Grazing Behavior Affects Daily Ruminal pH and NH₃ Oscillations of Dairy Cows on Pasture

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ABSTRACT

Grazing behavior of Holstein cows in late lactation at 2 pasture allowances without or with supplementation was studied in a single reversal design. Twenty multiparous cows (4 ruminally cannulated) grazed a brome/grass/orchardgrass pasture offered at 2 pasture allowances: 1) low, and 2) high, with 25 and 40 kg/d of DM per cow, respectively. Half of the cows were supplemented with a mineral/vitamin mixture (1 kg/d of the mix in a corn/molasses carrier) and the other half supplemented with a corn-based concentrate (1 kg of concentrate per 4 kg of milk). Automatic behavior recorders were used to measure grazing time and number of bites. For the mineral/vitamin mixture-supplemented cows, grazing time and number of bites after the p.m. milking was greater and ruminal pH was numerically lower at the high pasture allowance. For the concentrate-supplemented cows, grazing behavior and ruminal pH did not differ between the 2 pasture allowances. Pattern of grazing time of mineral/vitamin mixture-supplemented and concentrate-supplemented cows influenced daily oscillations of ruminal pH and NH₃-N concentration. Pasture allowance affected grazing behavior of mineral/vitamin mixture-supplemented cows; however grazing behavior of concentrate-supplemented cows was not affected by pasture allowance.

(Key words: grazing behavior, pasture allowance, supplementation, ruminal fermentation)

Abbreviation key: CS = concentrate-supplemented, MVMS = mineral/vitamin mixture-supplemented, PAL = pasture allowance.

INTRODUCTION

A challenge of managing the dairy cow on pasture is to achieve high levels of pasture DMI and milk pro-

duction by manipulating pasture management and supplementation (Bargo et al., 2003). Dry matter intake of pasture is related to grazing time, biting rate, and bite mass (Rook, 2000). The amount of pasture offered per cow on a daily basis or pasture allowance (PAL) is important to maximize pasture DMI of dairy cows, and therefore influences grazing behavior (Rook, 2000). Concentrate supplementation did not affect biting rate (58 bites/min) or bite mass (0.48 g of DM/bite) but reduced grazing time by 12 min/kg of concentrate compared with unsupplemented cows (574 min/d) (Bargo et al., 2003).

There is a lack of information on the grazing behavior of dairy cows under pasture type and management, supplementation strategies, and climatic conditions of the Northeast United States. Grazing behavior at different PAL of dairy cows with or without concentrate supplementation measured by methodology that does not disturb cows, such as automatic behavior recorders (Rutter et al., 1997), has not previously been reported in the United States.

The objective was to evaluate the effect of PAL on grazing behavior of mineral/vitamin mixture-supplemented (MVMS) and concentrate-supplemented (CS) dairy cows and its influence on daily oscillations of ruminal pH and NH₃-N concentration. The hypothesis is that PAL affects grazing behavior of MVMS cows but does not affect grazing behavior of CS cows. We also hypothesize that grazing time affects ruminal oscillations of pH and NH₃-N concentration (e.g., increasing PAL increases grazing time and leads to a decrease in ruminal pH).

MATERIALS AND METHODS

Cows and Treatments

Twenty multiparous Holstein cows (4 fitted with ruminal cannulas) [BW, 651 ± 76 kg; milk yield, 32.1 ± 7.1 kg/d; parity, 2.8 ± 0.8; DIM, 212 ± 35 (mean ± SD)] were selected from The Pennsylvania State University Dairy Cattle Research and Education Center (University Park, PA). Cows were milked twice daily at 0600 and 1730 h. Walking distance from pasture to the milk-

Received February 18, 2004.

Accepted August 31, 2004.

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Table 1. Ingredient and chemical composition (mean $\pm$ SE) of the mineral-vitamin mix in a corn/molasses carrier and the concentrate used for the mineral/vitamin mixture- and concentrate-supplemented dairy cows, respectively.

