Effect of pre- versus postmilking supplementation on traffic and performance of cows milked in a pasture-based automatic milking system

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ABSTRACT

Cows milked in a pasture-based automatic milking system tend to have a lower daily milking frequency in comparison with cows milked in indoor systems. Milking events with intervals beyond 16 h have been reported to have a negative effect on milk yield and udder health, and therefore it is important to minimize their occurrence. As feed is the main incentive to encourage cow traffic around the system, a study was conducted to compare pre- (PRE) versus postmilking (POST) supplementary feed placement strategies in a pasture-based automatic milking system. We hypothesized that PRE cows would have a stronger incentive to walk voluntarily from the paddock to the dairy facility to get milked (due to the reward being more immediate), thereby reducing their milking interval and increasing daily milking frequency and milk yield. The PRE cows returned to the dairy facility sooner (PRE = 11.9 vs. POST = 13.27 h) but had longer milking intervals (PRE = 15.3 vs. POST = 14.28 h). This was due to the additional time spent in the prefeeding area (PRE = 56 versus POST = 23 min) combined with a longer average time spent in the premilking waiting yard (PRE = 97 versus POST = 77 min). Treatment did not affect daily milk yield per cow. The result of this study demonstrates the potential of manipulating feeding management strategies to influence cow behavior and traffic in voluntary milking systems.

Key words: automatic milking system, milking interval, supplementation

INTRODUCTION

Over 10,000 farms globally have incorporated the use of an automatic milking system (AMS) since their introduction in the early 1990s (de Koning, 2011). In 2001 they were incorporated for the first time in a pasture-based system, with installations occurring almost simultaneously in a commercial farm in Victoria, Aus-

tralia (Greenall et al., 2004) and within the Greenfield Project in New Zealand (Jago et al., 2002). In 2006, the FutureDairy Project commissioned its AMS research dairy in Australia (Garcia et al., 2007).

Automatic milking systems rely on voluntary and distributed traffic of cows. Contrary to what happens in conventional milking systems, cows in AMS are not subject to discrete milking sessions given that milkings occur throughout the day and night. Failure to achieve these conditions could have an effect on technology uptake as well as profitability and success of farmers adopting this technology.

Milk harvested per cow at any given milking is directly related to the time interval from the previous milking [milking interval (MI) = interval between consecutive milking events measured in hours from the previous milking]. This relationship is linear up to 16 h, but flattens thereafter (Schmidt, 1960; Delamaire and Guinard-Flament, 2006). Intervals greater than 16 h can adversely affect milk yield (in kilograms of milk accumulated and subsequently harvested per hour of MI) and udder health (Hammer et al., 2012). Thus, management decisions should aim to minimize the incidence of MI extending beyond 16 h. This does not necessarily mean increasing overall milking frequency (MF; the number of milking events per cow in any 24-h period), as this should be optimized to meet the farm targets with regard to robot harvesting level and overall farm productivity. Yet, it is recognized that AMS do allow for greater MF and detailed real-time data related to production and the health of individual cows.

Milking frequency has become a common key performance indicator in AMS. Given the voluntary nature of the system, in any AMS a range of MI, and therefore MF, can be observed within and among cows, which is not the case in conventional milking systems. Furthermore, cows milked in a pasture-based AMS tend to have a lower average MF in comparison with cows milked in indoor AMS (Davis et al., 2005; Jago and Burke, 2010). In pasture-based systems, around 30% of all milking events can have intervals above 16 h (N. A. Lyons, unpublished data), which is much higher than the 4.2% reported in indoor systems (Hogeveen et al., 2001). By allowing for higher potential MF, AMS could

