of the nutrient composition of individual ingredients were entered into a CPM Dairy model (version 3.08; Cornell University, Ithaca, NY; University of Pennsylvania, Kennett Square, PA; and William H. Miner Agricultural Research Institute, Chazy, NY) to calculate the nutrient composition of the treatments. Energy balance pre- and postpartum was calculated using equations described by NRC (2001) individually for each cow. Net energy intake was determined by multiplying the DMI by the calculated mean NE_L density of the diet. The NE_L value of each individual feed (Dairyland Laboratories) was used to calculate the mean NE_L content of the diet. Dairyland Laboratories used the Ohio State-NRC summative energy equation for predicting total digestible nutrients at maintenance (1×). The NE_L 3× maintenance was predicted from total digestible nutrients according to the NRC (2001). The NE_L value for forages was adjusted with the variable

Table 4. Cow descriptive measures as assigned to treatments and days dry

Item	Treatment ¹				SEM
	AWS	AOG	RWS	ROG	
Days dry	43.1	38.8	41.3	39.4	2.2
BW at dry off, kg	663.3	636.8	686.1	721.5	39.7
Parity at dry off	3.1	2.7	2.8	2.7	0.4
Breed ²	4H:6X	3H:7X	3H:7X	4H:6X	—
Previous lactation 305ME, ³ kg	10,888	10,976	10,687	11,243	490

¹AWS = ad libitum-fed TMR with 30% wheat straw; AOG = ad libitum-fed TMR with 30% orchardgrass hay; RWS = restricted to 70% of predicted ad libitum DMI of TMR with 30% wheat straw; ROG = restricted to 70% of predicted ad libitum DMI of TMR with 30% orchardgrass hay.

²H = Holstein; X = Holstein-cross.

³305ME = 305-d mature-equivalent milk yield.

discount method of Van Soest et al. (1991). Treatment means were used as model inputs for prepartum DMI, and weekly means of cow BW were used for prepartum energy balance calculations. Postpartum energy balance was calculated using inputs of weekly averages of DMI, BW, milk yield, and milk composition.

BW and BCS

Body weight was measured and BCS was assigned on 0.25-unit increments (Ferguson et al., 1994) for each cow weekly from dry off to 30 DIM. Three individual scorers assigned BCS weekly, and averages of the 3 scores are reported.

Milk Yield and Composition

Milk weights were recorded daily from 1 to 30 DIM, and samples were obtained from consecutive a.m. and p.m. milkings weekly through 30 DIM. Milk samples were preserved (800 Broad Spectrum Microtabs II; D and F Control Systems Inc., San Ramon, CA) and were analyzed for fat, protein, lactose, urea nitrogen, and SCC by using midinfrared procedures (AOAC International, 1995) at the Minnesota DHIA Laboratory (Zumbrota, MN). Dairy efficiency was calculated on a weekly basis for individual cows using the following formula: dairy efficiency = 3.5% FCM/DMI.

Blood and Metabolites

Blood samples were collected from the coccygeal vein or artery on d -28, -21, -14, -10, -7, -5, and -3 relative to expected parturition and at +1, +3, +5, +7, +10, +14, +21, and +28 d relative to the calving date. Samples were collected before feeding (0800 h) into evacuated serum tubes (SST; Becton Dickinson Vacutainer Systems, Franklin Lakes, NJ) containing clot activator. Serum was obtained by centrifugation at $1,300 \times g$ for 20 min at 4°C. Aliquots of serum were frozen at -20°C until later analysis for contents of NEFA [HR Series NEFA-HR (2) Kit; Wako Chemicals USA Inc., Richmond, VA] and BHBA (Ranbut Kit; Randox Laboratories Ltd., Oceanside, CA).

Liver Composition

Liver was sampled via puncture biopsy (Hughes, 1962; Veenhuizen et al., 1991) from cows under local anesthesia at approximately 0700 h on d -30, -14, +14, and +28. Liver was frozen in liquid nitrogen, transferred to a -80°C freezer for storage, and later

analyzed for contents of total lipids (Hara and Radin, 1978) and triacylglycerols (Fletcher, 1968; Foster and Dunn, 1973).

Nutrient Digestibility

To estimate apparent total tract DM, OM, and NDF digestibilities during the dry period from d -21 to -14, TMR and feed refusal samples were collected once per day for 1 wk, and 9 fecal grab samples per cow were collected at 5- to 8-h intervals over a 72-h period. Total mixed ration and feed refusals were composited by treatment, and fecal samples were composited by cow on a wet weight basis, dried at 60°C until reaching a static weight, and ground through a 1-mm screen in a Wiley mill. Analysis of TMR, feed refusals, and fecal samples included DM, OM, and NDF digestibilities using acid-insoluble ash as an internal marker as described by Block et al. (1981). Amylase-treated NDF, for calculation of total-tract NDF digestibility (**NDFd**) of feed ingredients and fecal samples, was determined using methods described by Van Soest et al. (1991).

Cow Feeding and Lying Behavior

To monitor cow feeding and lying behavior, color video cameras were placed in the front of each stall and 24-h video surveillance was recorded from d -5 prepartum to d 5 postpartum. Behaviors evaluated included eating bouts (ears of the cow were in front of the neck rail and the cow was actively eating), feeding time, and lying behavior, using 10-min video scans of the 24-h video as described by Endres et al. (2005). Because of limitations in camera availability, data from 24 cows ($n = 6/\text{treatment}$) were used in the behavioral analysis.

