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Variation in feeding behavior and milk production among dairy cows when supplemented with 2 amounts of mixed ration in combination with 2 amounts of pasture

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ABSTRACT

Variation in feeding behavior and milk production of grazing dairy cows fed a mixed ration was measured. Experiments were conducted in spring (early lactation) and autumn (late lactation) with 48 Holstein-Friesian dairy cows. Pasture allowance (low vs. high) and amounts of supplement (low vs. high) were applied to determine the effect on variation among cows in feeding behavior and milk production. The experiments investigated 4 dietary treatments in a 2 × 2 factorial arrangement of treatments. Daily pasture allowances were 15 kg of DM/cow per day (low) and 37 kg of DM/cow per day (high; to ground level); and 12 kg of DM/cow per day (low) and 31 kg of DM/cow per day (high; to ground level), for the spring and autumn experiments, respectively. Supplements were offered at 6 kg of DM/cow per day (low) and 14 kg of DM/cow per day (high); and 6 kg of DM/cow per day (low) and 12 kg of DM/cow per day (high), for the spring and autumn experiments, respectively. There were 2 groups of 6 cows per treatment. All treatments received a partial mixed ration, defined as a total mixed ration fed between periods of grazing that contained wheat grain, corn grain, alfalfa hay, and canola meal. The grain-to-forage ratio of the supplements was 78:22 (DM basis) in both spring and autumn. In both experiments, the pre-experimental period was 14 d followed by a 10-d experimental period. The variation among cows within a group in feeding behavior was influenced by the amount of supplement but not the amount of pasture offered. The variation among cows in pasture eating time approximately doubled when the amount of supplement offered increased, indicating that to reduce the variability among cows, supplement feeding management strategies need to be considered. Increasing pasture allowance had no effect on pasture eating time although pasture intake increased as a result of increased grazing intensity compared with the low pasture allowance. However, increasing the amount of supplement in the partial mixed ration feeding system reduced pasture eating time by 51 min/cow per day.
Key words: partial mixed ration, feeding behavior, milk production, variation

INTRODUCTION

In southeastern Australia and many other parts of the world, grazed pasture is the primary source of nutrients for lactating dairy cows due to its inherent low cost (Dairy Australia, 2013). However, pasture alone cannot provide high-producing dairy cows with enough energy or an optimal mix of nutrients throughout their lactation to support milk production (Kolver and Muller, 1998; Bargo et al., 2002a). Fluctuations in pasture DM production and nutrient supply are often managed with supplements traditionally in the form of cereal grain or pelleted concentrates fed in the parlor during milking. The provision of supplements in this manner is relatively controlled as cows are individually fed known amounts of concentrates. As a result, the main source of variation in DMI in traditional feeding systems is likely to occur with the pasture component of the diet. Feeding supplements as a partial mixed ration (**PMR**), defined as a TMR fed on a feed pad between periods of grazing (Bargo et al., 2002b), is becoming more common in Australia, with approximately 16% of Australian dairy farmers using this system for at least part of the year (Dairy Australia, 2012).

Within a group of cows, many factors contribute to the variation among cows in DMI, including the interrelated factors of social hierarchy, competition among cows, and feed availability (Grant and Albright, 2001). Previous research revealed a coefficient of variation up to 36% in DMI among cows when cows were offered

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corn silage and pasture in a group environment (García et al., 2000). The provision of a ration in combination with pasture to groups provides the potential for cows to alter their diet selection and vary their intake of dietary components. This increased variability in terms of nutrient intake may result in nutrient imbalances and affect milk production. Therefore, it is necessary to quantify the size of this variation in a PMR feeding system, and this will require a measure of individual intake in a group-fed situation. Previous research has suggested that knowledge of feeding behavior variables that contribute to intake can assist in estimating DMI. For example, Woodward (1997) demonstrated that the DMI of grazing cows can be estimated from a time budget of searching, prehension, mastication, and rumination. Furthermore, number of bites, grazing and ruminating time, and daily intake are derived as functions of bite mass and composition (Gibb et al., 1997). Recent research by Galli et al. (2011) found that acoustic monitoring of short-term ingestive behavior can also be used to predict intake.

Feeding management strategies are generally employed by farmers to optimize the nutrient intake of their herd. In pasture-based systems, such strategies primarily involve decisions at the pasture and supplement feeding level, which may potentially affect the feeding behavior and DMI of the herd (Chilibroste et al., 2015). Bargo et al. (2002a) reported that supplementing pasture with 7.9 kg of DM/cow per day of a corn-based concentrate reduced grazing time by 75 min/cow per day at a low pasture allowance (25 kg of DM/cow per day) and by 104 min/cow per day at a high pasture allowance (40 kg of DM/cow per day). It is necessary to investigate the effect of varying the amounts of supplement and pasture on feeding behavior to optimize the intake of dietary components of cows in the PMR feeding system and reduce the variability of the herd.

The current experiments were conducted to quantify the variation among cows in feeding behavior and milk production in a PMR feeding system. The variation among cows in DMI was not determined in these experiments due to difficulty in determining individual DMI. In addition, these experiments aimed to identify feeding management strategies in the PMR feeding system that optimize DMI and determine the effect of the variation among cows in the PMR feeding system. The hypotheses tested were as follows: (1) the variation among cows in feeding behavior and milk production will not differ when different amounts of supplements and pasture are fed in a PMR feeding system; (2) increasing pasture allowance in a PMR feeding system will result in an increase in pasture eating time, bite rate, and bite mass; and (3) increasing the amount of supplements fed in a PMR feeding system will result in a reduction in pasture eating time, bite rate, and bite mass.

MATERIALS AND METHODS

Cows and Design

Two experiments were conducted at the Department of Economic Development, Jobs, Transport and Resources (**DEDJTR**) Ellinbank Centre, Victoria, Australia (38°14′S, 145°56′E). All procedures were conducted in accordance with the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes (National Health and Medical Council, 2004). Approval to conduct the experiments was obtained from the DEDJTR Agricultural Research and Extension Animal Ethics Committee.

