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Drinking Behavior of Lactating Dairy Cows and Prediction of Their Water Intake

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ABSTRACT

The water intake of 41 lactating dairy cows managed according to current dairy farm practices was individually and continuously monitored to 1) investigate drinking behavior and 2) determine factors affecting water intake. The cows were housed in a free-stall barn and fed once daily with a corn silage and concentrate-based total mixed ration (48% dry matter content; 20.6 ± 3.3 kg/d of dry matter intake). Cows were milked twice daily, with a yield of 26.5 ± 5.9 kg/d. The daily free water intake (FWI) was 83.6 ± 17.1 L, achieved during 7.3 ± 2.8 drinking bouts. The drinking bout water intake was 12.9 ± 5.0 L. Almost three-fourths of the FWI occurred during working hours (0600 to 1900 h). Consumption peaks corresponded to feeding and milking times. More than one quarter of the daily FWI was met during the 2 h after each milking. About 75% of the present cows visited the watering point at least once during the 2 h after the evening milking. It is probable that drinking behavior evolved with lactation, but further studies are required to identify the relationship between lactation stage and drinking behavior. The most relevant factors affecting the daily FWI of lactating cows were best combined according to the following predictive equation: (R^2 = 0.45; n = 41 cows, n = 1,837): FWI, L/d = 1.53 × dry matter intake (kg/d) + 1.33 × milk yield (kg/d) + 0.89 × dry matter content (%) + 0.57 × minimum temperature (°C) − 0.30 × rainfall (mm/d) − 25.65. The results obtained using these equations were in agreement with the equations developed by other researchers.
Key words: drinking behavior, prediction of water intake, lactating cow

INTRODUCTION

Water supplies for both humans and livestock are becoming a subject of increasing importance. Indeed, climate change and drinking water deficits in certain areas have meant that supplies of clean water for livestock are becoming problematic, at least during certain periods of the year. Water is considered the most important nutrient for health and performance in dairy herds (NRC, 2001), and water deprivation can markedly affect the health, behavior, and performance of animals. Low water intake increases hematocrit and blood urea (Steiger Burgos et al., 2001), reduces the respiratory rate and rumen contractions (Little et al., 1980), reduces BW and milk yield (Little et al., 1980; Steiger Burgos et al., 2001), and provokes aggressive behavior around waterers (Little et al., 1980). Unfortunately, the water intake of dairy cows is rarely considered a potential limiting factor for milk production in modern dairy farms. Despite the attention paid to other nutrients, the quantity and quality of water are not sufficiently considered (Beede, 2005).

Several factors affect free water intake (**FWI**). Some of the most frequently cited parameters include DMI (Holter and Urban, 1992; Dado and Allen, 1994), milk yield (Dahlborn et al., 1998; Meyer et al., 2004), dry matter content (Dahlborn et al., 1998), and different expressions of climate conditions (Murphy et al., 1983; Meyer et al., 2004), and to a lesser extent, BW (Dado and Allen, 1994; Meyer et al., 2004) and sodium intake (Popovici et al., 1971; Meyer et al., 2004).

Although a considerable body of knowledge was developed on the prediction of water intake, very few studies have addressed the drinking behavior of dairy cattle. Indeed, dairy cows require large quantities of water, but there is little data to indicate how often and when dairy cows drink, or to describe the relationship between their behavior and the amount of water ingested. It is essential to answer these questions to ensure sufficient water supplies for all cows in a high-yielding dairy herd.

The aims of this study were to 1) verify information provided by the literature to validate factors affecting FWI and determine a prediction model, 2) investigate the drinking behavior of dairy cows managed in a mod-

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Table 1. Summary of the available data

Data	
Experimental period, d	70
Cows, n	41
Data available per cow,[1] n	50
Total observations,[2] n	1,837

[1]No data were collected during weekends.

[2]Some cow-day data were deliberately excluded when abnormal circumstances existed (e.g., clinical lameness or mastitis).

ern dairy farm, and 3) clarify links between behavior and water intake.

