Influence of limit-feeding and time of day of feed availability to growing calves on growth performance and feeding behavior in cold weather¹

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ABSTRACT: Objectives were to determine the effects of limit-feeding and time of feed access in cold weather on growth performance and feeding behavior of growing calves fed a corn silage-based diet. Sixty-six steers (BW = 317 ± 5.3 kg) and 30 heifers (BW = 239 ± 7.6 kg) were assigned randomly to dietary treatment: 1) ad libitum feed intake (AL), 2) limit-fed to 80% of the average DMI of the AL group on a BW basis in the daytime (0601–1759 h; LF-D), 3) limit-fed to 80% of the average DMI of the AL group on a BW basis in the nighttime (1800–0559 h; LF-N), and 4) limit-fed to 80% of the average DMI of the AL group on a BW basis, split 1/2 in the daytime and 1/2 in the nighttime (LF-S). Feed intake and feeding behavior were monitored over 84 d using the Insentec feeding system. Average daily gain, DMI, and G:F were greater ($P \leq 0.002$) in the AL group compared with others. Dry matter intake was not different ($P = 0.17$) when comparing the LF-D with the LF-N groups. Average daily gain and G:F were

greater ($P \leq 0.05$) when comparing the LF-N group to the LF-D group, and were not different ($P \geq 0.51$) when comparing the LF-S group with the mean of the LF-D and LF-N groups. Number of visits and meals per d was greater ($P \leq 0.001$) in the LF-N than the LF-D group. Feed intake per visit was not different ($P = 0.55$) when comparing the AL group and others, and tended to be greater ($P = 0.06$) in the LF-D than the LF-N group. Feed intake per meal was greater ($P < 0.001$) when comparing the AL group with others, and the LF-D with the LF-N group. Feed intake per minute (eating rate) was not influenced by treatment. In conclusion, limit-feeding at 80% of ad libitum intake decreased ADG and G:F. Limit-feeding in the nighttime as compared to limit-feeding in the daytime improves growth performance and increases feeding activity (number of visits and meals per d) which could be because of increased heat production to help maintain body temperature and thus reduce maintenance energy requirements.

Key words: backgrounding diet, beef cattle, feeding behavior, feeding time, feed restriction, growth performance

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INTRODUCTION

Changes in feed intake and feeding behavior influence the productivity of cattle (Gonzalez et al., 2012). Some research has suggested that more efficient calves, as measured using residual feed intake, consume smaller meals with slower eating rates,

while spending less total time at the feeder per d when compared to less efficient calves (Montanholi et al., 2010; Schwartzkopf-Genswein et al., 2002). Feed intake and feeding behavior (number of feeding events, time per d or per feeding event, and amount of feed consumed per d or per feeding event) are thought to be regulated by ruminal fill as well as metabolic feedback mechanisms (Rines, 1971; Fisher et al., 2003).

Limit-feeding can improve growth efficiency (Galyean, 1999) potentially through improvements in digestion (Murphy et al., 1994a; Murphy et al., 1994b). Moreover, research has suggested that feeding cattle in the evening results in improved growth performance in cold climates (Bergen et al., 2008; Holt and Pritchard,

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2005; Small et al., 2004), which could be because of increased heat production associated with digestion of feedstuffs that helps to maintain body temperature. Less is known about how feeding in the evening may influence feeding activity. Allowing for balanced feed consumption with 1/2 consumed during the day and 1/2 at night could be another approach that influences digestion by providing a more continual supply of dietary substrate throughout the day and reducing the risk for digestive disturbance (González et al., 2012).

Therefore, the objectives of this research were to determine the effects of limit-feeding and feeding time (daytime, nighttime, or 1/2 in the daytime + 1/2 in the nighttime) on growth performance and feeding behavior of growing calves fed a corn silage-based diet. We hypothesize that feeding behavior will be altered and growth performance improved when growing calves are limit-fed with feed access during the nighttime.

