Estimating optimal observational sampling frequency of behaviors for cattle fed high- and low-forage diets

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ABSTRACT: Video recordings of behavioral activities including eating, ruminating, drinking, standing, and lying were monitored to determine the minimum number of sampling days and sampling frequency required to obtain reliable estimates of these behaviors. Eight continental crossbred heifers, individually housed in a tie-stall barn with total mixed ration provided once per day, were divided by BW into two blocks and assigned to each of the two dietary treatments in a crossover design: high-forage diet (HF, forage:concentrate ratio 70:30) and low-forage diet (LF, forage:concentrate ratio 30:70). The cows were monitored continuously using a digital video recording system for 6 d in each of the two periods and a trained observer manually recorded the behavioral activities by minute. Mean time spent performing each behavior for 6 d with instantaneous samples of 1 min was compared with those obtained using fewer sampling days (1, 2, 3, 4, and 5 d) and less frequent scanning (2, 3, 4, 5, 10, 15, 30, and 60 min) using linear regression analysis, and the minimum number of sampling days or frequency was determined. Diet did not affect the accuracy and precision of predicting behavior from video recordings of the cows. When sampling days and

scanning intervals were combined, the minimum recommended sampling frequency for accurately estimating a specific set of behaviors of beef heifers in tie stalls was: eating, 2 d with 4-min intervals; ruminating, 3 d with 4-min intervals; drinking, 2 d with 3-min intervals; and standing and lying, 2 d with 15-min intervals. Increasing sampling frequency beyond these minimums further enhanced the accuracy and precision of predictions. The total time of each behavioral activity was different between cows fed HF and LF diets with eating, ruminating, total chewing, and standing of heifers fed the HF diet greater ($P < 0.01$), but the lying ($P < 0.01$) and drinking time ($P = 0.028$) of heifers fed the LF diet greater. Meal patterns were different ($P < 0.05$) between the treatments except when meal size (kg) was expressed as DM or OM intake. For rumination patterns, the mean or maximum bout length (min/bout) was greater, but the maximum or minimum length of time heifers took to ruminate after eating was lower for the HF diet. From a practical standpoint, it is recommended to use 3 days of observations scanned at an interval of 4 min to reliably estimate the behavior of cows. If the focus is only lying and standing time, then 2 days with 15 min intervals can be used.

Key words: cattle, feeding behavior, forage:concentrate ratio, instantaneous recording, sampling time

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INTRODUCTION

Various methods have been used to assess animal behavior: recording jaw movements, use of sensors to detect sound or movement (Müller and Schrader, 2003; González et al., 2015), manual observation (Kononoff et al., 2002; Schlecht et al., 2004), and

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continuous video recording (Mitlöhner et al., 2001; Mattachini et al., 2011, 2013). Video records are potentially more accurate than other methods, but processing the recordings to interpret activity is labor intensive (Mitlöhner et al., 2001). Summarizing the precise start and end time of each behavior for individual animals is ideal (i.e., continuous recording), but extremely labor intensive and prone to error. An alternative is the use of scan sampling (i.e., instantaneous or fixed interval scanning), whereby the behavior of the animal is assessed at a predetermined interval, with the behavior assumed to be constant during the scanning interval. Compared with continuous recording, time sampling requires less labor and it allows the operator to examine a group of animals simultaneously (Mitlöhner et al., 2001; Ledgerwood et al., 2010; Mattachini et al., 2013).

To minimize labor, the scanning interval should be as long as possible without risking the accuracy of estimates (Hämäläinen et al., 2016), and the number of days will depend on day-to-day repetitiveness of the behavior. However, few studies have examined the conditions needed to provide reliable estimates of animal behaviors. It is well known that the behavior of cattle is affected by forage:concentrate (F:C) ratio (Yang et al., 2001; Kargar et al., 2010); feeding concentrate to cattle decreases ruminating and eating time (Phillips, 2004). It is possible that the optimum sampling methods required to accurately predict behavior of cattle are diet dependent, particularly for cows fed high-grain diets with less eating and rumination time. The objective of this study was to determine the minimum sampling days and maximum interval needed to reliably estimate behavior of cattle fed diets varying in F:C ratio. A second objective was to determine the effects of high and low F:C ratio on behavior of beef cattle.

MATERIALS AND METHODS

This study was conducted at Agriculture and Agri-Food Canada Lethbridge Research and Development Centre, Alberta, Canada. The study procedures were approved by the Research Centre's Animal Care and Use Committee. Animals were cared for in accordance with the guidelines of the Canadian Council on Animal Care (2009).

Animals and Experimental Design

Eight continental crossbred heifers that averaged 409.8 ± 14.0 kg were used in a study designed as a crossover with two dietary treatments and 49-d periods. Heifers were divided by BW into two blocks (four animals per block). Blocks were

staggered for ease of sampling. Each heifer received two treatment diets over the two periods. Diets were fed once daily at 1100 h for ad libitum intake and water was freely available at all times. Heifers were individually housed in a tie-stall barn on mattresses bedded with wood shavings.

Dietary Treatments

The dietary treatments were two F:C ratios (DM basis): 70:30 for the high-forage (HF) diet and 30:70 for the low-forage (LF) diet. The diets consisted of barley silage, dry rolled barley grain, and mineral and vitamin supplement with compositions described by Chibisa et al. (2016) (Table 1). The rations were prepared daily (Data Ranger; American Calan Inc., Northwood, NH) and offered as a total mixed ration. Diets were formulated to provide sufficient energy, protein, minerals, and vitamins to exceed the nutrient requirements of animals gaining 1.0 kg/d (NRC, 1996).

Heifers were adapted to the dietary treatments gradually during the first 12-d of each period. To transition from the 70:30 to the 30:70 diet, heifers were fed diets containing 60%, 50%, and 40% forage for 4 d each (DM basis). The opposite approach was used to transition from the 30:70 to the 70:30 diet. Feed offered and refused was recorded daily during the entire experiment for individual heifers to calculate feed intake. Samples of feed were collected once weekly to determine DM content. Orts from individual heifers were collected daily and composited weekly for DM measurement and particle size analysis.

