Effect of frequency of feed delivery on the behavior and productivity of lactating dairy cows

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ABSTRACT

The objective of this study was to determine the effect of feed delivery frequency on the behavioral patterns and productivity of lactating dairy cows. Twelve freestall-housed, lactating Holstein dairy cows, including 6 primiparous (PP) and 6 multiparous (MP), milked 3×/d (at 1400, 2200, and 0600h), were exposed to each of 3 treatments (over 21-d periods) in a replicated Latin square design. Treatments included feed delivery frequency of (1) 1×/d (at 1400 h), (2) 2×/d (at 1400 and 2200 h), and (3) 3×/d (at 1400, 2200, and 0600 h). Milk production as well as feeding, lying, and rumination behaviors were electronically monitored for each animal for the last 7 d of each treatment period. Milk samples were collected for the last 3 d of each period for milk component analysis. Dry matter intake (DMI) varied with feed delivery frequency, with greatest DMI observed in cows fed 3×/d (27.8 kg/d) compared with those fed 2×/d (27.0 kg/d) or 1×/d (27.4 kg/d). Treatment had no effect on milk yield (41.3 kg/d) or efficiency of production (1.54 kg of milk/kg of DMI). Cows that did not receive delivery of feed following the 2200 h milking (treatment 1) and 0600 h milking (treatments 1 and 2) had lower DMI during the first hour after milking than those that received feed at all milkings (treatment 3). Total feeding time and meal frequency, size, and duration did not vary by treatment, but PP cows consumed smaller meals at a slower rate, resulting in lower DMI compared with MP cows. Primiparous cows consumed 50.1% and 26.1% less dry matter than MP cows during the first meal following the first and second milkings, respectively. Lying time did not vary by treatment, but PP cows spent more time lying (10.3 vs. 8.3 h/d) than MP cows. Under 3×/d milking schedules, greater feed delivery frequency resulted in greater DMI as a function of increased DMI

following the return from milking and the delivery of feed.

Key words: dairy cow, feed delivery frequency, behavior

INTRODUCTION

The delivery of fresh feed and the act of returning from milking stimulate feeding activity in lactating dairy cattle group-housed and group-fed indoors (DeVries et al., 2003a). Because the delivery of fresh feed has been demonstrated to be a stronger stimulus to initiate feeding activity than is the return from milking (DeVries and von Keyserlingk, 2005), increased frequency of feed delivery has the potential to influence feeding behavior, health, and productivity. Cows fed more frequently consume feed more evenly after each feed delivery and throughout the day (DeVries et al., 2005; Mäntysaari et al., 2006) and, therefore, exhibit more desirable feeding patterns to support rumen health. Such desirable feeding patterns are conducive to more consistent rumen pH (French and Kennelly, 1990), which may contribute to the improved milk fat (Rottman et al., 2011), fiber digestibility (Dhiman et al., 2002), and production efficiency (Mäntysaari et al., 2006) observed when cows are fed more frequently than 1×/d. In contrast, 1×/d feed delivery frequency results in a significant peak in feeding activity in the immediate period following feed delivery (DeVries et al., 2005), known as slug feeding, which predisposes cows to SARA (Shaver, 2002) due to large diurnal fluctuations in ruminal pH (Shabi et al., 1999).

Some reports indicate that cows fed more frequently spend more time feeding and show no difference in DMI (DeVries et al., 2005), whereas others have shown no difference in feeding time but lower DMI for cows delivered feed more frequently compared with 1×/d feed delivery (Phillips and Rind, 2001; Mäntysaari et al., 2006). From this latter research (Phillips and Rind, 2001; Mäntysaari et al., 2006), it was concluded that the disturbances caused by increased feed delivery frequency may have detrimental effects on behavior patterns

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and thus productivity of dairy cattle. Previous research has demonstrated no effect of feed delivery frequency on daily lying time of cows milked 2×/d (DeVries et al., 2005). It is possible that for cows milked 3×/d, the time required for an extra milking in conjunction with greater feed delivery frequency may alter the amount of time devoted to behavioral activities such as lying, feeding, and rumination, all of which are critical for milk production, maintenance of energy balance, efficient digestion, cow health, and welfare.

Thus, the objective of this study was to determine the effect of feed delivery frequency on the behavior and productivity of lactating dairy cows milked 3×/d. We hypothesized that under a 3×/d milking schedule, an increased frequency of feed delivery would result in increased feeding activity, particularly after fresh feed delivery. We further hypothesized that greater frequency of feed delivery would result in a more uniform distribution of feeding activity throughout the day, thus providing the required plane of nutrition for the increased milk production demand of 3×/d milking schedules. We also hypothesized that more frequent delivery of feed would result in greater time spent feeding, thus potentially reducing the amount of time devoted to other critical behavioral activities (lying and ruminating) throughout the day.

MATERIALS AND METHODS

Animals and Housing

Twelve lactating Holstein dairy cows, including 6 primiparous (PP) and 6 multiparous (MP; parity = 2.5 ± 0.8 ; mean $\pm$ SD), were used in this study. The animals were 79.1 ± 32.4 DIM and producing 39.6 ± 5.0 kg/d of milk at the beginning of the trial. Cows were housed 6 at a time in a freestall research pen located at the University of Guelph, Kemptville Campus Dairy Education and Innovation Centre (Kemptville, ON, Canada). Cows had access to 6 freestalls with waterbeds (DCC Waterbeds, Advanced Comfort Technology Inc., Reedsburg, WI). Waterbeds were topped with wood shavings, and bedding was replaced as needed. Manure was manually scraped to within reach of the alley scrapers 3× daily at 0600, 1400, and 2200 h. Cows were milked 3×/d (at 0600, 1400, and 2200 h) using a robotic milking system (Lely A3 Next, Lely Industries N.V., Maassluis, the Netherlands). At the specified milking times, cows were moved from the research pen into a small holding area adjacent to the robotic milker, from where they were milked individually and sequentially. Cows did not receive any supplemental feed from the robotic milking system while being milked. Cow BW was automatically recorded at each milking by

the robotic milking system; BW averaged 557 ± 53 kg for PP cows and 660 ± 54 kg for MP cows across the study. The experiment was conducted from May 16 to September 26, 2012. The average environmental temperature during the data collection period was $18.8 \pm 4.4^\circ\text{C}$. Use of cows and experimental procedures were approved by the University of Guelph's Animal Care Committee. Cows were managed according to the guidelines set forth by the Canadian Council on Animal Care (CCAC, 2009).