MATERIALS AND METHODS

Animals, Housing, and Diet

Data from 41 (13 primiparous and 28 multiparous) Holstein cows were collected over 3 consecutive winters (November to April) within 70-d periods at our experimental farm. No data were collected during the weekends; thus, a maximum of 50 cow-days were possible per animal (Table 1). Some cow-day data were deliberately excluded when abnormal circumstances existed (e.g., clinical lameness or mastitis). Cows were continuously housed in a free-stall barn. Data were not collected in the summer, because cows were grazing part of the day and the facilities, and spatial and temporal conditions were too different from data recorded during winter. The number of animals present in the pen ranged from 11 to 36, depending on calving dates and the numbers included in the different trials. The size of the barn was permanently adjusted to the animal numbers to ensure that 1 stall would be available for each animal. Cows were bedded in stalls with straw on rubber mats, and scrapers automatically cleaned the concrete floor 4 times daily. The layout and dimensions of the free-stall barn used (2-row tail-to-tail) and the placement of waterers are shown in Figure 1.

At all times, the care of animals complied with the General Guidelines of the Council of the European Community (1986, no. 86/609/EEC).

Animals were milked twice daily (0600 and 1700 h) in a double- 6 herringbone milking parlor (M2100, Bou-Matic, Saint-Nom-la- Bretêche, France). Cows were in mid-lactation (the average DIM at the start of the experiment was 74.2 ± 17.8) and their milk yield was recorded automatically at each milking (Isalait 2045 system, BouMatic) and summed to produce a daily milk yield (**MY**).

Maximum temperature, minimum temperature (**MINT**), and rainfall (**RF**) were recorded at an official station located 2 km from the farm. Mean temperatures were calculated as the average of maximum and minimum temperatures. Sixty-five days or 655 cow-days (35.7%) of the total 1,837 cow-days used in the analysis included a rainfall event.

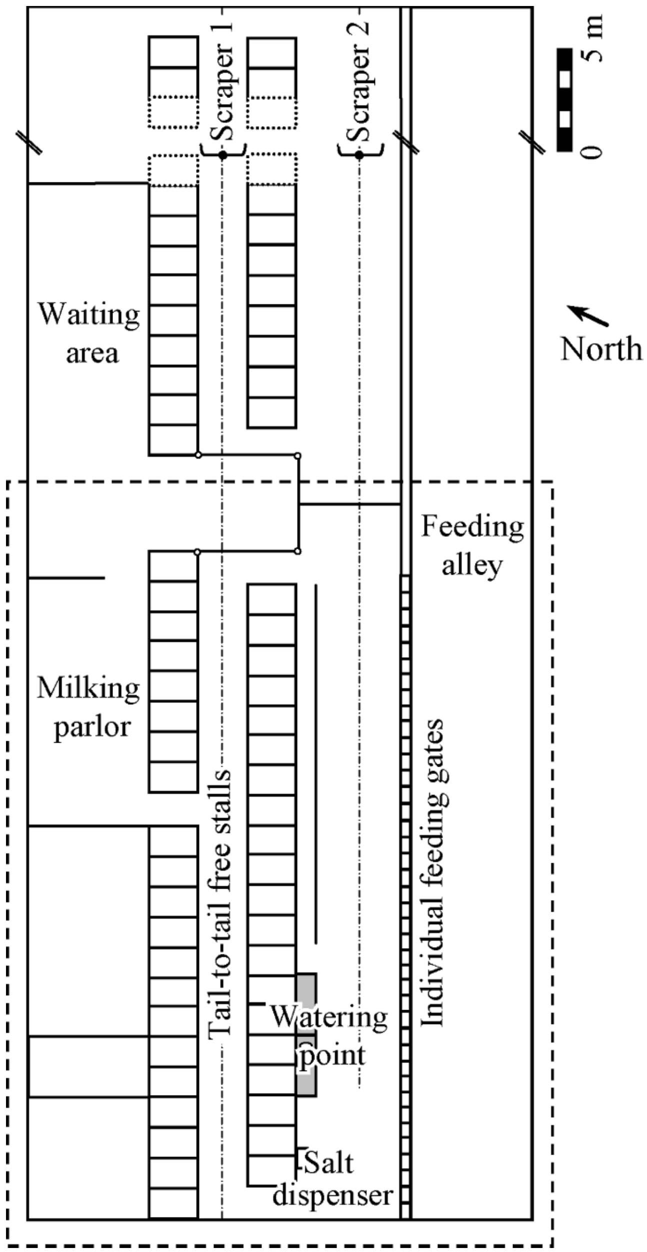

Figure 1. Layout and dimensions of the experimental barn (dashed line) used for free water intake studies.

