Effects of Concentrate Intake on Subsequent Roughage Intake and Eating Behavior of Cows in an Automatic Milking System


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ABSTRACT

Twenty-three cows were kept in a free-stall barn with an automatic system for milking and feeding. The cows were offered mixed silage for ad libitum consumption. Concentrates were fed with the automatic milking system. This experiment examined the eating behavior of cows and the relationship between the intake of concentrate and the subsequent intake of roughage in a free-stall barn with an automatic milking system. An individual meal criterion was used to characterize the meal pattern of each cow. Daily roughage intake and the time spent on meals ranged from 25.6 to 40.2 kg/d and from 70.1 to 240.0 min/d, respectively. Meal duration and size did not differ, regardless of whether concentrate was eaten or not eaten during the premeal interval. Multiple regression analysis showed that the partial regression coefficient for the duration of the premeal interval was significant for each cow, and the regression coefficient for the intake of concentrate during the premeal interval was significant for 78% of the cows. Separation of the eating phases into concentrate and roughage showed that the cows made many repeated traffic cycles through the automatic milking system and feeding section of the barn, thus revealing a high demand for concentrate under the experimental conditions.

(Key words: automatic milking, feed intake, group housing, cow traffic)

Abbreviation key: AMS = automatic milking system, BMI = between-meal interval, PMI = premeal interval.

INTRODUCTION

Feed intake of dairy cows is essential to maintain high milk production. Although the importance of roughage may differ during different stages of lactation, roughage intake remains an important aspect of feed intake. Roughage intake generally decreases as concentrate intake increases (10, 23). Campling and Murdoch (1), however, reported that the roughage intake was higher when small amounts of concentrate were fed than when no concentrate was fed. There are many reports (23) regarding the effect of concentrate intake on fermentation in the rumen. In some reports (9, 14), the effect of concentrate intake on roughage consumption was sequential; cows ate more roughage (14), and digestibility of fiber in the rumen was greater (20), when cows were given roughage before concentrate than when cows received roughage after concentrate.

Relationships between concentrate intake and roughage intake have often been described based on daily data. For feed intake and eating behavior measured in units shorter than a day, characteristics of the meal state (duration and frequency of the meals and eating speed) need to be considered. Some reports (2, 11, 14) have analyzed the meal state, but in those reports, the dairy cows were housed individually. Many commercial dairy farms keep their cows in groups. In group housing, eating behavior of dairy cows during the day, eating time, or both vary with social dominance (12). During periods when many cows are eating (after milking and feeding), cows with a lower social rank may have to wait.

Automatic milking systems (AMS) have been developed to improve efficiency and flexibility and are being introduced on commercial farms. In an AMS, milking time is not fixed. Because cows can enter the AMS voluntarily, and feedstuffs are available for ad libitum intake, cows do not eat simultaneously. Therefore, results of restricted intake cannot be applied to results of ad libitum intake because the size and duration of the meal might be related to other

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factors, such as duration of the premeal interval (PMI) (2, 11, 16).

To discuss the feeding management and the layout of the barn in relation to the AMS, the relationship between concentrate intake and roughage intake under ad libitum feeding conditions must be examined. Therefore, this experiment studied the eating behavior of cows kept in a group housing system with an AMS and examined the relationship between the concentrate intake per visit to the AMS and the subsequent roughage intake of cows. Moreover, the behavioral patterns of consumption of roughage and concentrate were examined in relation to cow movements.