MATERIALS AND METHODS

All animal procedures were approved by the North Dakota State University Animal Care and Use Committee and followed guidelines stated in the Guide for the Care and Use of Agriculture Animals in Research and Teaching (American Dairy Science Association et al., 2010)

Animals, Experimental Design, and Dietary Treatments. Sixty-six steers (average initial BW of 317 ± 5.3 kg) and 30 heifers (average initial BW of 239 ± 7.6 kg) of Angus, Simmental, and Shorthorn breeding were blocked by sex (3 steer pens and 1 heifer pen) and stratified by initial BW (for steers) by pen. Calves also were balanced within treatments and pens according to breed type. Within each pen, animals were assigned to 1 of 4 dietary treatments: 1) ad libitum (AL) feed consumption, 2) limit-fed 80% of the AL group's average DMI on a BW basis in the daytime (LF-D), 3) limit-fed 80% of the AL group's average DMI on a BW basis in the nighttime (LF-N), and 4) limit-fed 80% of the AL group's average DMI on a BW basis split 1/2 in the daytime and 1/2 in the nighttime (LF-S). Calves on the LF-D treatment were allowed access to the allotted amount of feed between 0600 and 1759 h, calves on the LF-N treatment were allowed access to the allotted amount of feed between 1800 and 0559 h of the next day, and calves on the LF-S treatment were allowed access to 1/2 of the allotted feed in the daytime and 1/2 in the nighttime. Calves were adapted to the feeding system for 30 d prior to the beginning of the experiment. Calves were adapted to the feeding schedule over 3 wk at the beginning of the test period where, for calves in the LF-N group, the time feeders were allowed to be activated by calves shifted 2 h forward every 3 to 4 d to adapt to nighttime feeding.

All calves were fed a corn silage-based backgrounding diet (Table 1). Feed was delivered to the feeders at 0800 and 1700 h daily. Animals were fed from November through February (84 d) for the experiment. The facility contains a covered feed alley and feeding area with concrete flooring containing the Insentec feeders and waterers and is open to the south where there is an outdoor dirt yard. There was no use of artificial lighting.

Body Weight and Feed Intake Measurements.

Body weight was measured on 2 consecutive d at the beginning and end of the experiment. Feed intake and feeding behavior were summarized over the length of the experiment. Average daily gain for each individual animal was calculated as the final average 2-d BW minus the initial average 2-d BW divided by 84 d.

Radio frequency identification tags were placed in the right ear prior to the experiment. Each pen contained 8 Insentec electronic feeding stations (Hokofarm Group, Marknesse, The Netherlands) as described previously (Mader et al., 2009; Islas et al., 2014) allowing for monitoring and controlling individual feed intake (2 bunks per treatment) in a group-housed environment, in addition to regulating access to specific feeders during specific periods of the day utilizing electronic identification monitoring and pneumatic gates to limit access to feeders. The system also records attempted feeding visits (with the gate up) and if animals are able to consume feed over the pneumatic gate when the gate is up.

Total DMI and feeding behavior traits were summarized (Montanholi et al., 2010; Swanson et al., 2014) as follows: events (number of bunk visits and meals daily), eating time (minutes; per visit, per meal, and per d), and feed intake (grams; per visit, per meal, and per min). A visit was defined as each time the Insentec system detected a steer at a bunk. A meal was defined as eating periods that might include short breaks separated by intervals not longer than 7 min (Forbes, 1995; Montanholi et al., 2010). Variance in daily DMI was calculated over the entire feeding period. Dry matter intake and feeding behavior traits also were averaged for each week and for each hour over the entire feeding period (data included in Fig. 1 and 2).

Feed Analysis. Feed samples were collected twice monthly for nutrient analysis (Table 1). Feed samples were dried in a 55°C oven for at least 48 h and ground to pass a 1-mm screen. Feed samples were analyzed for DM, ash, N (Kjeldahl method), Ca, and P by standard procedures (AOAC, 1990); NDF (assayed with heat stable amylase and sodium sulfite and expressed inclusive of residual ash); and ADF (expressed inclusive of residual ash) concentration sequentially (Robertson and Van Soest, 1981) using a fiber analyzer (Ankom Technology Corp., Fairport, NY). Crude protein was calculated by multiplying N concentration $\times 6.25$.