The animals enrolled were simultaneously used for feeding trials evaluating feed additives. All cows received a similar diet based on corn silage, wheat straw, and concentrate (cracked wheat and soybean meal). Samples were composited every 4 wk and the average composition is presented in Table 2. Because the number of cows differed between years, weighted means and

Table 2. Nutrient and ingredient composition of the diet fed to the cows (DM basis)

Item	Weighted mean	Weighted SD
Energy and nutrients[1]		
DM, %	47.9	5.6
CP, %	14.5	0.7
NFC,[2] %	36.9	3.1
Starch, %	24.4	2.1
Fat, %	3.0	0.0
NDF, %	41.1	3.2
ADF, %	19.4	0.9
Ash, %	4.4	0.2
NE_L, Mcal/kg of DM	1.6	0.0
Ingredients		
Corn silage, %	64.4	2.3
Wheat straw, %	2.8	2.8
Protein concentrate,[3] %	12.1	3.3
Energy concentrate,[4] %	19.2	5.4
Minerals, %	1.5	0.1

[1]Values represent averages of samples composited every 4 wk.

[2]NFC was calculated as [1,000 – (NDF + CP + Fat + Ash)], NRC 2001.

[3]Mainly soybean meal, 46% CP.

[4]Mainly cracked wheat.

SD were calculated rather than simple means. Gross composition of the diet was identical for all of the cows evaluated during the experiment at the same time. Feed additives (yeast products or amino acids) resulted in very small changes in ration nutrient composition between feeding trials. Nevertheless, diet composition could differ slightly between years because of the quality of the silage. But no cow was subjected to different diets because no cow was used for more than one year. The CP content followed European standards, but was slightly lower than commonly recommended in American feeding strategies.

The ration was mixed and offered for ad libitum intake as a TMR once daily at 0900 h. Electronic feeding gates (Sefer Co., Neuville-le-Poitou, France) were used to measure individual feed consumption. Feed deliveries and refusals were weighed, dried (48 h at 85°C), and recorded daily to determine the DMI and DM content (**DMC**).

Animals were allowed free access to 2 automatic drinking bowls (F60, La Buvette, Charleville-Mézières, France), located 4 m from the feed bunk (Figure 1). The water bowls were fixed at a height of 65 cm. The watering point was equipped with barriers at each side to prevent cows from disturbing those drinking. Because the number of water bowls remained the same throughout the experimental period, the number of cows per bowl ranged from 5 to 18. Even if most of the cows were familiar with other cows of the herd (except for primiparous cows) and were adapted to commingling in previous experiments, repeated mixing may have affected FWI and drinking behavior. It was not possible to separate the potential effects of commingling on FWI and drinking behavior.

Drinking Behavior

Drinking activity was recorded continuously and simultaneously for randomly enrolled cows using a data acquisition system based on an individual radio frequency identification collar (Nedap, Groenlo, the Netherlands) and a flow meter (Bürkert, Ingelfingen, Germany) on each water bowl. During each of the 3 periods of data collection, other cows were in the experimental barn (running a feed trial), but their drinking behavior was not monitored. Different variables were recorded: a "visit" corresponded to the identification of a cow at the watering point (whether to drink or not). A "drink" or "drinking action" corresponded to the delivery of water to an identified cow present at the watering point. Finally, 2 separate "drinking bouts" (**DRB**) were defined when at least 4 min was spent without any drinking, as suggested by Dado and Allen (1994). One drinking bout could be made up of one or several drinking events.

The FWI, and the number and volume of DRB (i.e., volume recorded by the flow meter) were recorded daily and linked to the identified collar number. Variables for each DRB included the starting time and volume of each drinking action.

Statistical Analysis

Daily Drinking Behavior. Distributions of FWI and DRB within a day, and distribution of waterer use (i.e., the number of cows drinking at the watering point per hour) were analyzed using the MIXED procedure of SAS (version 9.1, 2001, SAS Institute Inc., Cary, NC). Percentage of daily water intake per hour, number of DRB per hour, and number of cows visiting the watering point per hour were the dependent variables, and time of the day (on an hourly basis) was the independent variable. In this approach, hours were included as repeated measures option of the MIXED procedure of SAS and cow was used as the subject effect. Differences between hours were determined with Tukey's test.