Animal Behavior Data Measurement

Activity of each heifer was continuously recorded onto video tape using color CCTV cameras (model WV-CP484, Panasonic Corp., Kadoma, Osaka, Japan) mounted on tripods. These cameras were placed on a wall shelf installed in the barn, approximately 3 m in front of each stall at a height of 2 m. The cameras were connected to a digital video recording system (model SRD-470D, Samsung Techwin Co, Ltd., Changwon, Gyengsangnam-do, South Korea). Three 1,400 lumen lights were used to facilitate video recording at night. Continuous observations were video-recorded throughout the day for exactly 24 h starting from 11:00 a.m. on d 29 to 11:00 a.m. on d 35 of each period. Video footage was downloaded on d 35 and a trained observer reviewed the tapes and noted the beginning and end of each behavior of each heifer including

Table 1. Mean ($\pm$ SD) behavioral activities measured for 1–6 days using 1- to 60-min sampling intervals ($n = 16$ observations)*

Behavioral activity and interval	Number of days					
	1	2	3	4	5	6
Eating						
1 min	237 $\pm$ 33.8	241 $\pm$ 34.6	246 $\pm$ 35.3	245 $\pm$ 34.3	246 $\pm$ 34.3	245 $\pm$ 33.5
2 min	237 $\pm$ 32.6	246 $\pm$ 34.2	246 $\pm$ 34.3	246 $\pm$ 34.3	246 $\pm$ 34.2	245 $\pm$ 33.4
3 min	236 $\pm$ 36.7	247 $\pm$ 34.0	247 $\pm$ 34.1	247 $\pm$ 34.1	247 $\pm$ 34.0	246 $\pm$ 33.4
4 min	235 $\pm$ 34.2	245 $\pm$ 34.9	246 $\pm$ 34.9	246 $\pm$ 34.9	245 $\pm$ 34.9	244 $\pm$ 34.2
5 min	234 $\pm$ 38.1	246 $\pm$ 36.2	247 $\pm$ 36.7	247 $\pm$ 36.7	246 $\pm$ 36.2	244 $\pm$ 36.0
10 min	234 $\pm$ 44.4	245 $\pm$ 40.8	247 $\pm$ 40.7	247 $\pm$ 40.7	245 $\pm$ 40.8	244 $\pm$ 40.4
15 min	240 $\pm$ 53.4	246 $\pm$ 43.4	247 $\pm$ 43.7	247 $\pm$ 43.7	246 $\pm$ 43.4	246 $\pm$ 42.9
30 min	266 $\pm$ 57.8	243 $\pm$ 51.0	242 $\pm$ 52.0	242 $\pm$ 52.0	243 $\pm$ 51.0	244 $\pm$ 49.6
60 min	240 $\pm$ 72.7	243 $\pm$ 55.9	240 $\pm$ 56.1	240 $\pm$ 56.1	243 $\pm$ 55.9	244 $\pm$ 55.2
Ruminating						
1 min	522 $\pm$ 53.7	514 $\pm$ 71.7	511 $\pm$ 69.1	513 $\pm$ 63.4	515 $\pm$ 56.5	518 $\pm$ 52.0
2 min	522 $\pm$ 54.0	516 $\pm$ 54.9	516 $\pm$ 55.8	516 $\pm$ 55.8	516 $\pm$ 54.9	518 $\pm$ 52.1
3 min	523 $\pm$ 51.8	516 $\pm$ 55.8	515 $\pm$ 56.3	515 $\pm$ 56.3	516 $\pm$ 55.8	518 $\pm$ 52.7
4 min	522 $\pm$ 51.7	517 $\pm$ 54.0	516 $\pm$ 54.7	516 $\pm$ 54.7	517 $\pm$ 54.0	519 $\pm$ 51.1
5 min	516 $\pm$ 54.9	515 $\pm$ 55.5	514 $\pm$ 56.5	514 $\pm$ 56.5	515 $\pm$ 55.5	517 $\pm$ 52.6
10 min	520 $\pm$ 57.7	515 $\pm$ 57.0	514 $\pm$ 57.5	514 $\pm$ 57.5	515 $\pm$ 57.0	517 $\pm$ 53.6
15 min	513 $\pm$ 57.2	515 $\pm$ 57.3	515 $\pm$ 58.1	515 $\pm$ 58.1	515 $\pm$ 57.3	517 $\pm$ 53.9
30 min	523 $\pm$ 75.1	519 $\pm$ 58.7	520 $\pm$ 60.0	520 $\pm$ 60.0	519 $\pm$ 58.7	520 $\pm$ 55.6
60 min	529 $\pm$ 118	525 $\pm$ 57.8	523 $\pm$ 63.5	523 $\pm$ 63.5	525 $\pm$ 57.8	526 $\pm$ 54.2
Drinking						
1 min	37.9 $\pm$ 17.6	38.8 $\pm$ 16.5	38.1 $\pm$ 14.3	38.3 $\pm$ 14.1	37.3 $\pm$ 13.9	37.4 $\pm$ 14.1
2 min	37.3 $\pm$ 18.9	36.9 $\pm$ 14.5	37.1 $\pm$ 14.3	37.1 $\pm$ 14.3	36.9 $\pm$ 14.5	36.9 $\pm$ 14.9
3 min	37.3 $\pm$ 15.8	35.9 $\pm$ 13.4	35.9 $\pm$ 13.4	35.9 $\pm$ 13.4	35.9 $\pm$ 13.4	36.1 $\pm$ 14.1
4 min	38.3 $\pm$ 23.1	37.1 $\pm$ 15.9	37.3 $\pm$ 15.8	37.3 $\pm$ 15.8	37.1 $\pm$ 15.9	36.8 $\pm$ 16.6
5 min	37.8 $\pm$ 19.8	37.1 $\pm$ 14.2	37.0 $\pm$ 14.2	37.0 $\pm$ 14.2	37.1 $\pm$ 14.2	36.9 $\pm$ 14.6
10 min	41.9 $\pm$ 27.1	35.4 $\pm$ 15.5	35.4 $\pm$ 15.2	35.4 $\pm$ 15.2	35.4 $\pm$ 15.5	35.4 $\pm$ 15.9
15 min	35.6 $\pm$ 18.1	36.8 $\pm$ 16.7	36.4 $\pm$ 16.2	36.4 $\pm$ 16.2	36.8 $\pm$ 16.7	36.1 $\pm$ 17.2
30 min	35.6 $\pm$ 27.3	35.1 $\pm$ 16.7	35.8 $\pm$ 15.7	35.8 $\pm$ 15.7	35.1 $\pm$ 16.7	34.1 $\pm$ 17.5
60 min	22.5 $\pm$ 37.1	36.0 $\pm$ 28.7	35.9 $\pm$ 26.7	35.9 $\pm$ 26.7	36.0 $\pm$ 28.7	34.4 $\pm$ 29.2
Standing						
1 min	489 $\pm$ 68.3	489 $\pm$ 70.4	503 $\pm$ 63.4	500 $\pm$ 61.2	495 $\pm$ 60.9	495 $\pm$ 71.9
2 min	489 $\pm$ 68.0	496 $\pm$ 68.6	499 $\pm$ 66.5	499 $\pm$ 66.5	496 $\pm$ 68.6	495 $\pm$ 71.9
3 min	488 $\pm$ 69.6	496 $\pm$ 68.8	498 $\pm$ 66.8	498 $\pm$ 66.8	496 $\pm$ 68.8	495 $\pm$ 72.5
4 min	490 $\pm$ 71.4	495 $\pm$ 69.0	498 $\pm$ 66.9	498 $\pm$ 66.9	495 $\pm$ 69.0	494 $\pm$ 72.7
5 min	491 $\pm$ 67.8	495 $\pm$ 67.9	497 $\pm$ 66.3	497 $\pm$ 66.3	495 $\pm$ 67.9	495 $\pm$ 71.5
10 min	490 $\pm$ 69.7	495 $\pm$ 65.1	498 $\pm$ 63.6	498 $\pm$ 63.6	495 $\pm$ 65.1	494 $\pm$ 69.0
15 min	499 $\pm$ 75.0	490 $\pm$ 72.4	492 $\pm$ 69.8	492 $\pm$ 69.8	490 $\pm$ 72.4	491 $\pm$ 76.1
30 min	504 $\pm$ 72.0	485 $\pm$ 70.1	487 $\pm$ 67.9	487 $\pm$ 67.9	485 $\pm$ 70.1	486 $\pm$ 74.7
60 min	461 $\pm$ 104	480 $\pm$ 83.7	481 $\pm$ 82.4	481 $\pm$ 82.4	480 $\pm$ 83.7	479 $\pm$ 87.3
Lying						
1 min	951 $\pm$ 68.3	952 $\pm$ 70.2	937 $\pm$ 63.4	940 $\pm$ 61.2	945 $\pm$ 60.9	945 $\pm$ 72.0
2 min	951 $\pm$ 68.0	944 $\pm$ 68.6	942 $\pm$ 66.5	942 $\pm$ 66.5	944 $\pm$ 68.6	945 $\pm$ 71.9
3 min	952 $\pm$ 69.6	945 $\pm$ 68.8	942 $\pm$ 66.8	942 $\pm$ 66.8	945 $\pm$ 68.8	945 $\pm$ 72.2
4 min	950 $\pm$ 71.4	945 $\pm$ 69.0	942 $\pm$ 66.9	942 $\pm$ 66.9	945 $\pm$ 69.0	946 $\pm$ 72.7
5 min	949 $\pm$ 67.8	945 $\pm$ 67.9	943 $\pm$ 66.3	943 $\pm$ 66.3	945 $\pm$ 67.9	946 $\pm$ 71.5
10 min	950 $\pm$ 69.7	945 $\pm$ 65.1	943 $\pm$ 63.7	943 $\pm$ 63.7	945 $\pm$ 65.1	946 $\pm$ 69.0
15 min	941 $\pm$ 75.0	950 $\pm$ 72.3	949 $\pm$ 69.8	949 $\pm$ 69.8	950 $\pm$ 72.3	950 $\pm$ 76.1
30 min	936 $\pm$ 72.0	955 $\pm$ 70.1	954 $\pm$ 67.7	954 $\pm$ 67.7	955 $\pm$ 70.1	954 $\pm$ 74.7
60 min	979 $\pm$ 104	960 $\pm$ 83.7	959 $\pm$ 82.4	959 $\pm$ 82.4	960 $\pm$ 83.7	961 $\pm$ 87.3