**MATERIALS AND METHODS**

**Cows and Housing**

Twenty-three cows (Holstein Friesian × Friesian Holland; 6 cows of parity 1, 9 cows of parity 2, 4 cows of parity 3, and 3 cows of parity 4; mean BW of 626 kg) were kept in a free-stall barn with a lying area, an AMS, and a feeding area (Figure 1). The cows could move through the barn from the lying area to the AMS, from the AMS to the feeding area, and from the feeding area to the lying area (one-way traffic). The lying area had 27 cubicles. The AMS consisted of two selection units (stalls) and one milking unit. Cows were given concentrate (6490 kJ of NE/kg; 192 g of CP/kg) in the selection units and in the milking stall of the AMS. The mean concentrate offering was 11.4 kg/d, and mean milk production was 33.4 kg/d. The time and number of milkings were variable. The total amount of concentrate was offered in six 4-h periods daily. If a cow entered the AMS more than once within a period and if the predefined fixed amount of concentrate had already been eaten, the cow was not offered any concentrate until the next period. The feeding area contained an automatic feeding system with 12 feeding troughs (5). Cows were offered a mixed roughage consisting of 65% grass silage (37% DM, 6904 KJ of NE/kg of DM, 244 g of CP/kg of DM, and 403 g of NDF/kg of DM), 28% corn silage (35% DM, 6317 KJ of NE/kg of DM, 74 g of CP/kg of DM, and 411 g of NDF/kg of DM), and 7% sugar beet pulp (88% DM, 6926 KJ of NE/kg of DM, 94 g of CP/kg of DM, and 450 g of NDF/kg of DM) for ad libitum intake at the troughs. If necessary, the troughs were refilled every 30 min. Artificial light was constant during the experimental period.

**Data Collection**

The experiment was carried out for 30 d. For each feeding bout (occupation of a feeding trough), the time the bout began, the time the bout ended, and the amount of roughage eaten were recorded by the automatic feeding system. Intervals between feeding bouts were classified as a within-meal interval or a between-meal interval (BMI) based on the distribution of the frequency of BMI. The minimum duration of a BMI, the meal criterion, was determined per cow according to Metz (11). During this procedure, log survivor curves for the intervals between feeding bouts as a function of the interval duration were created for each cow. Lines for linear regression were fitted for the steep and flat portions of the curves. The intersection of the two linear regression lines was defined as the meal criterion. A meal was defined as the period between two BMI; therefore, a meal could consist of one or more feeding bouts. The meal size was defined as the amount (kilograms) of silage eaten during a meal, and the meal duration (minutes) was defined as the time from the start of the first feeding bout to the end of last feeding bout in one meal. According to the individual definition of the meal criterion, the daily meal frequency, meal duration, and mean meal size were calculated. The eating speed was calculated from meal size and duration. Diurnal eating patterns were created using the percentage of time per hour that was spent on meals. A traffic cycle was determined as the period from exit of the AMS until entrance of the AMS, thus excluding the time spent in the AMS. During 4 d of the experimental period, social interactions among the cows in the part of the lying area before the selection units were observed. When a cow had one or more interactions with another cow, a dominance relationship was determined that indicated whether the cow was dominant or subordinate to the other cow. Using the dominance relationships for each cow, a dominance

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**Figure 1.** Layout of the barn with the feeding area (FA), lying area (LA), and automatic milking system (AMS). The AMS consists of two selection units (SU) and a milking unit (MU).
value \( (dv) \) was calculated: 
\[
dv_i = \frac{\text{(number of cows subordinate to cow } i)}{\text{(number of known dominance relationships of cow } i)}.
\]

**Analyses**

**Roughage eating.** Descriptive statistics were calculated to describe the roughage eating of the cows. The effect of parity (primiparous vs. multiparous cows) on eating was determined with a Mann-Whitney U test (18), using a significance level of 0.05. Correlations between various aspects of eating behavior were calculated using correlation coefficients and Spearman's coefficient of rank correlation (18).

**Diurnal eating pattern.** The diurnal eating pattern was based on the percentage of time per hour spent on meals. Using the diurnal eating pattern, the theoretical number of cows per feeding place was calculated. A mean diurnal eating pattern as well as individual diurnal eating patterns were fitted to a cubic equation:

\[
Y_t = \beta_0 + \beta_1X_t + \beta_2X_t^2 + \beta_3X_t^3 + \epsilon_t
\]

where

- \( Y_t \) = percentage of time spent on meals during hour \( t \) (\( t = 1, 2, \ldots, 24 \)),
- \( \beta_0 \) = intercept,
- \( \beta_{1,2,3} \) = partial regression coefficients,
- \( X_t \) = hour of the day (\( t = 0, 1, 2, \ldots, 23 \)), and
- \( \epsilon_t \) = residual.

The overall significance of the cubic equations was determined using the \( F \) value (18). For significant equations, the hours of the day during which the maximum and minimum percentage of time was spent on meals were calculated from the equations.