Table 1. Dietary composition and analyses of diets fed to growing calves fed for ad libitum intake or limit-fed during the daytime, nighttime, or 1/2 during the daytime and 1/2 during the nighttime

Item	%, DM basis
Ingredient	
Corn silage	68.00
Bromegrass Hay	21.00
Dried corn distillers grains with solubles	3.00
Corn	4.64
Soybean meal	2.06
Urea	0.94
Salt	0.14
Limestone	0.12
Trace mineral premix ¹	0.05
Vitamin premix ²	0.05
Analysis³	
DM, %	48.5
Crude protein, % of DM	13.4
Neutral detergent fiber, % of DM	49.9
Acid detergent fiber, % of DM	46.2
Calcium, % of DM	0.46
Phosphorus, % of DM	0.24

¹Contained 3.62% Ca, 2.56% Cu, 16% Zn, 6.5% Fe, 4.0% Mn, 1,050 mg/kg I, and 250 mg/kg Co.

²Contained 48,510 kIU/kg vitamin A and 4,630.5 kIU/kg vitamin D.

³Average of twice monthly diet samples.

Temperature and Humidity Monitoring. Temperature (°C) and relative humidity (%) were recorded using HOBO Pro v2 Temp/RH sensors (Onset Computer Corporation, Bourne, MA; Table 2). Sensors were placed at the front of the pens close to the feeders in between pens 1 and 2 and pens 3 and 4. Measurements were collected every 15 min beginning on wk 3 of the experiment. Data from the 2 sensors were averaged.

Statistical Analysis. Data were analyzed using a completely randomized block (sex and breed) design using PROC Mixed of SAS (SAS Inst. Inc., Cary, NC); means were compared between treatment groups utilizing contrast statements: 1) AL vs. others, 2) LF-D vs. LF-N, and 3) LF-S vs. LF-D and LF-N. To examine effects over time (weekly averages), DMI, time, and visits per d were analyzed with repeated measures (wk) using PROC MIXED with treatment, wk, the interaction of treatment and wk, sex, and breed included in the model (data included in Fig. 1). To examine effects of time of day (averaged by h), DMI, time, and visits were analyzed with repeated measures (h) using PROC MIXED with treatment, wk, the interaction of treatment and h, sex, and breed included in the model (data included in Fig. 2). Appropriate (minimized information criterion) covariance structures were utilized (Wang and Goonewardene, 2004). Data were considered significant when $P \leq 0.05$.

RESULTS

Initial BW was not different among treatments (Table 3). Final BW and ADG were greater ($P \leq 0.009$) in the AL group compared to others. Final BW was not different between LF-D and LF-N groups. Average daily gain was greater ($P = 0.03$) in the LF-N group than the LF-D group. Final BW and ADG was not different when comparing LF-S with LF-D and LF-N groups. Dry matter intake was greater ($P < 0.001$) for AL than other groups and was not different when comparing the LF-D with the LF-N groups and when comparing LF-S with LF-D and LF-N groups. Dry matter intake variance was greater ($P < 0.001$) for the AL group than other treatments and was not different when comparing the LF-N to the LF-D group and when comparing the LF-D and LF-N groups with the LF-S group. Gain:feed was greater ($P = 0.002$) in the AL group when compared to others, was greater ($P = 0.05$) in the LF-N group than the LF-D group, and was not different when comparing the LF-S group with the LF-D and LF-N groups.

Number of visits to the feeder per d was not different between the AL group and the others and between the LF-S group and the LF-D and LF-N groups and was lesser ($P = 0.001$) in the LF-D than the LF-N group (Table 4). Number of meals per d was lesser ($P = 0.004$) in the AL group compared to others, was greater ($P < 0.001$) in the LF-N than the LF-D group, and was not different when comparing the LF-S group with the LF-D and LF-N groups. Eating time per visit was not different when comparing the AL group with others and when comparing the LF-D with the LF-N group, and was greater ($P = 0.02$) when comparing the LF-S group with the LF-D and LF-N groups. Eating time per meal was greater ($P = 0.02$) in the AL group when compared to the others and was not different when comparing the LF-D with the LF-N group and when comparing the LF-S with the LF-D and LF-N groups. Eating time per d was not different among treatments. Feed intake per visit was not different between the AL group and others and when comparing the LF-D group to the LF-N group and was greater ($P < 0.001$) in the LF-S group than the LF-D and LF-N groups. Feed intake per meal was greater ($P \leq 0.03$) in the AL group compared to others, in the LF-D than the LF-N group, and in the LF-S group compared to the LF-D and LF-N groups. Feed intake per min (eating rate) was not influenced by treatment.