Experimental Design

The number of animals required per treatment was determined through sample size and power analysis (Morris, 1999) to detect a 10% level of observed difference for the primary outcome variables, including behavior, DMI, sorting, and milk production and composition. Cows were divided into 2 groups of 6, which were balanced according to DIM, milk production, and average parity. Within each group of 6, cows were randomly exposed to each of 3 treatments using a replicated 3×3 Latin square design (with groups replicated over time), with 21-d treatment periods. The treatments were the delivery of feed: (1) 1×/d (at 1400 h), (2) 2×/d (at 1400 and 2200 h), and (3) 3×/d (at 1400, 2200, and 0600 h). Cows received 14 d of adaptation to each treatment followed by 7 d of data collection.

Feeding Procedure

Cows were individually assigned to one roughage intake feed bin (Insentec RIC, Marknesse, the Netherlands) to measure individual feed intake and feeding behavior, as validated by Chapinal et al. (2007). Cows received 3 d of training before the start of the experimental period to learn to access their own unique feed bin. Cows were fed a base TMR formulated to meet the nutrient requirements of a cow producing 40 kg of milk according to the NRC (2001) nutrient recommendations for high-producing lactating dairy cows. The TMR consisted of 24.1% grass/legume silage, 28.3% corn silage, 23.4% high-moisture corn, 14.3% protein concentrate, and 9.9% robotic pellet supplement on a DM basis (Table 1).

The TMR (without the robotic pellet supplement) was mixed once daily in a TMR mixer wagon (Jaylor 4425, Jaylor Fabricating, Orton, ON, Canada) and delivered via conveyor into a motorized feed cart (WIC RTM-55, WIC Inc., Wickham, QC, Canada) between 1100 and 1200 h. The robotic pellet supplement was included at a rate of 0.05 kg of pellet to 1 kg of TMR based on the diet formulation for 40 kg/d milk production for the milking herd. The robotic pellet supplement

Table 1. Chemical composition and particle size distribution of the experimental ration and components (mean $\pm$ SD)

Composition	Corn silage	Grass/legume silage	High moisture corn	Protein concentrate ¹	Robotic supplement ²	TMR
Chemical composition ^{3,4}						
DM (%)	45.6 $\pm$ 11.2	35.5 $\pm$ 2.7	81.0 $\pm$ 1.4	94.0 $\pm$ 0.8	91.9 $\pm$ 0.9	50.4 $\pm$ 2.1
OM (% of DM)	97.1 $\pm$ 0.1	89.6 $\pm$ 0.6	98.5 $\pm$ 0.1	78.0 $\pm$ 3.9	93.0 $\pm$ 0.9	92.4 $\pm$ 0.8
CP (% of DM)	8.1 $\pm$ 0.3	19.2 $\pm$ 1.0	9.3 $\pm$ 0.3	40.7 $\pm$ 1.1	20.1 $\pm$ 0.6	17.1 $\pm$ 0.7
ADF (% of DM)	20.1 $\pm$ 1.3	37.3 $\pm$ 2.4	3.9 $\pm$ 0.6	10.8 $\pm$ 4.1	8.9 $\pm$ 0.7	20.4 $\pm$ 1.5
NDF (% of DM)	33.2 $\pm$ 1.3	52.2 $\pm$ 4.2	10.8 $\pm$ 0.7	17.1 $\pm$ 4.0	23.9 $\pm$ 5.0	31.7 $\pm$ 1.7
NFC (% of DM)	52.7 $\pm$ 1.3	16.8 $\pm$ 3.7	74.2 $\pm$ 0.9	—	—	41.1 $\pm$ 2.6
Calcium (% of DM)	0.2 $\pm$ 0.0	1.1 $\pm$ 0.2	0.0 $\pm$ 0.0	4.4 $\pm$ 0.7	1.4 $\pm$ 0.3	1.1 $\pm$ 0.1
Phosphorus (% of DM)	0.2 $\pm$ 0.0	0.3 $\pm$ 0.0	0.3 $\pm$ 0.0	1.1 $\pm$ 0.1	0.8 $\pm$ 0.2	0.5 $\pm$ 0.0
Magnesium (% of DM)	0.2 $\pm$ 0.0	0.4 $\pm$ 0.1	0.1 $\pm$ 0.0	0.9 $\pm$ 0.1	0.3 $\pm$ 0.1	0.4 $\pm$ 0.0
Potassium (% of DM)	0.6 $\pm$ 0.1	2.5 $\pm$ 0.2	0.4 $\pm$ 0.0	1.6 $\pm$ 0.1	0.9 $\pm$ 0.2	1.3 $\pm$ 0.2
Sodium (% of DM)	0.0 $\pm$ 0.0	0.1 $\pm$ 0.0	0.0 $\pm$ 0.0	2.7 $\pm$ 1.5	0.3 $\pm$ 0.1	0.5 $\pm$ 0.3
Iron (mg/kg)	48.2 $\pm$ 5.6	899.5 $\pm$ 325.1	41.2 $\pm$ 6.8	462.0 $\pm$ 203.6	141.3 $\pm$ 15.1	433.7 $\pm$ 59.9
Manganese (mg/kg)	13.2 $\pm$ 1.2	48.8 $\pm$ 5.7	5.0 $\pm$ 0.0	166.0 $\pm$ 114.0	93 $\pm$ 24.1	55.0 $\pm$ 28.1
Zinc (mg/kg)	25.3 $\pm$ 3.6	38 $\pm$ 9.9	25.8 $\pm$ 3.6	248.5 $\pm$ 165.2	134.0 $\pm$ 11.1	67.3 $\pm$ 29.2
Copper (mg/kg)	6.0 $\pm$ 0.0	12.2 $\pm$ 0.8	2.0 $\pm$ 0.0	74.7 $\pm$ 57.2	29.0 $\pm$ 3.0	18.9 $\pm$ 9.6
TDN (% of DM)	77.0 $\pm$ 0.4	58.4 $\pm$ 0.9	87.6 $\pm$ 0.4	—	—	71.3 $\pm$ 1.7
NE _L (Mcal/kg)	1.8 $\pm$ 0.0	1.3 $\pm$ 0.0	2.0 $\pm$ 0.0	—	—	1.5 $\pm$ 0.0
NE _M (Mcal/kg)	1.8 $\pm$ 0.0	1.3 $\pm$ 0.0	2.2 $\pm$ 0.0	—	—	1.8 $\pm$ 0.0
NE _G (Mcal/kg)	1.3 $\pm$ 0.0	0.7 $\pm$ 0.0	1.5 $\pm$ 0.0	—	—	1.1 $\pm$ 0.0
Particle size ⁴ (%)						
Long	4.0 $\pm$ 2.4	37.2 $\pm$ 7.9	—	—	—	12.6 $\pm$ 7.0
Medium	59.4 $\pm$ 7.2	44.1 $\pm$ 6.2	—	—	—	46.5 $\pm$ 2.2
Short	34.1 $\pm$ 7.1	15.7 $\pm$ 2.9	—	—	—	31.9 $\pm$ 4.7
Fine	2.5 $\pm$ 1.1	3.0 $\pm$ 1.7	—	—	—	9.0 $\pm$ 2.4