Cow Health

Cow health ($n = 10/\text{treatment}$) was monitored daily throughout the study, and rectal temperature and visual evaluations were collected for 7 d after calving. Daily observations and general health records were maintained throughout the study.

Statistical Analysis

Statistical computations were performed using SAS software (release 9.2; SAS Institute Inc., Cary, NC) as a 2×2 factorial design with forage amount, breed, and time and the interaction of forage amount and time (week or day) when appropriate. Fixed effects included forage type, forage amount, week, and interactions of

forage amount and week, and the random effect was cow nested within treatment. Interaction of forage type or amount and week or 3-way interactions of forage type, forage amount, and week were evaluated. Data were subjected to ANOVA using the MIXED procedure of SAS (Littell et al., 1996). Prepartum and postpartum data were analyzed separately. Data measured over time were subjected to ANOVA by using the REPEATED statement in the MIXED procedure of SAS (Littell et al., 1996). For each variable analyzed, cow nested within treatment was subjected to 3 covariance structures: compound symmetry, autoregressive order 1, and unstructured covariance. The covariance structure that resulted in the Akaike information criterion closest to zero was used (Littell et al., 1996). Because of uneven spacing of blood samples, the spatial power covariance structure was used for analysis of NEFA and BHBA. Data not analyzed over time were subjected to ANOVA by using the MIXED procedure of SAS (Littell et al., 1996). Least squares means for treatment effects were separated by use of the PDIF statement when the overall *F*-test was $P < 0.05$. Trends were indicated when $P < 0.10$.

RESULTS

Intake and Digestibility

As planned, prepartum DMI was higher ($P < 0.0001$) for A-fed than R-fed cows (Table 5). Ad libitum-fed cows ate $2.4 \pm 0.1\%$ of their BW as DM during the dry period, and R-fed cows consumed $1.4 \pm 0.1\%$ of their BW in DM. Weekly DMI decreased ($P < 0.0001$) for all treatments 1 wk before calving (Figure 1). Prepartum energy intake, energy balance, and energy balance expressed as a percentage of requirements were higher ($P < 0.0004$) for A-fed than R-fed cows (Table 5). Prepartum total-tract DM digestibility was higher ($P < 0.003$) for OG than for WS, and OM digestibility tended ($P = 0.07$) to be higher for the OG diet compared with the WS diet (Table 5). Intake of WS averaged 4.7 and 2.8 kg/d for cows fed AWS and RWS and intake of OG averaged 4.6 and 2.9 kg/d for cows fed AOG and ROG. Intake of NDF was similar between forages but was greater ($P < 0.001$) for A- than R-fed cows. The amount of NDFd was higher ($P < 0.0012$) for OG than for WS and was higher ($P < 0.0007$) for A- than R-fed

Table 5. Effects of a prepartum diet varying in forage type (wheat straw vs. orchardgrass hay) and feeding amount (ad libitum vs. restricted) on prepartum (−42 d to calving) intake, energy balance, diet digestibility, BW, and BCS and postpartum (calving to 30 DIM) intake, energy balance, BW, and BCS

Variable	Treatment ¹				SEM	P-value			
	AWS	AOG	RWS	ROG		Forage	Amount	F × A ²	Week
Prepartum									
DMI, kg/d	15.8	15.5	9.4	9.6	1.0	0.97	<0.0001	0.78	0.06
DMI, % of BW	2.4	2.3	1.4	1.4	0.1	0.87	0.09	0.49	0.43
Energy intake, Mcal/d	24.7	23.7	13.9	15.1	1.7	0.94	<0.0001	0.50	0.53
Energy balance, Mcal/d	+10.6	+9.5	−0.4	+0.9	1.7	0.95	<0.0001	0.41	0.13
Energy balance, % of requirement	175.9	165.2	97.4	107.2	11.7	0.97	<0.0001	0.33	0.08
DM digestibility, %	56.1	68.2	52.4	61.2	3.2	<0.003	0.10	0.61	—
OM digestibility, %	59.1	67.5	55.5	59.6	3.4	0.07	0.10	0.53	—
NDF intake, kg/d	6.3	6.2	3.5	4.1	0.5	0.63	<0.001	0.44	<0.001
NDF digestibility, %	33.5	53.6	30.6	49.0	4.0	<0.0036	0.32	0.82	—
NDF digested, kg/d	2.0	3.5	1.1	1.9	0.3	<0.0012	<0.0007	0.28	—
BW, kg	679.9	680.6	668.5	678.4	34.4	0.96	0.90	0.84	<0.0001
BW change, kg	+43.3	+30.0	+35.3	+52.7	8.5	0.79	0.35	0.06	—
BCS	3.48	3.45	3.52	3.50	0.15	0.82	0.88	0.99	<0.0001
BCS change	+0.22	+0.34	+0.30	+0.59	0.15	0.14	0.27	0.56	—
Postpartum									
DMI, kg/d	17.6	22.2	18.4	19.6	1.5	<0.04	0.52	0.25	<0.0001
DMI, % of BW	3.0	3.6	3.1	3.2	0.2	0.14	0.43	0.24	<0.0001
Energy intake, Mcal/d	32.0	36.3	30.5	31.7	3.6	0.42	0.37	0.64	<0.0001
Energy balance, Mcal/d	−7.2	−2.0	−8.5	−11.4	3.2	0.70	0.08	0.19	0.02
Energy balance, % of requirement	80.2	96.6	81.0	74.6	8.1	0.49	0.16	0.13	0.09
BW, kg	617.6	639.2	618.3	645.1	28.4	0.14	0.43	0.24	<0.0001
BW change, kg	−41.6	−26.5	−38.6	−35.2	12.9	0.26	0.89	0.40	—
BCS	3.1	3.2	3.1	3.2	0.14	0.57	0.99	0.73	<0.0001
BCS change	−0.29	−0.23	−0.25	−0.38	0.11	0.90	0.78	0.26	—

¹AWS = ad libitum-fed TMR with 30% wheat straw; AOG = ad libitum-fed TMR with 30% orchardgrass hay; RWS = restricted to 70% of predicted ad libitum DMI of TMR with 30% wheat straw; ROG = restricted to 70% of predicted ad libitum DMI of TMR with 30% orchardgrass hay.

