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Productive response to two concentrate allocation strategies in dairy cows grazing with restricted pasture allowance

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Abstract: The objective of this study was to compare the effects of two concentrate allotment strategies on the performance of dairy cows grazing on restricted pasture and supplemented with conserved forage. Dairy cows fed equal amounts of concentrate (fixed daily rate: 5.5 kg DM/cow) were compared to cows supplemented with concentrate according to their lactation stage as follows: 10.0, 5.0, and 1.5 kg DM/cow daily during early, mid, and late lactation, respectively (average daily dose: 5.5 kg DM/cow). There was a supplementation strategy × lactation stage interaction ($P < 0.05$) for energy-corrected milk (ECM). For early lactation cows, supplementation at a variable rate increased ECM yield by 14.61% ($P < 0.05$). There was a supplementation strategy × lactation stage interaction ($P < 0.05$) for body weight change. At late lactation stage, cows supplemented at a fixed rate gained weight (+ 0.16 kg/day), whereas those supplemented at a variable rate lost weight (– 0.08 kg/day; $P < 0.05$). No significant effect was found for body condition score. The prioritization of milk production rather than the attenuation of body reserve mobilization suggests that concentrate allowance based on lactation stage may be unsuitable for minimizing the negative energy balance in early lactation cows.

Key words: Dairy cattle, grazing, energy balance, lactation stage

1. Introduction

Argentina is ranked in the top 10 largest cow milk-producing countries in the world, with 1.71 million dairy cows and production of 10.19 billion liters per year (1). It is important to point out that the national dairy cow inventory has remained relatively stable since 2008. The Argentine government has proposed to increase cow milk production up to 18.30 billion liters by 2020, which represents an 80% increase from the current production. In order to achieve this ambitious goal, it is required to adopt management strategies for increasing both milk yield and cow number.

Meeting nutrient requirements of dairy cows by optimal concentrate supplementation, relative to days in milk (DIM), is needed for maximizing milk production (2) while minimizing negative energy balance (3) and preventing health-related welfare issues (4) associated with premature exiting of cows from dairy herds. Furthermore, concentrate feed represents a major proportion of the feeding cost for dairy herds. Therefore, the optimization of concentrate supply, according to lactation stage, should also help farmers to improve business profitability (5).

In Argentinean dairy farms, concentrate feeding at a fixed rate (i.e. regardless of the stage of lactation) is the most common supplementation strategy for cows that often graze with restricted pasture allowances. Because of simplicity, concentrate supplementation at a fixed rate is more attractive for farmers (6). However, for cows with higher potential for production, particularly in early lactation, the above-mentioned feeding strategy may adversely affect their lactation performance.

In view of this, the main aim of this study was to assess the milk yield and composition, dry matter intake (DMI), body condition score (BCS), and bodyweight (BW) change of dairy cows supplemented with corn-based concentrate according to their stage of lactation as compared with cows fed on a herd basis.

2. Materials and methods

2.1. Experimental site, animals, and treatments

The trial was conducted in the research dairy herd of the National Institute of Agricultural Technology, located in Rafaela, province of Santa Fe, Argentina (31°12′S,

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61°30′W). Forty-two multiparous Argentinean Holstein dairy cows (milk yield 28.6 ± 13.25 kg/day; DIM 242 ± 164 days; parity 3 ± 1.2; bodyweight 690 ± 81 kg; mean ± SD) were used in this study. All cows were equipped with neck transponders that served both to record daily milk production and allocate concentrate on an individual basis in the milking parlor (ALPRO version 6.60/DeLaval, Tumba, Sweden). Cows were milked twice daily starting at approximately 0500 and 1530 hours. Animals had free access to drinking water. The experiment lasted 57 days and was conducted in spring between October and December 2013. Before the beginning of the study, cows were acclimated to the feeding management for 7 days. During the adaptation period, a mid-lactation cow was excluded because of a hoof lesion unrelated to the experiment.