**Roughage intake in relation to consumption of concentrate.** The daily meal frequency, the mean meal duration, and the mean meal size were compared with intake of concentrate during the PMI (defined as the BMI before a specific meal), and the duration of the PMI. The comparisons between means were carried out using Wilcoxon's signed rank test (18). For each cow, the combined effect of concentrate intake during the PMI and the duration of the PMI on meal size was investigated using multiple regression analysis:

\[
MS_i = \beta_{0i} + \beta_{1i}L_i + \beta_{2i}CI_i + \epsilon_i
\]

where

- \( MS_i \) = meal size of cow \( i \),
- \( \beta_{0i} \) = intercept,
- \( \beta_{1i,2i} \) = partial regression coefficients,
- \( L_i \) = duration of PMI,
- \( CI_i \) = concentrate intake during PMI, and
- \( \epsilon_i \) = residual.

**Cow traffic.** Traffic cycles were classified into six categories according to the amount of concentrate offered in the AMS (0 kg, >0 and \( \leq 1 \) kg, or >1 kg) and roughage intake in the feeding area (roughage intake or no roughage intake). The frequency and duration of the six different categories of traffic cycles were compared with one another. The meal size and duration for the three categories of traffic cycles in which roughage was consumed were compared to define the relationship between concentrate intake and subsequent eating behavior when cows were offered roughage. The frequencies of occurrence of sequences from one traffic cycle to the next were compared within cows using a chi-square test for each cell (7). In this analysis, traffic cycles were classified into four categories according to the presence of concentrate and roughage eating: 1) traffic cycle without roughage eating or the presence of concentrate, 2) traffic cycle with roughage eating and without the presence of concentrate, 3) traffic cycle without roughage eating and with the presence of concentrate, and 4) traffic cycle with roughage eating and with the presence of concentrate.

**RESULTS AND DISCUSSION**

**Meal Criterion**

The frequency distribution of the meal criterion (minimum duration of PMI) is presented in Figure 2. The mean duration of the meal criterion was 13 min (SD, 2.1; range, 8 to 17). The mean number of PMI was 816 (SD, 319; range, 326 to 1674). Dourmad (4) used a 10-min meal criterion to characterize meals, the mean meal criterion of 7 min was used to avoid overestimation of the number of meals caused by a low meal criterion (11). Herein, an individual meal criterion was used to characterize the meals of each cow; therefore, it was not necessary to use a meal criterion that was longer than the mean.

**Roughage Eating**

The daily intake of roughage, the daily eating time, and the speed of eating roughage are presented in Table 1. The daily intake of roughage was 32.3 kg/d, the daily eating time was 154.1 min/d, and the mean
eating speed was 0.249 kg/min. Eating speed could be affected by quality of feed, parity, social ranking, and daily time of access to the diet (19). In this study, the quality of roughage was held constant during the experimental period, and roughage was fed for ad libitum intake. No significant \( (P > 0.05) \) effect of parity on eating speed was found (means for primiparous and multiparous cows were 0.252 and 0.248 kg/min, respectively). These results were in agreement with observations of Dado and Allen (2). Deswysen et al. (3) found that heifers with higher feed intake spent less time eating per unit of feed intake. The coefficient of variation was considerably larger for daily eating time \( (24.4\%) \) than for the daily roughage intake \( (13.3\%) \). There was a significant, negative correlation between daily eating time and eating speed \( (r = -0.850; P < 0.05) \). No significant correlation was found between eating speed and roughage intake \( (r = 0.085; P > 0.05) \), which implied that the higher variation of eating speed was caused by the individual difference of daily eating time, not by a variation of roughage intake. Spearman’s coefficient of rank correlation between dominance value and daily eating time was not significant \( (r_s = -0.179; P > 0.05) \). Given that heifers with a lower social rank spend less time eating when feeding space is reduced (12), in this experiment, cows with a lower social rank would have sufficient time to eat roughage. The correlation coefficient between the daily roughage intake and the meal size was significant \( (r = 0.664; P < 0.05) \), but the correlation coefficient between daily roughage intake and meal frequency was not significant \( (r = -0.095; P > 0.05) \). These results indicated that cows increased daily roughage intake by increasing the meal size rather than by increasing meal frequency.