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likely drive an increase in milk production (Garcia and Fulkerson, 2005; Stockdale, 2006) without extra labor, which is a common limitation and key contributor to the cost of production in most dairy farms (Hogeveen et al., 2004). Consequently, optimizing the frequency of voluntary milking events is a key element of AMS. Careful planning of farm layout and management of incentives is required to encourage frequent cow traffic around the system, thus creating opportunities for cows to be drafted for milking at timely intervals and frequencies. Feed is the main incentive used to encourage consistent cow traffic around the farm system (Prescott et al., 1998a,b). Modifying the timing, placement, and frequency of feed allocations (pasture or supplements or both) can enhance cow traffic. Previous studies have compared different cow traffic management options (Ketelaar-de Lauwere et al., 1998; Hermans et al., 2003; Melin et al., 2005; Bach et al., 2009) and different concentrate allowances (Halachmi et al., 2005; Bach et al., 2007) on cows' attendance to the milking station and milk production. Furthermore, from a simulation study in a cowshed, dominance level was found to influence when cows gained access to the milking unit (Halachmi, 2009). In a previous study comparing the effect of the number of feed allocations in a pasture-based AMS on animal performance, it was noted that by offering 3 pasture allocations per day (rather than 2) MF could be increased by 40% (Lyons et al., 2013). To date, no published studies have reported the effect of location of supplementary feed on MI in grazing systems, nor the time spent in different areas of the farm system (pasture, feeding area, or premilking waiting area). Previous exploration of cow traffic data from cows milked in a pasture-based AMS within the FutureDairy Project has indicated that the main factor explaining extended MI is the time it takes for cows to return to the dairy facility, where up to 94% of milking events with intervals above 16 h had return times over 14 h (N. A. Lyons, unpublished data). However, during that period, whenever supplementary feed was offered it was available after milking on the way out to the paddock.

Offering supplements premilking may entice cows to come back to the dairy facility sooner, reducing total return time and therefore MI.

The aim of this study was to compare 2 different supplementary feed placement strategies, made available to cows at the dairy facility either before (**PRE**), or immediately after (**POST**) milking, on the cow traffic and milk production of cows in a pasture-based AMS. It was hypothesized that allocating supplementary feed before being milked would encourage cows to traffic voluntarily from the paddock back to the dairy facility at shorter intervals (due to the immediacy of the reward), than cows that were offered supplementary feed after milking. In turn, this would result in a lower average MI and a reduced incidence of MI exceeding 16 h.

MATERIALS AND METHODS

Animals and Treatments

A field study was conducted between September 12 and October 10, 2011, at the FutureDairy AMS research dairy (Elizabeth Macarthur Agricultural Institute, Camden, Australia). The herd comprised 175 cows (30% primiparous and 70% multiparous cows), the majority Holstein-Friesian and approximately 10 to 15% Illawara (611 ± 88 kg average liveweight $\pm$ SD). Cows were randomized into 2 groups, balanced for stage of lactation (DIM), that were managed in 1 herd throughout the study. Treatments were then allocated to each group in a cross-over design trial with 2 periods of 13 d each. Each period comprised a 7-d adaptation period followed by 6 d of data collection. Group description and treatment allocations are shown in Table 1.

Cows were drafted to either PRE or POST using automatic drafting gates. All cows were fitted with a unique electronic transponder, by which they were electronically identified at each automatic drafting gate as they trafficked around the farm system, being sorted

Table 1. Group description and trial description (all values represent mean $\pm$ SD)¹

Item	Group 1	Group 2
Number of cows	88	87
Treatment period 1	PRE	POST
Treatment period 2	POST	PRE
DIM ²	173 $\pm$ 108	176 $\pm$ 117
Age ² (mo)	60 $\pm$ 27	65 $\pm$ 35
7-d average milk yield ² (kg/cow per day)	20.89 $\pm$ 6.98	20.48 $\pm$ 6.64
7-d average milking frequency (milking events/cow per day)	1.60 $\pm$ 0.40	1.59 $\pm$ 0.34

¹Supplementary feed made available before (PRE) or after (POST) milking.

²All at trial start date.

accordingly. The transponder allowed the electronic log of gate passing to be used to calculate time spent by individual cows in different areas.