Furthermore, 3 periods were defined before the experiment to compare drinking patterns during the day: 1) a period of supposedly "high" drinking activity (2 h after each milking and feeding); 2) nighttime drinking activity (from 2000 to 0559 h); and 3) a period of "normal" daylight drinking activity (hours of daylight except for the 2 h after each milking and feeding). Water intake, volume of DRB, and number of DRB were the dependent variables of interest, and period of the day was the independent variable. In this approach, the 3 periods were included as repeated measures option of

Table 3. Summary of the experimental conditions in the consecutive trials

	Feed trial 1	Feed trial 2		Feed trial 3
Dates	02/12/2003 to 04/23/2003	11/19/2003 to 01/30/2004	01/07/2004 to 04/02/2004	11/22/2004 to 01/14/2005
Primiparous cows,[1] n	3	3	5	2
Multiparous cows,[1] n	3	8	14	3
Total cow-days, n	275	492	876	194
Mean cow-days/cow	45.8	44.6	46.2	38.8
Range in cow-days/cow	43 to 50	44 to 46	43 to 48	37 to 40
Mean stocking density[2]	21.0	26.6	25.0	17.8
Range in stocking density	11 to 34	15 to 36	14 to 36	17 to 18
Mean milk yield, kg/d	27.5	23.7	26.4	33.2
Range in milk yield, kg/d	9.8 to 38.1	7.3 to 33.8	10.6 to 42.6	13.2 to 46.3
Mean DMI, kg/d	20.0	19.7	21.0	21.9
Range in DMI	9.8 to 28.4	7.6 to 26.1	7.6 to 33.9	5.4 to 31.0
Mean DM content, %	41.3	51.7	50.1	39.3
Range in DM content, %	36.3 to 45.7	48.1 to 57.0	39.6 to 55.5	37.6 to 41.6
Mean ambient temperature, °C	5.8	3.2	3.9	2.4
Range in ambient temperature, °C	–5 to 16.2	–2.7 to 11.2	–1.8 to 13.6	–6.8 to 9.2
Mean daily rainfall, mm/d	2.6	5.5	3.3	2.1
Range in daily rainfall, mm/d	0.2 to 6.2	0.2 to 33.2	0.2 to 33.2	0.2 to 12.2
Cow-days with rainfall, n	43	253	253	105
Tested feed additives in the diet	Amino acids	Yeasts	Yeasts	Yeasts

[1]Number of primiparous and multiparous cows monitored within the experiment.

[2]Stocking rate includes all cows in the study pen. Drinking behavior was not monitored for all cows.

the MIXED procedure of SAS, and cow was used as subject effect. Differences between each period were analyzed with contrasts.

Effect of Stocking Density. Concerning the effects of stocking density, 3 classes were compared: 11 to 20 cows in the pen, 21 to 30 cows in the pen, and 31 to 40 cows in the pen. Dependent variables of interest were daily FWI, volume of DRB, and number of DRB. The effect of the number of animals in the barn sharing the 2 drinking bowls was determined by ANOVA (GLM procedure of SAS), in which density and cow were independent variables. Differences between each density were determined with Tukey's test.

Water Intake Prediction. Means, coefficients of variation, and correlation coefficients were calculated using the DESCO procedure under SPAD (SPAD Soft 6.0, Decisia, Levallois- Perret, France). A prediction model was constructed using multiple linear regression in a stepwise manner with the VAREG and FUWIL procedures of SPAD. The best model was chosen using the lowest value of the Akaike information criterion (Akaike, 1969), and the variance estimation of the parameters of the model was evaluated by jackknife variance estimation (Shao and Wu, 1989) using Tukey's conjecture. According to this predictive model, daily FWI was the dependent variable and DMI, MY, DMC, temperature, and RF were independent variables.

Specific effects of year or tested feed additive were not integrated in the statistical analyses. These effects were not studied but were integrated indirectly via the aforementioned factors. Furthermore, feed additives did not modify in any way the nutrient and ingredient composition of the diet and, to our knowledge no publication has reported any metabolic pathway inducing a specific effect of feed additives on water intake or drinking behavior. It should be noted that no cows participated in the study for more than 1 yr.