Experiments were conducted in spring and autumn, each using 48 multiparous Holstein-Friesian dairy cows that had calved in late winter/early spring. All cows were between 3 and 11 yr old and were an average of 44 ± 16.3 DIM (mean ± SD) before the commencement of the spring experiment (early lactation) and 260 ± 20.4 DIM before commencement of the autumn experiment (late lactation).

Cows were selected from concurrent parent experiments that each used 144 cows, which aimed to investigate milk production responses in PMR feeding systems at 3 pasture allowances (15, 25, and 40 kg of DM/cow per day in spring and 12, 20, and 32 kg of DM/cow per day in autumn, to ground level) and 4 supplement rates (6, 10, 12, and 14, or 6, 8, 10, and 12 kg of DM/cow per day, in spring and autumn, respectively). Extreme treatments from the parent experiments were selected for investigation in the current experiments. As soon as all cows had calved they were randomly allocated to groups in the parent experiment, balanced for DIM, age, BW, number of previous lactations, and 7-d average of milk production according to the experimental design method of Baird (1994), which describes how to balance groups based on covariate data.

The current experiments used 4 of the dietary treatments in a 2 × 2 factorial arrangement of treatments. Extreme treatments selected were low (15 and 12 kg of DM/cow per day in spring and autumn, respectively) and high (target of 40 and 32 kg of DM/cow per day, but actual pasture allowance was 37 and 31 kg of DM/cow herd in spring and autumn, respectively) pasture allowance and low (6 kg of DM/cow per day in spring and autumn) and high (14 and 12 kg of DM per cow per day in spring and autumn, respectively) amount of supplement. Each dietary treatment consisted of 2 replicate groups of 6 cows. Both spring and autumn ex-

Table 1. Mean nutritive characteristics of feed components and pasture for cows fed different pasture allowances and amounts of supplements during spring and autumn[1]

Item	CP	ADF	NDF	Lignin	NFC	Starch	CF[2]	Ash	ME[3]
Experiment 1: spring									
Grain mix	17.1	7.3	13.7	2.7	65.2	52.5	2.9	2.5	15.5
Alfalfa hay	22.8	28.8	35.1	6.0	34.6	8.2	2.4	8.8	12.4
Pasture offered	20.9	29.0	47.4	4.4	23.1	1.2	4.2	9.3	12.4
Pasture residual	15.1	33.9	54.7	3.6	21.6	0.6	2.8	9.8	11.6
Pasture consumed: low allowance	24.0	23.4	39.0	4.4	24.7	1.5	5.2	8.7	12.8
Pasture consumed: high allowance	29.4	22.2	36.8	6.1	22.1	2.1	5.6	8.7	12.7
Experiment 2: autumn									
Grain mix	18.1	7.2	14.8	2.8	60.6	52.2	3.3	3.0	13.8
Alfalfa hay	20.2	39.0	49.4	8.9	20.7	1.3	1.6	8.1	9.1
Pasture offered	24.5	31.1	48.7	4.6	8.1	0.6	5.3	12.1	10.5
Pasture residual	21.2	34.4	56.3	5.2	6.7	0.4	3.6	12.3	9.4
Pasture consumed: low allowance	26.6	29.5	44.6	4.5	7.3	0.6	6.0	12.4	10.9
Pasture consumed: high allowance	26.9	29.1	42.4	4.4	10.2	0.8	6.6	12.4	11.2

[1]Data are means (% of DM, unless otherwise indicated) for all samples collected during the 10-d experimental period for each experiment.

[2]Crude fat.

[3]Estimated ME (MJ/kg of DM).

periments consisted of a 14-d pre-experimental period, during which cows were gradually adapted to the rates of supplement feeding, followed by a 10-d experimental period, when measurements were taken.

Supplements

All cows were fed a ration that contained crushed wheat grain (38% DM), corn grain (19% DM), alfalfa hay (21% DM), and canola meal (22% DM). The ration was mixed and chopped in a feed wagon (model K160, Richard Keenan and Co. Ltd., Co. Carlow, Ireland), and water was added such that the final DM concentration of the ration was approximately 50%. The ratio of grain:forage fed as supplement was 78:22 (DM basis). The ration was fed twice daily on a concrete feed pad, immediately after each milking (half the ration was offered after each milking). While on the feed pad, groups of 6 cows were separated by electric tapes.

Ration offered and refused was weighed every day of the experimental period to determine group DMI. Cows also received 500 g/cow per day (in 2 equal amounts on top of the ration at each feeding) of a vitamin and mineral pellet (Ridley custom concentrate pellets) containing monensin (360 mg/cow per day) and tylosin (200 mg/cow per day). Sodium bicarbonate (80 g/cow per day), ground limestone (150 g/cow per day), and magnesium oxide (30 g/cow per day) were also added to the ration before being presented on the feed pad. Cows receiving the high amount of supplement were introduced gradually to the dietary regimens, reaching their full amount of ration 10 d after the commencement of the pre-experimental period. All cows had opportunities each day to access water from troughs located in and adjacent to the dairy, and in laneways adjacent to the paddocks used for grazing.

Concentrations of CP, ADF, NDF, lignin, NFC, starch, CF, ash, and estimated ME of the ration and pasture offered and consumed are presented in Table 1. Concentrations of estimated ME were calculated using the following formula (NRC, 2001):

$$\text{ME (MJ/kg of DM)} = \{[(1.01 \times (0.04409 \times \text{TDN }\%)] - 0.45\} \times 4.84.$$

Grazing and Measurement of Pasture Mass

After consuming their ration on the feed pad, cows returned to their paddock to graze predominantly perennial ryegrass (*Lolium perenne* L.) pasture. Pasture was presented in 2 equal allotments each day (one after each milking) and groups grazed separately in adjacent plots, separated by electric tapes. Cows did not return to the same plot during the course of the 10-d experimental period and were prevented from regrazing areas that had been grazed on previous days.