¹Supplied by Ritchie Feed & Seed Ltd. (Winchester, ON, Canada); contained 38.0% canola, 30.0% cottonseed meal, 9.0% soy meal, 6.6% gluten feed, 3.0% 60% gluten meal, 1.8% Optigen (Alltech Inc., Nicholasville, KY), 6.8% limestone, 3.0% salt, 0.9% magnesium oxide, 0.7% dicalcium phosphate, and 0.2% power punch flavor.

²Supplied by Ritchie Feed & Seed Ltd.; contained 27.5% wheat, 26.0% gluten feed, 22.0% barley, 9.5% citrus pulp, 8.3% cottonseed meal, 3.5% limestone, 1.2% salt, 0.6% vitamin ADE, 0.1% Ritchie dairy Pac, 0.2% power punch flavor, 1.2% Ameri-Bond 2 $\times$ (LignoTech USA Inc., Rothschild, WI).

³Values were obtained from chemical analysis of TMR and components; OM = 100 – % ash. NDF composition (DM basis) of the long, medium, short, and fine particle fractions was 41.6 $\pm$ 3.0%, 32.0 $\pm$ 1.9%, 21.7 $\pm$ 1.7%, and 19.7 $\pm$ 1.4%, respectively.

⁴Particle size determined by Penn State Particle Separator, which has a 19-mm screen (long), 8-mm screen (medium), 1.18-mm screen (short), and a pan (fine).

was weighed on a scale (model 2020, Mettler-Toledo, Columbus, OH) and mixed into the TMR, for approximately 4 min, using the motorized feed cart.

Cows were denied access to the feed bins beginning at 1330 h daily, at which time feed refusals were removed and sampled as needed, and fresh feed was manually delivered into each feed bin. The total amount of feed offered was adjusted daily to ensure approximately 10% feed refusal per cow. The actual feed refusal averaged 10.0 $\pm$ 7.1% (mean $\pm$ SD) of the feed offered as fed over the course of the experiment and did not vary by treatment ($P = 0.8$). Cows on treatments 2 and 3 received approximately 50% of their daily allotment of feed at 1400 h. The approximate amount of feed required for subsequent feedings was weighed into 80-L containers using a scale (model 2020, Mettler-Toledo), and stored without lids in front of the feeders. At 1400 h, all cows were moved into the holding area and milked individually; this time point served as the start of each data collection day. Upon individual and sequential return from milking, cows had full feed access. At the specified

2 $\times$ and 3 $\times$ feeding times, according to treatment, feed stored in the 80-L containers was added to the feed bins after the cows had been moved into the holding area.

Behavioral Data Collection

Feeding behavior was automatically monitored for each cow for the last 7 d of each experimental period using the Insentec system. From the recorded data, we were able to determine the duration of each visit to the feed bin, the amount of feed consumed (start weight – end weight) during each visit, and the rate of consumption for each visit. These data were then summarized to calculate daily DMI (kg/d), daily time spent feeding (min/d), and average feeding rate (kg/min).

Lying behavior patterns of the cows were automatically collected using data loggers (Hobo Pendant G Logger, Onset Computer Corp., Pocasset, MA) for the last 7 d of each experimental period. These devices measured leg orientation at 1-min intervals, and allowed all the standing and lying behavior data to be

collected electronically (Ledgerwood et al., 2010). On d 14 of each period, data loggers were placed on the hind leg of each cow using veterinary bandaging tape (Vetrap Bandaging Tape, 3M, London, ON, Canada) while the cow was restrained in a stall. Data loggers were removed from the cows on d 1 of the subsequent experimental period to ensure a complete 7-d recording period. Data collected were used to calculate standing and lying duration (min/d), bout frequency (no./d), and bout length (min/bout). Duration of postmilking standing (min) was calculated as the difference in time between the end of milking and the first recorded instance when the cow lay down following milking.