continued

Table 1. *Continued*

Behavioral activity and interval	Number of days					
	1	2	3	4	5	6
Meals/d						
1 min	13.9 ± 5.2	13.7 ± 4.1	13.8 ± 3.6	13.8 ± 3.6	13.7 ± 3.6	13.6 ± 3.6
2 min	12.8 ± 4.4	12.8 ± 3.3	12.8 ± 3.2	12.8 ± 3.2	12.8 ± 3.3	12.8 ± 3.3
3 min	13.1 ± 4.4	12.6 ± 3.1	12.6 ± 3.0	12.6 ± 3.0	12.6 ± 3.1	12.6 ± 3.1
4 min	11.6 ± 3.2	11.6 ± 2.9	11.6 ± 2.9	11.6 ± 2.9	11.6 ± 2.9	11.6 ± 2.9
5 min	12.7 ± 3.1	13.5 ± 2.7	13.5 ± 2.7	14.7 ± 6.9	13.5 ± 2.7	13.3 ± 2.7
10 min	9.3 ± 2.4	9.5 ± 1.7	9.5 ± 1.6	10.2 ± 3.4	9.5 ± 1.7	9.5 ± 1.7
15 min	7.4 ± 2.2	7.4 ± 1.4	7.7 ± 1.6	8.0 ± 2.6	7.4 ± 1.4	7.4 ± 1.4
30 min	5.2 ± 1.3	4.7 ± 1.1	4.7 ± 1.1	4.9 ± 1.3	4.7 ± 1.1	4.7 ± 1.1
60 min	2.7 ± 0.9	2.7 ± 0.6	2.7 ± 0.6	2.8 ± 0.9	2.7 ± 0.6	2.7 ± 0.6

*No interaction by treatment × day ($P > 0.05$).

eating, ruminating, drinking, standing, and lying down for 6 days (i.e., continuous recording). Fixed-interval time point sampling (Martin and Bateson, 2007), also called instantaneous sampling (Chen et al., 2016), was used to divide the 1440-min observation session into 1-min sampling intervals, giving 1,440 sample points. Successive sample points were denoted by a signal from the video recorder. At each sample point, a record was made of whether or not a given behavior pattern was occurring, and this behavior was assumed to last until the end of the sampling interval. The total time (min) spent for each of the behavioral activities over 24 h was calculated each day. The procedure was repeated using 2, 3, 4, 5, 15, 30, and 60 min sampling intervals.

Eating activity was defined as when the heifer's muzzle was in the feed bunk or chewing or swallowing feed with its head over the bunk. Drinking was considered as the time when the heifer had its muzzle in the waterer or swallowing the water. Using instantaneous sampling, the activity was recorded as rumination when repetitive jaw movement occurred while the cow was not eating. Rumination was defined as regurgitation, remastication, and swallowing of boluses (Schake and Riggs, 1969). The beginning of a rumination bout was defined as the time when a bolus came up the esophagus and reached the mouth before the animal began to chew rhythmically, and the ending time was when the final bolus was swallowed. Total chewing was the sum of eating and ruminating activities. Standing was defined as when the body was upright and supported by at least three legs (including locomotion), whereas lying down was defined as the body resting on the floor or in contact with the ground on the left or right side (Munksgaard and Simonsen, 1996).