In each experiment, pre- and postgrazing pasture mass was determined every day for each of the 8 groups with a calibrated rising plate meter; this information was used to calculate average pasture DMI for each group. The pasture meter was calibrated using 48 prequadrat cuts and 48 post-quadrat cuts, for each new set of paddocks the cows entered, to construct calibration equations plotting actual pasture mass against pasture meter reading. The pregrazing pasture mass was used to set the appropriate area for the required pasture allowance. The plate meter was calibrated for both pre- and postgrazing pasture mass for each new set of paddocks.

Nutritive Characteristics of Ration and Pasture

Representative samples of the ration and individual ingredients (wheat grain, corn grain, alfalfa hay, and canola meal) were collected on 4 separate occasions during the measurement period and bulked for analysis of nutritive characteristics. Samples of orts were also collected for nutritive characteristics. Daily subsamples of ration offered and orts were collected for the determination of DM, which allowed for the calculation of daily ration DMI by each group of 6 cows.

For each new plot, pasture nutritive characteristics were determined on representative samples of pasture offered to cows before entering the paddock. Samples of pasture were also collected postgrazing from each group of 6 cows. All pre- and postgrazing pasture samples were collected by cutting pasture to ground level using electric shears at several points along a transect of each plot.

All samples for nutritive determination were frozen, freeze-dried, ground through a 0.5-mm sieve, thoroughly mixed, subsampled, and analyzed at a commercial laboratory (Dairy One Forage Laboratory, Ithaca, NY) for nutritive characteristics by wet chemistry (AOAC International, 2000).

Milk Sampling and Analyses

Cows were milked twice daily, at approximately 0700 and 1500 h, with milk yields of individual cows recorded at each milking using a DeLaval ALPRO milk metering system (DeLaval International AB, Tumba, Sweden). Three days per week during the measurement period, representative samples were collected using in-line milk meters (DeLaval International AB) from consecutive p.m. and a.m. milkings. These samples were analyzed separately for fat and protein concentration using an infrared milk analyzer (model 2000, Bentley Instruments Inc., Chaska, MN). Energy-corrected milk was calculated using the formula of Tyrrell and Reid (1965), where

$$\text{ECM (kg/cow per day)} = \text{milk yield (kg/cow per day)} \times [376 \times \text{fat (\%)} + 209 \times \text{protein (\%)} + 948]/3{,}138.$$

Feeding Behavior

Feeding behavior data were collected for every cow enrolled in these experiments. Institute of Grassland and Environmental Research behavior recorders (Rutter et al., 1997) were fitted to 10 cows at a time for 23 consecutive hours during each measurement period until feeding behavior data were collected for each cow, at least once, in each group. Each of the 10 recorders was fitted to at least one cow in each group for each 23-h period. The Institute of Grassland and Environmental Research behavior recorders were fitted after each p.m. milking and removed before the following p.m. milking to allow for data download and battery replacement. Feeding behavior data were obtained and analyzed using Graze analysis software (Rutter, 2000), and the following parameters were quantified: eating time, eating bouts, eating prehensions, eating mastications, bite rate, ruminating time, ruminating mastications, ruminating bouts, ruminating boli, and idling time. Feeding behavior were further categorized into ration and pasture feeding behavior. The average per cow DMI per group was matched to the same day that feeding behavior data were collected for each cow. These data were not used in the determination of among cow variation, but were used in the calculation of intake rates and bite mass.

Intake rates were calculated as

$$[\text{Group average DMI (kg of DM/cow per day)} \times 1{,}000]/\text{eating time}.$$

Bite masses were calculated as

$$[\text{Group average DMI (kg of DM/cow per day)} \times 1{,}000]/\text{eating prehensions per day}.$$

Statistical Analyses

Initially, feeding behavior and milk data were averaged over the treatment period within seasons for each cow, for each variable. Means and standard deviations for the 16 groups (8 groups by 2 seasons) were then calculated over cows within groups. Variation among cows within a group was determined by calculating coefficients of variation. Group coefficients of variation for the feeding behavior data were calculated as standard deviations divided by cow means within groups. The group mean (for milk and feeding behavior variables) and group coefficients of variation (for milk and feeding behavior variables) were then subjected to ANOVA with factorial treatment structure, pasture allowance by amount of supplement by season, with group as the experimental unit. In the case of milk variables, the corresponding pre-experimental variable was included as a covariate. Residuals were checked graphically for constant variance and normality of distribution. Data analyses were performed using GenStat 17 (GenStat release 17, VSN International Ltd., Hemel Hempstead, UK) statistical software.

RESULTS

Coefficient of Variation

Mean coefficients of variation and ranges for primary feeding behavior and milk production variables are presented in Table 2. More variation was found among cows within groups in time spent consuming the ration when a low supplement amount was offered (CV: 25.2%) compared with an increased amount of supplement (CV: 19.0%). In contrast, variation among cows in the time spent grazing increased when more supplement was offered (CV: 15.8%) compared with the low amount of supplement treatment (CV: 9.0%). Interestingly, pasture allowance did not affect the variation among individual cows with regard to feeding behavior or milk production. More variation was found among cows within a group in terms of milk yield (CV: 24.8 vs. 13.1%), ECM (CV: 27.7 vs. 14.2%), and protein concentration (CV: 6.1 vs. 3.8%), in autumn than in spring. However, there was no effect of season on the variation among cows in terms of feeding behavior variables. Overall, the ranges show that some animals within a group spent twice as long consuming the ration as others.