Cows were first categorized into lactation stages. For the purpose of this study, lactation stages were stated as follows: early (64–85 DIM), mid (161–231 DIM), and late (306–590 DIM) lactation. For each lactation stage (n = 14), cows were paired on the basis of milk yield, DIM, and

Table 1. Effects of two rates of concentrate supplementation (fixed and variable) on feed intake and waste, eating rate, and sorting behavior of dairy cows

Item	Supplementation strategy (SS)				P-value
	Fixed rate		Variable rate		
	Mean	SE	Mean	SE	SS
Concentrate supply (kg/cow daily)[1]					
Early lactation	5.5	0.00	10.00	0.00	-
Mid lactation	5.5	0.00	5.00	0.00	-
Late lactation	5.5	0.00	1.50	0.00	-
Average dose	5.5	0.00	5.5	0.8	-
Conserved forage[2]					
Daily delivery (kg DM/cow)	8.99	0.11	8.99	0.11	1.00
Daily disappearance (kg DM/cow)[3]	8.95	0.12	8.95	0.13	0.97
Daily waste (kg DM/cow)[4]	0.61	0.07	0.86	0.11	0.15
Waste (%)[5]	6.88	0.89	9.65	1.39	0.17
Daily DMI (kg/cow)[6]	8.34	0.17	8.08	0.18	0.38
Average eating rate, (g DM/min)[7]	69.47	1.42	67.33	1.65	0.38
Sorting index, as-fed basis[8]					
>19.0 mm	90.67	2.81	91.29	3.07	0.88
19.0 to 8.0 mm	102.60	0.77	102.70	0.47	0.92
<8.0 mm	101.60	0.75	100.50	0.69	0.37
Pasture[9]					
Daily DMI (kg/cow)	9.07	0.57	9.25	0.88	0.57

[1]Corn- based concentrate pellets were split into two equal amounts allocated in the milking parlor during milking.
[2]Cows on pasture were also fed a mixture of conserved forages including 82% whole plant corn (*Zea mays*) silage and 18% chopped alfalfa (*Medicago sativa*) hay, on DM basis.
[3]Conserved forage fed less residuary (feed remaining in the feeder) at the end of a 2-h period.
[4]Conserved forage thrown out of the sides of the feed bunk during the 2-h period.
[5]Conserved forage waste as a percentage of conserved forage disappearance.
[6]DMI = dry matter intake (conserved forage disappearance less conserved forage waste).
[7]Calculated as daily conserved forage DMI divided by feeding time (2 h/day).
[8]A sorting index value of <100% indicates sorting against particles (selective refusal), a sorting index value of >100% particles (preferential consumption) indicates sorting for, and a sorting index value of 100% indicates no sorting (13).
[9]Cows grazed a pasture composed of 77% alfalfa (*Medicago sativa*) and 23% prairie grass (*Bromus catharticus*), on DM basis.

parity. Within each pair, cows were randomly assigned to one of the two concentrate allocation strategies (fixed vs. variable rate; Table 1) on an individual basis.

The average of milk production by lactation stage was used to determine the concentrate dose for the cows allotted to a variable rate of supplementation with regard to their lactation stage. According to the National Research Council (7) dairy cattle nutrient requirements, the daily concentrate dose was as follows: 10.00, 5.00, and 1.50 kg DM/cow (average dose: 5.50 kg DM/cow) for cows in early, mid, and late lactation, respectively. For concentrate allocation at a fixed rate, cows were fed on a herd basis and hence they were daily supplied with 5.50 kg DM/cow (i.e. the average concentrate dose, as defined above). For both allocation strategies, the concentrate doses were maintained constant during the entire experiment (Table 1). On DM basis, concentrate pellets were composed of corn grain (70%), soybean expeller (20%), and wheat bran (8%) and the remaining by minerals and vitamins. The daily dose of corn-based concentrate was split into two equal amounts individually allocated in the milking parlor during the milking process.