To determine the inter-observer reliability of this measure, two trained observers independently

watched a subset of the video recordings (eight cows for 5 h), and then repeated the observations from the same video 28 d later. Reliability was expressed as a Pearson correlation coefficient (PROC CORR; SAS Inst. Inc., Cary, NC) for the behavioral activity analysis. Assessments of the two independent observers were highly correlated ($r = 0.99$, $P < 0.001$).

Chemical Analysis and Particle Determination

The composited feed and orts samples for each week were dried in an oven at 55 °C for 48 h and then ground (1 mm screen; Wiley Mill, Arthur A. Thomas Co., Philadelphia, PA) for chemical analysis of OM, NDF, ADF, and CP content. Chemical analysis was performed for each sample in duplicate (CV < 5%). Dry matter content of the samples was determined by drying at 135 °C for 3 h (AOAC, 2005), followed by hot-weighing. The ash content was measured by combustion at 550 °C overnight with OM content calculated as the difference between DM and ash contents. The NDF (Mertens, 2002) and ADF (AOAC, 2005, method 973.18) contents were determined with modifications to each procedure for use in a fiber analyzer (F57 Fiber Filter Bags, 200 Fiber Analyzer, ANKOM Technology), with heat-stable α amylase (Termamyl 120, Sigma-Aldrich, St. Louis, MO) and sodium sulfite (S430-3 sodium sulfite anhydrous, Fisher Scientific, Pittsburgh, PA) used in the NDF procedure. Total N in the samples was determined by flash combustion and thermal conductivity detection (model 1500; Carlo Erba Instruments, Milan, Italy).

Particle size for TMR was measured using the Penn State Particle Separator (PSPS, Kononoff

et al., 2003) equipped with three sieves (19, 8, and 1.18 mm) and a pan. The physical effectiveness factor ($\text{pef}_{8.0}$ and $\text{pef}_{1.18}$) of the TMR was determined as the sum of the proportion of particles retained on two sieves (19 and 8 mm; Lammers et al., 1996) and three sieves (19, 8, and 1.18 mm; Kononoff et al., 2003), respectively, of the PSPS. Physically effective NDF ($\text{peNDF}_{8.0}$ and $\text{peNDF}_{1.18}$) was calculated by multiplying the NDF content of the TMR by $\text{pef}_{8.0}$ and $\text{pef}_{1.18}$, respectively.

Data Analysis

Data were expressed as daily behavior including eating, ruminating, drinking, standing, and lying activities by calculating the total minutes of each behavioral activity over a 24-h period. Activities were expressed per unit of intake of DM, OM, NDF, $\text{peNDF}_{8.0}$, and $\text{peNDF}_{1.18}$. A meal criterion of 300 s was used thus a meal was defined as all eating events separated by less than 5 min and meal duration was the sum of the duration of eating events and the time between eating events within a meal (Schwartzkopf-Genswein et al., 2002). This criterion was calculated from data of animals managed similarly to those in this study. Meal length and size were calculated using this criterion. Rate of eating (g DM/min) was calculated as the ratio of daily DMI and daily time spent eating. The number of rumination bouts; the mean, maximum, and minimum length of rumination bouts; and the mean, maximum, and minimum length of time heifers took before ruminating occurred after eating stopped (latency period) were calculated for each heifer.

Statistical Analysis

Relationships between estimates of total eating, ruminating, drinking, standing, and lying time obtained from 1, 2, 3, 4, and 5 d and continuous data of 6 d were analyzed using linear regression by SAS (SAS Inst., Inc., Cary, NC). Linear regression analysis was also used to compare instantaneous sampling at intervals of 2, 3, 4, 5, 10, 15, 30, and 60 min with intervals of 1 min. The criteria described by Ledgerwood et al. (2010) of coefficient of determination (r^2) ≥ 0.90 and slope and intercept not statistically different ($P > 0.05$) from 1 and 0, respectively, were used to assess the relationships. To determine the effects of F:C ratio on activities, data for all variables such as intake, behavioral activity, meals, and rumination pattern data were calculated for each heifer for each

day by treatment within period and were analyzed using PROC MIXED of SAS (SAS Inst., Inc., Cary, NC) as a crossover design treating day as a repeated measure. The degrees of freedom method of Kenward–Roger and covariance structure of variance components were used. The model included the fixed effect of period, crossover sequence group, and treatment, the random effects of heifer nested within sequence, and the residual error. Significance was declared at $P \leq 0.05$, and a tendency was considered at $0.05 < P \leq 0.10$. The Bonferroni correction method was used to adjust the overall P -value.

To determine whether differences ($P < 0.05$) existed among sampling intervals or sampling days, the data for behavioral activities were calculated for each heifer in each period by sampling day or time interval and were analyzed using PROC MIXED of SAS (SAS Inst., Inc., Cary, NC). The final model included the fixed effects of period, sequence, day (time) interval, treatment, and treatment $\times$ day or treatment $\times$ interval interaction, the random effect of heifer within sequence, and the residual error. The interactions of treatment $\times$ day and treatment $\times$ interval were tested in the initial model and were not significant, so they were removed from the final analysis.

RESULTS

Sampling Days and Intervals

The mean activity data for the five behaviors and meal frequency summarized for 1 to 6 d of instantaneous sampling at 1- to 60-min intervals are presented Table 1. No treatment $\times$ day interactions were found ($P > 0.25$); thus, the data are averaged over both dietary treatments. Table 2 shows the coefficients of determination and significance for these behaviors summarized by sampling day and interval. As expected, decreasing the number of sampling days reduced the r^2 of the linear regression compared with sampling for 6 d. With 1-min intervals, the number of sampling days that showed a strong relationship with 6 d with no difference from 1 and 0 for slope and intercept, respectively, were: 2 or more days for total eating time ($r^2 \geq 0.908$; $P < 0.01$), 3 or more days for drinking time ($r^2 \geq 0.952$; $P < 0.01$), 5 or more days for standing and lying behaviors ($r^2 \geq 0.918$; $P < 0.01$), and 4 or more days for meals ($r^2 \geq 0.938$; $P < 0.01$). For ruminating time, using 3 days or more met the criterion for coefficient of determination ($r^2 \geq 0.929$), but not that for slope and intercept.