Feeding Behavior and DMI

The increase in pasture allowance (14 vs. 33 kg of DM/cow per day) resulted in an increase in time to consume the supplement (38 vs. 47 min/cow per day) but not pasture eating time (Table 3). Total eating time was not affected by pasture allowance (400 vs. 417 min/cow per day). Increasing pasture allowance increased the duration of each bout while cows were consuming the ration (18 vs. 22 min/bout per cow·d) but not pasture bout duration (44 min/bout per cow·d). The group average bite mass when consuming ration decreased with the increase in pasture allowance (8.1 vs. 6.0 g of DM/bite) but increased when consuming pasture (0.5 vs. 0.8 g of DM/bite). The intake rate of ration decreased with increased pasture allowance (247 vs. 193 g of DM/min), but the intake rate of pasture increased with increased pasture allowance (24 vs. 39 g of DM/min). Ration DMI was not influenced by pasture allowance (9 kg of DM/cow per day), but pasture DMI increased with the increased pasture allowance (8.7 vs. 14.0 kg of DM/cow per day). Total DMI also increased with the increased pasture allowance (17.8 vs. 23.1 kg of DM/cow per day). The increase in pasture allowance resulted in increased ruminating time (390 vs. 430 min/cow per day) and ruminating mastications (21,400 vs. 25,510 bites/cow per day). The duration of each ruminating bout increased with the increased pasture allowance (28 vs. 31 min/cow per day). There was also a reduction in the time spent not chewing with the increased pasture allowance (598 vs. 543 min/cow per day). The total number of jaw movements increased with the increased pasture allowance (49,000 vs. 54,000 jaw movements/cow per day).

Increasing the amount of supplement offered, in both spring and autumn, resulted in an increase in the time spent eating the ration (35 vs. 50 min/cow per day) and a reduction in the time spent eating pasture (391 vs. 340 min/cow per day). Total eating time decreased with an increased amount of supplement (average 426 vs. 390 min/cow per day). The duration of each eating bout when ration was consumed increased with the increased amount of supplement (16 vs. 24 min/cow per day) but the duration of each eating bout of pasture decreased with the increase in the amount of supplement (49 vs. 38 min/cow per day). The number of chews where ration was prehended did not alter with the amount of supplement (20 prehensions/cow per day), but the number of pasture prehensions decreased with the increased amount of supplement (22,300 vs. 18,200 prehensions/cow per day). The total number of prehensions also decreased with the increased amount of supplement (23,600 vs. 20,000 prehensions/cow per day). The number of mastications after the prehension of ration increased with the increased amount of supplement (1,000 vs. 1,700 mastications/cow per day). The amount of supplement did not influence the bite rate while cows were consuming ration (36 vs. 36 bites/min), but when cows were consuming pasture, bite rate decreased with an increased amount of supplement (57 vs. 53 bites/min). The mass of each bite of ration increased with the increased amount of supplement (6.5 vs. 7.6 g of DM/cow per day) but did not affect pasture bite mass (0.6 g of DM/cow per day). Increasing the amount of supplement increased the intake rate of ration (177 vs. 262 g of DM/min) but did not affect the intake rate of pasture (32 g of DM/cow per day). Increasing the amount of supplement resulted in an increased ration (6 vs. 12 kg of DM/cow per day) and total DMI (17 vs. 24 kg of DM/cow per day), but not pasture DMI (11 kg of DM/cow per day).

Season, defined as spring compared with autumn, also influenced feeding behavior and intake. The number of pasture prehensions was higher in spring compared with autumn (21,900 vs. 18,700 prehensions/cow per day), resulting in a higher total number of prehensions (23,600 vs. 20,000 prehensions/cow per day) in spring compared with autumn. However, the number

Table 2. Mean CV (%) of feeding behaviors and milk production for cows fed different pasture allowances and amounts of supplements during spring and autumn, with the range of each variable shown in parentheses[1]

	Low pasture allowance				High pasture allowance							
	Low amounts of supplement		High amounts of supplement		Low amounts of supplement		High amounts of supplement			*P*-value		
Item	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn	SED	Amounts of supplement	Pasture allowance	Season
Ration eating time	21.5 (20.4–54.8)	27.4 (19.8–46.9)	14.6 (35.7–59.2)	26.1 (28.0–68.5)	25.0 (19.5–51.5)	26.7 (19.2–52.0)	19.7 (36.1–94.9)	15.6 (37.6–72.4)	3.88	0.013	0.732	0.094
Pasture eating time	10.6 (302.8–438.1)	7.2 (338.4–473.2)	18.6 (217.8–450.4)	12.1 (354.6–532.1)	6.7 (275.0–499.4)	11.5 (313.8–443.9)	17.5 (246.2–441.0)	15.0 (242.4–417.5)	3.19	0.003	0.737	0.275
Ruminating time	16.9 (291.0–547.2)	20.6 (239.4–465.7)	10.5 (354.6–532.1)	15.2 (275.0–499.4)	12.7 (353.5–534.5)	14.7 (273.3–508.1)	16.8 (224.0–597.1)	14.4 (301.0–495.7)	3.98	0.347	0.577	0.348
No. of jaw movements	9.6 (44.2–62.1)	11.4 (37.2–54.0)	16.1 (39.1–68.7)	12.7 (28.2–49.7)	8.4 (48.7–69.2)	12.7 (36.0–59.8)	15.2 (41.6–72.2)	11.6 (34.1–53.8)	4.95	0.197	0.885	0.961
Milk yield	11.3 (21.3–40.7)	24.2 (9.2–18.5)	14.7 (25.7–44.5)	25.0 (14.9–28.1)	18.0 (25.5–42.8)	35.9 (4.7–26.1)	12.8 (33.3–48.1)	25.6 (9.6–31.9)	6.66	0.378	0.161	0.002
ECM	11.3 (21.7–38.0)	19.2 (9.8–18.7)	13.0 (23.5–43.4)	20.3 (14.8–27.3)	16.0 (23.4–41.1)	33.7 (4.7–23.1)	11.9 (31.1–42.0)	25.8 (10.1–27.6)	6.98	0.509	0.098	0.008
Fat	10.6 (3.0–4.3)	7.0 (3.9–4.9)	10.8 (3.1–4.6)	8.1 (3.8–4.8)	9.7 (3.1–4.3)	10.7 (3.0–4.6)	17.0 (2.7–4.3)	10.4 (3.0–4.3)	3.03	0.173	0.079	0.081
Protein	3.3 (2.8–3.2)	6.3 (3.3–3.9)	4.3 (3.0–3.4)	5.7 (3.2–4.0)	3.1 (3.0–3.4)	5.8 (3.3–3.8)	4.5 (3.1–3.5)	6.5 (3.0–4.0)	1.60	0.423	0.905	0.022

[1]No interactions were significant and therefore are not presented.