²F × A = interaction of forage type and amount fed.

Figure 1. Effects of a prepartum diet varying in forage type (wheat straw vs. orchardgrass hay) and feeding amount (ad libitum vs. restricted) on DMI expressed as a percentage of BW. AWS = ad libitum-fed TMR with 30% wheat straw; AOG = ad libitum-fed TMR with 30% orchardgrass hay; RWS = restricted to 70% of predicted ad libitum DMI of TMR with 30% wheat straw; ROG = restricted to 70% of predicted ad libitum DMI of TMR with 30% orchardgrass hay.

cows. Additionally, the amount of apparent total-tract NDFd was greater for the OG treatments and was almost twice as high for A- as for R-fed cows. Despite

being fed diets varying in forage type and amount, cows fed AWS and ROG had almost identical amounts (2.0 kg/d) of apparent NDF digested. Prepartum BW and BCS and the change in BW and BCS during the prepartum period were unaffected by treatments (Table 5).

Postpartum DMI during the first 30 d of lactation was higher ($P < 0.046$) for cows fed OG compared with WS prepartum (Table 5). Postpartum energy intake was similar across treatments. Postpartum energy balance of the A-fed cows tended ($P = 0.08$) to be higher than energy balance of the R-fed cows. Postpartum energy balance was negative for all treatments through 30 DIM, but was least for cows fed AOG prepartum. During the first 30 d postpartum, cows lost a similar amount of BW (35.5 ± 28.4 kg) and BCS (0.29 ± 0.1).

One week before calving, forage type had no effect on DMI or energy balance, and A-fed cows continued to consume greater amounts of energy compared with R-fed cows (Table 6). During the week before calving, the energy balance of cows fed RWS and ROG became negative. Calf birth weight was not different among treatments and averaged 44 ± 1.3 kg (Table 6).

During the first week postpartum, DMI expressed as a percentage of BW was higher ($P < 0.0131$) for A-than R-fed cows. The energy balance decreased for all treatments after calving and was lower for R-fed cows during the first week after calving than for A-fed cows. By wk 1, prepartum cows had slightly decreased

Table 6. Effects of prepartum diet varying in forage type (wheat straw vs. orchardgrass hay) and feeding amount (ad libitum vs. restricted) on wk 1 prepartum intake and energy balance and on wk 1 postpartum intake, energy balance, milk yield, and milk component yield

Variable	Treatment ¹				SEM	P-value		
	AWS	AOG	RWS	ROG		Forage	Amount	F × A ²
wk 1 prepartum								
DMI, kg/d	15.4	16.4	8.2	9.1	1.2	0.43	<0.0001	0.95
DMI, % of BW	2.2	2.3	1.3	1.3	0.2	0.79	<0.0001	0.86
Energy intake, Mcal/d	24.0	24.2	12.6	13.4	2.3	0.83	<0.0001	0.84
Energy balance, Mcal/d	9.5	9.5	-2.1	-1.3	22	0.72	<0.0001	0.96
Energy balance, % of requirement	166.3	163.0	85.5	91.5	15.3	0.92	<0.0001	0.74
Calf BW, kg	43.5	44.8	43.3	44.5	1.3	0.33	0.83	0.99
wk 1 postpartum								
DMI, kg/d	17.3	18.5	15.2	15.0	1.9	0.79	0.12	0.70
DMI, % of BW	2.5	2.7	2.3	2.2	0.4	0.34	<0.013	0.92
Energy intake, Mcal/d	32.8	29.6	24.3	24.0	4.8	0.69	0.12	0.75
Energy balance, Mcal/d	-5.0	-5.5	-10.8	-15.5	4.7	0.57	0.08	0.63
Energy balance, % of requirement	85.9	83.9	78.6	60.7	12.9	0.41	0.21	0.51
Milk yield, kg	29.4	32.5	25.7	33.5	2.1	<0.01	0.51	0.24
3.5% FCM, kg/d	40.4	39.2	36.9	39.6	3.2	0.82	0.61	0.54
True protein, %	4.1	4.1	4.1	4.2	0.2	0.71	0.79	0.92
Fat, %	5.8	5.6	5.1	5.1	0.4	0.11	0.84	0.74
Fat:protein	1.5	1.3	1.4	1.2	0.1	0.10	0.65	0.77
Lactose, %	4.4	4.7	4.6	4.6	0.1	0.07	0.87	0.15

¹AWS = ad libitum-fed TMR with 30% wheat straw; AOG = ad libitum-fed TMR with 30% orchardgrass hay; RWS = restricted to 70% of predicted ad libitum DMI of TMR with 30% wheat straw; ROG = restricted to 70% of predicted ad libitum DMI of TMR with 30% orchardgrass hay.

²F × A = interaction of forage type and amount fed.