Table 2. Coefficients of determination¹ (r^2) and significance of the slope and intercept differing from 1 and 0,² respectively, for different combinations of sampling intervals and days compared with 6 d of observation using 1-min sampling interval

Behavioral activity and interval	Number of sampling days					
	1	2	3	4	5	6
Eating						
1 min	0.812	0.908	0.953	0.971	0.991	1.000
2 min	0.771	0.997	0.996	0.996	0.997	0.999
3 min	0.771	0.995	0.993	0.993	0.995	0.995
4 min	0.825	0.991	0.986	0.986	0.991	0.993
5 min	0.783	0.982*	0.980*	0.980*	0.982*	0.986*
10 min	0.658**	0.971**	0.967**	0.967**	0.971**	0.964**
15 min	0.676**	0.885**	0.888**	0.888**	0.885**	0.900**
30 min	0.688**	0.835**	0.833**	0.833**	0.835**	0.862**
60 min	0.485**	0.792**	0.800**	0.800**	0.792**	0.829**
Ruminating						
1 min	0.732	0.867*	0.929*	0.943*	0.996*	1.000
2 min	0.740	0.996**	0.981*	0.981*	0.996**	1.000
3 min	0.758	0.997**	0.983*	0.983*	0.997**	1.000
4 min	0.705	0.996*	0.982	0.982	0.996*	0.999
5 min	0.745	0.996**	0.980*	0.980*	0.996**	0.998
10 min	0.593	0.983*	0.980**	0.980**	0.983*	0.985
15 min	0.664	0.963*	0.942*	0.942*	0.963*	0.958
30 min	0.512**	0.957*	0.954**	0.954**	0.957*	0.943
60 min	0.161**	0.812	0.774*	0.774*	0.812	0.814
Drinking						
1 min	0.856*	0.945*	0.952	0.967	0.994	1.000
2 min	0.880**	0.992	0.988	0.988	0.992	0.990*
3 min	0.776	0.983	0.973	0.973	0.983	0.992
4 min	0.709**	0.937*	0.922*	0.922*	0.937*	0.928**
5 min	0.829**	0.895	0.847	0.847	0.895	0.936
10 min	0.674**	0.924	0.872	0.872	0.924	0.953*
15 min	0.397**	0.781*	0.749*	0.749*	0.781*	0.841*
30 min	0.427**	0.641*	0.551	0.551	0.641*	0.710*
60 min	0.250**	0.480**	0.455**	0.455**	0.480**	0.536**
Standing						
1 min	0.410	0.671	0.605	0.804	0.918	1.000
2 min	0.405	0.987	0.969	0.969	0.987	1.000
3 min	0.416	0.985	0.964	0.964	0.985	1.000
4 min	0.409	0.987	0.969	0.969	0.987	0.999
5 min	0.395	0.985	0.966	0.966	0.985	0.997
10 min	0.372	0.976	0.954	0.954	0.976	0.995
15 min	0.363	0.974	0.959	0.959	0.974	0.986
30 min	0.427	0.886	0.846	0.846	0.886	0.927
60 min	0.389**	0.778*	0.711	0.711	0.778*	0.886**
Lying						
1 min	0.410	0.669	0.604	0.802	0.918	1.000
2 min	0.405	0.986	0.967	0.967	0.986	1.000
3 min	0.416	0.984	0.964	0.964	0.984	0.999
4 min	0.409	0.986	0.968	0.968	0.986	0.999
5 min	0.395	0.984	0.966	0.966	0.984	0.998
10 min	0.371	0.975	0.953	0.953	0.975	0.995
15 min	0.362	0.975	0.958	0.958	0.975	0.986
30 min	0.428	0.886	0.846	0.847	0.886	0.927
60 min	0.390**	0.778*	0.710	0.710	0.777*	0.886**

continued

Table 2. *Continued*

Behavioral activity and interval	Number of sampling days					
	1	2	3	4	5	6
Meals/d						
1 min	0.770*	0.889	0.886	0.938	0.987	1.000
2 min	0.783*	0.967	0.952	0.952	0.967	0.977
3 min	0.664*	0.938	0.922	0.922	0.938	0.969*
4 min	0.547	0.930*	0.910	0.909	0.930*	0.943*
5 min	0.618	0.672	0.648	0.667**	0.672	0.694
10 min	0.168	0.507	0.487	0.794	0.507	0.484
15 min	0.327	0.198	0.189	0.598	0.198	0.211
30 min	0.036	0.015	0.010	0.361	0.015	0.014
60 min	0.035	0.0003	0.002	0.239	0.0003	0.0004

¹All relationships were significant at $P < 0.01$.

²Slope and intercept were significant (* $P < 0.05$, ** $P < 0.01$) from 1 and 0, respectively.

With 6 d of observation, the sampling intervals that could be used to predict behavioral activities at 1-min observation with no difference from 1 and 0 for slope and intercept were (Table 2): up to 4-min scanning intervals for eating time ($r^2 \geq 0.993$; $P < 0.01$), 2 to 30 min for ruminating time ($r^2 \geq 0.943$; $P > 0.05$), 3- and 5-min sampling intervals for drinking time, and intervals of 2 to 30 min for standing and lying times ($r^2 \geq 0.927$; $P > 0.05$). To detect meal frequency, only a scanning frequency of 2 min with 6 d of observation met the criteria. The optimum sampling frequency for meals is likely dependent on the meal criterion used to define a meal. The relatively short meal criterion used in this study may account for the relatively short scanning frequency needed.

The optimum combinations of sampling days and intervals to monitor an activity were chosen based on the minimum number needed to obtain a strong relationship ($r^2 \geq 0.90$) with 6 d of observations at 1-min scanning intervals, with slope and intercept not different ($P > 0.05$) from 1 and 0, respectively. For estimating eating, the combination of 2 d of recording scanned at an interval of 4 min was selected as suitable ($r^2 = 0.991$, $P < 0.001$; Table 2 and Figure 1a). Using more observational days with longer intervals did not allow for less frequent scanning because the slope and intercept differed ($P < 0.05$) from 0 and 1 (Table 2). For estimating ruminating, 3 d with 4-min sampling was highly ($r^2 = 0.982$, $P < 0.001$; Figure 1b) related to 1-min time sampling of 6 d with slope and intercept not different ($P > 0.05$) from 1 and 0, respectively (Table 2). Fewer observation days and less frequent scanning intervals also had a strong relationship, but the slope and intercept were different ($P < 0.05$) from 0 and 1. For estimating drinking behavior, the combination of 2 d at 10-min intervals was suitable for representing instantaneous sampling at 1-min

intervals for 6 d ($r^2 = 0.924$, $P < 0.001$, Table 2). However, because the 4-min scan had slope and intercept different ($P < 0.05$) from 1 and 0, respectively, the recommendation is to use at least a 3-min scan for drinking ($r^2 = 0.983$, $P < 0.001$, Figure 1c). For standing and lying behaviors, 2 d at 15-min scanning intervals was suitable for estimating 1-min sampling for 6 d ($r^2 = 0.97$, $P < 0.001$, Table 2 and Figure 1d and e). For estimating meal frequency, the combination of 2 d at 3-min scanning intervals was suitable ($r^2 = 0.938$, $P < 0.001$, Table 2).