In addition, all experimental cows were group-fed a diet comprising grazed pasture supplemented with a mixture of conserved forages. The botanical composition of the pasture was 77% (±21%) alfalfa (*Medicago sativa*) and 23% (±21%) prairie grass (*Bromus willdenowii*) on DM basis. The experimental grazing area consisted of 12 ha. Pasture was managed on a daily rotational grazing system with an electric fence. Cattle had access to a new pasture strip every day after morning milking (0600 hours). For each cow, the daily pasture allowance was 13 kg DM. To achieve the targeted pasture allowance, pregrazing herbage mass was measured at 4 cm above ground level once weekly to adjust the size of the daily strip to control the quantity of pasture offered. On DM basis, the mixture of conserved forages (henceforth referred to as conserved forage) included 82% whole plant corn (*Zea mays*) silage (WPCS) and 18% coarsely chopped alfalfa hay. Whole corn plants were harvested as silage with a forage harvester equipped with a 6-row corn head and a kernel processor. For each cow, the daily conserved forage allotment was about 9.00 kg DM. Conserved forage was delivered at 0800 hours in feed bunks located in a laneway, along the electric fence line. Feed bunks provided 1 m of linear space per animal. Conserved forage was offered for a 2-h period, starting from the precise moment that consumption began. On rainy days, conserved forage was offered on a feed-pad for 2 h after morning milking. Thereafter, cows were allowed to graze.

2.2. Feed intake measurements

On an individual basis, the DMI of concentrate was measured daily by the difference between the amount offered and the amount refused. For pasture and conserved forage, DMI was measured 3 times on consecutive days (21–24 November 2013). For this particular assessment, both cow groups according to their concentrate allocation strategy (i.e. fixed and variable rate) were assigned to different pasture strips and feed bunks. However, because the cows within each treatment could not be divided by lactation stage, the treatment effect on DMI with regard to lactation stage was not determined.

On each paddock, pasture DMI was estimated for each treatment by the difference between pre- and postgrazing pasture mass according to the method described by Gallardo et al. (8).

To facilitate the collection of conserved forage tossed out of the feed bunk by cattle, a plastic fabric (1 m wide) was placed around the perimeter of the rectangular troughs during the measuring period. To avoid contamination with manure and urine, and to be successful in collecting all the feed that fell on the plastic fabric, conserved forage was immediately collected after completing the 2-h eating period. Daily feed disappearance was calculated as the amount of conserved forage delivered, less the residual amount of feed remaining in the feed bunk at the end of a 2-h period. The total amount of conserved forage recovered daily from the plastic fabric surrounding the feed bunk was considered feed waste. Expressed as a percentage, feed waste was obtained by dividing the amount of waste by the feed disappearance. Conserved forage intake was estimated as the difference between conserved forage disappearance and conserved forage waste (9). The average eating rate (g DM/min) was calculated according to DeVries et al. (10). For grazed pasture and conserved forage, group DMI was divided by the number of cows in each treatment group on the measurement day to provide average cow intake (11). From now on, DMI is expressed on a per cow basis.

2.3. Feed sampling and analysis

Feed samples of concentrate pellets (n = 2), WPCS (n = 3), pasture (n = 4), and alfalfa hay (n = 2) were taken for chemical analysis throughout the experiment (Table 2). Pasture was sampled by hand-plucking method. Furthermore, samples of conserved forage (n = 3) were taken for neutral detergent fiber (NDF) analysis every day of the DMI assessment. For chemical composition, feed samples were dried in a forced-air oven at 65 °C until constant weight to determine DM content. Samples were then ground in a Wiley Mill (Arthur H. Thomas, Philadelphia, PA, USA) to pass through a 1-mm screen and analyzed for NDF (aNDF: assayed with sodium sulfite with heat-stable alpha amylase and expressed inclusive of residual ash), acid detergent fibre (ADF: expressed inclusive of residual ash), ether extract (EE), acid detergent lignin (ADL), total nitrogen (Kjeldahl method), crude protein (CP: total nitrogen × 6.25), and ash (12). Nonfibrous carbohydrates (NFCs) were calculated using the following equation: 100 – (% aNDF + % CP + % EE +