Item	Mineral-vitamin mix	Concentrate
Ingredient composition, % DM		
Dry corn grain	29.3	62.3
Wheat middlings	...	10.4
Barley grain	...	7.8
Roasted soybeans	...	5.2
Molasses	24.4	5.2
Corn gluten meal	...	2.6
Limestone	...	1.3
Dicalcium phosphate	19.5	2.1
Salt	11.7	1.4
Magnesium oxide	6.8	0.8
Dynamate	4.9	0.6
Selenium premix (0.06% Se)	1.5	0.15
Trace mineral premix ¹	1.4	0.1
Vitamins A, D, E ²	0.5	0.05
Chemical composition		
DM, %	93.9 $\pm$ 0.2	91.1 $\pm$ 0.5
OM, % of DM	62.4 $\pm$ 2.9	91.7 $\pm$ 0.5
CP, % of DM	9.6 $\pm$ 0.3	14.1 $\pm$ 0.9
NSC, ³ % of DM	19.7 $\pm$ 1.5	57.1 $\pm$ 0.6
NDF, % of DM	20.3 $\pm$ 0.7	18.2 $\pm$ 0.9
ADF, % of DM	12.6 $\pm$ 0.2	6.9 $\pm$ 0.1
IVDMD, ⁴ % of DM	86.6 $\pm$ 2.4	89.5 $\pm$ 9.8

¹Contained 25.3% Ca, 5.8% S, 11,111 mg/kg Cu, 303 mg/kg Co, 13,535 Fe, 909 mg/kg I, 20,202 mg/kg Mn, and 58,589 mg/kg Zn.

²Contained 1.36 million IU/kg of vitamin A, 454,545 IU/kg of vitamin D, and 1363 IU/kg of vitamin E.

³NSC = Nonstructural carbohydrates.

⁴IVDMD = In vitro DM digestibility (2-stage procedure; Tilley and Terry, 1963).

ing parlor averaged 0.9 km (range: 0.75 to 1.20 km). The 20 cows were grouped in 10 pairs of cows that were similar in DIM, milk production, and BW. Each of these pairs was randomly assigned to 1 of 2 supplementation strategies: MVMS or CS. The MVMS cows individually received a mineral-vitamin mixture in a corn (29.3% dry corn grain)/molasses (24.4%) carrier fed at a rate of 1 kg/d. The CS cows individually received a corn-based concentrate fed at a rate of 1 kg of concentrate/4 kg of milk, determined before the start of the experiment. The ingredients of the supplements and the chemical composition are included in Table 1. Supplements were individually fed twice daily after each milking and refusals were weighed daily. Within the 10 pairs, each cow was randomly assigned to 2 PAL treatments during the first of two 21-d sequential sampling periods: low PAL or high PAL. Table 2 lists the chemical composition of the low and high PAL treatments. A single rumen-cannulated cow was represented in each treatment group. During the second sampling period, the assignment of cows to PAL treatments was reversed. The first 10 d of each sampling

Table 2. Chemical composition of low and high pasture allowance (PAL) treatments.

Item	Pasture allowance ¹			Average
	Low PAL	High PAL	SEM	
DM, %	16.3	16.0	0.8	16.15
OM, % of DM	91.1	91.0	0.2	91.05
CP, % of DM	21.3	20.7	0.5	21.00
Soluble CP, % of CP	25.7	26.3	0.9	26.00
NSC, ² % of DM	14.9	16.2	0.6	15.55
NDF, % of DM	52.9	50.8	0.9	51.85
ADF, % of DM	27.4	26.2	0.6	26.80
IVDMD, ³ % of DM	70.3	74.9	1.1	72.60

¹Pasture allowance targets: Low PAL = 25 kg DM/cow per d, High PAL = 40 kg DM/cow per d.

²NSC = Nonstructural carbohydrates.

³IVDMD = In vitro DM digestibility (2-stage procedure; Tilley and Terry, 1963).

period was used to adjust the cows to the treatments and the last 11 d were used for experimental measures. Pasture allowance targets were 25 and 40 kg DM/d per cow measured to the ground level for the low and high PAL, respectively. To achieve these targets, pregrazing pasture mass was measured every 2 d to adjust the size of the paddock. Pregrazing pasture mass (kg of DM/ha) was measured by cutting 10 quadrants (0.124 m²/quadrant, 10 samples per paddock) of pasture to ground level, and drying at 55°C in a forced air oven. A new paddock was constructed daily using a temporary polywire. New paddocks were given to the cows each morning at approximately 0700 h.

Experimental Measures and Sample Analyses

Ruminal fluid samples from the 4 cannulated cows were collected while adjacent to their grazing plots to minimize disruption to grazing activity on d 20 of each period at 0, 4, 8, 12, 16, and 20 h beginning at 0530 h, as described by Bargo et al. (2002). The pH of the filtered ruminal fluid was measured immediately using a portable digital pH meter (Cole Palmer, Vernon Hills, IL) and 15-mL aliquot preserved with 3 mL of 25% metaphosphoric acid and 3 mL of 0.6% 2-ethyl butyric acid (internal standard). These samples were stored at -20°C and subsequently analyzed for NH₃-N as described by Bargo et al. (2002). Grazing behavior was measured from d 14 to 21 of each period using the automatic IGER behavior recorders (Okehampton, UK; Rutter et al., 1997) as described by Bargo et al. (2002). Each day, recorders were placed on one cow per treatment, twice daily after each milking and before cows were moved to the pasture. The objective was to have a total of 8 data points per treatment resulting from the combination of PAL and supplementation, therefore recorders were placed on the cows for

Figure 1. Changes in daily ruminal pH and grazing time for a 24-h period for mineral/vitamin mixture-supplemented dairy cows grazing at low (□) or high (■) pasture allowance. $†P < 0.10$, $*P < 0.05$, $**P < 0.01$.