Effects of F:C Ratio on Behavioral Activities

Effects of F:C ratio of diets on behavioral activities (eating, ruminating, chewing, drinking, standing, and lying) for beef heifers are shown in Table 3. Eating time (min/d) was greatly ($P < 0.001$) affected by F:C ratio with greater eating time for HF compared with LF. As expected, the time spent ruminating for heifers fed the HF diet was greater ($P < 0.001$) than for those fed the LF diet, and consequently total chewing time was also greater ($P < 0.001$) for the HF diet. When expressed as minute per unit intake of DM, OM, NDF, or peNDF_{1,18}, eating ($P < 0.01$), ruminating ($P \leq 0.01$), and total chewing time ($P < 0.01$) remained greater for heifers fed HF compared with heifers fed LF. However, the opposite was true when these chewing activities were expressed as min per unit of peNDF_{8,0}. Greater F:C ratio decreased time devoted to drinking ($P = 0.028$) and lying down ($P = 0.007$), but increased standing time ($P = 0.007$).

The number of meals per day for heifers fed the LF diet was greater ($P = 0.033$) than that of heifers fed the HF diet, but the length of meals for heifers fed the LF diet was shorter ($P = 0.010$) than that of heifers fed the HF diet (Table 4). The amount of

Figure 1. Relationship between (a) eating activity observed for 2 d with 4-min scanning interval, (b) ruminating activity observed for 3 d with 4-min scanning interval, (c) drinking activity observed for 2 d with 3-min scanning interval, (d) standing activity observed for 2 d with 15-min scanning interval, (e) lying behavioral activity for 2 d with 15-min scanning interval, and observations for 6 d with 1-min scanning. Optimum observation days and scanning activities for the various activities shown in were chosen based on $r^2 > 0.90$ and intercept and slope not different ($P > 0.05$) from 0 and 1, respectively.

DM or OM consumed per meal was not ($P > 0.05$) affected by the treatments. However, amounts of NDF, $\text{peNDF}_{8.0}$ and $\text{peNDF}_{1.18}$ consumed per meal were greater ($P \leq 0.03$) for heifers fed HF compared with those fed LF. Heifers that consumed HF also had a slower ($P < 0.001$) eating rate (g of DM/min) than those consuming LF.

There was no difference ($P > 0.05$) in the number of rumination bouts between HF and LF

diets (Table 5). Heifers fed HF had greater mean ($P = 0.003$) and maximum ($P = 0.014$) length of rumination bouts, but the minimum lengths of the bouts were not different ($P > 0.05$). The latency period after rumination bouts (length of time before ruminating occurred after eating stopped) tended ($P = 0.082$) to be lower for the HF diet, as were the maximum ($P = 0.016$) and minimum ($P = 0.037$) latency periods.

Table 3. Eating, ruminating, chewing, drinking, standing, and lying activities for heifers fed HF or LF diets based on 6 d of observation using 1-min scanning interval

Item	Treatment		SEM	P-value
	HF	LF		
Eating				
Min/d	272	218	6.1	<0.001
Min/kg of DM	33.4	19.7	1.0	<0.001
Min/kg of OM	35.7	20.6	1.1	<0.001
Min/kg of NDF	83.9	72.3	2.8	0.004
Min/kg of peNDF _{8.0}	238.5	481.2	12.8	<0.001
Min/kg of peNDF _{1.18}	87.2	74.7	2.9	0.003
Ruminating				
Min/d	553	483	14.7	<0.001
Min/kg of DM	67.8	43.8	2.0	<0.001
Min/kg of OM	72.5	45.7	2.1	<0.001
Min/kg of NDF	170.4	160.3	5.7	0.011
Min/kg of peNDF _{8.0}	484.3	1067.4	28.7	<0.001
Min/kg of peNDF _{1.18}	177.0	165.8	5.9	0.008
Chewing				
Min/d	825	701	18.3	<0.001
Min/kg of DM	101.2	63.5	2.8	<0.001
Min/kg of OM	108.2	66.3	3.0	<0.001
Min/kg of NDF	254.3	232.6	8.0	0.004
Min/kg of peNDF _{8.0}	722.8	1548.6	38.9	<0.001
Min/kg of peNDF _{1.18}	264.2	240.5	8.3	0.003
Drinking	32.5	42.4	4.9	0.028
Standing ¹	534	457	16.6	0.007
Lying ²	907	984	16.6	0.007

peNDF_{8.0} and peNDF_{1.18} = physically effective NDF determined as NDF content of diet multiplied by pef_{8.0} and pef_{1.18}, respectively.

¹Period effect ($P = 0.007$; 534 and 457 min/d for periods 1 and 2, respectively).

²Period effect ($P = 0.007$; 907 and 984 min/d for periods 1 and 2, respectively).

DISCUSSION

Animal behavior can be used to predict, identify, and assess health problems in animals to design more efficient production systems (González et al., 2008; Weary et al., 2009). Video recording and visual observation can provide accurate assessments of behavior of cattle in research settings, but continuous monitoring is labor intensive. A number of electronic sensors can be used to monitor behavior, particularly on commercial farms, but the accuracy and precision of these devices can be relatively low compared with video recordings (Mattachini et al., 2013). Therefore, when using electronic sensors, a large number of animals monitored over a longer period of time is needed. However, metabolic research studies often use few animals, with more intensive sampling. Thus, determining the minimum number of days and maximum scanning interval

Table 4. Meal patterns for heifers fed HF or LF diets based on 6 d of observation using 1-min scanning interval

Item	Treatment		SEM	P-value
	HF	LF		
Meals/d	12.2	15.0	1.21	0.033
Meal length, min/meal	25.4	17.4	2.07	0.010
Meal size, kg				
DM	0.70	0.79	0.07	0.243
OM	0.65	0.76	0.07	0.182
NDF	0.28	0.22	0.022	0.034
peNDF _{8.0}	0.099	0.031	0.005	<0.001
peNDF _{1.18}	0.266	0.209	0.021	0.033
Eating rate, g of DM/min	30.2	51.1	1.41	<0.001
DMI, kg/d	8.2	11.1	0.16	<0.001

peNDF_{8.0} and peNDF_{1.18} = physically effective NDF determined as NDF content of the diet multiplied by pef_{8.0} and pef_{1.18}, respectively.