Table 2. Chemical composition of the experimental diet ingredients

Item[1]	Chemical composition, mean ± SD			
	Concentrate[2]	WPCS[3]	Pasture[4]	Alfalfa hay
	(n = 2)	(n= 3)	(n= 4)	(n= 2)
DM (% as-fed)	91.19 ± 1.08	38.64 ± 2.88	20.66 ± 1.39	82.34 ± 7.60
CP (% DM)	17.05 ± 1.21	8.15 ± 0.16	30.91 ± 9.53	17.11 ± 5.53
NDF (% DM)	19.73 ± 3.72	32.13 ± 4.26	25.36 ± 7.90	59.88 ± 9.33
$peNDF_{>8}$ (% DM)[5]	n.d.[6]	24.91 ± 3.30	n.d.	n.d.
ADF (% DM)	9.72 ± 1.94	18.85 ± 4.97	16.13 ± 4.30	36.82 ± 6.58
NFC (% DM)[7]	52.63 ± 1.82	48.16 ± 4.11	30.85 ± 7.55	11.66 ± 2.69
ADL (% DM)	0.50 ± 0.12	1.64 ± 1.40	2.80 ± 0.83	7.18 ± 1.72
EE (% DM)	4.78 ± 1.30	5.06 ± 0.49	3.06 ± 1.46	1.37 ± 0.60
Ash (% DM)	5.82 ± 0.62	6.50 ± 0.54	9.83 ± 0.51	9.99 ± 0.51
NE_L (Mcal/Kg DM)[8]	1.86 ± 0.08	1.67 ± 0.05	1.64 ± 0.12	1.13 ± 0.14

[1]DM, dry matter; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin and EE, ether extract.
[2]Commercial concentrate pellets composed, on DM basis, of corn grain (70%), soybean expeller (20%), and wheat bran (8%) and the remaining of minerals and vitamins.
[3]WPCS = whole plant corn silage.
[4]Pasture comprised 77% alfalfa (*Medicago sativa*) and 23% prairie grass (*Bromus catharticus*), on DM basis.
[5]$peNDF_{>8}$: physically effective NDF >8 mm, measured as the NDF content of the WPCS (DM basis) multiplied by proportion of particles retained on 19- and 8-mm sieves of the Penn State Particle Separator (10).
[6]n.d. = not determined.
[7]NFC: nonfibrous carbohydrates, determined by the following equation: 100 – (% NDF + % CP + % EE + % ash) (7).
[8]NE_L= net energy for lactation calculated based on National Research Council (7).

% ash) (7). Net energy for lactation (NE_L) was estimated from total digestible nutrients by equations of the National Research Council (7).

The samples of WPCS were also sieved and separated by size using the 2-screen (19- and 8-mm) Penn State Particle Separator (PSPS). In order to assess the extent of sorting activity, conserved forage (offered and orts) was sampled for particle-size separation each day of the DMI assessment. For this trial, orts included both the waste and the residual (as defined above) from the conserved forage delivered. Sorting activity was calculated as the ratio of actual intake to expected intake for particles retained on each sieve of the PSPS. A sorting index value of <100% indicates sorting against particles (selective refusal), >100% indicates sorting for particles (preferential consumption), and =100% indicates no sorting (13). For both WPCS and conserved forage samples, physical effective aNDF of >8 mm ($peNDF_{>8}$) was determined as the proportion of particles (DM basis) retained on the 19-mm and 8-mm screens of the PSPS, multiplied by the aNDF content of the feed (14).

2.4. Animal measurements and milk sample analysis

Milk yield of every cow was recorded daily with the DeLaval ALPRO milk metering system (DeLaval International AB, Tumba, Sweden). Individual milk samples for milk composition were taken fortnightly at consecutive morning and afternoon milkings by using milk meters. Individual morning and afternoon milk samples were composited before analyzing for content of fat, total protein, lactose, total solids, solids-nonfat (SNF), and milk urea nitrogen (MUN) by infrared spectrophotometry (MilkoScan Minor; FOSS Electric, Hillerød, Denmark). Samples were also used for determination of somatic cell count (SCC) by flow cytometry (Fossmatic 5000; FOSS Electric, Hillerød, Denmark). By the formula of Gaines and Davidson (15), milk production was adjusted to 4% of fat content, fat-corrected milk (FCM). Energy-corrected milk (ECM), standardized to 4% fat and 3.3% true protein, was calculated by the NRC equation (7). Milk true protein was also estimated by the NRC method (7). Cows were weighed biweekly with an electronic scale, which was calibrated before weighing. Concurrently, BCS was recorded by a single evaluator using a scoring system based on a five-point scale.