DMI, and the energy balance for R-fed cows became negative. One of the objectives of this experiment was to determine whether R feeding a high-NDF diet would maintain the DMI during the last week of the dry period before calving compared with ad libitum feeding. The increase in DMI from wk -1 to 1 was 0.3% of BW for cows fed AWS and AOG and was 0.95% of BW for cows fed RWS and ROG. Ad libitum-fed cows were in a less negative energy balance than R-fed cows because of the greater DMI. Milk yield during the first week of lactation was higher ($P < 0.001$) for cows fed OG compared with those fed WS, but 3.5% FCM yield was unaffected by treatments. Milk fat and protein were unaffected by treatment during the first week of lactation and fat:protein averaged 1.3 ± 0.1 and was similar among treatments. Lactose tended ($P = 0.07$) to be the highest for OG compared with WS.

Milk and milk component yields for the first 30 DIM are described in Table 7. Milk yield averaged 39.3 ± 2.2 kg/d and was similar among treatments. A forage $\times$ amount interaction ($P < 0.04$) was observed, in which the yield of 3.5% FCM was higher for ROG than for AOG and RWS but was similar for AWS. As expected, milk production increased ($P < 0.05$) with DIM. Dairy efficiency, and proportions of fat, protein, and lactose in milk, fat:protein yield, MUN concentration, and SCC were all similar among treatments. A forage type $\times$ forage amount interaction was observed, in which cows fed ROG had a higher milk fat yield than did cows fed AWS, AOG, and RWS.

Prepartum circulating NEFA were similar among forage types and feeding amounts and increased ($P < 0.0001$) as cows approached parturition (Table 8).

Serum BHBA increased as cows approached the calving date but was similar among treatments. Prepartum liver total lipids were higher ($P < 0.03$) on d -30 and -14 for R-fed cows compared with A-fed cows. Prepartum liver triglycerides were similar among treatments. Serum NEFA were higher postpartum than prepartum but were not affected by treatment. Postpartum circulating NEFA peaked on d 3 and decreased thereafter. An interaction of forage type $\times$ forage amount ($P < 0.05$) was observed, in which serum from cows fed AWS had the highest postpartum BHBA compared with cows in the other treatments. Postpartum liver lipid and triglyceride concentrations peaked on d 14 but were unaffected by treatment.

Feeding Behavior and Cow Health

Prepartum eating time tended ($P = 0.09$) to be higher for cows fed WS compared with those fed OG and averaged 190.1, 150.1, 180.2 and 130.3 ± 25.9 min/d for those fed AWS, AOG, RWS, and ROG, respectively (Table 9). The eating rate of DM tended ($P = 0.07$) to be highest for R-fed cows compared with A-fed cows; however, the eating rate for NDF intake was similar among treatments. Feeding bouts also tended ($P = 0.09$) to be higher for WS compared with OG, with AWS averaging 4.4 more feeding bouts per day than AOG and with RWS averaging 5.9 more feeding bouts per day than ROG. Restricted-fed cows tended ($P = 0.07$) to spend more time lying (an average of 92 min more per day) than A-fed cows. Postpartum time spent eating and eating bouts were not different among treatments and increased ($P < 0.05$) with time (Table 9).

Table 7. Effects of prepartum diet varying in forage type (wheat straw vs. orchardgrass hay) and feeding amount (ad libitum vs. restricted) on milk, milk composition, component yield, and dairy efficiency during the first 30 DIM

Variable	Treatment ¹				SEM	P-value			
	AWS	AOG	RWS	ROG		Forage	Amount	F $\times$ A ²	Week
Milk yield, kg/d	39.2	38.9	36.7	42.6	2.3	0.20	0.80	0.16	<0.0001
3.5% FCM, kg/d	45.5 ^{ab}	44.0 ^a	42.7 ^a	50.5 ^b	2.3	0.15	0.40	0.04	<0.0001
Dairy efficiency	2.5	1.8	2.0	2.2	0.3	0.29	0.87	0.10	0.24
Fat, %	4.8	4.4	4.6	4.7	0.2	0.72	0.34	0.48	<0.0001
True protein, %	3.4	3.4	3.4	3.4	0.1	0.89	0.98	0.76	<0.0001
Fat:protein	1.4	1.3	1.3	1.4	0.1	0.82	0.39	0.33	0.89
Fat, kg/d	1.7 ^a	1.7 ^a	1.6 ^a	2.0 ^b	0.1	0.20	0.26	0.03	0.09
True protein, kg/d	1.3	1.3	1.2	1.4	0.1	0.13	0.73	0.13	<0.0001
Lactose, %	4.7	4.7	4.8	4.8	<0.1	0.12	0.79	0.89	<0.0001
MUN, mg/dL	15.1	15.3	15.3	15.6	1.0	0.80	0.80	0.91	0.0037
SCC, cells/mL	217,500	171,220	254,090	67,789	75,000	0.97	0.60	0.47	0.15

^{a,b}Means within a row with different superscripts differ significantly ($P < 0.05$).

¹AWS = ad libitum-fed TMR with 30% wheat straw; AOG = ad libitum-fed TMR with 30% orchardgrass hay; RWS = restricted to 70% of predicted ad libitum DMI of TMR with 30% wheat straw; ROG = restricted to 70% of predicted ad libitum DMI of TMR with 30% orchardgrass hay.

²F $\times$ A = interaction of forage type and amount fed.