Table 3 gives an overview of the experimental conditions for each trial. Data from the different trials were pooled into a single data set. The reasonableness of this approach was assessed using the overall FWI prediction model and plotting residuals against predicted FWI for each trial. Unless otherwise specified, treatment effects were declared significant at $P < 0.05$.

RESULTS AND DISCUSSION

Water Intake and Its Prediction

Minimum, mean, and maximum values, SD, and correlation coefficients to FWI for each studied variable are presented in Table 4.

Daily FWI. Taking account of the differences between experiments, the daily FWI (83.6 ± 17.1 L/d) generally supported results of other studies, and FWI was similar to 82 L/d of Meyer et al. (2004) and 84 L/d of Melin et al. (2005). Melin et al. (2005) had a similar DMC (45%), a slightly increased DMI (22.9 kg/d), and a greater MY (34.3 kg/d). Meyer et al. (2004) reported that cows ingested (20.5 kg/d) amounts that were similar to those we recorded, although those cows received a drier diet (54.5 ± 9.5%) and had more MY (31.1 kg/d).

Table 4. Means, ranges and correlation coefficients to free water intake (FWI)

Variable	Mean	SD	Minimum	Maximum	r to FWI
FWI, L/d	83.6	17.1	23.5	143.3	1
DMI, kg/d	20.6	3.3	5.4	33.9	0.540**
Milk yield, kg/d	26.5	5.9	7.3	46.3	0.531**
Dietary DM content, %	48.1	5.0	36.3	57.0	0.088**
Minimum temperature, °C	0.1	4.0	−11.1	9.1	0.097**
Rainfall, mm/d	1.3	3.9	0.0	33.2	−0.064**
Ambient temperature, °C	3.8	4.4	−6.8	16.2	0.081**
Drinking bouts/d	7.3	2.8	1	27	0.044*
Drinking bouts FWI, L	12.9	5.0	2.5	50.6	0.412**
Cows/pen, n	24.1	6.8	11	36	−0.049*
Lactation number	2.4	1.4	1	7	0.252**
DIM	108.4	26.2	35	173	−0.141**

*$P < 0.05$; **$P < 0.01$.

The slightly greater FWI (89.2 kg/d) reported by Murphy et al. (1983) could have been due to high salt intake (74 g/d), because increased salt content increased FWI (Popovici et al., 1971). Moreover, the MY (33.1 kg/d) was greater than in our study. The lower FWI of 13 L/d observed by Holter and Urban (1992) seems surprising. The DMC in their ration was slightly greater than in ours (50 vs. 48%), and the cows ate less (18.7 kg/d) but produced more milk (34.6 kg/d).

Predicting FWI. The variables best correlated to daily FWI (Table 4) were DMI, MY, lactation number, MINT, DMC, and RF. The daily FWI of lactating cows was best predicted by combining these variables in the following equation ($R^2 = 0.45$; $P < 0.01$; n = 41 cows, 1,837 data; Table 5):

$$\text{FWI, L/d} = 1.54 \times \text{DMI (kg/d)} + 1.33 \times \text{MY (kg/d)} + 0.89 \times \text{DMC (\%)} + 0.58 \times \text{MINT (°C)} - 0.30 \times \text{RF (mm/d)} - 25.65.$$

Minimum temperature and RF explained only a very small part of the variability of FWI in the model (1.6 and 0.2%, respectively; $P < 0.01$; Table 5). Our predictive equation for FWI confirmed the main variables cited in the literature as affecting FWI: DMI, MY, DMC, and weather (Dado and Allen, 1994; Dahlborn et al., 1998; Meyer et al., 2004).

The ratios of FWI/kg of DMI (4.1 L/kg) or per kg of MY (3.1 L/kg) were slightly greater, but supported values in other recent studies: 3.4 (Dado and Allen, 1994), 3.6 (Melin et al., 2005), and 3.9 (Meyer et al., 2004) for FWI:DMI and 2.3 (Melin et al., 2005), 2.4 (Meyer et al., 2004), and 2.6 (Dado and Allen, 1994) for FWI/MY.