When analyzing DMI and feeding behavior traits (time at feeder and visits per d) over the experimental period (summarized by wk; Fig. 1), interactions ($P < 0.001$) were observed between treatment and wk demonstrating differential effects of treatment by wk. When analyzing DMI and feeding behavior traits (time at feeder and visits per d) over the day (summarized by

Figure 1. Effect of dietary treatment (ad libitum, limit-fed during the daytime, nighttime, or 1/2 daytime and 1/2 nighttime) and experimental week on DMI (A), time at feeder (B), and visits to feeder/d in calves fed a corn silage-based diet. For DMI, time, and visits, respectively, pooled SEM = 0.262, 9.51, and 3.57 for the treatment*wk interaction ($n = 1,152$) for daytime DMI; pooled SEM = 0.196, 12.2, and 3.42 for nighttime DMI, pooled SEM = 0.287, 16.7, and 4.96 for total DMI. For DMI, time, and visits, respectively, $P \leq 0.01$ for treatment, $P \leq 0.001$ for wk, and $P \leq \text{treatment*wk}$ during the daytime, nighttime, and total. Daytime considered between 0600 and 1759 h and nighttime considered between 1800 and 0559 h. Limit-fed daytime, limit-fed nighttime, and limit-fed 1/2 daytime and 1/2 nighttime treatments fed at 80% of the ad libitum treatment.

Figure 2. Effect of dietary treatment (ad libitum, limit-fed during the daytime, nighttime, or 1/2 daytime and 1/2 nighttime) and time of day (in 1 h increments) on DMI (A), visits to feeder/d (B), time at feeder/d in calves fed a corn silage-based diet. For DMI, visits, and time, respectively, pooled SEM = 0.154, 0.695, and 3.64, for the treatment*h interaction ($n = 2304$). For DMI, visits, and time, $P < 0.001$ for treatment, h, and treatment*h. Daytime considered between 0600 and 1759 h and nighttime considered between 1800 and 0559 h. Limit-fed daytime, limit-fed nighttime, and limit-fed 1/2 daytime and 1/2 nighttime treatments fed at 80% of the ad libitum treatment.

Table 2. Average weekly temperature ($^{\circ}\text{C}$) and relative humidity (%) throughout the experimental period for growing calves fed a corn-silage and hay-based diet for ad libitum intake or limit-fed during the daytime, nighttime, or 1/2 during the daytime and 1/2 during the nighttime

Item	Week									
	3	4	5	6	7	8	9	10	11	12
Temperature, $^{\circ}\text{C}$	0.10	-7.41	-5.62	-13.8	-11.4	-6.21	-8.84	-14.2	-10.3	-16.2
Relative humidity, %	79.6	77.1	86.2	78.2	81.7	79.7	79.5	73.2	81.5	78.6

Table 3. Influence of ad libitum- or limit-feeding during the daytime, nighttime, or 1/2 during the daytime and 1/2 during the nighttime on growth performance of calves fed a corn silage-based diet

Item	Treatment				SEM ⁵	Contrast <i>P</i> -value		
	AL ¹	LF-D ²	LF-N ³	LF-S ⁴		AL vs. others	LF-D vs. LF-N	LF-S vs. LF-D and LF-N
Initial BW, kg	283	285	284	286	8.6	0.82	0.90	0.84
Final BW, kg	372	339	349	348	9.8	0.009	0.43	0.66
ADG, kg/d	1.06	0.64	0.77	0.74	0.049	< 0.001	0.03	0.52
DMI, kg/d	8.07	6.20	6.53	6.42	0.183	< 0.001	0.17	0.77
DMI variance ⁶ , kg ² /d	3.04	0.53	1.01	1.01	0.218	< 0.001	0.10	0.31
Gain:feed, kg gain/kg DMI	0.131	0.100	0.117	0.113	0.0065	0.002	0.05	0.51

¹Ad libitum feed consumption.