Rumination behavior was electronically monitored for the last 7 d of each treatment period using automatic rumination detection devices (Lely Qwes-HR collars, Lely Industries N.V.). The rumination logger, placed on the neck collar of the cow, continuously records the time spent ruminating within 24 h in 2-h intervals, as validated by Schirmann et al. (2009). Data were transferred at each milking using an automatic reader located within the robotic milking system.

Feed Sampling and Analysis

For the last 7 d of each experimental period, samples of fresh feed were collected at each feeding (1400, 2200, and 0600 h) for the determination of DM and nutrient content. An additional sample was collected at the first feeding (1400 h) for determination of particle size distribution of that TMR. Samples of feed refusal from each cow were collected at 1330 h for particle size separation to determine feed sorting. On d 1, 8, and 15 of each treatment period, duplicate samples of dietary components were collected for DM, chemical, and particle size analysis. All samples were immediately frozen at -20°C until they were further analyzed.

Samples collected for particle size separation were separated using the 3-screen (19, 8, 1.8 mm) Penn State Particle Separator (**PSPS**; Kononoff et al., 2003). This separated the particles into 4 fractions: long (>19 mm), medium ($<19, >8$ mm), short ($<8, >1.18$ mm), and fine (<1.18 mm) particles. After separation, the DM of each separated fraction was determined by oven drying at 55°C for 48 h. The particle fractions of the fresh TMR samples were ground to pass through a 1-mm screen (Wiley mill, Arthur H. Thomas Co., Philadelphia, PA), and were analyzed for NDF using an Ankom²⁰⁰⁰ Fiber Analyzer (Ankom Technology, Macedon, NY) with heat-stable α -amylase and sodium sulfite (Van Soest et al., 1991).

Samples collected for DM and chemical analysis were oven-dried at 55°C for 48 h and then ground to pass through a 1-mm screen (Wiley mill, Arthur H. Thomas

Co.). These samples were sent to Cumberland Valley Analytical Services Inc. (Maugansville, MD) for analysis of DM (135°C ; AOAC International, 2000; method 930.15), ash (535°C ; AOAC International, 2000; method 942.05), ADF (AOAC International, 2000; method 973.18), NDF with heat-stable α -amylase and sodium sulfite (Van Soest et al., 1991), and CP ($\text{N} \times 6.25$; AOAC International, 2000; method 990.03; Leco FP-528 Nitrogen Analyzer, Leco, St. Joseph, MI).

Milk Production and Components

Milk yield was automatically recorded at each milking for the last 7 d of each treatment period by the robotic milking system (Lely A3 Next, Lely Industries N.V.). Milk samples were collected from each milking for the last 3 d of each experimental period using the Lely Shuttle Sampling Device (Lely Industries N.V.). These samples were sent to the DHI testing laboratory (CanWest DHI, Guelph, ON, Canada) for analysis. Milk samples were analyzed for milk fat and protein percentage using a near-infrared analyzer (Foss System 4000 Infrared Transmission Analyzer, Foss, Hillerød, Denmark). For those days when milk components were measured, the yield of 3.5% FCM (kg/d) was calculated (NRC, 2001) as $[0.432 \times \text{milk yield (kg/d)}] + [16.23 \times \text{fat yield (kg/d)}]$. Energy-corrected milk was calculated using the following equation: $\text{ECM} = [0.327 \times \text{milk yield (kg/d)}] + [12.95 \times \text{fat yield (kg/d)}] + [7.2 \times \text{protein yield (kg/d)}]$ (Tyrrell and Reid, 1965). Efficiency of milk production was determined by calculating the kilograms of milk, 3.5% FCM yield, or ECM yield per kilogram of DMI for each treatment period.

Calculations and Statistical Analysis

Individual feeding bouts were separated into meals using an individual meal criterion for each cow on each treatment. Meal criteria were determined, as described by DeVries et al. (2003b), using a software package (MIX 3.1.3; MacDonald and Green, 1988) to fit a mixture of normal distributions to the distributions of $\log_{10}$ -transformed time intervals between moments of feeding (across all 7 d of data recorded per treatment period). The average meal criterion was 25.5 ± 11.5 min and did not vary by treatment ($P = 0.9$). The calculated meal criteria were used to calculate meal frequency (meals/d), by counting the number of intervals that exceeded the criterion and adding 1. Meal duration (min/meal) was calculated as the time from the start of the first feeding bout until the end of the last feeding bout at which time the meal criterion was exceeded. Meal size (kg/meal) was calculated by dividing DMI by meal frequency. Meal duration and meal size were

also calculated for the first meal consumed after each milking based on the calculated meal criteria for each cow and period.

Feed sorting was calculated as the actual DMI of each fraction of PSPS expressed as a percentage of the predicted DMI of that fraction (Leonardi and Armentano, 2003). The actual intake of each individual fraction was calculated as the difference between the DM amount of each fraction in the offered feed and that in the refused feed. The predicted intake for each individual fraction was calculated as the product of the DMI of the total diet multiplied by the DM percentage of that fraction in the offered diet. Values equal to 100% indicate no sorting, <100% indicate selective refusals (sorting against), and >100% indicate preferential consumption (sorting for).