2.5. Statistical analysis

Treatments are the combination of two factors, lactation stage and supplementation strategy. To make sure that pasture allowance, chemical quality, and botanical composition were equal for all experimental treatments, cows were pastured as one herd (except for DMI assessment). This allowed using cows as replicates (16) for the statistical analysis of milk production and composition, SCC, BCS, and BW. SCC and BCS values were not normally distributed. Therefore, data were transformed to $\log_{10}$. Data were analyzed as a completely randomized design in a 3 × 2 factorial arrangement (3 lactation stages and 2 strategies for concentrate feeding) with repeated measurements by ANOVA using the PROC MIXED procedure of SAS (17). For each variable analyzed, the covariate was included in the statistical model. Data collected during the adaptation phase to feeding management were used as covariate.

Differences among means were assessed with the least significant difference test. BW change was analyzed using the same model but without including covariance or repeated measures. The data were analyzed using ANOVA (PROC GLM, 17). For the variables associated with DMI, the group of cows was used as the experimental unit. Hence, the lactation stage was not included as a factor in the statistical analysis. For each treatment (2 supplementation strategies), three observations were recorded. The difference between means was assessed by t-test analysis (PROC TTEST, 17). Unless otherwise stated, data are reported as mean ± standard error (SE). A 5% significance level was used.

3. Results

The chemical composition of the feeds used in this trial is presented in Table 2. WPCS had lower aNDF and $peNDF_{>8}$ content than the conserved forage (37.83 ± 6.97 and 28.17 ± 5.35% DM, respectively; data not shown). Estimated values for feed intake measurements are shown in Table 1. The amount of concentrate offered was entirely eaten. The average daily amount of concentrate provided per cow was equal within each concentrate allocation strategy. The disappearance and the waste of conserved forage were not different ($P > 0.10$) between treatments. Conserved forage waste, as a percentage of conserved forage disappearance, was unchanged ($P > 0.05$) across treatments; corresponding mean values ranged from 6.88% to 9.65% for concentrate allocation at a fixed and variable rate, respectively. In addition, conserved forage and pasture DMI did not differ ($P > 0.05$) between treatments and averaged 8.21 and 9.16 kg/cow daily, respectively. For conserved forage, no differences ($P > 0.10$) were found in the eating rate, which averaged 68.40 g DM/min, or the sorting index between treatments. Overall, cow groups sorted against long particles (>19 mm) and preferred medium (<19 mm, >8 mm) over short (<8 mm) ones.

Effects of two rates of concentrate supplementation on milk production and composition, BW, and BCS of dairy cows at various stages of lactation are shown in Table 3. Concentrate supplementation at a variable rate increased FCM 7.15% ($P < 0.05$; 22.10 vs. 23.68 kg/day) but changes in ECM ($P > 0.05$) were not observed. However, there was a supplementation strategy × lactation stage interaction ($P < 0.05$) for FCM and ECM. For early lactation cows, supplementation at a variable rate increased both ECM yield by 14.61% ($P < 0.05$; 27.79 vs. 31.85 kg/day; Figure) and FCM yield by 15.47% ($P < 0.05$; 28.63 vs. 33.06 kg/day; data not shown). For both concentrate feeding strategies, no significant differences were found for milk content of fat, total protein, true protein, total solids, SNF, and MUN. Milk lactose content was higher ($P < 0.05$) in cows supplemented at a fixed rate (4.69 vs. 4.61%). However, as a supplementation strategy × lactation stage interaction was detected ($P < 0.05$), it was analyzed. For late lactation cows, supplementation at a fixed rate increased milk lactose content 4.80% ($P < 0.05$; 4.54 vs. 4.76%; data not shown). Milk fat yield was 7.00% greater in cows supplemented at a variable rate ($P < 0.05$; 0.85 vs. 0.91 kg/day), with a supplementation strategy × lactation stage interaction ($P < 0.05$). Upon analysis of the interaction, at the early lactation stage, milk fat yield increased 17.40% in those cows supplemented at a variable rate ($P < 0.05$; 1.09 vs. 1.28 kg/day; data not shown). No significant effects were found for milk total protein yield and SCC.