²Limit-fed at 80% of AL in the daytime (between 0600 and 1759 h).

³Limit-fed at 80% of AL in the nighttime (between 1800 and 0559 h the next day).

⁴Limit-fed at 80% of AL, 1/2 in daytime and 1/2 in nighttime.

⁵Standard error of the mean ($n = 24$).

⁶Calculated using daily DMI over the entire feeding period.

h; Fig. 2), interactions ($P < 0.001$) were observed between treatment and wk suggesting differential effects of treatment at different times of the day.

DISCUSSION

Feed costs make up a large proportion of total production costs and changing feeding management can lead to changes in feeding behavior that may be associated with differences in cattle performance. Our data suggest that feeding for ad libitum intake vs. limit-feeding at 80% of the AL group results in increased ADG. However, contrary to our hypothesis, calves from the AL group had greater G:F than those limit-fed. The effects of limit-feeding may differ depending on the level of restriction, type of diet fed (forage vs. concentrate), and energy density of the diet. We chose the 80% DMI relative to the AL group to ensure that all calves on the limit-fed group would consume their daily allotment. Much of the research on limit-feeding where improvements in efficiency were observed were in cattle fed high-concentrate finishing diets (Galyean, 1999). Our results suggest that with a corn silage-based diet, the effects of limit-feeding at 80% of ad libitum intake results in decreased ADG and G:F. This may be because of the nonlinear relationship between DMI (ME intake) and energy gain (Ferrell and Jenkins, 1998) as the slope is flatter at higher ME intakes typical of high-concentrate diets where improvements in efficiency with less effect on ADG have been reported (Galyean, 1999), whereas the slope is greater at lower ME intakes that would be more typical of the diet fed in the current experiment. As designed, DMI was greater in the AL group than the limit-fed groups. Because the AL group had unlimited access to feed resulting in changes in DMI from day to day, DMI variance was greater in the AL group compared to the limit-fed groups. Limit-feeding also altered feeding behavior with less meals and

eating time per meal, which would be expected as calves had access to less feed so would spend less time and visit the feed bunk less per d. In dairy heifers, limit-feeding also influenced feeding behavior by decreasing feeding time (Greter et al., 2015).

Similar to previous research (Kennedy et al., 2004; Small et al., 2004; Holt and Pritchard, 2005; Bergen et al., 2008) in cold climates, we observed improvements in ADG and G:F when comparing calves from the LF-N group to calves from the LF-D group that potentially could be because of increased heat production that could be used to maintain body temperature during the night when temperatures were lower, resulting in lower maintenance energy requirements. The potential increased heat production in calves with feed access during the nighttime vs. the daytime could come from a combination of heat of fermentation (Ferrell, 1988), heat increment of feeding (Emmans, 1994), or physical activity (van Milgen et al., 1998; van den Borne et al., 2007). Cattle typically eat more during the daytime than in the nighttime (Fraser and Broom, 1997), which also was observed in the current experiment for the AL group. Also, altering time of feed availability may result in changes in eating patterns as supported by the differences observed in feeding behavior (increased visits and meals per d) between the LF-D and LF-N groups in the current experiment. These differences support the idea that increased activity during the nighttime associated with feeding may be associated with increased heat production, which at least partly may be responsible for the observed improvements in ADG and G:F.