Before analyses, all data were screened for normality using the UNIVARIATE procedure (SAS Institute, 2009). The 7 d of data collected for each cow-treatment period were summarized to create one value for each cow-treatment period. Body weight change was calculated across the 21 d of each treatment period by subtracting the average BW from the last 3 d of each period from the average BW of the first 3 d of each period. To test whether feed sorting occurred, sorting activity for each fraction of the PSPS was summarized by treatment and tested for a difference from 100 using *t*-tests. All data were analyzed using the MIXED procedure (SAS Institute, 2009). The final model included the fixed effects of parity (PP or MP), period (1, 2 or 3), treatment (1×/d, 2×/d or 3×/d feed delivery), parity × treatment interaction, and period × treatment interaction. Other interactions of the fixed effects were tested in the initial model and were not significant; therefore, they were removed from the final model. Degrees of freedom for fixed effects were estimated using the Kenward-Roger option in the MODEL statement. When a parity × treatment interaction was detected, the Tukey-Kramer method was used to adjust the probability differences between least squares means. The random effects were replicate, square within replicate, and cow within square × replicate. Linear and quadratic orthogonal contrasts of treatment effects were tested using the CONTRAST statement of SAS when the overall treatment effect was significant. To test the prediction that intake and behavior may have varied by treatment in the first hour after return from milking, DMI, feeding time, and feeding rate data were summarized for each cow during this period, and analyzed for each milking of the day (at 1400, 2200, and 0600 h) using the above-mentioned model.

Data for DMI, feeding time, and feeding rate were also summarized on an hourly basis, whereas ruminating time was summarized on a 2-h basis, for each ani-

mal on each treatment. Differences among treatments in the distribution of these variables over a 24-h period were analyzed using the MIXED procedure of SAS, treating hour as a repeated measure. The final model included the fixed effects of hour (1 to 24), treatment (1×/d, 2×/d or 3×/d feed delivery), and hour × treatment interaction. The random effects were replicate, square within replicate, and cow within square × replicate. Cow within square × replicate was included in the model as the subject of the repeated statement. Compound symmetry was selected as the covariance structure on the basis of best fit according to Schwarz's Bayesian information criterion. Degrees of freedom were estimated using the Kenward-Roger option in the MODEL statement. All values reported are least squares means. Significance was declared at $P \leq 0.05$.

RESULTS

Results for the effect of treatment on milk yield, composition, and efficiency are presented in Table 2. Treatment had no effect on milk yield; however, MP cows produced 6.9 kg/d (18.0%) more milk, 8.5 kg/d (23.0%) more 3.5% FCM, and 8.4 kg/d (22.4%) more ECM than PP cows. Milk fat percentage did not differ by treatment or parity, resulting in MP cows having a greater fat yield than PP cows due to greater milk yield for MP cows. We observed no discernible effect of treatment on milk protein percentage as we found a significant period × treatment interaction ($P = 0.02$) for this variable. Treatment had no effect on milk yield, but period did affect milk yield ($P = 0.05$); thus, milk protein percentage increased later in lactation as milk yield increased. Milk protein yield varied by parity, resulting in MP cows having the greatest protein yield (1.45 kg/d). We observed no effect of treatment, parity, or parity × treatment interaction on milk production efficiency (Table 2).

Dry matter intake varied with feed delivery frequency (Table 3), with greater DMI observed ($P_{\text{quadratic}} = 0.03$) in cows delivered feed 3×/d (27.8 kg/d) compared with cows delivered feed 2×/d (27.0 kg/d) or 1×/d (27.4 kg/d). Neither treatment nor parity affected total feeding time (Table 3), but PP cows consumed feed more slowly, resulting in lower DMI compared with MP cows. Treatment had no effect on BW change during each treatment period (Table 3).

Primiparous cows consumed smaller meals than MP cows, but we found no effect of treatment, parity, or parity × treatment interaction on meal frequency or meal duration (Table 3). However, the size of the first meal consumed after each milking was affected by parity. The PP cows consumed 2.0 kg (50.1%) less DM during the first meal following the first milking compared

Table 2. Effect of frequency of feed delivery (1, 2, or 3× daily) and parity (PP = primiparous; MP = multiparous) on milk yield, milk composition, milk component yield, and efficiency of production

Variable	1×		2×		3×		SE	<i>P</i> -value ¹		
	PP	MP	PP	MP	PP	MP		P	T	P × T
Milk yield (kg/d)										
Milk ²	38.4	45.4	38.8	45.2	38.2	45.6	1.6	0.005	0.98	0.76
3.5% FCM ³	37.7	46.8	37.0	44.1	36.7	46.1	2.8	<0.001	0.23	0.48
ECM ³	38.0	47.0	37.6	44.5	37.2	46.7	2.4	<0.001	0.30	0.33
Milk composition ³ (%)										
Fat	3.37	3.71	3.19	3.49	3.27	3.55	0.31	0.38	0.19	0.95
Protein	3.09	3.21	3.16	3.15	3.15	3.27	0.10	0.54	0.03	0.01
Milk component yield ³ (kg/d)										
Fat	1.29	1.67	1.24	1.54	1.25	1.61	0.14	0.01	0.14	0.64
Protein	1.19	1.45	1.23	1.40	1.19	1.49	0.05	0.03	0.52	0.09
Efficiency of milk production ³ (kg/kg)										
Milk/DMI	1.59	1.50	1.60	1.54	1.57	1.48	0.08	0.44	0.08	0.72
3.5%FCM/DMI	1.55	1.53	1.52	1.49	1.50	1.48	0.09	0.70	0.26	0.98
ECM/DMI	1.57	1.54	1.55	1.50	1.52	1.51	0.07	0.60	0.37	0.89

¹P = parity; T = frequency of feed delivery; P × T = interaction.²Data averaged over 7 d for 12 cows on each treatment.³Data averaged over 3 d for 12 cows on each treatment.

with MP cows. We also observed a parity × treatment interaction such that MP cows fed 1×/d consumed the largest meal following the first milking (at 1400 h). Primiparous cows consumed 0.8 kg (26.1%) less DM during the first meal following the second milking (at 2200 h) than MP cows. We observed no difference in the size of the first meal following the third milking (at 0600 h) and no effect of treatment or parity on the length of the first meal following each milking.