Table 8. Effects of prepartum diet varying in forage type (wheat straw vs. orchardgrass hay) and feeding amount (ad libitum vs. restricted) on prepartum and postpartum concentrations of NEFA, BHBA, and liver lipids

Variable	Treatment ¹				SEM	P-value			
	AWS	AOG	RWS	ROG		Forage	Amount	F × A ²	Day
Prepartum									
NEFA, μEq/L	217.7	142.9	199.2	192.8	29.9	0.15	0.56	0.23	<0.0001
BHBA, mmol/L	550.0	534.4	446.0	497.0	51.1	0.73	0.17	0.51	0.007
Total lipids, %	4.9	4.7	7.1	6.0	0.9	0.37	0.03	0.54	0.49
Triglycerides, %	0.18	0.18	0.23	0.40	0.16	0.56	0.37	0.55	0.89
Postpartum									
NEFA, μEq/L	365.2	366.3	366.3	388.0	49.3	0.66	0.94	0.68	<0.0001
BHBA, mmol/L	1,162.0 ^a	642.0 ^b	716.3 ^b	986.0 ^b	211.4	0.50	0.79	0.04	0.97
Total lipids, %	8.5	7.7	8.5	7.8	1.1	0.98	0.49	0.94	0.82
Triglycerides, %	3.2	2.6	2.0	1.9	0.9	0.72	0.26	0.75	0.05

^{a,b}Means within a row with different superscripts differ significantly ($P < 0.05$).

¹AWS = ad libitum-fed TMR with 30% wheat straw; AOG = ad libitum-fed TMR with 30% orchardgrass hay; RWS = restricted to 70% of predicted ad libitum DMI of TMR with 30% wheat straw; ROG = restricted to 70% of predicted ad libitum DMI of TMR with 30% orchardgrass hay.

²F × A = interaction of forage type and amount fed.

Compared with prepartum eating time, postpartum eating time decreased for all treatments except ROG. The postpartum eating rate per unit of DM was lower ($P < 0.04$) for R- than A-fed cows. Postpartum lying time decreased for all treatments compared with prepartum lying time, but no significant differences were observed among treatments, averaging 8.9, 7.3, 9.3, and 9.8 h/d postpartum for AWS, AOG, RWS, and ROG, respectively. The frequencies of health disorders are reported in Table 10. No cows had a displaced abomasum in this study. The total numbers of cows with at least 1 health disorder were 4, 8, 4, and 3 for AWS, AOG, RWS, and ROG, respectively.

DISCUSSION

Prepartum Intake and Digestibility

Cows were fed in restricted amounts to provide 70% (1.4% of BW) of predicted ad libitum intake (2.0% of BW), to reduce energy intake to 15 Mcal/d to meet energy requirements for maintenance and fetal growth. Ad libitum-fed cows consumed 2.4% of BW as DM, which is greater than the amounts reported previously (Dann et al., 2006; Janovick and Drackley, 2010). The greater DMI as a percentage of BW in this trial may be due to diet and environmental factors. Limiting energy

Table 9. Effects of prepartum diet varying in forage type (wheat straw vs. orchardgrass hay) and feeding amount (ad libitum vs. restricted) on periparturient behavior (eating, number of meals per day, and lying time pre- and postpartum)

Variable	Treatment ¹				SEM	P-value			
	AWS	AOG	RWS	ROG		Forage	Amount	F × A ²	Day
Prepartum									
Eating time, min/d	190	150	180	130	26.0	0.09	0.64	0.97	0.81
Eating minute/kg of DMI	8.7	11.1	17.8	14.0	3.9	0.83	0.07	0.33	—
Eating minute/kg of aNDFI ³	29.7	35.3	45.2	33.6	8.8	0.73	0.42	0.33	—
Eating bouts, no./d	19	15	18	14	2.6	0.09	0.64	0.97	0.82
Lying time, min/d	592	612	721	666	83	0.62	0.07	0.80	<0.05
Postpartum									
Eating time, min/d	163	137	166	153	16.0	0.19	0.56	0.66	<0.05
Eating minutes/kg of DMI	9.3 ^a	12.8 ^a	16.5 ^b	13.5 ^b	2.2	0.89	0.04	0.08	—
Eating minutes/kg of aNDFI	34.8	31.7	43.7	31.3	4.5	0.09	0.33	0.29	—
Eating bouts, no./d	16	14	17	15	2	0.19	0.56	0.66	<0.05
Lying time, min/d	536	435	557	590	76	0.65	0.24	0.37	0.60

^{a,b}Means within a row with different superscripts differ significantly ($P < 0.05$).

¹AWS = ad libitum-fed TMR with 30% wheat straw; AOG = ad libitum-fed TMR with 30% orchardgrass hay; RWS = restricted to 70% of predicted ad libitum DMI of TMR with 30% wheat straw; ROG = restricted to 70% of predicted ad libitum DMI of TMR with 30% orchardgrass hay.

²F × A = interaction of forage type and amount fed.

³aNDFI = amylase-treated NDF intake.

Table 10. Effects of a prepartum diet varying in forage type (wheat straw vs. orchardgrass hay) and feeding amount (ad libitum vs. restricted) on frequency¹ of health disorders for multiparous cows fed different dry-period diets

Variable	Treatment ²			
	AWS	AOG	RWS	ROG
Milk fever ³	0	1	2	1
Ketosis ⁴	1	1	0	0
Displaced abomasum	0	0	0	0
Retained placenta	1	1	0	0
Metritis	1	1	0	0
Dystocia	0	0	1	1
Mastitis	0	1	0	0
Udder edema	1	3	1	1
Total health disorders ⁵	4	8	4	3

¹Number of cows with at least 1 incidence.