Rainfall was cited for the first time as an independent variable affecting FWI when feeding TMR. But RF and high humidity reduced FWI by cattle on pasture (Castle, 1972). Other studies feeding TMR observed negative correlations between relative humidity and FWI (Meyer et al., 2004). Rainfall and ambient temperature are directly linked to relative humidity. Nevertheless, no consistent relationship was found between RF and ration DMC at the time of TMR preparation. Ration DM was evaluated just after delivery to the feed bunk and it is not known whether DMC changed during the course of a day with RF. Thus, the effect of RF on FWI may be due to 1) RF decreasing the ration DM and thereby, reducing demand for FWI; 2) RF decreasing the ambient temperature and FWI decreasing due to the positive correlation between FWI and temperature; or 3) RF increasing relative humidity, which in turn decreased thirst during the winter months. Nevertheless, it should be noted that the correlation between RF and FWI was small (Table 4).

The FWI prediction model was satisfactory regarding the explained part of variability ($R^2 = 0.45$). However,

Table 5. Estimated value, SE and increase in R^2 for each variable used in the water intake prediction model (n = 1,837 observations)

	Variable[1]						
Item	DMI	MY	DMc	MINT	RF	Intercept	R^2
Estimated parameter	1.54	1.33	0.89	0.58	−0.30	−25.65	0.446
Level of significance	**	**	**	**	**	**	
SE	0.156	0.076	0.088	0.080	0.124	5.443	0.052
Increase in R^2	0.287	0.088	0.053	0.016	0.002		

[1]MY = milk yield; DMc = DM content; MINT = minimum temperature; RF = rainfall.

**$P < 0.01$.

Table 6. Comparison of predicted free water intake (FWI; L/d) with models developed by different authors

Model reference	Predicted FWI[1]	SE of the estimate for equation	R^2
Murphy et al. (1983)	74.93	10.25	0.59
Dahlborn et al. (1988)	59.70	Not available	0.67
Meyer et al. (2004)	72.50	Not available	0.60
Our results	78.11	14.49	0.45

[1]Taking account of the following elements when included in the model: BW, 600 kg; DMI, 18 kg/d; milk yield, 25 kg/d; DM content, 45%; average temperature, 10°C; minimum temperature, 5°C; sodium intake, 40 g/d.

this could probably be improved in 2 ways: 1) by measuring other factors such as BW or relative humidity in the barn; and 2) by running the experiment over a longer period to obtain a broader range of values. Although the range of our prediction for FWI is similar to others (Table 6), it appears higher than other predicted values. Some differences related to the experimental conditions and animals involved might explain this.

Drinking Behavior

General Drinking Behavior. The frequency of 7.3 DRB/d supported the range of values reported in the literature from 5.2 (Jago et al., 2005) to 9.4 DRB/d (Huzzey et al., 2005). The average intake per DRB (12.9 L) was very similar to Jago et al. (2005; 14.9 L) during a study conducted in free stalls. The water intake during DRB was correlated ($P < 0.01$) with lactation number (r = 0.41), MY (r = 0.37), and DMI (r = 0.35).

In support of Dado and Allen (1994; r = –0.8), the number of the DRB was negatively correlated to their size (r = –0.77). With an average FWI near our observations (77.6 L/d), they noted an increased drinking frequency (14 DRB/d) under tie-stall conditions, with a reduced FWI per DRB (6.4 L). This observation could have been due to the watering system used. Indeed, during their experiment, the drinking rate was low (4.3 L/min) compared with other reports (Pinheiro Machado Filho et al., 2004; 18.1 L/min). Andersson et al. (1984) observed that increasing the flow rate of waterers from 2 to 12 L/min led to a 25% reduction in drinking frequency (40 vs. 30 DRB/d) and increased FWI.

Considering the relationship between daily FWI and drinking behavior, it appeared that variations in FWI were mainly due to variations in the quantity of water drunk during a DRB (r = 0.41; Table 4). Indeed, the number of DRB was lowly correlated to daily FWI (r = 0.04). These results agree with those obtained by Dado and Allen (1994), where the FWI was correlated with the volume of DRB (r = 0.47), but lowly correlated with the number of DRB (r = 0.04).

Fifteen percent of DRB were made up of several drinks. In that case, the first drink was the largest in volume (11.0 ± 4.7 L); subsequent drinks averaged 2.8 ± 1 L. Nevertheless, consumption during DRB including several drinks was greater than that seen during DRB involving only 1 drink (14.0 vs. 12.1 L; $P < 0.01$). Regarding their distribution within the day, no difference was observed between DRB made up of several drinks and DRB involving only 1 drink.