There was a supplementation strategy × lactation stage interaction ($P < 0.05$) for both BW and BW change. The interaction for BW change was analyzed (Figure). At late lactation stage, cows supplemented at a fixed rate gained weight (+ 0.16 kg/day), whereas those supplemented at a variable rate lost weight (– 0.08 kg/day; $P < 0.05$). For BCS analysis, the only significant effect was lactation stage. As a result, BCS for cows in late (3.38) and mid (3.18) lactation was significantly higher than that for cows in early lactation (3.02; data not shown).

4. Discussion

Under a daily rotational grazing management, dairy cows are usually assigned to restricted pasture allowance. In practice, to increase DMI and consequently to also raise milk production, grazing cows are supplemented with both grain-based concentrates fed twice daily in the milking parlor and conserved forages provided either under an electric wire fence in the grazing area or in feed bunks located at the laneway. However, regardless of their lactation stage, cows are commonly supplemented with the same amount of concentrate feed. Nowadays, computer-controlled feeders allow allocating concentrate in the milking parlor according to the requirements of each cow

Table 3. Effects of two rates of concentrate supplementation (fixed and variable) on milk production and composition, SCC, BW, and BCS of dairy cows at different lactation stages.

Item	Supplementation strategy (SS)				P-value			
	Fixed rate (n = 21)		Variable rate (n = 20)					
	Mean	SE	Mean	SE	SS	LS[1]	SS x LS	Covariable
Milk yield (kg/cow daily)								
4% FCM[2]	22.10	0.67	23.68	0.68	0.040	<0.001	0.034	0.001
ECM[3]	21.94	0.64	23.35	0.65	0.061	<0.001	0.046	<0.001
Milk composition (%)								
Fat	3.76	0.09	3.81	0.09	0.670	0.284	0.714	<0.001
Total protein (TP)	3.41	0.04	3.37	0.04	0.386	0.050	0.139	<0.001
True protein	3.17	0.03	3.14	0.03	0.403	0.051	0.148	<0.001
Lactose	4.69	0.03	4.61	0.03	0.037	0.318	0.039	<0.001
Total solid	12.70	0.14	12.61	0.14	0.575	0.124	0.599	<0.001
SNF[4]	8.95	0.06	8.85	0.06	0.171	0.042	0.141	<0.001
MUN[5] (mg/dl)	13.92	0.28	13.50	0.28	0.316	0.248	0.277	<0.001
Milk component yield (kg/day)								
Fat	0.85	0.03	0.91	0.03	0.048	< 0.001	0.046	<0.001
TP	0.77	0.02	0.81	0.02	0.156	0.001	0.132	<0.001
SCC[6]	5.43	0.07	5.42	0.07	0.919	0.163	0.087	<0.001
Bodyweight (BW; kg/cow)	687.51	1.87	682.50	1.92	0.070	<0.001	<0.001	<0.001
BW change (kg/cow daily)	−0.16	0.05	−0.25	0.05	0.106	<0.001	0.012	-
BCS[7]	0.50	0.01	0.50	0.01	0.944	0.046	0.689	<0.001

[1]LS = lactational stages, categorized into early, mid, and late lactation.
[2]FCM = fat-corrected milk.
[3]ECM = energy-corrected milk.
[4]SNF = solids-notfat.
[5]MUN = milk urea nitrogen.
[6]SCC = somatic cell count, expressed as log10 (SCC/1000).
[7]BCS = body condition score (1 to 5), expressed as log10.

in the herd. Taking advantage of this technology, the aim of this study was to compare the effects of two concentrate supplementation strategies, namely fixed and variable rates, on the performance of dairy cows at different stages of lactation grazing restricted pasture and supplemented with conserved forage.