²AWS = ad libitum-fed TMR with 30% wheat straw; AOG = ad libitum-fed TMR with 30% orchardgrass hay; RWS = restricted to 70% of predicted ad libitum DMI of TMR with 30% wheat straw; ROG = restricted to 70% of predicted ad libitum DMI of TMR with 30% orchardgrass hay.

³Cows were treated for milk fever.

⁴Cows were treated for clinical ketosis, determined using a reagent strip for urinalysis.

⁵Summation of the frequencies of milk fever, ketosis, displaced abomasum, retained placenta, metritis, dystocia, mastitis, and udder edema.

intake during the entire dry period has previously been used to control energy intake to make comparisons with ad libitum intake and also to prevent the decline in DMI that occurs before calving (Tesfa et al., 1999; Agenäs et al., 2003; Holtenius et al., 2003; Douglas et al., 2006). Previous research has not been able to demonstrate a significant effect of prepartum energy restriction on increasing postpartum DMI. Several studies (Holcomb et al., 2001; Agenäs et al., 2003; Holtenius et al., 2003; Dann et al., 2006; Douglas et al., 2006; Winkelman et al., 2008; Janovick and Drackley 2010) reported no significant effect on postpartum DMI with energy restriction prepartum. This study is the first to apply a high-fiber diet approach to feeding dry cows by using WS in diets fed in restricted amounts.

We predicted that compared with diets containing OG, because of its higher NDF content, diets containing WS would result in lower DMI and thus lower energy intake. The lower digestibility for WS compared with OG is not surprising, given the differences in chemical composition between these 2 forages. The trend for lower digestibility for R- than A-fed cows is possibly due to differences in diet sorting. Restricted-fed cows consumed essentially all their feed, whereas ad libitum feeding resulted in 4 to 8% feed refusals and therefore increased the risk of diet sorting compared with R feeding. Intakes of NDF for A-fed cows were 57.1 and were 40.8% higher for WS and OG, respectively, than the NDF intakes of R-fed cows.

The research evaluating forage options for dry cows is limited in scope. Wheat straw has received considerable interest because of its low energy density; however, many nutritionists and producers have expressed interest in using either OG or a combination of both forages to dilute the energy density of diets. The higher postpartum DMI for OG compared with WS is intriguing. Reasons for the improvement in postpartum intake in cows fed OG are unclear but may be due to differences in the fermentation profiles of the diets or reduced rumen fill at calving. Dry cows fed high-forage diets ate less DM prepartum and had a tendency to eat more DM postpartum than did dry cows fed a low-forage, higher energy TMR (Holcomb et al., 2001). Because of the greater DMI, energy intake was greater for OG than for WS. Energy balance as a percentage of requirements was less negative for AOG, although treatment averages of energy balance for all cows were negative for the first 30 DIM.

The lack of difference in the change in BW or BCS despite a higher energy intake for A- than R-fed cows is somewhat surprising. Similar to the present study, Dann et al. (2006) observed no change in BW despite feeding diets varying in energy density during the dry period. Improvements in the efficiency of energy use between ad libitum and restricted feeding may be partially explained by lying behavior because R-fed cows spent 1.5 h/d more time lying than did A-fed cows. Additionally, BCS does not access internal fat storage, which has been demonstrated to be altered in cows fed diets during the dry period that varied in energy amount (Nikkhah et al., 2008).

Postpartum Performance at wk 1

Restricted-fed cows had lower DMI as a percentage of BW and tended to have a lower energy balance than did A-fed cows during the first week of lactation. Forage type did not significantly affect nutrient intake during the first week postpartum, but cows fed WS had slower starts in milk production during wk 1. Reasons for the slower start are unclear but may be due in part to the high fiber and low digestibility of WS affecting the turnover of rumen contents and restricting intake after freshening. Moderate energy intake compared with high energy intake during the dry period tended to increase DMI as a percentage of BW and increased energy balance but did not increase milk yield during the first 10 d of lactation (Dann et al., 2006). High-energy dry period diets, however, resulted in a nonsignificant milk production advantage of 8.8 and 7.6 kg over a controlled-energy diet containing 30% WS or a corn silage, alfalfa silage, and hay diet (Janovick and Drackley, 2010).

Milk Yield and Composition for the First Month of Lactation

Despite higher DMI as a percentage of BW and greater milk production for A-fed cows during wk 1, milk yield was not different among treatments during the first month of lactation. During the first month of lactation, cows fed ROG and AWS produced the highest amount of 3.5% FCM, and fat yield was highest for ROG. Cows fed ROG had the lowest average SCC and the fewest health disorders, indicating that perhaps ROG within this study provided the best opportunity for a successful transition into lactation. A more mechanistic exploration of the milk yield response by cows fed ROG is warranted.

Lipid Metabolism

Lipid mobilization in this study, as evidenced by BW and BCS loss, serum NEFA and BHBA, and total lipids and triglycerides in liver biopsies, was low. The higher BHBA for cows fed AWS may indicate that cows fed lower forage-to-concentrate ratios or perhaps a diet that is sortable, allowing for selection against long forage particles, may place cows at higher risk for subclinical ketosis postpartum. Previous research has demonstrated that cows fed to have a lower versus higher energy balance prepartum tended to have lower serum NEFA and had lower BHBA concentrations during the first 10 DIM (Dann et al., 2006).