Daily Drinking Behavior. Most of the daily FWI (72.7 ± 14%) was achieved during working hours on the farm (0600 to 1859 h), supporting other studies (Nocek and Braun, 1985; Sowell et al., 1999; Osborne et al., 2002). Consequently, nocturnal drinking behavior (i.e., between 1900 and 0559 h) accounted for only a small percentage (27%) of the FWI. Osborne et al. (2002) found similar results (25% of daily FWI met during night), although their animals were fed twice daily. In this situation, cows could have been attracted to the feed bunk by the second delivery of fresh feed in the afternoon and may consume water later in the night.

In our experiment, 2 main consumption peaks were observed between 0900 and 1059 h and 1700 and 1859 h (Figure 2). Three smaller peaks could be observed between 0700 and 0759 h, 1400 and 1559 h, and 1900 and 1959 h (Figure 2). As described by others, drinking bouts occurred at all times of the day and night, but consumption peaks were associated with feed delivery

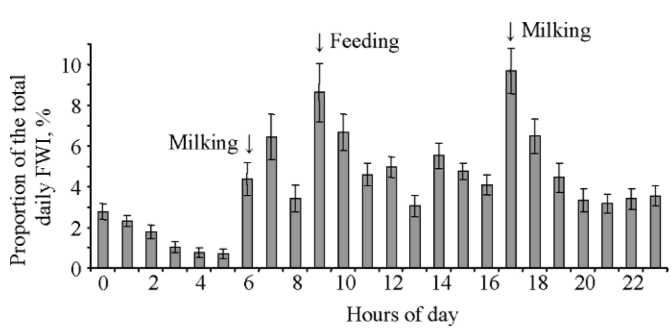

Figure 2. Distribution of free water intake (FWI) during a day in hourly intervals. Bars represent the SEM.

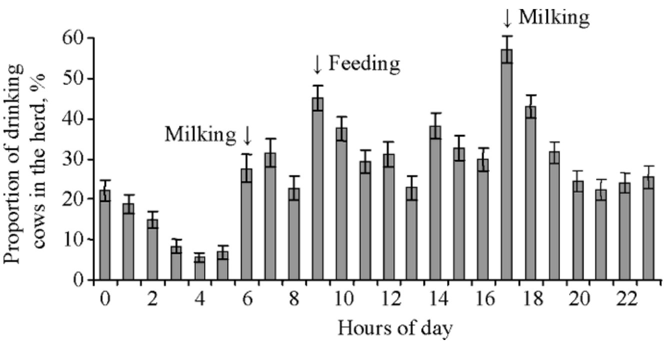

Figure 3. Proportion of cows drinking during a day in hourly intervals. Bars represent the SEM.

and milking times (Nocek and Braun, 1985; NRC, 2001; Osborne et al., 2002). In contrast, low drinking activity was observed during the period 0300 to 0559 h, whereby 1, 0.8, and 0.7% of the daily FWI was met, respectively, during each of these 3 h. Furthermore, 7, 22, and 32% of the cows never visited the watering point during each of these 3 h, respectively (data not shown). Our results confirm that 1) feeding and drinking are mostly synchronized activities, and 2) with respect to feeding (Shabi et al., 2005; DeVries et al., 2003), drinking is a diurnal activity.

During our experiment, 75% of the cows came to the waterer within 2 h of the evening milking (Figure 3). The strength of the relationship between milking and drinking time was reported differently by Wieclaw et al. (1973): they reported that 90% of cows drank within 2 h postmilking. In the context of field measurements, Beede (2005) found that 50 to 60% of the daily water needs were met immediately after milking. In our study, only 27% (22.3 L) of the daily FWI was consumed during the 2 h after each milking, but considering the 2 h after milking and feeding, our observation of 42.3% of daily FWI corresponded to the results of Osborne et al. (2002), who found that 40% of the FWI was met within this period.

On average, half (54%) of the herd frequented the waterer within 1 h following the evening milking (Figure 3). This means that up to 10 cows used the same water bowl within 1 h. No water trough was available at exit from the milking parlor, which could explain why water consumption was distributed differently than in Beede (2005). Furthermore, the large number of cows visiting the watering point within 1 h of leaving the milking parlor seems to indicate a rush at the watering point.