Cows were milked using a 16-bail prototype robotic rotary (RR; Automatic Milking Rotary AMR, DeLaval, Tumba, Sweden; Kolbach et al., 2012). A blanket, 4-h minimum MI was set for all cows regardless of parity or DIM. Cows deemed to have an incomplete milking (defined as any one quarter which had yielded less than 75% of the expected yield) were returned to the premilking waiting yard ($24 \times 6 \text{ m} = 144 \text{ m}^2$) through a set of automatic drafting gates, avoiding their respective treatment.

Target DMI according to liveweight and target milk production was set at 23 kg of DM/cow per day. During the experimental period, around 60% of daily diet was supplied as grazable pasture, with the remaining 40% as supplementary feed (Table 2). In addition, and not included in the daily ration, cows received 0.41 ± 0.01 kg of concentrate per milking, which was offered at the first 2 bails of the RR as a small incentive to encourage them to walk onto the platform.

The farm operated as a pasture-based system, consisting of 10 paddocks (ranging from 1.38–9.54 ha in size) with a distance ranging between 100 and 1,000 m from the dairy facility. The predominant pasture species in the sward was ryegrass (*Lolium perenne* and *Lolium multiflorum*). Weekly pasture assessments were

conducted by a trained technical staff member using an electronic rising plate meter (Electronic Plate Counter, Farmworks, Feilding, New Zealand). Calibration equations, developed previously at the same experimental site for each season of the year (Garcia et al., 2008) were used to estimate pasture cover, and therefore calculate area required per allocation (according to herd size, target feed allowances, and target postresidual covers). Cows were managed under a 2-way grazing system in which they were granted access to 2 fresh pasture allocations per 24-h period. These were referred to as day and night allocations, and had a 40:60 daily pasture allowance.

Cows presenting at the dairy facility with no milking permission or leaving the dairy facility after milking, were automatically drafted to the day paddock between 0900 and 2100 h (a 12-h active-access period). Likewise, the active access time for the night paddock was from 2100 to 0900 h. Each active access period was followed by a 10-h voluntary exit period, in which no further cows were drafted to the given allocation, and during which cows were expected to voluntarily traffic from the allocation to the subsequent pasture allocation (via the drafting gates at the dairy facility). By 0700 h for day breaks, or 1900 h for night breaks, any cows that had not volunteered out were fetched and herded to the dairy facility. Records were kept of all cows requiring fetching. In essence, the grazing management system

Table 2. Ingredient and compositional feed analysis description of the daily target feed ration offered to cows in a pasture-based automatic milking system with provision of supplementary feed either before or after milking (all values as mean $\pm$ SE)

Item (%, unless otherwise indicated)	Pasture allocation		PMR ¹	Feed stations concentrate
	Day	Night		
Daily ration (% of total DM)	26	35	27	12
DM	22 $\pm$ 1	22 $\pm$ 1	48 $\pm$ 1	89 $\pm$ 0
OM	89 $\pm$ 0	89 $\pm$ 0	90 $\pm$ 0	90 $\pm$ 0
IVDMD ²	85 $\pm$ 1	82 $\pm$ 1	67 $\pm$ 0	73 $\pm$ 1
IVOMD ³	84 $\pm$ 1	80 $\pm$ 1	64 $\pm$ 1	70 $\pm$ 1
ME (MJ/kg of DM)	12.4 $\pm$ 0.1	11.9 $\pm$ 0.1	9.5 $\pm$ 0.1	10.5 $\pm$ 0.1
NDF	42 $\pm$ 1	40 $\pm$ 1	32 $\pm$ 1	25 $\pm$ 0
ADF	21 $\pm$ 0	22 $\pm$ 1	19 $\pm$ 1	15 $\pm$ 0
Hemicellulose	21 $\pm$ 1	18 $\pm$ 1	13 $\pm$ 1	10 $\pm$ 0
Celullose	17 $\pm$ 0	18 $\pm$ 1	14 $\pm$ 1	12 $\pm$ 0
Lignin	2 $\pm$ 0	3 $\pm$ 0	3 $\pm$ 0	2 $\pm$ 0
Ash	11 $\pm$ 0	11 $\pm$ 0	10 $\pm$ 0	10 $\pm$ 0
Nitrogen	4.1 $\pm$ 0.1	3.5 $\pm$ 0.1	2.1 $\pm$ 0.1	2.3 $\pm$ 0.0
CP	25.9 $\pm$ 0.7	21.9 $\pm$ 0.7	12.9 $\pm$ 0.6	14.6 $\pm$ 0.1
Ammonia (mM/L)	17.7 $\pm$ 2.0	14.7 $\pm$ 1.0	8.8 $\pm$ 0.4	9.5 $\pm$ 0.4
WSC ⁴	12.5 $\pm$ 0.5	15.1 $\pm$ 0.4	6.4 $\pm$ 0.5	3.8 $\pm$ 0.0
pH	5.7 $\pm$ 0.0	5.6 $\pm$ 0.0	5.5 $\pm$ 0.0	5.4 $\pm$ 0.0
Total gas (mL/g of DM)	116.4 $\pm$ 3.6	121.9 $\pm$ 2.6	122.0 $\pm$ 3.6	125.8 $\pm$ 1.7