**Diurnal Eating Pattern**

Figure 3 shows the diurnal pattern of daily eating time. The percentage of time spent per hour on meals from midnight to early morning appeared to be lower than that during the afternoon. Cows have been reported to spend more time eating during the period immediately after feed becomes available or after milking (2). Wierenga and Hopster (21) pointed out that, in group housing circumstances, the number and time of eating peaks were dependent on the time that the feed was offered. During the eating peaks, cows ate roughage simultaneously. If, in group housing systems, the feeding space was insufficient during those periods, cows with a low social ranking had to wait for cows with a higher social ranking. In the present study, the milking time was variable, and, if needed, additional roughage was offered every 30 min; therefore, the cows were not tempted to eat roughage quickly, and the variation among cows in the percentage of time spent on meals during the day was small \( (range, 2.6\% to 5.7\%) \). The diurnal eating pattern suggested that cows had a daily rhythm of roughage intake even under these milking and feeding conditions.

The coefficients of variation for the percentage of time spent eating over the day varied from 28.4% at 1500 h to 59.9% at 0100 h. When roughage was fed, the mean time spent eating did not decrease if the number of cows per feeding place was about 2.5 cows.
TABLE 1. Daily roughage intake (DM basis), daily eating time, and eating speed.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
<th>SD</th>
<th>CV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughage intake, kg/d</td>
<td>32.3</td>
<td>25.6</td>
<td>40.2</td>
<td>4.3</td>
<td>13.3</td>
</tr>
<tr>
<td>Daily eating time, min/d</td>
<td>154.1</td>
<td>70.1</td>
<td>240.0</td>
<td>38.2</td>
<td>24.4</td>
</tr>
<tr>
<td>Eating speed, kg/min</td>
<td>0.249</td>
<td>0.142</td>
<td>0.487</td>
<td>0.072</td>
<td>28.8</td>
</tr>
</tbody>
</table>

1Eating speed = roughage intake/daily eating time.

Observations of Metz (12) showed that, when the number of feeding places for heifers was reduced to 3 heifers per place, cows with lower social rank spent less time eating and adjusted their feeding times. These results suggested that some cows shifted their eating time. However, using the data collected in the current experiment, the theoretical number of cows per feeding place was 5. (Cows spent a maximum of 12 min/h eating roughage.) Therefore, the shift in eating time might have been because cows could only eat roughage after visiting the AMS, and the selection unit of the AMS could only be visited by 2 cows at once, causing the cows with a low social rank to shift their eating time.

The cubic equation for the diurnal eating pattern for all cows (n = 23) and the calculated minimum and maximum percentages of time per hour spent eating are presented in Table 2. The maximum (5.4%) and minimum (2.9%) eating times per hour were at 1744 and 0402 h, respectively (Figure 3). Although the cubic equation described the diurnal pattern of eating behavior well, the fit worsened (Figure 3) after 1700 h, which might indicate that the eating pattern was different at night than during the day.

Individual equations were significant for 8 of the 23 cows. The cubic equations and the dominance values of the cows are presented in Table 2. Six of these cows had approximately the same pattern of eating times, which could be compared with the overall eating pattern. One cow had an eating pattern in which the maximum and minimum percentages of eating time were at 2000 and 0800 h, respectively. Maximum and minimum percentages of eating time were at 1600 and 0200 h, respectively, for another cow. These 2 cows had the lowest dominance value. Although these results were for only 8 of 23 cows, they supported the observation that cows in a group housing system with a low social rank shifted their time schedule. This time shift might be affected by the limited entrance to the AMS, as has been discussed previously. For more conclusive results, the individual pattern of visits to the AMS in relation to social interaction of cows before entrance to the AMS should be examined.

Roughage Intake in Relation to Consumption of Concentrates

The daily meal frequency, meal duration, meal size, and eating speed for roughage, in relation to the consumption of concentrate during the PMI (the BMI before the meal) are presented in Table 3. On aver-

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TABLE 2. Estimated diurnal patterns of time spent eating meals for all cows and, if significant (P < 0.05), for individual cows.