Periparturient Eating Behavior

We hypothesized that R feeding would result in less time eating; therefore, cows would likely experience a greater relative change in eating behavior after calving. It is interesting that R feeding did not have significant effects on pre- or postpartum eating time. The observation that cows fed WS tended to spend more time eating and had more frequent eating bouts fits with the hypothesis that the physical and chemical properties of WS may help serve as a bridge during the dry period to maintain the time invested in feeding from late lactation to calving. Linking the eating behavior of cows from late lactation through the next lactation may be an important step to reducing the number of adaptive hurdles experienced by a dairy cow at freshening. High-producing cows allowed continuous access to TMR ate 9 to 14 meals/d (Vasilatos and Wangsness, 1980), whereas lower producing cows consumed 7 to 9 meals daily (Heinrichs and Conrad, 1987). Differences in meal frequency between this and previous studies are likely due to the stage in lactation and housing conditions. Time spent eating is one of the most important

factors affecting DMI. Cows within 2 wk of parturition spent 8.9% of 24 h, or 2.1 h/d, at the feed bunk (Grant and Albright, 1995). Cows in the current study fed WS and OG spent 2.7 and 2.3 h/d, respectively, eating during the first week of lactation. Promoting the time investment in eating behavior with high-fiber diets likely confers an advantage if the eating behavior carries over after parturition.

Postpartum Health

The frequency of individual health disorders is described in Table 10. No abomasa were displaced in this study. Total health disorders were highest for AOG.

CONCLUSIONS

In summary, feeding OG prepartum resulted in higher prepartum DM and NDF digestibilities, higher postpartum DMI, and higher postpartum energy intake compared with diets containing WS. The postpartum energy balance tended to be higher for ad libitum versus restricted feeding. Milk yield for wk 1 was greater for OG than for WS, but the yield of FCM was similar among forage types. During the first month of lactation, cows fed ROG produced the greatest amount of milk and had the highest fat yield. Serum BHBA was highest for AWS. Diets containing WS tended to increase prepartum eating time versus OG, but this altered eating behavior did not carry over into differences in early postpartum feeding behavior. Feeding diets containing OG prepartum resulted in greater DMI postpartum and a greater milk yield during the first week postpartum compared with feeding WS.

REFERENCES

- Agenäs, S., E. Burstedt, and K. Holtenius. 2003. Effects of feeding intensity during the dry period. 1. Feed intake, body weight, and milk production. *J. Dairy Sci.* 86:870–882.
- AOAC International. 1995. *Official Methods of Analysis*. 16th ed. AOAC Int., Arlington, VA.
- Block, E., L. H. Kilmer, and L. D. Muller. 1981. Acid insoluble ash as a marker of digestibility for sheep fed corn plants or hay for lactating dairy cattle fed hay ad libitum. *J. Anim. Sci.* 52:1164–1169.
- Dann, H. M., N. B. Litherland, J. P. Underwood, M. Bionaz, A. D'Angelo, J. W. McFadden, and J. K. Drackley. 2006. Diets during far-off and close-up dry periods affect periparturient metabolism and lactation in multiparous cows. *J. Dairy Sci.* 89:3563–3577.
- Dias, R. S., H. O. Patino, S. López, E. Prates, K. C. Swanson, and J. France. 2011. Relationships between chewing behavior digestibility, and digesta passage kinetics in steers fed oat hay at restricted and ad libitum intakes. *J. Anim. Sci.* 89:1873–1880.
- Douglas, G. N., T. R. Overton, H. G. Bateman II, H. M. Dann, and J. K. Drackley. 2006. Prepartal plane of nutrition, regardless of dietary energy source affects periparturient metabolism and dry matter intake in Holstein cows. *J. Dairy Sci.* 89:2141–2157.
- Endres, M. I., T. J. DeVries, M. A. G. von Keyserlingk, and D. M. Weary. 2005. Short communication: Effect of feed barrier design