¹PMR = partial mixed ration consisting of 11% cereal hay (89% DM, 74% NDF, and 46% IVDMD), 44% maize silage (26% DM, 39% NDF, and 63% IVDMD), and 44% concentrate (89% DM, 25% NDF, and 73% IVDMD).

²IVDMD = in vitro DM digestibility.

³IVOMD = in vitro OM digestibility.

⁴WSC = water-soluble carbohydrates.

described meant that the maximum amount of time a cow could spend in any given pasture allocation (i.e., if a cow were the first one in and the last one out of the allocation) was 22 h.

Supplements were offered in a feeding area (28×4 m = 112 m²) located within the dairy facility at a distance of 10 m from both the entrance to the premilking waiting yard and the exit of the RR. In the feeding area, pelleted concentrates were supplied through 4 automatic feed stations (FSC400, DeLaval), whereas a partial mixed ration (**PMR**) was offered in the same feeding area via 37 individual headlocks. Delivery of fresh PMR ration occurred once per day at around 1000 h. Prior to delivery, the feed pad was cleaned and any refusals were weighed. Both PRE and POST groups were supplemented in the same feeding area, but the use of electronic drafting gates allowed for each group to be restricted to the regimen of allocation either before milking or after milking.

Each ingredient of the PMR was sampled at the start of each period and pooled for compositional analysis. In addition, pregrazing pasture samples were taken by hand-plucking across the paddock within 12 h of cows entering a new allocation. Results presented in Table 2 are a summary of compositional feed analyses across both periods. All feed samples were stored at 4°C before wet weight was recorded. Samples were then dried at 60°C (in a forced-draft oven) for 48 to 72 h. Dry weight was then used to calculate the DM percentage. A representative subsample of each dried feed sample was ground through a 1-mm screen, and analyzed for ADF and α -NDF using sodium sulfite (Van Soest et al., 1991), hemicellulose, cellulose, lignin (Robertson and Van Soest, 1981), and ash (AOAC International, 1995). Total N percentage and CP were determined by combustion (AOAC International, 1995) using a Leco FP-628 Nitrogen Determinator (Leco Corporation St. Joseph, MI). The WSC content of forages was determined using a modification of the method described by Smith (1969). In vitro DM digestibility and gas production was performed on all feed samples using batch culture in vitro fermentation. Samples were analyzed for ammonia-N by phenyl-hypochlorite reaction (Weatherburn, 1967).

During the experimental period, all cows with abnormal milk (e.g., mastitis, antibiotics, colostrum) were managed as a separate batch-milked herd. This herd was milked twice daily before the scheduled system washes (occurring at approximately 0600 and 1700 h daily). No cows were moved from this herd into the main milking herd (experimental herd) during either of the data collection periods. Cows required for treatment or inspections were drafted into a sort pen after milking, as per normal farm practice.