<table>
<thead>
<tr>
<th>Time</th>
<th>Maximum</th>
<th>Minimum</th>
<th>$\beta_0$</th>
<th>$\beta_1$</th>
<th>$\beta_2$</th>
<th>$\beta_3$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17.72</td>
<td>4.03</td>
<td>3.700</td>
<td>-0.416</td>
<td>0.0634</td>
<td>-0.0019</td>
<td>0.861</td>
</tr>
<tr>
<td>All</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cows</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$d_v$</td>
<td>0.27</td>
<td>15.36</td>
<td>2.528</td>
<td>-0.259</td>
<td>0.0785</td>
<td>-0.0030</td>
<td>0.787</td>
</tr>
<tr>
<td></td>
<td>0.29</td>
<td>19.55</td>
<td>8.081</td>
<td>-1.588</td>
<td>0.1355</td>
<td>-0.0032</td>
<td>0.792</td>
</tr>
<tr>
<td></td>
<td>0.45</td>
<td>17.00</td>
<td>3.446</td>
<td>-0.619</td>
<td>0.0100</td>
<td>-0.0032</td>
<td>0.668</td>
</tr>
<tr>
<td></td>
<td>0.52</td>
<td>16.53</td>
<td>4.856</td>
<td>-1.110</td>
<td>0.1440</td>
<td>-0.0038</td>
<td>0.657</td>
</tr>
<tr>
<td></td>
<td>0.59</td>
<td>17.47</td>
<td>4.726</td>
<td>-1.147</td>
<td>0.1440</td>
<td>-0.0042</td>
<td>0.692</td>
</tr>
<tr>
<td></td>
<td>0.69</td>
<td>17.31</td>
<td>2.924</td>
<td>-0.716</td>
<td>0.1203</td>
<td>-0.0038</td>
<td>0.698</td>
</tr>
<tr>
<td></td>
<td>0.76</td>
<td>17.01</td>
<td>4.334</td>
<td>-0.776</td>
<td>0.1070</td>
<td>-0.0033</td>
<td>0.564</td>
</tr>
<tr>
<td></td>
<td>0.83</td>
<td>15.38</td>
<td>4.396</td>
<td>-0.647</td>
<td>0.0893</td>
<td>-0.0028</td>
<td>0.592</td>
</tr>
</tbody>
</table>

1Estimated percentage of time spent eating meals per hour.

2$Y_t = \beta_0 + \beta_1X_t + \beta_2X_t^2 + \beta_3X_t^3 + \epsilon_t$; where $Y_t =$ percentage of time spent eating meals during hour $t$ ($t = 1, 2, \ldots, 24$), $\beta_0 =$ intercept, $\beta_{1,2,3} =$ partial regression coefficients, $X_t =$ hour of the day ($t = 0, 1, 2, \ldots, 23$), and $\epsilon_t =$ residual.

3Dominance value.

TABLE 3. Daily frequency, duration, and size of the meals that followed a premeal interval with or without the presence of concentrate.

<table>
<thead>
<tr>
<th>Concentrate intake during premeal interval</th>
<th>No</th>
<th>Yes</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>SD</td>
<td>X</td>
</tr>
<tr>
<td>Frequency, no. of meals/d</td>
<td>3.9</td>
<td>1.5</td>
<td>4.5</td>
</tr>
<tr>
<td>Meal duration, min per meal</td>
<td>17.9(^a)</td>
<td>4.1</td>
<td>19.8(^b)</td>
</tr>
<tr>
<td>Meal size, kg per meal</td>
<td>3.9</td>
<td>1.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Eating speed, kg/min</td>
<td>0.252</td>
<td>0.075</td>
<td>0.248</td>
</tr>
</tbody>
</table>

\(^{a,b}\)Means within the same row followed by different superscript letters differ (\(P < 0.05\)).

age, cows ate 4.5 meals/d after eating concentrate during the PMI and 3.9 meals/d when no concentrate was consumed in the PMI. The variation of meal frequency was considerably larger for the PMI with consumption of concentrate than for the PMI without consumption of concentrate. When concentrate was eaten during the PMI, the meal duration was prolonged. Meal size was not related to concentrate intake during the PMI. Eating speeds did not differ, regardless of whether or not cows ate concentrate during the PMI. When feeding time was restricted, cows ate roughage when it was provided before concentrate supplementation instead of after concentrate supplementation. This result was caused by a prolonged eating time and increased eating frequency during the feeding period (14). Feeding sequence also has been reported to affect digestion of fiber in the rumen (20). According to research results on restricted feeding times (14), the meal size and duration should have been larger when the intake of roughage followed an interval during which no concentrate was consumed than when the intake of roughage followed an interval during which concentrate was consumed. However, the results of the present study showed no differences in meal size and opposite results in meal duration between the two types of PMI. Other reports (2, 11) concluded that, under ad libitum conditions, the meal size, meal duration, or both increased when the PMI was prolonged. This result might indicate that meal size or duration was not only affected by concentrate intake during the PMI but also by the duration of the PMI.

