J. Dairy Sci. 98:1–12
http://dx.doi.org/10.3168/jds.2014-8859

The effects of feeding rations that differ in neutral detergent fiber and starch concentration within a day on production, feeding behavior, total-tract digestibility, and plasma metabolites and hormones in dairy cows

L. W. Rottman,[1] Y. Ying, K. Zhou, P. A. Bartell, and K. J. Harvatine[2]
Department of Animal Science, Penn State University, University Park 16802

ABSTRACT

Dairy cows exhibit a daily pattern of feed intake and milk synthesis, and feeding a single total mixed ration over the day may not synchronize ruminal fermentation, nutrient absorption, and milk synthesis. Our hypothesis was that feeding a high-fiber diet during the high-intake period of the day and a low-fiber diet during the low-intake overnight period would stabilize rumen fermentation, nutrient absorption, and the availability of nutrients for milk synthesis. Nine ruminally cannulated cows were used in a 3 × 3 Latin square design with 23-d periods. Diets were a control [CON; 33.3% neutral detergent fiber (NDF)], a low-fiber diet (LF; 29.6% NDF), and a high-fiber diet (HF; 34.8% NDF). The HF and LF diets were balanced to provide the same nutrient composition as the control diet when cows were fed a 7:3 ratio of HF:LF. Control cows were fed once daily at 0900 h. Cows in the high/low treatment (H/L) were fed HF at 70% of daily offering at 0900 h and LF at 30% of daily offering at 2200 h; cows in the low/high (L/H) treatment were fed LF at 30% of daily offering at 0900 h and HF at 70% of daily offering at 1300 h. Dry matter intake was decreased 1.9 kg/d by H/L compared with CON, but intake did not differ between H/L and L/H. The H/L and L/H treatments resulted in a large amount of feed consumed after each feeding, which shifted the daily patterns of starch and fiber intake. Treatments did not differ in total-tract digestibility. We detected no differences between CON and H/L for milk yield and composition. The H/L treatment unexpectedly tended to reduce milk and reduced milk fat yield compared with L/H, although L/H was expected to result in poorer rumen fermentation and decreased milk fat yield. Treatment did not affect milk fat concentrations of *trans*-10 C18:1, *trans*-11 C18:1, or de novo synthesized fatty acids, but H/L increased milk fat concentration of preformed fatty acids compared with CON (39.15 vs. 37.38% of FA, respectively). Treatment had no effect on plasma insulin or glucose at individual time points but did modify the phase and amplitude of the daily rhythms. Daily average plasma nonesterified fatty acids (NEFA) were decreased by H/L compared with CON and L/H, and H/L treatments decreased the amplitude of the daily rhythm of NEFA by 3.4 and 6.7 μEq/L compared with CON and L/H, respectively. The amplitude of the daily rhythm of plasma blood urea N was increased by more than 15% by H/L compared with CON and L/H. Feeding multiple rations over the day changed the daily pattern of starch and fiber intake and decreased daily intake without decreasing milk yield or body weight gain over the 23-d observation periods. Feeding a high-fiber diet during the high-intake period of the day and a low-fiber diet during the low-intake overnight period failed to show other benefits, likely because of the change in feeding behavior.

Key words: circadian, diurnal, feed intake

INTRODUCTION

Cattle have naturally occurring daily patterns of feeding, with higher rates of intake occurring around dawn and dusk in pasture-fed animals (Albright, 1993). Total mixed rations, which are typically fed 1 to 3 times per day, are used to supply a constant composition of nutrients in each meal and minimize the detrimental effects of high-starch diets (Coppock et al., 1981). Environmental factors influencing feeding behavior have been extensively investigated and these include the frequency and timing of feed delivery, stocking density, and cow parity (reviewed by von Keyserlingk and Weary, 2010). For example, increasing the number of times per day that a TMR is fed can change the daily pattern of feed intake by shifting intake toward the times feed is delivered (DeVries et al., 2003, 2005). In addition to the distinct daily pattern of intake, cows have the ability to sort TMR and tend to consume a more fermentable

Received September 15, 2014.
Accepted December 30, 2014.
[1]Currrent address: Novozymes Biologicals Inc., Salem, VA 24153.
[2]Corresponding author: kjh182@psu.edu

diet during the first part of the day (DeVries et al., 2005). The daily pattern of intake and sorting causes fluctuations in the rate of nutrients entering the rumen and is expected to change rumen digesta composition, but TMR feeding generally does not consider the daily pattern of intake.