Table 3. Mean feeding behaviors and intakes of cows when fed different pasture allowances and amounts of supplements, while consuming ration (R) and pasture (P) during spring and autumn[1]

	Spring				Autumn							
	Low pasture allowance		High pasture allowance		Low pasture allowance		High pasture allowance			*P*-value		
Item	Low amount of supplement	High amount of supplement	Low amount of supplement	High amount of supplement	Low amount of supplement	High amount of supplement	Low amount of supplement	High amount of supplement	SED	Pasture allowance	Amount of supplement	Season
R eating time (min)	33	47	39	64	31	39	35	49	6.9	0.027	0.002	0.075
P eating time (min)	380	343	425	349	383	341	377	328	22.3	0.493	0.002	0.170
T eating time (min)	413	391	463	413	414	380	413	378	23.1	0.169	0.015	0.076
R eating bouts	2	2	2	2	2	2	2	2	0.1	0.579	0.494	0.132
P eating bouts	8	9	8	9	8	10	9	9	0.7	0.434	0.112	0.156
R eating bout duration (min)	15	22	18	30	16	19	16	24	3.0	0.026	0.001	0.103
P eating bout duration (min)	52	41	55	39	47	36	43	37	4.3	0.942	0.001	0.022
R eating prehensions	1,210	1,610	1,500	2,570	1,130	1,370	1,240	1,750	495.0	0.117	0.054	0.195
P eating prehensions	22,333	19,460	25,955	19,795	21,273	17,653	19,737	15,960	1630.8	0.829	0.001	0.004
T eating prehensions	23,539	21,074	27,456	22,363	22,400	19,024	20,847	17,711	1891.3	0.553	0.006	0.005
R eating mastications	1,189	1,907	986	1,690	994	1,514	1,024	1,843	255.1	0.908	<.001	0.458
P eating mastications	4,831	4,539	4,463	3,657	4,923	4,302	5,953	5,748	1051.2	0.576	0.387	0.141
T eating mastications	6,019	6,446	5,887	5,347	5,917	5,817	7,189	7,591	1204.1	0.472	0.940	0.276
R bite rate (bites/min)	37	34	38	40	37	34	34	35	5.9	0.647	0.849	0.528
P bite rate (bites/min)	59	56	61	56	55	52	52	48	2.6	0.487	0.021	0.002
R bite mass (g of DM/bite)	5.69	9.39	4.94	5.98	5.92	11.36	6.11	7.10	1.488	0.024	0.006	0.170
P bite mass (g of DM/bite)	0.42	0.49	0.53	0.70	0.43	0.50	0.76	1.02	0.129	0.002	0.058	0.056
R intake rate (g of DM/min)	192	291	138	211	198	305	181	242	24.2	0.002	<0.001	0.087
P intake rate (g of DM/min)	24	26	32	38	23	24	38	48	4.9	<0.001	0.083	0.237
R DMI (kg of DM/cow per day)	6.0	13.4	5.8	12.9	5.8	11.3	5.9	11.6	0.35	0.612	<0.001	0.001
P DMI (kg of DM/cow per day)	9.1	8.6	13.5	12.6	8.7	8.2	14.3	15.7	2.14	0.001	0.897	0.483
T DMI (kg of DM/cow per day)	15.1	22.0	19.3	25.5	14.5	19.5	20.2	27.2	2.01	0.001	<0.001	0.910
T ruminating time (min)	426	427	469	477	360	348	366	406	18.2	0.002	0.341	<0.001
T ruminating mastications	24,983	25,966	29,020	28,909	18,421	16,364	21,547	22,564	1965.4	0.003	0.967	<0.001
T ruminating boli	491	415	527	533	365	400	349	357	52.3	0.391	0.812	0.001
T ruminating bouts	16	15	15	15	14	14	14	13	1.1	0.261	0.342	0.015
T ruminating bout duration (min)	28	29	31	33	28	26	27	32	1.9	0.015	0.189	0.078
T boli per bout	31	28	35	36	28	29	25	27	3.7	0.360	0.857	0.018
T idling (min)	524	552	452	490	628	690	607	623	39.7	0.024	0.105	<0.001
T jaw movements	54,541	53,487	62,363	56,619	46,738	41,205	49,584	47,866	3084.7	0.011	0.052	<0.001

[1]Total (T) behaviors, the sum of R and P behaviors are also presented. No interactions were significant and therefore are not presented.

of prehensions when consuming ration were not different between seasons (1,500 prehensions/cow per day). The duration of pasture eating bouts decreased from spring (47 min/bout per cow·d) to autumn (41 min/bout per cow·d), as did the bite rate when consuming pasture (58 vs. 54 bites/min). Ration DMI decreased from spring (9.5 kg of DM/cow per day) compared with autumn (8.6 kg of DM/cow per day) but pasture (11.3 kg of DM/cow per day) and total DMI (20.4 kg of DM/cow per day) were not affected. Ruminating time decreased in from spring (450 min/cow per day) to autumn (370 min/cow per day), as did the number of ruminating mastications (27,220 vs. 19,724 ruminating mastications/cow per day), the number of boli (482 vs. 368 kg of DM/cow per day), the number of ruminating bouts (15 vs. 14 ruminating bouts/cow per day), and the number of boli per ruminating bout (33 vs. 27 boli/bout). Total not chewing time increased from spring (504 min/cow per day) compared with autumn (637 min/cow per day). The total number of jaw movements also decreased from spring to autumn (56,800 vs. 46,300 jaw movements/cow per day).