When comparing the LF-S group with the LF-D and LF-N groups, fewer differences in growth performance and feeding behavior were observed. Increasing eating time per d with reduced eating rate potentially could be more beneficial when higher grain diets are fed, which could result in a more balanced feed intake

Table 4. Influence of ad libitum- or limit-feeding during the daytime, nighttime, or 1/2 during the daytime and 1/2 during the nighttime on feeding behavior of growing calves fed a corn silage-based diet

Item	Treatment				SEM ⁵	Contrast <i>P</i> -value		
	AL ¹	LF-D ²	LF-N ³	LF-S ⁴		AL vs. others	LF-D vs. LF-N	LF-S vs. LF-D and LF-N
Eating events, no./d								
Visits	57.9	45.5	62.6	48.0	3.94	0.15	0.001	0.17
Meals	11.2	11.8	14.1	12.1	0.48	0.004	< 0.001	0.12
Eating time, min								
Per visit	4.50	5.08	4.36	5.77	0.396	0.17	0.17	0.02
Per meal	21.1	17.5	16.4	18.9	1.11	0.02	0.43	0.12
Per day	215	186	209	198	8.9	0.07	0.06	0.95
Feed intake, g								
Per visit	161	170	131	212	15.8	0.55	0.06	< 0.001
Per meal	800	607	518	658	30.4	< 0.001	0.03	0.005
Per minute (eating rate)	38.9	38.6	35.9	39.7	1.79	0.64	0.24	0.21

¹Ad libitum feed consumption.²Limit-fed at 80% of AL in the daytime (between 0600 and 1759 h).³Limit-fed at 80% of AL in the nighttime (between 1800 and 0559 h the next day).⁴Limit-fed at 80% of AL, 1/2 in daytime and 1/2 in nighttime.⁵Standard error of the mean (*n* = 24).

throughout the day, which may improve digestibility and/or help to reduce the incidence of digestive disturbance (González et al., 2012).

Over the feeding period, DMI and total time and visits per d changed relative to treatment differently as the week progressed as indicated by the significant treatment*wk interactions. This primarily was driven by the adaptation period (first 3 wk) when the LF-N group was adapted to LF-N feeding. Figure 2 illustrates that over the entire experiment the AL group consumed the majority of their feed, spent the majority of time, and had the majority of visits in the daytime as expected, similar to what has been reported previously (Fraser and Broom, 1997; DeVries et al., 2003). As designed, the LF-S group had a more balanced DMI, time, and visits over the daytime and nighttime, and calves in the LF-D and LF-N groups consumed the majority of the feed, spent the majority of time, and had the majority of visits during the daytime and nighttime, respectively.

Over the day, DMI and total time and visits per d changed relative to treatment differently as hour progressed as indicated by the significant treatment*h interactions. The majority of DMI, time at feeder, and visits per d for the AL group occurred during the daytime with 2 primary peaks in DMI occurring around 1200 and 1700 h (Fig. 2). Also, for the AL group, time at the feeder was more variable throughout the day and visits were greatest in mid-afternoon. This agrees with research suggesting that the majority of visits occur in the daytime (Fraser and Broom, 1997). Generally, the intake patterns represented the dietary treatments for the limit-fed calves; however, time at the feeder and visits were more variable over time.

Calves on different feeding treatments were housed in the same facility and in the same pens allowing for comingling of calves on different treatments. This interaction with calves on different feeding schedules could influence how calves respond to changes in time of feed availability in regards to feeding behavior. In practice, the feeding schedule would likely be similar for all cattle within a facility. Also, the electronic feeders allow only 1 calf access to each bunk, whereas in a typical production environment several calves would have access to a larger bunk. Therefore, the social interactions between animals are likely different between the differing feeding systems. However, these results do provide insight into potential differences between feeding behavior when feed is available during the daytime or nighttime.

In conclusion, limit-feeding at 80% of an ad libitum corn silage-based diet to growing calves is not recommended as ADG and G:F were decreased. Limit-feeding during the nighttime as compared to the daytime increased ADG and G:F, suggesting that this approach may be beneficial in cold environments. Limit-feeding during the nighttime when compared to the daytime altered feeding behavior by increasing the number of visits and meals per d. Limit-feeding a corn silage-based diet 1/2 in the daytime and 1/2 in the nighttime did not improve growth performance relative to calves fed during only the daytime or nighttime. Limit-feeding in the nighttime as compared to limit-feeding in the daytime improves growth performance and increases feeding activity (number of visits and meals per d), which potentially could result in increased heat production to maintain body temperature and thus reduce maintenance energy requirements.

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