The analysis of diurnal feeding activity indicated no treatment or treatment × hour interactions, but we

did find differences in the magnitude of feeding activity during the first hour following the return from milking. There was no difference in DMI, feeding time, or feeding rate between treatments following the first milking (1400 h). Following the second milking (2200 h), cows fed 1×/d consumed less DM than cows fed 3×/d ($P = 0.04$; Figure 1), but we found no difference in feeding time (Figure 2) or feeding rate (Figure 3). Following the third milking (0600 h), cows that did not receive fresh feed (i.e., those fed 1×/d and 2×/d) consumed less DM ($P < 0.01$; Figure 1) than cows that received

Table 3. Effect of feed delivery (1, 2, or 3× daily) and parity (PP = primiparous; MP = multiparous) on DMI, feeding behavior, rumination time, and BW change¹

Variable	1×		2×		3×		SE	<i>P</i> -value ²		
	PP	MP	PP	MP	PP	MP		P	T	P × T
DMI (kg/d)	24.3	30.6	24.3	29.7	24.4	31.1	0.9	<0.001	0.05	0.11
Feeding time (min/d)	238.6	219.9	247.0	220.6	234.3	219.3	16.0	0.27	0.79	0.85
Feeding rate (kg/min)	0.11	0.15	0.10	0.14	0.11	0.14	0.01	0.003	0.17	0.75
Meal frequency (meals/d)	9.3	9.5	9.3	9.6	9.5	9.6	0.8	0.84	0.96	0.97
Meal size (kg/meal)	2.7	3.3	2.7	3.2	2.7	3.3	0.2	0.03	0.77	0.90
Meal duration (min/meal)	26.7	23.6	27.9	23.3	26.0	23.6	2.3	0.15	0.92	0.82
Postmilking meal measurements ³										
Length at 1400 h (min)	44.0	48.5	57.0	45.9	48.0	43.2	6.0	0.46	0.49	0.38
Size at 1400 h (kg)	3.6	6.3	4.4	5.5	3.8	5.9	0.6	0.01	0.85	0.02
Length at 2200 h (min)	35.4	31.1	38.0	34.0	32.3	30.4	5.1	0.53	0.36	0.92
Size at 2200 h (kg)	3.0	3.8	3.3	3.9	2.9	3.9	0.4	0.04	0.70	0.80
Length at 0600 h (min)	36.2	27.4	44.7	33.7	36.3	33.0	6.0	0.31	0.24	0.66
Size at 0600 h (kg)	2.8	2.9	2.9	3.3	3.1	3.7	0.3	0.14	0.18	0.60
Rumination time (min/d)	431.6	522.6	451.8	533.0	489.6	547.9	52.7	0.24	0.34	0.83
BW change ⁴ (kg/d)	0.386	0.239	0.451	0.157	0.314	0.614	0.157	0.69	0.48	0.12

¹Data averaged over 7 d for 12 cows on each treatment.²P = parity; T = frequency of feed delivery; P × T = interaction.³Length (min) and size (kg) of the first meal consumed following the return from milking, based on individual cow meal criteria.⁴Over 21 d of each treatment period.

Figure 1. Hourly average DMI (kg) of lactating dairy cows having received feed delivery (1) 1×/d (at 1400 h), (2) 2×/d (at 1400 and 2200 h), or (3) 3×/d (at 1400, 2200, and 0600 h). Data are averaged over 7 d for 12 cows on each treatment.

fresh feed at all milking times (3×/d). Cows fed 1×/d spent less time feeding ($P = 0.02$; Figure 2) than cows fed 3×/d following the third milking. We observed no difference in feeding rate following the second or third milkings (Figure 3). Neither treatment nor parity affected total rumination time (Table 3), but we observed a treatment × hour interaction for rumination activity ($P = 0.04$; Figure 4).

We observed no effect of treatment, parity, or parity × treatment interaction on the total lying bouts throughout the day. Treatment did not affect total lying time; however, PP cows spent 121.9 min/d (24.5%) longer lying down than MP cows (Table 4). We found no effect of treatment, parity, or parity × treatment interaction on the daily average postmilking standing time (Table 4). Average postmilking standing time following each milking did not differ (Table 4). However, MP cows spent the greatest amount of time standing following the second milking compared with PP cows (Table 4).

We observed no sorting for or against long particles (100.2%), medium particles (100.6%), or fine particles (98.7%). We did observe a treatment effect for sorting of short particles (<8.0, >1.18 mm), indicating that cows fed 1×/d sorted against short particles (98.9%, SE = 0.3; $P = 0.04$), and cows fed 2×/d sorted against short particles (99.2%, SE = 0.3; $P = 0.06$). Cows fed 3×/d showed no significant sorting of this fraction ($P = 0.2$).

DISCUSSION

Many dairy producers have opted to deliver feed only 1×/d as a means to minimize labor costs. The objective of this study was to determine if increasing feed delivery frequency affects both the behavior and productivity of lactating dairy cows. Previous research in this area has focused on the effect of feed delivery frequency on milk yield and composition and feed intake. A review of 35 studies, conducted more than 30 yr ago, reported that increased frequency of feed delivery could lead to increased milk yield, milk fat yield, milk fat percentage, and milk protein yield, but apparently had little or no effect upon milk protein percentage (Gibson, 1984). More recent research shows no effect of feed delivery frequency on milk fat and protein percentage or milk yield (Dhiman et al., 2002; Mäntysaari et al., 2006). Phillips and Rind (2001) observed an increase in milk protein percentage for cows delivered feed more frequently, and they attributed this result to a concentration effect due to decreased milk yield for cows fed more frequently. Shabi et al. (1999) observed a similar increase in milk protein percentage for cows fed 4×/d, but attributed this to an improvement in postruminal digestion of CP and NSC for cows fed more frequently. Although we observed a numerical increase in milk protein percentage with greater frequency of feed delivery in the present study, it was not possible to quantify this effect, as there was a period × treatment interaction for

Figure 2. Hourly average feeding time (min) of lactating dairy cows having received feed delivery (1) 1×/d (at 1400 h), (2) 2×/d (at 1400 and 2200 h), or (3) 3×/d (at 1400, 2200, and 0600 h). Data are averaged over 7 d for 12 cows on each treatment.

this variable. This interaction was driven by an increase in milk protein percentage over the course of the study. Treatment had no effect on milk yield, but period did affect milk yield ($P = 0.05$); thus, milk protein percentage increased later in lactation as milk yield decreased. In the present study, frequency of feed delivery had no

effect on ECM yields, which is consistent with previous research (Dhiman et al., 2002; Mäntysaari et al., 2006).