Feeding Behavior Patterns

Eating and ruminating patterns of cows fed the different dietary treatments are presented in Figure 1, demonstrating that following the consumption of PMR on the feed pad, the low pasture allowance had longer grazing bouts within the first 4 h of accessing

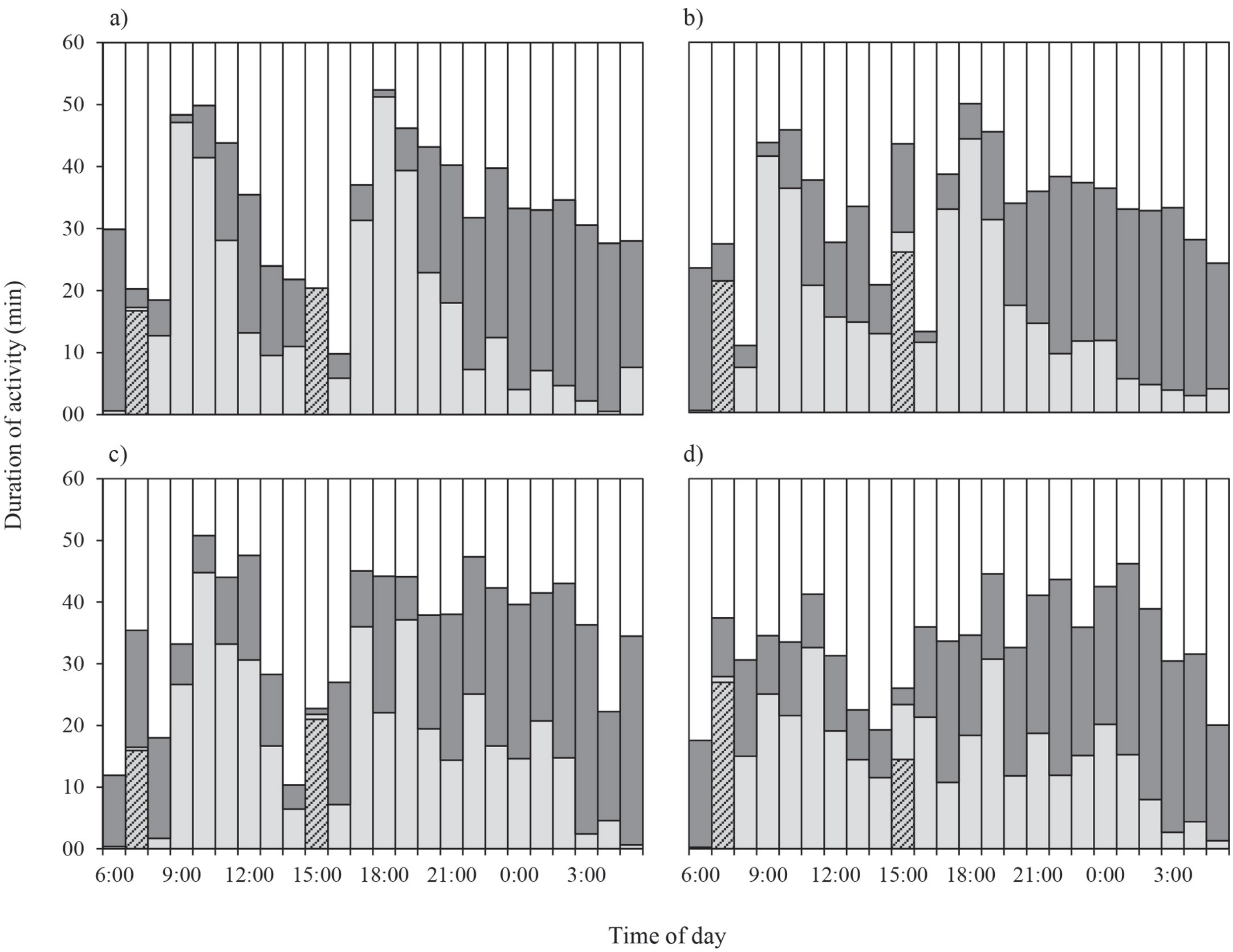

Figure 1. Feeding patterns of cows fed different pasture allowances and amounts of supplement, averaged across spring (early lactation) and autumn (late lactation): (a) low pasture allowance and low amount of supplement; (b) low pasture allowance and high amount of supplement; (c) high pasture allowance and low amount of supplement; and (d) high pasture allowance and high amount of supplement. Feeding activities are represented as eating ration (dashed bars); grazing (light gray bars); ruminating (dark gray bars); and idling (white bars).

the pasture. It is also evident from this figure that the combination of the high amount of supplement and the high allowance of pasture resulted in a reduced desire to graze when given access to pasture.

Milk Production

Mean milk, ECM, fat, and protein yields, and concentrations of milk fat and protein for cows on the 4 treatments are presented in Table 4. Yields of milk, ECM, fat, and protein increased when increased amounts of supplement were offered, whereas fat concentration was reduced. Yields of milk, ECM, and protein, and the concentration of milk protein increased when pasture allowance increased. On the other hand, the milk fat concentration decreased when more pasture was offered. Yields of milk, ECM, fat, and protein were reduced in autumn compared with spring (late vs. early lactation), whereas milk fat and protein concentrations were higher in autumn.