Based on information in the literature, 3 periods were defined before the experiment to compare drinking patterns during the day using a contrast test: 1) a period of supposedly high drinking activity (2 h after each milking and feeding); 2) night-time drinking activity (from 2000 to 0559 h); and 3) a period of supposedly normal daylight drinking activity (the rest of the day). The average FWI during DRB that occurred within 2 h of feeding and milking was greater than the FWI during other daylight hours or at night (13.6, 11.9, and 11.6 L, respectively; $P < 0.01$). This may have been due to dehydration caused by milk output or eagerness caused by the rush to the watering station.

Furthermore, cows visited the watering point 7.6 ± 3.4 times/d, which means that cows went to the watering point but did not drink 0.3 ± 1.1 times/d. This behavior was observed at least once with each cow during the experiment, but only 4.9% of these cows (2 of 41) tended to adopt it once a day or more. During the evening high drinking activity period (1700 to 1859 h; data not shown), the frequency of nondrinking visits to the watering point decreased, which indicated that cows visited the waterer at that time to actually drink.

Effect of Stage of Lactation. Because DMI, MY, and hence, FWI evolve throughout lactation, we can expect that drinking behavior varied with lactation stage. Indeed, the water intake of DRB was correlated to MY (r = 0.37; $P < 0.01$) and DMI (r = 0.35; $P < 0.01$). Nevertheless, during our experiment, DIM was only lowly correlated with DRB (r = 0.09; $P < 0.01$ and r = –0.09; $P < 0.01$, for the number of DRB and DRB water intake, respectively). This could be because the cows were in mid-lactation or because the duration of the experiment was relatively short (i.e., even MY and DIM were slightly correlated: r = –0.2 ($P < 0.01$).

Number of Cows Sharing the Water Bowls. The effect of the number of animals in the barn sharing the 2 drinking bowls could not be investigated clearly. However, although our statistical power was insufficient to reach a threshold of significance, a slight but clear trend was observed regarding number of cows sharing the 2 drinking bowls and drinking behavior (Table 7). No other variable (DMI, DMC, MY, or lactation number) was affected significantly by stocking density. Social effects due to commingling cattle may play a role in varying DRB volume.

As for high drinking activity periods, increasing the number of cows in the barn tended to reduce the number of nondrinking visits to the waterer (0.51, 0.32, and 0.20/d; $P = 0.07$). Because the observed effect of the number of animals was low when compared with individual variations, about 100 cows would have been necessary to demonstrate statistical differences. The NRC (2001) recommends 1 water bowl per 10 cows, whereas during our experiment, the maximum number of cows per drinking bowl was 18. Andersson et al. (1984) observed that when pairs of tied cows shared the same water bowl, submissive cows drank 7% less than domi-

Table 7. Means and SD of the studied variables when considering stocking density (pooled data from all trials, except number 3)

	Stocking density		
Item	11 to 20	21 to 30	31 to 40
Volume of drinking bouts, L	12.2 ± 4.8	12.9 ± 4.4	13.9 ± 4.9
Number of drinking bouts/d	7.9 ± 2.8	7.2 ± 2.3	6.8 ± 2.7
Free water intake, L/d	82.6 ± 12.1	82.6 ± 12.0	83.0 ± 14.4
Milk yield, kg/d	25.2 ± 5.1	25.6 ± 4.8	27.0 ± 5.4
DMI, kg/d	19.8 ± 2.2	20.6 ± 2.4	20.2 ± 2.7
DM content, %	49.5 ± 4.5	49.4 ± 3.6	48.5 ± 3.7
Lactation number	2.5 ± 1.5	2.5 ± 1.4	2.5 ± 1.4
Cow-days within category, n	340	956	347

nant ones. These elements support the suggestion that overstocking of animals may exert an effect on drinking behavior.

CONCLUSIONS

Our results confirm that environmental factors such as diet composition and climatic conditions and individual factors such as MY or the amount of DMI can affect drinking behavior, water intake, or both. The predictive model can efficiently predict FWI for lactating cows using easily recordable factors. Our results supported those in the literature: most drinking activity occurred during daylight hours and was correlated with feeding and milking events. Yet, the description only concerns cows in mid-lactation. This study was conducted during the winter months and behavioral effects may be different during the heat of summer when cows need more water per day.

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