- on the behavior of loose-housed lactating dairy cows. *J. Dairy Sci.* 88:2377–2380.
- Ferguson, J. D., D. T. Galligan, and N. Thomsen. 1994. Principal descriptors of body condition score in Holstein cows. *J. Dairy Sci.* 77:2695–2703.
- Fletcher, M. J. 1968. A colorimetric method for estimating serum triglycerides. *Clin. Chim. Acta* 22:393–397.
- Foster, L. B., and R. T. Dunn. 1973. Stable reagents for determination of serum triglycerides by a colorimetric Hantzsch condensation method. *Clin. Chem.* 19:338–340.
- Galvani, D. B., C. C. Pires, T. P. Wommer, F. Oliveira, and M. F. Santos. 2010. Chewing patterns and digestion in sheep submitted to feed restriction. *J. Anim. Physiol. Anim. Nutr. (Berl.)* 94:e366–e373.
- Grant, R. J., and J. L. Albright. 1995. Feeding behavior and management factors during the transition period in dairy cattle. *J. Anim. Sci.* 73:2791–2803.
- Grum, D. E., J. K. Drackley, R. S. Younker, D. W. LaCount, and J. J. Veenhuizen. 1996. Nutrition during the dry period and hepatic lipid metabolism of periparturient dairy cows. *J. Dairy Sci.* 79:1850–1864.
- Hall, M. B., W. H. Hoover, J. P. Jennings, and T. K. Miller Webber. 1999. A method for partitioning neutral detergent-soluble carbohydrates. *J. Sci. Food Agric.* 79:2079–2086.
- Hammon, H. M., G. Stürmer, F. Schneider, A. Tuschscherer, H. Blum, T. Engelhard, A. Genzel, R. Staufienbiel, and W. Kanitz. 2009. Performance and metabolic and endocrine changes with emphasis on glucose metabolism on high-yielding dairy cows with high and low fat content in liver after calving. *J. Dairy Sci.* 92:1554–1566.
- Hara, A., and N. S. Radin. 1978. Lipid extraction of tissues with a low-toxicity solvent. *Anal. Biochem.* 90:420–426.
- Heinrichs, A. J., and H. R. Conrad. 1987. Measuring feed intake patterns of lactating dairy cows. *J. Dairy Sci.* 70:705–711.
- Hoffman, P. C., C. R. Simson, and M. Wattiaux. 2007. Limit feeding of gravid Holstein heifers: Effect on growth, manure nutrient excretion, and subsequent early lactation performance. *J. Dairy Sci.* 92:946–954.
- Holcomb, C. S., H. H. Van Horn, H. H. Head, M. B. Hall, and C. J. Wilcox. 2001. Effects of prepartum dry matter intake and forage percentage on postpartum performance of lactating dairy cows. *J. Dairy Sci.* 84:2051–2058.
- Holtenius, K., S. Agenäs, D. Delavaud, and Y. Chilliard. 2003. Effect of feeding intensity during the dry period. 2. Metabolic and hormone response. *J. Dairy Sci.* 86:883–891.
- Horst, R. L., and J. P. Goff. 1997. Milk fever and dietary potassium. Pages 181–189 in *Proc. Cornell Nutr. Conf. Feed Manuf.*, Rochester, NY. Cornell Univ., Ithaca, NY.
- Hughes, J. P. 1962. A simplified instrument for obtaining liver biopsies in cattle. *Am. J. Vet. Res.* 23:1111–1113.
- Janovick, N. A., Y. R. Boisclair, and J. K. Drackley. 2011. Prepartum dietary energy intake affects metabolism and health during the periparturient period in primiparous and multiparous Holstein cows. *J. Dairy Sci.* 94:1385–1400.
- Janovick, N. A., and J. K. Drackley. 2010. Prepartum dietary management of energy intake affects postpartum intake and lactation performance by primiparous and multiparous Holstein cows. *J. Dairy Sci.* 93:3086–3102.
- Knudsen, B. 1997. Carbohydrate and lignin contents of plant and materials used in animal feeding. *J. Anim. Feed Sci. Technol.* 67:319–338.
- Kunz, P. L., J. W. Blum, I. C. Hart, J. Bickel, and J. Landis. 1985. Effects of different energy intakes before and after calving on food intake, performance and blood hormones and metabolites in dairy cows. *Anim. Prod.* 40:219–231.
- Lean, I. J., P. J. DeGaris, D. M. McNeil, and E. Block. 2006. Hypocalcemia in dairy cows: Meta-analysis and dietary cation anion difference theory revisited. *J. Dairy Sci.* 89:669–684.
- Littell, R. C., G. A. Milliken, W. W. Stroup, and R. D. Wolfinger. 1996. SAS[®] System of Mixed Models. SAS Inst. Inc., Cary, NC.
- McCarthy, S. D., S. M. Walters, D. A. Kenny, M. G. Diskin, R. Ritzpatrick, J. Patton, D. C. Wathes, and D. G. Morris. 2010. Negative energy balance and hepatic gene expression patterns in high-yielding dairy cows during the early postpartum period: A global approach. *Physiol. Genomics* 42A:188–199.
- Nikkhah, A., J. J. Loo, L. Wallace, D. E. Graugnard, J. Vasquez, B. Richards, and J. K. Drackley. 2008. Moderate excesses of dietary energy markedly increase visceral adipose tissue mass in non-lactating dairy cows. *J. Dairy Sci.* 91(E-Suppl. 1):ii. (Abstr.)
- NRC. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Sci., Washington DC.
- Overton, T. R., and M. R. Waldron. 2004. Nutritional management of transition dairy cows: Strategies to optimize metabolic health. *J. Dairy Sci.* 87 (E-Suppl.):E105–E119.
- Tesfa, A. T., M. Tuori, L. Syrjälä-Qvist, R. Pösö, H. Saloniemi, K. Heinonen, K. Kivilahti, T. Saukko, and L. A. Lindberg. 1999. The influence of dry period feeding on liver fat and postpartum performance of dairy cows. *Anim. Feed Sci. Technol.* 76:275–295.
- Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74:3583–3597.
- Vasilatos, R., and P. J. Wangsness. 1980. Feeding behavior of lactating dairy cows as measured by time lapse photography. *J. Dairy Sci.* 63:412–416.
- Veenhuizen, J. J., J. K. Drackley, M. J. Richards, T. P. Sanderson, L. D. Miller, and J. W. Young. 1991. Metabolic changes in blood and liver during development and early treatment of experimental fatty liver and ketosis in cows. *J. Dairy Sci.* 74:4238–4253.
- Wathes, D. C., Z. Cheng, W. Chowdhury, M. A. Fenwick, R. Fitzpatrick, D. G. Morris, J. Patton, and J. J. Murphy. 2009. Negative energy balance alters global gene expression and immune responses in the uterus of postpartum dairy cows. *Physiol. Genomics* 39:1–13.
- Winkelman, L. A., T. H. Elsasser, and C. K. Reynolds. 2008. Limit feeding a high energy diet to meet energy requirements in the dry period alters plasma metabolite concentration but does not affect intake or milk production in early lactation. *J. Dairy Sci.* 91:1067–1079.
- Zanton, G. I., and A. J. Heinrichs. 2007. The effects of controlled feeding of a high-forage or high-concentrate ration on heifer growth and first-lactation milk production. *J. Dairy Sci.* 90:3388–3396.