DISCUSSION

The major finding from the current experiments was that the variation among individual cows in terms of any feeding behavior and milk production variables was not influenced by pasture allowance. However, reducing the amount of supplements offered to grazing dairy cows resulted in increased variation among individual cows within groups in the time spent consuming ration on the feed pad. Interestingly, the variation among individual cows in terms of time spent consuming pasture approximately doubled when the amount of supplement increased, evident in Figure 2. DeVries et al. (2003) reported that whereas some measures of feeding behavior are highly repeatable within cows, significant variation among cows is present. Though variation in feeding behavior among cows has been previously demonstrated, this research is limited with feeding behavior research primarily reporting group means (DeVries and von Keyserlingk, 2005). Previous research by Auldist et al. (2013) reported improvements to milk production when cows were fed a corn-based PMR compared with the same metabolizable energy provided as barley grain in the dairy and forage in the paddock, which were only apparent when feeding over 10 kg of DM supplement/cow per day. Based on the current experiments, farmers should use strategies to reduce the variation among grazing cows when feeding over 10 kg of DM supplement/cow per day. It is probable that the cows fed the increased amount of supplement had less uniform pasture residual sward heights that subsequently increased the variability in pasture eating time. The variation among individual cows in terms of feeding

Table 4. Mean daily yields of milk and ECM, and concentrations and yields of milk protein and fat, for cows fed different pasture allowances and amounts of supplement during spring and autumn[1]

Item	Low pasture allowance				High pasture allowance				SED	*P*-value		
	Low amount of supplement		High amount of supplement		Low amount of supplement		High amount of supplement					
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn		Amount of supplement	Pasture allowance	Season
Milk yield (kg of DM/cow per day)	30.2	14.4	36.6	19.3	34.7	16.8	39.8	20.9	1.21	<0.001	0.002	<0.001
ECM (kg of DM/cow per day)	28.6	15.2	34.8	20.0	33.2	17.1	36.8	20.6	1.51	<0.001	0.013	<0.001
Fat (%)	3.74	4.39	3.69	4.15	3.71	4.03	3.41	3.72	0.137	0.011	0.02	<0.001
Protein (%)	2.98	3.57	3.10	3.56	3.21	3.60	3.27	3.59	0.039	0.057	<0.001	<0.001
Fat (kg of DM/cow per day)	1.13	0.62	1.35	0.80	1.29	0.67	1.34	0.77	0.068	0.004	0.187	<0.001
Protein (kg of DM/cow per day)	0.90	0.51	1.14	0.69	1.11	0.60	1.30	0.74	0.050	<0.001	<0.001	<0.001

[1]No interactions were significant and therefore are not presented.

behavior may be a result of several factors, as cows use a range of feeding behavior strategies to achieve their desired level of intake, which are influenced by social interactions and physiological mechanisms (Friggens et al., 1998).

Future research is required to investigate if among cow variation is apparent in terms of individual DMI. Due to limitations with measuring individual DMI within this feeding system, individual measurements of DMI were not conducted and instead DMI was determined using group means. Previous research has indicated that DMI can be calculated using feeding behavior variables, as feed intake is a product of bite rate, bite mass, and total eating time (Gibb et al., 1997). However, it is sensible to think of feeding behavior as a means of explaining observed effects on intake not as a means of estimating intake itself (Hodgson, 1982). Hills et al. (2015) stated that factors such as pasture eating time, bite rate, and bite mass are behavioral proxies for the balance between the physiological factors regulating hunger and satiety. Therefore, a method of estimating individual DMI in the PMR feeding system is required to determine the variation among individual cows.

In the current experiments, it was found that pasture allowance did not affect pasture eating time therefore, the first part of the second hypothesis was rejected. But despite this, average pasture DMI increased with the increased pasture allowance. This increase in pasture DMI was a result of increased average pasture intake rate and bite mass, thus supporting the second part of the second hypothesis.

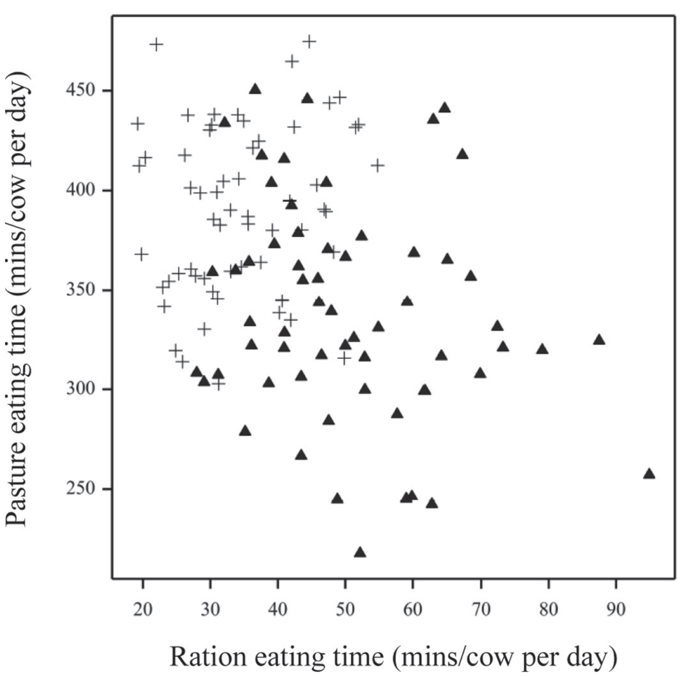

Figure 2. Relationship between ration eating time and pasture eating time when cows were fed either a low amount of supplement (+) or a high amount of supplement (▲).

Grazing activity is a process that continually modifies the sward, influencing both intake rate and bite mass. In turn these variables are determined by pasture characteristics (Barrett et al., 2001). Cows offered the low pasture allowance presumably decreased the sward surface height of the pasture earlier than the high pasture allowance treatment, and as a consequence, prehending pasture became difficult, resulting in both pasture allowance treatments consuming the pasture in comparable amounts of time. It was also found that altering pasture allowance influenced feeding behavior when cows were consuming the ration, which is a novel finding. When cows were offered more pasture they spent more time consuming the ration by reducing their feeding intensity primarily by reducing bite mass and intake rate. This finding has important potential implications for the dairy industry, as increasing pasture allowance in combination with large amounts of supplements could result in the mitigation of any inefficiencies in rumen fermentation, previously shown when large amounts of grain-based supplements are ingested quickly (Dixon and Stockdale, 1999; Wales et al., 2000). However, more research is required to investigate the effect of this finding on substitution rate and subsequent effect on profitability. As previously mentioned, bite mass and intake rate were derived from group average DMI per cow and individual cow behaviors. Additional research is required to determine individual DMI to further investigate this finding.