Because feed delivery is a significant stimulus to initiate feeding activity in dairy cows (DeVries and von Keyserlingk, 2005), and feeding is the second greatest priority for dairy cows next to lying (Munksgaard et

Figure 3. Hourly average feeding rate (kg/min) of lactating dairy cows having received feed delivery (1) 1×/d (at 1400 h), (2) 2×/d (at 1400 and 2200 h), or (3) 3×/d (at 1400, 2200, and 0600 h). Data are averaged over 7 d for 12 cows on each treatment.

Table 4. Effect of feed delivery (1, 2, or 3× daily) and parity (PP = primiparous; MP = multiparous) on lying behavior and postmilking standing time¹

Variable	1×		2×		3×		SE	<i>P</i> -value ²		
	PP	MP	PP	MP	PP	MP		P	T	P × T
Lying bouts (no./d)	9.7	9.2	9.8	9.7	10.5	9.5	1.8	0.81	0.74	0.84
Lying time (min/d)	633.1	507.2	587.4	499.0	635.0	483.7	74.9	0.02	0.61	0.53
Postmilking standing (min/d)	104.2	91.2	93.6	115.0	75.6	116.7	32.2	0.40	0.86	0.23
PMST at 1400 h ³ (min)	116.6	121.0	151.6	137.9	118.3	103.4	44.6	0.72	0.06	0.75
PMST at 2200 h ³ (min)	58.0	73.3	53.8	96.6	52.4	69.4	12.2	0.02	0.08	0.06
PMST at 0600 h ³ (min)	68.2	87.5	70.1	129.3	52.7	107.7	34.2	0.13	0.26	0.34

¹Data averaged over 7 d for 12 cows on each treatment.²P = parity; T = frequency of feed delivery; P × T = interaction.³PMST = postmilking standing time (min) calculated from the time each cow finished milking until the first instance of lying at each milking time throughout the day (1400, 2200, and 0600 h).

al., 2005), there is interest in understanding the effect that frequency of feed delivery has on the behavioral patterns of lactating dairy cows. In the present study, cows fed 3×/d consumed more DM than those fed 1×/d and 2×/d, which is consistent with research reported by Shabi et al. (1999). However, other research has shown no effect of feed delivery frequency on DMI (Robinson and Sniffen, 1985; DeVries et al., 2005), and some research has found that cows fed more frequently have a lower DMI than those fed 1×/d (Nocek and Braund, 1985; Phillips and Rind, 2001; Mäntysaari et al., 2006). These varying results may be attributed to differences in experimental design (i.e., sample size, pen level measurements of DMI, housing system, cow genetics, stage of lactation, parity, length of observa-

tion period). For example, cows with low milk yield (e.g., Phillips and Rind, 2001) may not have the same physiological necessity to maximize DMI as those cows in the present study that were producing almost twice as much milk.

In the present study, the greater DMI achieved by cows delivered feed 3×/d had no effect on milk yield, composition, or milk production efficiency. It is known that the relationship of milk energy output to increments of feed intake is curvilinear, and this has been attributed to greater partitioning of nutrients toward body tissue synthesis as feed intake increases (Kirkland and Gordon, 2001); therefore, in the present study, given the stage of lactation of the cows, the nutrients consumed by cows achieving greater DMI when deliv-

Figure 4. Bihourly average rumination time (min/2 h) of lactating dairy cows having received feed delivery (1) 1×/d (at 1400 h), (2) 2×/d (at 1400 and 2200 h), or (3) 3×/d (at 1400, 2200, and 0600 h). Data are averaged over 7 d for 12 cows on each treatment.

ered feed 3×/d may have been metabolized for body stores rather than being directed toward milk synthesis. This is supported in part by the numerically, but non-significant, greater increase in BW when cows were fed 3×/d.

Over the course of the study period, MP cows had greater DMI and milk yield than PP cows, which is consistent with previous reports (Beauchemin et al., 2002; Azizi et al., 2009; DeVries et al., 2011). Dry matter intake and milk production were proportionally lower for PP cows than for MP cows; therefore, it is not surprising that the efficiency of milk production did not differ by parity.

The present study found no effect of feed delivery frequency on daily feeding time, which is in agreement with previous work reporting no difference in daily feeding time for group-housed cattle fed 1×/d and 4×/d (Phillips and Rind, 2001). However, these results contradict those of DeVries et al. (2005) and Shabi et al. (1999), who found that increased feed delivery frequency is associated with increased time spent feeding. The average rate of feed intake in the present study (0.12 ± 0.02 kg of DM/min; mean $\pm$ SD) was greater than that reported by Beauchemin et al. (2002; 0.09 ± 0.007 kg of DM/min; mean $\pm$ SD). However, Beauchemin et al. (2002) also reported that rate of feed intake did not vary by parity, whereas the present study observed that MP cows consume feed more quickly than PP cows. These results may be explained by differences in experimental design. In the study by Beauchemin et al. (2002), cows were housed in individual tie-stalls, where there was no competition between cows. In the present study, although cows were assigned to individual feed bins, the potential existed for aggressive interactions and for cows to be displaced from their feeder by neighboring cows. Cows tend to consume more feed and at a faster rate when they are fed in groups than when fed separately (Albright, 1993); thus, the social environment may have had a greater effect on rate of feed intake in the present study, specifically for PP cows, which are often of lower standing in the dominance hierarchy. Although we observed that PP cows consumed feed more slowly in the present study, this may be attributed to the fact that each cow had access to only one feeding location. A socially subordinate PP cow, therefore, may have had to retreat from her feeding station more frequently, thus reducing our measurable rate of feed intake.