Based on published evidence, Hills et al. (18) concluded that there is not enough information to support any productive advantage of allocating a larger amount of concentrate in early lactation than in mid and late lactation (i.e. variable rate) compared with supplementing the same amount of concentrate daily along lactation (i.e. fixed rate), when forage is offered ad libitum. In addition, these authors heightened the need to compare both concentrate allocation strategies in restricted pasture-based feeding systems. Under the experimental conditions of this study, concentrate allotment at a variable rate was able to significantly improve ECM yield (14.61%) of early lactation cows grazing restricted pasture. Among other factors (19), milk yield response to concentrate supplement is dependent on the physiological status of dairy cows according to their stage of lactation (20). In this regard, the present study showed that supplementation of late lactation cows with concentrate at a fixed rate did not increase milk production despite the fact that they were supplied daily with a higher amount of concentrate than late lactation cows allocated to a variable rate. Because concentrate allotment to mid lactation cows was similar for both feeding regimens, the potential benefits of these supplementation strategies on cow performance could not be determined.

Across lactation stages, milk fat concentration was not affected by the concentrate allocation schemes used in this study. This result is consistent with Rakes and Davenport

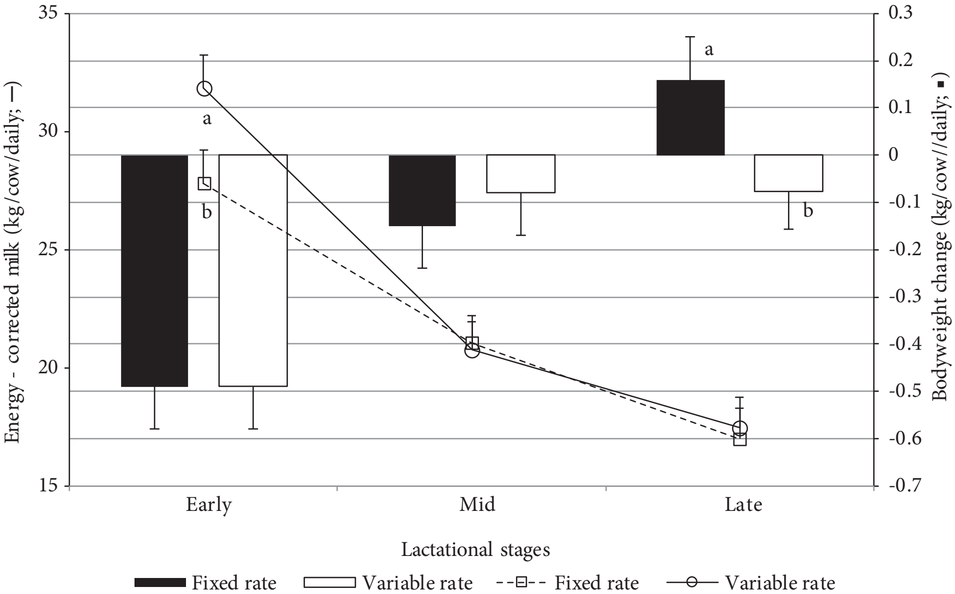

Figure. Effects of two rates of concentrate supplementation (fixed and variable) on milk production and bodyweight change of dairy cows at various lactation stages. There was a treatment × lactation stage interaction ($P < 0.05$) for both variables. For each one, means in the same lactation stage with different letters (a and b) differ ($P < 0.05$) between treatments.

(21), who reported no significant difference in milk fat concentration for cows fed concentrate supplement according to their lactation stage, as compared to cows fed equal amounts of concentrate each day during the course of lactation. However, for the current study, early lactation cows fed at variable rate produced more milk fat because of their significantly higher milk yield. In contrast to our results, it has been shown that concentrate allowance at a fixed rate lowered milk protein concentration relative to supplementation at a variable rate. It is important to point out that this finding was only reported for cows in their first and second lactation compared with third lactation cows (21). In this study, the number of lactations for experimental cows ranged from 2 to 7. However, the number of lactations was not considered for the statistical analysis.