The increased pasture allowance also resulted in more constant grazing and ruminating over the day (Figure 1), presumably as a result of increased rumen fill causing a reduced desire to eat. The more variable grazing pattern of the low pasture allowance may be a result of reduced pasture availability and, as previously mentioned, increased difficulty prehending pasture. The increased pasture allowance also had an increased number of total jaw movements, ruminating mastications, ruminating bouts, and ruminating time, as a result of the increased pasture DMI. This increase in ruminating time by 42 min/cow per day, with the increased pasture allowance, altered the time-budgets of these cows considerably, contributing to a 56 min/cow per day reduction in total idling time. Most research investigating pasture allowance has been conducted in pasture-only feeding systems and primarily excludes details of feeding behaviors; if feeding behaviors are described, results are often not definitive. Moate et al. (1999) reported that increasing pasture allowance from 20 to 40 kg of DM/cow per day resulted in a 1 h/cow per day increase in pasture eating time. Wales et al. (1999) found pasture eating time increased by an average of 66 min/cow per day when perennial ryegrass pasture allowance increased from ~20 to 35 kg of DM/cow per day with no further significant increases when pasture allowance increased to ~70 kg of DM/cow per day. Consistent with the current experiments, Bargo et al. (2002a) reported that increasing pasture allowance from 27 to 49 kg of DM/cow per day had no effect on pasture eating time, total number of bites, bite rate, bite mass, or ruminating time. Bargo et al. (2002a) also reported a comparable increase in pasture intake of 1.8 kg of DM/cow per day, which translated into an increase in milk yield. The current experiments also found that increasing pasture allowance increased the yield of milk, ECM, and protein and milk protein concentrations, but reduced milk fat concentrations, presumably a result of increased total DMI.

These experiments clearly demonstrated a reduction in pasture eating time with the increased amount of supplement in a PMR feeding system, thus supporting the third hypothesis. Pasture eating time reduced by 8.5 min/cow per day for each kilogram of supplement consumed. Feeding behavior research is limited in PMR feeding systems, with only 2 known published papers in this area (Bargo et al., 2002b; Hetti Arachchige et al., 2013). In one study, Hetti Arachchige et al. (2013) found a 54-min reduction in pasture eating time when cows were fed 14 kg of DM of supplement/cow per day compared with 8 kg of DM of supplement/cow per day, when consuming either grain in the dairy during milking and forage in the paddock or the same dietary components fed as a PMR. However, this was only tested at a restricted pasture allowance of 14 kg of DM/cow per day (Hetti Arachchige et al., 2013). In the current experiments, pasture eating time decreased by 41 min/cow per day with the low pasture allowance and 63 min/cow per day with the high pasture allowance, when supplement amount increased from low to high. Bargo et al. (2002a) reported a reduction in pasture eating time of 75 and 104 min/cow per day at a low (27 kg of DM/cow per day) and high pasture allowance (49 kg of DM /cow per day), respectively, when cows were fed 7.9 kg of concentrate DM/cow per day.

In the current experiments, the reduction in pasture eating time with the increased amount of supplement did not result in a corresponding reduction in pasture DMI. The absence of a corresponding reduction in pasture DMI was a result of reductions in grazing intensity when increased amounts of supplements were offered. This was evident as a reduction in the number of bites, bite rate, and bout duration while cows were consuming pasture. No difference was found in pasture bite mass and intake rate between the low and high amounts of supplement. Grazing intensity was reduced when the amount of supplement increased but the intensity of PMR consumption increased, evident in an increased PMR intake rate and bite mass, determined using group DMI per cow and individual feeding behaviors. No difference was observed in ruminating time between groups of cows fed low and high amounts of supplements, this being a result of comparable pasture intakes. The absence of a corresponding reduction in pasture DMI with increased amount of supplement enabled positive milk production responses, in particular milk, ECM, fat and protein yields for the cows on the high supplement treatments (although a reduction occurred in milk fat concentration). Thus, the provision of additional supplements in the PMR feeding system reduced pasture eating time with no resultant reductions in pasture intake due to an increase in grazing intensity, therefore enabling an increase in milk production.

We recognize that season was confounded by stage of lactation. Pasture allowances and amounts of supplement were different between seasons, as a result of expected differences in milk production at different stages of lactation. However, whereas season is confounded by stage of lactation, the data were representative of a rotational grazing system with a spring calving herd.

CONCLUSIONS

These experiments showed that increasing the amount of PMR offered to grazing cows alters feeding behavior and reduces pasture eating time, without affecting pasture DMI. Increasing pasture allowance did not affect pasture eating time but increased grazing intensity and pasture intake. Increasing pasture allowance resulted in slower consumption of PMR via reduced bite mass and intake rate. Assuming substitution rate can be controlled, it is proposed that the provision of large amounts of supplements should be combined with increased pasture allowances to slow down the consumption of large amounts of supplements and potentially mitigate adverse effects on rumen function. To reduce the variability among cows in feeding behavior, the management of supplementary feeding needs to be considered, as pasture allowance did not affect this variability. However, other pasture characteristics including pasture mass and height need investigation. This research has broad implications for the dairy industry as it provides a basis for optimizing supplementary feeding to reduce the variation among cows, within herds. A uniform group of cows with minimal variation in feeding behavior and milk production may assist in accurate ration formulation with the potential to promote milk production and reduce nutrient excretion, potentially minimizing the effect on the environment and land use (St-Pierre and Thraen, 1999). Future research is required to investigate the variation among individual cow DMI in PMR feeding systems.

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