8 d in each period. Recorders were not placed on the cannulated cows to avoid interference with the rumen sampling. During the day, recorders were on cows from 0730 to 1730 h. During the night, recorders were on cows from 1830 to 0600 h. Recorders were removed twice a day before milking to avoid damage and to download the data. Data recorded were analyzed using the software IGER GRAZE (GRAZE User's guide, documentation version 1.0, program version 0.74; Okehampton, UK).

Statistical Analyses

Data were analyzed as a single reversal design with two 21-d periods using the PROC MIXED model of SAS (SAS Institute, 1999). For the daily mean values of grazing behavior and rumen fermentation, the model included effects of supplementation, pairs within supplementation, PAL, the interaction of sup-

plementation and PAL, cows within pair within supplementation, period, and the interaction of period and supplementation. Error to test supplementation effects was pairs within supplementation. Error to test PAL and the interaction of supplementation with PAL was cows within pair within supplementation. Effect of period and the interactions of treatment effects with period were tested with residual.

The experimental design, as described above, confounds the period by PAL and the period by PAL by supplementation interactions with the main effect of PAL and its interaction with supplementation. It was assumed that these interactions were nonexistent because the length of periods was short.

For the hourly grazing time and ruminal pH and NH_3 data, the model was similar to that described above for mean daily values but the effect of hour and its interactions were included. Effect of hour and the interactions of treatments effects with hour were

Figure 2. Changes in daily ruminal $\text{NH}_3\text{-N}$ concentration and grazing time for a 24-h period for mineral/vitamin mixture-supplemented dairy cows grazing at low (□) or high (■) pasture allowance. † $P < 0.10$, * $P < 0.05$, ** $P < 0.01$.

tested with residual. When significant ($P < 0.05$) effects due to PAL (low vs. high) within supplementation were detected, mean separation was conducted by the PDIF option in SAS (SAS Institute, 1999). All means presented are least square means.

RESULTS AND DISCUSSION

Mineral/Vitamin Mixture-Supplemented Cows

Total grazing time was greater (636 vs. 478 min; $P < 0.05$) when MVMS cows grazed at the high PAL because of a longer grazing time (298 vs. 157 min; $P < 0.05$) after the p.m. milking. In agreement with our study, Wales et al. (2001) reported that grazing time increased as PAL increased. Total bites (including biting and manipulative chewing while grazing) per day were greater (35,669 vs. 25,802; $P < 0.05$) when MVMS

cows grazed at high PAL because of a greater number of bites (16,853 vs. 8604; $P < 0.05$) after the p.m. milking. The total bites per day of cows at high PAL was close to the maximum number of total bites (40,000 bites/d) estimated by Phillips and Leaver (1986) for dairy cows. Daily biting rate (54 bites/min) and average bite mass (0.59 g of DM/bite), calculated dividing pasture DMI by total bites per day (Bargo et al., 2002), of MVMS cows did not differ ($P > 0.05$) between PAL.

The main objective of measuring ruminal digesta was to study daily oscillations of pH and $\text{NH}_3\text{-N}$ concentration to see how they responded to the different grazing pattern. Oscillations of pH are the result of fermentation of pasture plus supplements and the balance of production and removal rates of acidic products and buffering capacity. Previous studies have reported ruminal fermentation characteristics in dairy cows

Figure 3. Changes in daily ruminal pH and grazing time for a 24-h period for concentrate-supplemented dairy cows grazing at low (□) or high (■) pasture allowance. † $P < 0.10$, * $P < 0.05$, ** $P < 0.01$.

grazing pasture without supplementation, however only Wales et al. (2001) evaluated the effect of PAL. Mean ruminal pH on MVMS cows tended to be lower ($P < 0.13$) at high PAL compared with low PAL (6.33 vs. 6.60). Ruminal $\text{NH}_3\text{-N}$ concentration of MVMS cows was not affected (17.2 mg/dL; $P > 0.05$) by PAL. Wales et al. (2001) reported no differences in $\text{NH}_3\text{-N}$ concentration for unsupplemented cows grazing a ryegrass pasture at low or high PAL.