Because there was no treatment effect on body reserve mobilization, as indicated by BCS and BW change, it is suggested that the greater ECM production observed for early lactation cows supplemented at a variable rate was likely owing to differences in concentrate supplement intake. In the current study, the greater nutrient amount provided by concentrate supplement did not attenuate body reserve mobilization because cows prioritized milk production. This is consistent with Hills et al. (18), who indicated that because of selection for greater milk production, dairy cows are hormonally regulated to partition nutrients towards milk constituents rather than body reserves for a longer time. As a result, these authors concluded that supplementation strategies in early lactation aimed at attenuating negative energy balance and, consequently, at improving pregnancy rate are poorly effective. In this study, an improved nutritional status of late lactation cows supplemented on herd basis was associated with both higher milk lactose concentration and earlier replenishment of body reserves as compared with those fed concentrate supplement with regard to their lactation stage.

Cattle fed on alfalfa pasture have low ruminal pH (22). Because of its high fiber content, WPCS supplementation was suggested as a means of increasing the ruminal pH of cattle under grazing conditions (23). However, reports by Bretschneider et al. (24) showed that the above-mentioned feeding strategy was unable to modify the ruminal pH of cattle grazing alfalfa-dominant pastures. The authors partially explained the finding by suggesting that WPCS particle size was not long enough to stimulate mastication. For this trial, corn plants were harvested as WPCS using a kernel processor, which also reduced particle size (24). Therefore, in order to maintain rumen health and functions, coarsely chopped alfalfa hay (mean particle length: 40 mm) was added to the WPCS. As a result, the $peNDF_{>8}$ content increased by 13%. Ruminal fermentation parameters were not assessed in this trial. However, the fact that milk fat content remained at high and unchanged levels for both feeding strategies across lactation stages may be sufficient evidence that rumen health and functions were properly maintained (25) despite experimental cows sorting against long particles.

Individual DMI of concentrate supplement averaged the same amount (5.5 kg DM/cow/day) for both supplementation strategies. For grazed pasture and conserved forage, DMI was unaffected by treatments. Nevertheless, because DMI was assessed on a group basis, the variation among individual cows could not be determined and hence the scope of the results is limited. To compensate for their nutritional needs in pasture-based dairy farms, high-producing dairy cows increase DMI of the feedstuff that is least restricted (6). In the present study, conserved forage was offered as an additional supplement for cows. However, due to the above-mentioned limitation, it could not be assessed whether conserved forage was more eagerly eaten by the most restricted cows (i.e. early lactation cows fed on a herd basis).

Following conserved forage delivery, cows rapidly approached feed bunks. Regardless of the dietary treatment, the average rate of eating of conserved forage by cow groups was high (68.40 g DM/min). This finding is consistent with Harb et al. (26), who reported a similar consumption rate (71 g DM/min) for group-fed cattle consuming grass silage. Consumption rate increases as corn silage allotment is restricted by either feeding space or access time to fodder (27). In this study, the feed bunk space (1 m) was greater than the recommended (0.61 m) for group-fed dairy cattle (28). In this regard, the greater feed bunk space is, the less social rank effect on feeding (29). Despite the fact that the access time to the feed bunks was limited, experimental cows consumed most of the delivered-conserved forage. However, this does not rule out the time-restricted access to feed bunks as responsible, at least in part, for the high consumption rate reported in this study.

Although feed wastage was not affected by feeding strategy, it was considerably elevated, with values that ranged from 6.9% to 9.7%. During feeding, some cows toss feed over their backs or along their sides. Such behavioral anomaly results in up to 5% feed loss (30). In this study, most of the feed wastage may be explained by feed tossing behavior.

As compared with a herd-based allotment strategy, concentrate allowance according to lactation stages increases ECM production of early lactation cows grazing restricted pasture and supplemented with conserved forage, at no additional cost. In contrast, body reserve mobilization was not attenuated in early lactation cows because of the concentrate allocation strategy. In summary, the prioritization of milk production rather than the attenuation of body reserve mobilization suggests that concentrate allowance based on lactation stage may be unsuitable for minimizing the negative energy balance in early lactation. To better understand the production response of cows at different stages of lactation to the strategy of concentrate allowance, further research evaluating individual DMI should be conducted.

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