Measurements

To further explore treatment effects on MI, individual MI times were subdivided into 3 main components: time to return to the dairy facility (**RT** = time elapsed from exiting the dairy facility to representation back at the dairy facility), feeding area time (**FT** = time elapsed from the entry to the feeding area to exit from the feeding area), and waiting area time (**WT** = time elapsed from entry to the premilking waiting yard to milking start). In addition to these times, although not included in the analysis due to their relatively small magnitude, were times spent on the rotary or between gates but in an undefined area or laneway (average 4% of MI time). In addition, milking yield (**MY** = yield of milk at a particular milking event, in kilograms of milk per cow per milking), MF, daily yield (**DY** = yield of milk on a particular day, in kilograms of milk per cow per day), and concentrate consumption (**CC** = amount of concentrates consumed per day, in kilograms of concentrate per cow per day) were also included. The likelihood of cows having a milking with an extended MI (over 16 h) or trafficking voluntary and not requiring fetching was also analyzed.

Dry matter intake could only be assessed at an individual cow level for concentrates offered in the feed stations by reports generated automatically in the herd management software (DelPro Software 3.5, DeLaval). Average (herd) pasture and PMR intake were calculated by using equation [1] and [2], respectively, and given that both groups had access to the same daily pasture allocations and feeding area, despite being managed under 2 different treatments, the assumption was made that they had the same mean intake for pasture and PMR. Actual pre- and postgrazing cover was also measured with the same device (Electronic Plate Counter, Farmworks) within 24 h of the first and last cow entering or exiting the corresponding allocation.

$$\begin{aligned} \text{Average pasture intake} = & (\text{Pregrazing cover} \\ & - \text{Postgrazing cover}) \times (\text{Allocation area}) / \\ & \text{Total number of animals in the herd,} \end{aligned} \quad [1]$$

$$\begin{aligned} \text{Average PMR intake} = & (\text{Amount offered} - \text{Amount} \\ & \text{Refused}) / \text{Total number of animals in the herd.} \end{aligned} \quad [2]$$

Statistical Analysis

Cow traffic parameters (RT, FT, WT, MI, and MF), milk production (MY and DY), and CC were analyzed

at cow level. Pasture and PMR consumption were analyzed at herd level.

Initial descriptive statistics were conducted to explore distribution of explanatory and outcome variables. Data of RT and MI are presented as frequency distribution graphs, with difference between categories analyzed through binomial test of proportions. Data was then analyzed using linear mixed modeling, with parameters and estimates calculated using REML and GLMM in Genstat 13th edition (VSN International, UK). All the models included the main effects of period (1 and 2), treatment (PRE and POST), treatment allocation sequence (0 to the group that was allocated to PRE in period 1 and POST in period 2, or 1 to the group that was allocated to POST in period 1 and PRE in period 2), parity (primiparous/multiparous), stage of lactation (SOL; early = ≤ 100 DIM; mid = >100 to ≤ 200 DIM, and late = >200 DIM), and milk yield category (based on pretrial 7-d average MY; cows were allocated into 1 of 3 equally sized categories: low = 7.08–16.81 kg of milk/d, mid = 16.82–22.60 kg of milk/d, and high = 22.61–39.65 kg of milk/d). Additionally, the double interactions, treatment $\times$ SOL and MY, were tested. If interactions were not significant, they were removed from the model; however, main effects were retained in the final model. Cow and sequence (nested within cow) were included as random effects.

The assumptions of linearity, normality, and homoscedascity were evaluated using residual diagnostics. The outcome was transformed if the assumption of normality or homoscedascity was invalid (FT and WT were log-transformed). Significance was determined at $P < 0.05$.

RESULTS

The entire data set comprised 3,394 records, which related to 3,225 individual milking events. The other

169 records were not specifically related to a particular milking, but to cow traffic; they were times spent in different areas.

Return time explained the greatest proportion (adjusted $R^2 = 67.94$; $P < 0.001$) of the total variation observed in MI. When FT and WT were included in the model, combined with RT, they explained almost all of the variation observed in MI (adjusted $R^2 = 95.13$; $P < 0.001$).