The grazing time pattern of MVMS dairy cows grazing at 2 PAL and the daily oscillations of ruminal pH and $\text{NH}_3\text{-N}$ concentration are shown in Figure 1 and Figure 2. The bottom part of the figure shows the grazing time in min/h for a 24-h period starting at 0500 h (e.g. at 0500 cows on the high PAL treatment grazed 12 min of the 60 min). In the top part of the figures, ruminal pH and $\text{NH}_3\text{-N}$ concentration, respectively, are presented at each of the 6 sampling times during the 24-h period starting at 0530 h. A significant PAL $\times$ hour interaction ($P < 0.05$) was found for both ruminal pH and $\text{NH}_3\text{-N}$ concentration. The morning grazing

time was not affected by PAL, however cows grazing at high PAL tended ($P < 0.12$) to graze more at 0900 h. This trend toward higher grazing activity could explain the numerically lower ruminal pH of cows at high PAL at 0930 and 1330 h (Figure 1). Cows grazing at high PAL had a greater grazing time after the p.m. milking than cows grazing at low PAL. Grazing time at high PAL was numerically greater at 1900, 2000, and 2100 h, and tended to be significantly greater ($P < 0.10$) at 2200, 2300, 2400, and 0400 h. The greater grazing time between 2200 and 2400 could explain the lower ($P < 0.05$) ruminal pH at 0130 h; the greater grazing time at 0400 h could explain the trend ($P < 0.13$) toward a lower ruminal pH at 0530 h (Figure 1). Only at the 0530 h sampling time, did the ruminal $\text{NH}_3\text{-N}$ concentration tend ($P < 0.10$) to differ between treatments (Figure 2).

Concentrate-Supplemented Cows

None of the grazing behavior variables of the CS cows were affected ($P > 0.05$) by PAL. Previous studies

Figure 4. Changes in daily $\text{NH}_3\text{-N}$ concentration and grazing time for a 24-h period for concentrate-supplemented dairy cows grazing at low ($\square$) or high ($\blacksquare$) pasture allowance. $\dagger P < 0.10$, $*P < 0.05$, $**P < 0.01$.

have not evaluated the effect of PAL on grazing behavior of dairy cows supplemented with concentrate. Total daily grazing time (550 min/d) was close to the maximum daily grazing time of 10 h/d estimated by Phillips and Leaver (1986). Similar grazing times were reported for dairy cows grazing ryegrass pasture and supplemented with 4 to 6 kg/d of concentrate (Rook and Huckle, 1996; Pulido and Leaver, 2001). Total bites per day (29,994 bites/d), biting rate (55 bites/min), and bite mass (0.55 g of DM/bite) of CS cows were not affected ($P > 0.05$) by PAL. Mean ruminal pH of CS cows did not differ (6.05; $P > 0.05$) between treatments. No previous studies have evaluated the

effect of PAL on ruminal fermentation of dairy cows supplemented with concentrate. Ruminal $\text{NH}_3\text{-N}$ concentration on CS cows did not differ (13.9 mg/dL; $P > 0.05$) between treatments.

The grazing time pattern of CS cows grazing at 2 PAL and the daily oscillations of ruminal pH and $\text{NH}_3\text{-N}$ concentration are shown in Figures 3 and 4. Although the mean ruminal pH of CS cows did not differ ($P > 0.05$) with PAL, a significant treatment $\times$ hour interaction ($P < 0.05$) was detected for ruminal pH (Figure 3). Concentrate-supplemented cows grazing at low PAL had a greater ($P < 0.05$) grazing time at 1500 h, which could explain the trend to a lower ($P < 0.09$)

ruminal pH at 1730 h (Figure 3). A trend to lower ($P < 0.08$) ruminal pH at 0130 h and a trend to greater ($P < 0.09$) grazing time at 0200 h were observed for CS cows at low PAL. For the ruminal $\text{NH}_3\text{-N}$ concentration, the treatment $\times$ hour interaction was not significant ($P > 0.05$), and this variable did not differ at any sampling time for CS cows (Figure 4).

CONCLUSIONS

Total grazing time was greater when MVMS cows grazed at the high PAL because of a longer grazing time after the p.m. milking. Total bites per day were greater when MVMS cows grazed at high PAL because of a greater number of bites after the p.m. milking. None of the grazing behavior variables of the CS cows were affected by PAL. Periods of greater grazing time at different hours explained reductions of ruminal pH in both MVMS and CS cows.

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