Figure 4 shows the relationship between the duration of the PMI and the meal size. Because meal size differed for cows in this study, we used the meal size index (meal size in relation to the mean meal size of the individual cow). The mean meal size index of the cows increased linearly with prolonged PMI.

The results of the multiple regression analyses for 23 individuals are summarized in Table 4. The minimum and maximum number of observations used for the multiple regression analysis was 178 and 332, respectively. The partial regression coefficient for the duration of the PMI was significant (\(P < 0.05\)) for each cow. The partial regression coefficient for the

![Figure 4. Relationship between meal size index ([mean range of meal size/mean meal size of all meals] \(\times 100\)), calculated for individual cows, and the premeal interval duration. The values on the x-axis resemble midpoints of the range (0 to 30, 30 to 60, . . . , and 270 to 300 min).](http://example.com/figure4.png)

Table 4. Results of the multiple regression analysis for individual cows with meal duration as the dependent variable and length of premeal interval (L) and concentrate intake during the premeal interval (CI) as independent variables.

<table>
<thead>
<tr>
<th>CI</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Significant(^1) (b \geq 0.20), no.</td>
</tr>
<tr>
<td></td>
<td>Significant positive (b), no.</td>
</tr>
<tr>
<td></td>
<td>Significant negative (b), no.</td>
</tr>
<tr>
<td></td>
<td>Lowest significant (b)(^2)</td>
</tr>
<tr>
<td></td>
<td>Highest significant (b)(^3)</td>
</tr>
<tr>
<td></td>
<td>Significant (0 &lt; b &lt; 0.20), no.</td>
</tr>
<tr>
<td></td>
<td>Significant (0.20 &lt; b &lt; 0.40), no.</td>
</tr>
<tr>
<td></td>
<td>Significant (0.40 &lt; b &lt; 0.60), no.</td>
</tr>
<tr>
<td></td>
<td>Significant (0.60 &lt; b &lt; 0.80), no.</td>
</tr>
<tr>
<td></td>
<td>Significant (0.80 &lt; b &lt; 1), no.</td>
</tr>
</tbody>
</table>

\(^1\)Significant according to Student’s \(t\) test (\(P < 0.05\)).
\(^2\)Partial regression coefficient.
\(^3\)Absolute value.
Concentrate intake during the PMI was significant ($P < 0.05$) for 78% of the cows. The values of the significant partial regression coefficients were positive for $\beta_1$ and negative for $\beta_2$. The mode of $\beta_1$ was in the range from 0.40 to 0.60, and the mode of $\beta_2$ was in the range from 0.20 to 0.40. These results suggested that a decrement of 1 kg of concentrate intake during the PMI increased roughage intake by 0.3 kg during the meal (67% of the cows had a significant partial regression coefficient for concentrate intake during the PMI). A prolonged PMI of 1 h increased the roughage intake in the subsequent meal by 0.5 kg. The relationship between the meal size and the duration of the PMI found in the multiple regression analyses corresponded to the regression line in Figure 4.

**Cow Traffic**

The characteristics of cow traffic and roughage eating are presented in Table 5. When a cow did not receive concentrate in the AMS (27.4% of the cases), cows went through the feeding area without eating roughage. This passage rate was higher than that during the cycles when concentrate was eaten in the AMS. After cows made an unrewarded visit to the AMS, they made a new attempt to obtain concentrate in the AMS. When cows ate roughage after leaving the AMS without eating concentrate (72.6% of the cases), the traffic cycle was 32.5 min longer than when cows did not eat roughage after leaving the AMS without eating concentrate. This increase was larger than the duration of the meal (18.9 min), indicating that the demand for concentrate after an unrewarded visit to the AMS was satisfied by the roughage intake. The meal size and duration of the traffic cycles without concentrate consumption was larger than duration of the traffic cycles with a concentrate intake $\geq 1$ kg but shorter than the traffic cycles occurring with concentrate intake between 0 and 1 kg.

Table 5. Cow traffic cycles in relation to concentrate (CI) and roughage intake (RI).