No interaction ($P > 0.05$) was observed between treatment and SOL or MY category for any of the variables analyzed. Compared with POST cows, PRE cows returned from the paddock to the dairy facility on average almost 1.5 h earlier ($P < 0.001$), but spent 33 more minutes in the feeding and 20 more minutes in the premilking waiting areas ($P < 0.001$; Table 3). Consequently, PRE cows had an MI 1 h longer ($P < 0.001$) and 5% reduced ($P = 0.003$) MF than POST cows. Despite PRE cows having a 5% greater ($P < 0.001$) MY, no difference ($P = 0.627$) was observed in DY (mean DY of 19.37 kg of milk/cow per day; Table 3).

The PRE cows had a greater proportion of RT between 6 to 8 h after the previous milking event, whereas the POST cows had a greater proportion of RT beyond 19 h (Figure 1a). Interactions were not significant in explaining the proportion of milking events occurring with extended intervals. However, PRE cows were 1.3 times more likely ($P < 0.001$) than POST cows to have an MI beyond 16 h. Furthermore, PRE cows had a 9% greater proportion of milking events with intervals exceeding 16 h (46.9 vs. 38.0% for PRE and POST cows, respectively). In comparison to POST cows, PRE cows had a greater proportion of MI between 1 and 2 h and between 9 and 10 h, whereas POST cows had a greater incidence of milking events occurring with MI greater than 24 h (Figure 1b).

Table 3. Predicted means for cows in a pasture-based automatic milking system with provision of supplementary feed either before (PRE) or after (POST) milking

Item	Treatment		SED ¹	P-value
	PRE	POST		
Return time (h)	11.9 ^a	13.27 ^b	0.15	<0.001
Log-transformed feeding area time	−3.25 ^a	−4.13 ^b	0.04	<0.001
Retransformed feeding area time (min)	56	23		
Log-transformed waiting time	−2.69 ^a	−2.92 ^b	0.04	<0.001
Waiting area time (min)	97	77		
Milking interval (h)	15.3 ^a	14.28 ^b	0.25	<0.001
Milking yield (kg of milk/milking)	12.58 ^a	11.93 ^b	0.19	<0.001
Milking frequency (milking events/d)	1.58 ^a	1.67 ^b	0.03	0.003
Daily yield (kg of milk/d)	19.29	19.45	0.33	0.627
Concentrate consumption (kg of DM/d)	2.63 ^a	2.55 ^b	0.04	0.047
Milking intervals above 16 h (%)	46.9 ^a	38.0 ^b	0.02	<0.001

^{a,b}Different letters within an effect for a particular outcome are significant at $P < 0.05$.

¹SED = standard error of the difference.

Figure 1. Frequency distribution of (a) return time (h) and (b) milking interval (h) of cows in a pasture-based automatic milking system with provision of supplementary feed either before (PRE) or after (POST) milking. Categories with significantly different proportion ($P > 0.05$) are identified accordingly (*). The time below each bar corresponds to the time category (i.e., the bar at 15 relates to all events that had a time between 14 and 15 h). The category 25 represents times greater than 24 h.

Concentrate consumption was greater ($P = 0.047$) for cows in the PRE treatment (Table 3). At the herd level, pasture intake was 4% above the target intake level (14.6 ± 0.6 kg/cow per day), which was mostly attributed to a greater average intake in night allocations (8.6 ± 0.4 kg/cow per day). Intake of PMR (6.0 ± 0.0 kg/cow per day) and pasture in day paddocks (6.0 ± 0.5 kg/cow per day) were according to target allocation.

Stage of lactation had no effect on any cow traffic parameter, milk production, or CC ($P > 0.05$). A difference ($P < 0.001$) was noted between MY and DY for each of the MY category groups. However, no difference ($P > 0.05$) was observed in any of the other parameters between yield categories.