within day required to obtain reliable estimates of behavior would help reduce labor requirements (Mitlöhner et al., 2001; Mattachini et al., 2013). Ito et al. (2009) using 3 d of continuous recordings (at 1-min intervals) reliably estimated 5 d of lying behavior on commercial dairy farms. This study examined the optimum sampling required to accurately predict the behavior using a baseline of 6 d of recordings with instantaneous scanning at 1-min intervals. Furthermore, behaviors of cows fed HF and LF diets were used to determine whether optimal scanning conditions were consistent for diets that vary in F:C ratio. In our study, all intervals started at the same time of day (start of each 24-h recording), and the data each day were processed once, unlike in the study by Hämmäläinen et al. (2016) in which processing of data started at various times. Because an important component of our study was to determine the minimum number of recording days needed, it was not possible to examine interval starting point, as it would have meant the days did not always represent unique 24-h recordings. The results from our study can be used by researchers monitoring cows visually in real time using trained observers, in addition to those using video recordings of cows.

Optimum Observational Sampling Frequency of Behavior

Research on utilizing different scanning intervals to predict the behavioral activities of individual cattle is limited (Mitlöhner et al., 2001). Longer scanning intervals of 30 min and 1 h have been used to monitor behavior of group-housed cattle, but the total number of animals performing each activity

Table 5. Rumination patterns for heifers fed HF or LF diets based on 6 d of observation using 1-min scanning interval

Item	Treatment		SEM	P-value
	HF	LF		
Number of bouts/d	15	15	0.57	0.816
Bout length				
Mean min/bout	38.4	32.4	1.57	0.003
Maximum min/bout	68.6	58.6	2.68	0.014
Minimum min/bout	11.9	10.6	1.12	0.210
Latency				
Mean min	19.4	26.0	2.79	0.082
Maximum min	44.5	70.6	6.65	0.016
Minimum min	4.1	6.0	0.93	0.037

Latency to ruminate = length of time before ruminating occurred after eating stopped.

is recorded rather than the activity of individual animals (feedlot cattle: [Ray and Roubicek, 1971](#); [Gonyou and Stricklin, 1981, 1984](#); dairy cows: [Overton et al., 2002](#)). To monitor the behavior of individual animals, some research studies have used trained observers to visually assess activity at 5-min intervals for 3 h/d ([Palacio et al., 2015](#)) to 1 or 2 d (e.g., [Beauchemin et al., 2002](#); [Krause et al., 2002](#)). This approach assumes that the observation session of each activity is divided into 5-min sampling intervals, and it is not clear how many days of monitoring is adequate. Video recordings are less obtrusive and can be done for longer periods of time, but manually summarizing the results is labor intensive. With sampling techniques, there is a trade-off between sampling efficiency and accuracy ([Hämäläinen et al., 2016](#)). To determine the optimum scanning frequency needed to monitor behavior, we used a baseline of 6 d with a fixed 1-min scanning interval generated from continuous video recordings. These baseline data were used to assess various scanning frequencies using criteria recommended by [Ledgerwood et al. \(2010\)](#): $r^2 \geq 0.90$ with slope and intercept not different ($P > 0.05$) from 1 and 0, respectively.

In contrast to our hypothesis, the optimum conditions required to accurately predict behavior did not differ for the two diets, as there were no diet $\times$ day or diet $\times$ scanning interval interactions. Regardless of diet, the results indicated that, when using a 1-min scanning frequency, at least 2 d is needed for eating, 3 d for ruminating and drinking, and 5 d for standing and lying. It should be noted that for rumination, however, a full 6 d was required to eliminate bias (significant slope and intercept). Alternatively, when activity is monitored for 6 d, scanning interval can be less frequent while

maintaining accuracy. In that case, 4 min is needed for eating, 30 min for ruminating, 5 min for drinking, and 30 min standing and lying. When sampling days and scanning intervals were examined together, the r^2 was not substantially improved by increasing the number of days beyond 2, but using a shorter scanning interval generally increased r^2 and eliminated bias and slope of predictions. The optimum minimum observation frequencies were: eating, 2 d with 4-min intervals; ruminating, 3 d with 4-min intervals; drinking, 2 d with 3-min intervals; and standing and lying, 2 d with 15-min intervals. Increasing the number of days or the sampling frequency beyond these minimums generally enhanced the accuracy of predictions, except in the case of rumination. Surprisingly, for rumination there was significant slope and intercept bias when 3 d was combined with a scanning interval of 2, 3, or 5 min, but not 4 min. Using 3 d with 4-min intervals, the difference between predicted and observed rumination for the range of times expected for cattle fed HF or LF diets would be less than ± 10 min/d. However, data obtained using observations at 4 min intervals were not useful for determining meal frequency.

An important finding of this study is that optimum scanning interval depends on the number of days of measurement. Other studies have examined optimum scanning interval without considering the impact of days of measurement. [Mittlöhner et al. \(2001\)](#) indicated scanning intervals of 5 ($r = 0.941$, $P < 0.01$) and 10 min ($r = 0.824$, $P < 0.01$) were accurate for measuring eating behavior in feedlot cattle over a 9-d period. [Miller-Cushon and DeVries \(2011\)](#) showed sampling intervals up to 5 min were sufficient to estimate continuous recording of eating activity in dairy calves when measured over 6 d. We also observed longer scanning intervals were highly related to observed data, but there was significant bias at intervals longer than 4 min. In agreement with our study, [Hämäläinen et al. \(2016\)](#) recommended a sampling interval of 4 min for eating activity with 90% confidence probability and 10% error bounds based on 29 d of continuous measurements. As errors increase with interval length, 15 min was recommended for ruminating in that study, which was considerably less frequent than the recommended 4 min interval in our study, probably due to the difference in recording duration.

Drinking was the behavior requiring the shortest scanning interval likely because drinking time is considerably less than other behaviors. [Chen et al. \(2016\)](#) reported that the amount of time cows spent visiting the water trough was accurately captured

using sampling intervals of ≤ 10 min. [Hämäläinen et al. \(2016\)](#) reported that when a 10-min scanning interval was used to estimate the behavior of dairy cows in tie-stalls, drinking produced the largest errors.