<table>
<thead>
<tr>
<th></th>
<th>CI = 0 kg</th>
<th>0 kg &lt; CI &lt; 1 kg</th>
<th>CI &gt; 1 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RI = 0</td>
<td>RI &gt; 0</td>
<td>RI = 0</td>
</tr>
<tr>
<td>Cycles, %</td>
<td>13.8$^b$</td>
<td>33.8$^a$</td>
<td>2.2$^d$</td>
</tr>
<tr>
<td></td>
<td>108.7$^d$</td>
<td>126.8$^c$</td>
<td>140.5$^b$</td>
</tr>
<tr>
<td>Duration of cycles, min</td>
<td>16.9$^a$</td>
<td>16.9$^b$</td>
<td>16.9$^b$</td>
</tr>
<tr>
<td>Passage rate,$^1$ %</td>
<td>27.4$^a$</td>
<td>4.1$^x$</td>
<td>4.3$^a$</td>
</tr>
<tr>
<td>Meal size, kg</td>
<td>...</td>
<td>18.9$^ab$</td>
<td>...</td>
</tr>
<tr>
<td>Meal duration, min</td>
<td>...</td>
<td>19.7$^a$</td>
<td>...</td>
</tr>
</tbody>
</table>

$^{a,b,c,d,e}$Means within the same row followed by different superscript letters differ ($P < 0.01$).

$^x$xMeans within the same row followed by different superscript letters differ ($P < 0.05$).

$^1$Percentage of passages through the feeding area without roughage consumption.

Roughage intake (1) and duration of meals (17) can be influenced by offering a small amount of concentrate daily. The data described herein indicated that roughage intake could also be influenced over time units $<1$ d.

To optimize the use of an AMS, the frequency of the traffic cycles without roughage consumption should be decreased. The position of the AMS relative to the feeding and lying areas might have influenced the traffic cycles and roughage intake. Figure 5 shows the possible transitions of traffic cycle patterns. After the cycles of category 1, there were more ($P < 0.001$) traffic cycles without roughage eating (categories 1 and 3) than had been expected (including transition from category 1 to category 1). Before the occurrence
of traffic cycles of category 1, more \( P < 0.001 \) traffic cycles without the presence of concentrate occurred than expected (categories 1 and 2). These results indicated that cows tended to pass through the feeding area without eating roughage when no concentrate was offered during the visit to the AMS. Thus, to reduce the cycles without roughage eating, concentrate has to be offered with each AMS visit; however, offering concentrate with each visit to the AMS is not advisable because the intake of concentrate cannot be controlled.

There has been much discussion about the combination of an AMS with one-way cow traffic (as in this study) or AMS with completely free cow traffic (cows can move from the feeding area to the lying area without entering the AMS) (8, 13, 22). Our results suggest that eating behavior should be included when traffic patterns are being considered. One problem that occurred in this study was the higher demand for concentrate in a one-way traffic system; but, in a completely free cow traffic system, this higher demand for concentrate might also occur, and cows might use the direct passage from the lying area to the feeding area only sporadically. However, the demand for concentrate can be satisfied by roughage intake. When the cows are fed a TMR instead of pure roughage, a decrement of the cycles without roughage intake can be expected; however, the amount of concentrate intake is not the only important factor affecting subsequent roughage intake. Other factors might include timing and schedule of concentrate feeding (15). Data on timing or schedule of concentrate feeding were not available in this study because hardly any time variation was negligible from the exit of the AMS to the start of the roughage meal.

**CONCLUSIONS**

The results emphasize the importance of meal size in relation to daily roughage intake. A relationship existed between concentrate intake and the size of a subsequent roughage meal. When feeding concentrate and roughage were separated in an AMS situation, many traffic cycles took place during which no roughage was eaten. These cycles were repeated (autotransition). To decrease this type of cycle in an AMS situation, a TMR might be offered to decrease the demand for concentrate. Although knowledge of the effects of feeding sequence on feed intake and traffic cycles is still limited, the results of this study may contribute to the development of methods of offering concentrate in relation to roughage in group housing systems. These results are applicable when an AMS with one-way cow traffic is used. Further research focusing on timing of the provision of concentrate (including TMR) and order of feed offering is necessary to improve the feeding methods for an optimal roughage intake in group housing circumstances with or without an AMS.

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**REFERENCES**