Although we observed no effect of treatment on meal patterns, the average values for meal frequency (9.4 ± 1.5 meals; mean $\pm$ SD), duration (25.5 ± 5.1 min), and size (2.9 ± 0.5 kg) are in agreement with other reports of meal patterns (Beauchemin et al., 2002; DeVries et al., 2003b; Azizi et al., 2009). The results of

the present study indicate that parity had an effect on the size of the first meal consumed after each milking, but no effect on the length of this meal. Multiparous cows consumed 1.51 kg more DM than PP cows following the first milking. These results may be attributed to differences in rumen capacity between MP and PP cows. More specifically, MP cows fed 1×/d consumed the most DM, whereas PP cows fed 1×/d consumed the least DM following the first milking. Evidently, the delivery of fresh feed at 1400 h had the greatest effect on MP cows fed 1×/d because 24 h had elapsed since their last delivery of fresh feed, and these cows may have had the greatest rumen capacity at this time. We also observed that MP cows consumed more feed following the second milking, but there was no difference in meal size following the third milking, suggesting that feeding motivation may have decreased throughout the day, potentially due to rumen fill.

The distribution of feeding activity throughout the day was not dramatically affected by the frequency of feed delivery in the present study. This contradicts previous research reporting that frequent feed delivery results in cows consuming feed more evenly after each feed delivery (Mäntysaari et al., 2006), and having a more even distribution of feeding time over the course of the day (DeVries et al., 2005). However, some researchers have concluded that the disturbance caused by frequent feed delivery can have detrimental effects on cow productivity, such as reduced milk yield (Phillips and Rind, 2001) and decreased lying times (Mäntysaari et al., 2006). Similar results may not have been observed in the present study because the most frequent feed delivery occurred 3×/d compared with 4×/d (DeVries et al., 2005) or 5×/d (Mäntysaari et al., 2006).

Feed delivery occurred in conjunction with milking times in the present study, whereas in the report by Mäntysaari et al. (2006), feed delivery occurred independently of milking times. It is known that the delivery of fresh feed and the return from milking are significant stimuli to initiate feeding activity (DeVries et al., 2003a). In the present study, only 3 management events occurred per day that are known to stimulate feeding, whereas in the study by Mäntysaari et al. (2006), when cows were delivered feed more frequently, 7 such events occurred per day. Although it is often suggested that it is beneficial for cows to consume smaller, more frequent meals throughout the day, as this is associated with reduced diurnal fluctuations in ruminal pH (Shabi et al., 1999), some research has actually observed that cows that consume the greatest number of meals throughout the day have the lowest daily DMI (Beauchemin et al., 2002). These varying results emphasize that multiple factors influence a cow's feeding behavior patterns. Although Beauchemin et al. (2002) observed that DMI

was lower for cows that consume a greater number of meals throughout the day, efficiency of milk production may be a better measure for comparison; however, production variables were not reported in that study.

Despite some comparable results with previous research, the freestall environment and management strategies used in commercial, parlor-milking production systems introduce greater constraints on the amount of time cows allocate to critical behavioral activities (feeding, lying, ruminating), because of the time spent away from the home pen for milking. For this reason, the results of previous studies may not be comparable to the current results and may not be applicable to all production scenarios. Most notably, all of the research previously conducted on this topic area has examined cows milked 2×/d. We hypothesized that greater frequency of feed delivery and the higher plane of nutrition required to meet the increased production demands of 3×/d milking schedules may alter the amount of time available for critical behavioral activities, specifically the amount of time devoted to lying. However, in the present study, feed delivery frequency had no effect on lying behavior for cows milked 3×/d, which was not surprising, as it has previously been demonstrated that lying has a higher priority over feeding (Metz, 1985; Munksgaard et al., 2005). The average lying bouts (9.76 ± 2.64 ; mean $\pm$ SD) and lying time (570 ± 121 min/d) were shorter than previously reported (Munksgaard et al., 2005; DeVries and von Keyserlingk, 2005). The average postmilking standing time (98 ± 49 min) was not affected by treatment, but was highly variable and significantly longer than previously reported (35 min: Tyler et al., 1997; 55 min: DeVries and von Keyserlingk, 2005; 62 min: DeVries et al., 2005; 33 min: Fregonesi et al., 2007). For this reason, we caution the interpretation of the results for lying behavior and postmilking standing time. This study was conducted during summer months; therefore, environmental temperature might have attributed to the variation observed for these results.

Lying has a greater priority over feeding and cows are able to partially compensate for time restrictions by increasing the rate of feed intake; thus, feed intake is reduced to a lesser degree than eating time under time budget constraints (Munksgaard et al., 2005). Therefore, we caution the interpretation of feeding behavior results for cows managed under varying milking frequencies, as the elasticity of behavioral priorities may differ under such time constraints. The lack of response observed between treatments in the current study might be attributed to a more inelastic response of feeding behavior variables when cows are under the time constraints and production demands of 3×/d milking schedules.

CONCLUSIONS

Cows delivered feed 3×/d consumed more DM than those fed 1×/d and 2×/d. Feed delivery frequency had no effect on milk yield, composition, or milk production efficiency. Therefore, the nutrients consumed by cows achieving greater DMI when delivered feed 3×/d may have been metabolized for body stores rather than being directed toward milk synthesis. Feed delivery frequency had little effect on feeding behavior, but altered the magnitude of DMI following feed delivery. The distribution of feeding activity was also not dramatically affected by feed delivery frequency, but did vary by parity. Under 3×/d milking schedules, greater feed delivery frequency resulted in greater DMI as a function of increased DMI following the return from milking and the delivery of fresh feed.

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