Diet nutrient concentration and diet composition affect rumen digestion rates (Firkins et al., 1998), and changes in the rate of nutrient entry into the rumen over the day are also expected to affect rumen digestion rates. Additionally, feed intake increases passage rates and may modify rumen dynamics (Girard, 1990). These observations directly contradict the steady state rumen environment assumed during TMR feeding by many nutritionists and models of digestion kinetics (Mertens, 1987). Taken together, the natural daily pattern of feed intake, feed delivery time, and sorting creates a daily rhythm of nutrient entry into the rumen that is not constant throughout the day and should be taken into account when designing feeding strategies.

It is commonly recognized that milk yield and composition vary over the day. Generally, higher milk yields are observed at the morning milking than at the evening milking, whereas fat percentage is higher at the evening milking than at the morning milking (Everett and Wadell, 1970; Quist et al., 2008). We recently reported a daily pattern of milk and milk component synthesis observed when milking 4×/d that was modified by feeding 4 equal meals every 6 h over the day compared with feeding once per day (Rottman et al., 2014). The daily rhythm of milk synthesis that is partly dependent on the timing of feed intake indicates that nutrient absorption may not always be synchronized with the timing of nutrients required for maximal milk synthesis.

Feed sorting, feeding a single TMR over the day, and the natural daily pattern of feed intake create large variations in the amount of fermentable carbohydrate entering the rumen over the day. This is not ideal for stable rumen fermentation and maximal milk synthesis over the entire day. Our hypothesis was that feeding a higher fiber ration during the high-intake period of the day and a lower fiber ration during the low-intake period during the night would stabilize rumen fermentation, nutrient absorption, and the availability of nutrients for milk synthesis. This strategy was compared with the current industry standard of feeding a single TMR once per day and the inverse feeding strategy that fed a low-fiber diet during the high-intake period after morning feeding and a high-fiber diet during the low-intake period during the night that was expected to increase the amount of starch consumed after the morning feeding. This paper reports the effects on intake and feeding behavior, total-tract digestibility, milk production, milk FA profile, and selected plasma metabolites and hormones. A companion paper (Ying et al., 2015) focuses on the effect in the rumen and reports the effect of treatment on rumen digesta nutrient concentration and pool size and rumen pH over the day.

MATERIALS AND METHODS

Animals and Experimental Design

Nine multiparous Holstein cows (158 ± 48 DIM, mean ± SD) from the Pennsylvania State University Dairy Herd were randomly assigned to 1 of 3 treatments in a 3 × 3 Latin square design with 23-d periods. Cows were housed in tie stalls, and lights were manually controlled with a dark phase from approximately 0000 to 0500 h. All animal procedures were approved by the Pennsylvania State University Institutional Animal Care and Use Committee (#31694). The 3 diets used included a control (**CON**; 33.1% NDF), a low-fiber diet (**LF**; 29.6% NDF), and a high-fiber diet (**HF**; 34.8% NDF; Table 1). Forage was substituted for corn grain to change diet NDF, and the HF and LF diets were balanced to offer the same diet nutrient composition as the CON diet when cows were fed a 7:3 ratio of HF:LF. Cows on CON were fed the control TMR at 0900 h; cows on the high/low treatment (**H/L**) were fed HF at 70% of daily offering at 0900 h and LF at 30% of daily offering at 2200 h; and cows on the low/high (**L/H**) treatment were fed LF at 30% of daily offering at 0900 h and HF at 70% of daily offering at 1300 h (Figure 1). All cows were fed at 110% of expected daily intake. Refused feed was removed before delivery of new feed at each feeding.

Milk Sampling and Analysis

Cows were milked twice a day at 0700 and 1700 h in a parlor and milk yield measured using an integrated milk meter (AfiMilk; SAE Afikim, Kibbutz Afikim, Israel). Milk was sampled at each milking from d 18 to 20 of each period. One subsample was stored at 4°C with a liquid preservative (Bronolab-WII; Advanced Instruments Inc., Norwood, MA) until analyzed for fat (filter B), protein, and MUN by infrared spectroscopy (4000 Milko-Scan, Foss Electric, Hillerød, Denmark; AOAC International, 2000, method 972.160; Dairy One Laboratory, State College, PA). Milk FA profile was determined at each milking on d 20, as described by Rico and Harvatine (2013).