For standing and lying time of dairy cows in loose housing monitored over 3 d, [Mattachini et al. \(2013\)](#) showed sampling intervals from 1 to 15 min were accurate and precise, while longer sampling intervals of 30 and 60 min were also positively related, but slope and intercept were significantly different from 1 and 0. For feedlot cattle, [Mittlöhner et al. \(2001\)](#) indicated 30 min scans were suitable for measuring lying behavior, but the r^2 value compared with continuous recording was quite low (0.605). For dairy cows, [Chen et al. \(2016\)](#) indicated that for 2 d of measurement sampling intervals ≤ 3 min accurately estimated the number of lying bouts. Sampling strategies for lateral lying were also examined in feedlot steers by [Stackhouse-Lawson et al. \(2015\)](#), but estimates generated with instantaneous scan sampling never met the criteria for accuracy. Recent work by [Madruga et al. \(2017\)](#) recorded behaviors over 6 non-consecutive days in contrast to the 6 consecutive days used in this study. Their results revealed that 2-min sampling produced an accurate estimate of drinking behavior, while 20-min sampling was optimal for ruminating behavior in heifers fed a high-concentrate diet.

In addition to the minimum recommended sampling frequency for accurately estimating common behaviors (i.e., eating, drinking, ruminating, standing, and lying) provided in this study, [Tresoldi et al. \(2016\)](#) similarly determined the sampling intervals that could be accurately used to capture behavioral events associated with heat stress, including respiration rate (sampling interval ≤ 90 min), use of shaded areas and sprayed water use (≤ 60 min), and drooling (≤ 30 min).

Effects of F:C Ratio

The observed times spent eating and ruminating for heifers fed the LF (218 and 483 min/d) and HF (272 and 553 min/d) diets were in the range of expected values. In a recent summary of treatment means for dairy cows from peer reviewed publications, [White et al. \(2017\)](#) reported a mean eating time of 284 min/d (ranging from 141 to 507 min/d). In that same study, mean ruminating time was 436 min/d (ranging from 236 to 610 min/d), while [Zebeli et al. \(2006\)](#) reported mean ruminating time was 434 min/d (ranging from 151 to 630 min/d). For lighter weight beef heifers fed very high-concentrate

(> 85%) diets, [Rotger et al. \(2006\)](#) and [Robles et al. \(2007\)](#) both reported rumination time of approximately 350 min/d.

Feeding HF and LF diets resulted in differences in behavior of the cattle as expected. It is well known that times spent eating and ruminating increase with intake of NDF and peNDF ([Beauchemin, 1991](#)). The greater times spent eating, ruminating, chewing, and standing observed for the cattle fed the HF diet are consistent with expectations that increased forage intake promotes chewing, and more time spent eating requires longer standing time ([DeVries et al., 2007](#)). Longer eating time is required for higher forage diets because eating rate is slower, as observed in this study where cattle fed HF consumed fewer, but longer meals, at a slower eating rate. The mechanics of eating and ruminating in cattle are well understood ([Church, 1969](#)). Cattle use their lips, teeth, and tongue to move feed into the mouth, where it is chewed, and feed is swallowed once the particle size is sufficiently reduced and the bolus is lubricated. Thus, forage requires greater mastication during chewing compared with concentrate due to its longer particle size.

The shorter time devoted to drinking activity for cows fed the HF diet is consistent with the greater moisture content of the barley silage (59%) compared with the concentrate (8%). Drinking behavior was the activity with shortest duration (10 to 130 min/d; [Table 1](#)), but within the expected range. For example, [González et al. \(2009\)](#) reported an average drinking time of 33 min/d in young Holstein heifers (BW, 134 kg) and [Huzzey et al. \(2005\)](#) reported that drinking time averaged 5.5 to 6.8 min/d for dairy cows pre- and postpartum. In addition to moisture content of the ration, water intake, and hence drinking time, is related to DMI ([Schake and Riggs, 1969](#)). Despite lower DMI of cows fed HF (11.1 vs. 8.2 kg/d) compared with LF, drinking time was still longer for cows fed HF; thus, moisture content of the feed was the dominant factor affecting drinking time in this study.

The greater NDF content and lower digestibility of the HF diet may have led to the lower DMI of cattle fed the HF. Decreased DMI of cattle corresponded to fewer, but longer meals with slower eating rate consistent with some ([Nielsen, 1999](#); [Abijaoudé et al., 2000](#)), but not all studies ([DeVries et al., 2007](#)). [DeVries et al. \(2007\)](#) reported no effect of F:C ratio on meal number, possibly because of how meals were defined in that study (meal criterion = 26.0 ± 10 min, which included periods of inactivity between eating bouts).

The effect of F:C ratio on length of rumination bouts (min/bout) can be variable. Our study showed that rumination bouts ranged from 11.9 to 68.6 min each for HF in contrast to 10.6 to 58.6 min/bout for the LF diet, respectively, with an average length of 38.4 min/bout observed for heifers fed the HF diet, which was greater than that of heifers fed the LF (32.4 min/bout) diet. The lack of F:C effects on the number of rumination bouts suggests that ruminating time is dependant mainly on duration of rumination bouts. Ruminants have an innate urge to ruminate with the duration and number of bouts increasing as the need to ruminate increases due to type, quantity, or physical form of the diet (Welch, 1982). The results from our study indicate that bout length is more responsive to increased need to ruminate caused by increased F:C ratio, than is bout frequency.

The longer latency period between eating and the onset of rumination in heifers fed LF compared with HF diets was likely the result of ingestion of highly fermentable carbohydrates. Rumination activity after meals can be delayed, despite a large quantity of feed in the rumen, because various chemical stimuli inhibit ruminal contractions (Titchen, 1958). Thus, it might be possible to use the length of this latency period as an indication of risk of acidosis although this would need to be examined in future research.

CONCLUSIONS

Increasing the proportion of forage in the diet of beef heifers increased eating, ruminating, and standing time, while time spent drinking and lying were decreased. However, diet did not affect the accuracy and precision of predicting behavior from video recordings of the cattle. The recommended minimum number of sampling days at 1-min sampling interval for accurately estimating a specific set of behaviors of beef heifers in tie-stalls was: 2 d for eating, 3 d for drinking, 5 d for standing and lying, and 4 d for meals. When activity is monitored for 6 d, sampling interval can be less frequent to maintain accuracy: 4 min is needed for eating, 30 min for ruminating, 5 min for drinking, 30 min for standing and lying, and 2 min for meals. When sampling days and scanning intervals are combined, the recommended minimum observational frequencies for accurately estimating behaviors were: eating, 2 d with 4-min intervals; ruminating, 3 d with 4-min intervals; drinking, 2 d with 3-min intervals; and standing and lying, 2 d with 15-min intervals. Increasing sampling frequency beyond these minimums further enhanced the accuracy and precision of predictions.

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