The interaction between treatment and SOL was significant ($P = 0.008$) for the likelihood of cows having a milking as a consequence of voluntarily walking to the dairy facility, and not requiring to be fetched from the previous allocation. No difference was noted in the proportion of cows trafficking voluntarily within treatment but a difference was observed on voluntary traffic within SOL between treatments. The early lactation PRE cows were 3 times more likely to voluntarily move from

the paddock to the dairy facility than early lactation POST cows. In late lactation, the scale of the difference was reduced to 2.7 times. No such difference could be observed for cows in mid lactation. On average, 24.5% of PRE cows and 34.3% of POST cows entering the premilking waiting yard with milking permission had been fetched from previous allocations.

DISCUSSION

The aim of this study was to evaluate the effects of pre- versus postmilking allocation of supplementary feed on cow traffic and animal performance. Our results showed that PRE cows returned to the dairy facility quicker than POST cows; however, PRE cows had greater FT and WT, and therefore greater MI and reduced MF than the POST cows. This indicated that the provision of supplementary feed upon arrival at the dairy facility, despite being a strong incentive for cows to volunteer out from the paddock, had no advantage from the MI or MF point of view.

Our findings are in line with research conducted by Prescott et al. (1998b), who suggested that the cost involved in getting a certain reward could affect the willingness to search for it, which could be the case for the POST cows. The PRE cows received their PMR feed reward immediately on presentation at the dairy facility, whereas POST cows had to progress through the premilking waiting yard and milking platform before receiving their PMR feed reward. The lack of any significant treatment interaction with either SOL or MY indicates that the PRE treatment created the potential to encourage quicker returns to the dairy facility regardless of the DIM or production level.

The lack of significant difference in RT for cows in different SOL is in disagreement with previous reports. Generally it is recognized that motivation and voluntary cow traffic decline as SOL progresses, with late lactation cows generally being a disproportionately high representation among fetched cows (Jago et al., 2006; Kerrisk, 2009). This finding may be related to the level of supplementary feeding and is discussed later in this section.

Our results show that the apparent initial advantage of a reduction in RT for PRE cows did not translate directly into a reduction on average MI or an increase in average MF. In our case, the reduced RT for PRE cows was offset by an increase in FT and WT.

The time spent in the feeding area per visit could affect the amount of feed that cows consume. The PMR intake was measured at the herd level, and feed disappearance could not be attributed to cows in a particular treatment as both treatment groups shared the same supplementary feeding area. However, the slightly

greater intake of PRE cows in concentrate feed stations located in the feeding area, although significant, cannot fully explain the longer time spent in that area. It is also recognized that it is possible POST cows spent less time in the feeding area without limiting their PMR consumption levels. The fact that they had already spent an average of 1.25 h on concrete in the premilking waiting yard before gaining access to the feeding area may have encouraged them to seek a more comfortable surface to stand on rather than loitering on the concrete feeding area. A study by Telezhenko et al. (2007) validates the concept that cows have a preference for soft, nonabrasive surfaces (e.g., rubber mats rather than concrete flooring).

Given that milking itself is not a strong reward (Prescott et al., 1998b), once PRE cows exit the feeding area they would be expected to have limited motivation to move onto the milking platform, therefore having a longer WT. This may be a direct result of the treatment on satiety level upon entering the premilking waiting yard or due to an increased level of engagement in other activities (e.g., ruminating). Conversely, POST cows did not receive a feed reward after having walked to the dairy facility in search of fresh feed, and would therefore be expected to have a greater level of motivation to move through the premilking waiting yard, get milked, and gain access to the feedpad. Research conducted in an indoor system to quantify usage relationship between facilities indicated a strong association between the milking procedure and feeding in a concentrate station in the exit lane (Halachmi et al., 2000), suggesting that feeding after milking was an effective way of increasing cow traffic through an AMS milking station. However, no comparison was made with feeding before milking in that study. Furthermore, in a trial conducted to study the effects of routing treatment and necessity for a waiting area, cows that had a premilking waiting area, and gained access to forage only after being milked, did not have a longer WT (Ketelaar-de Lauwere et al., 2000). Comparable results were found in a past trial that compared the presence or absence of a small feed allocation on the platform. When the feed was not offered, cows took twice as long to traffic through the premilking waiting area (Scott, 2011). Furthermore, similar WT were reported in an AMS study comparing water placement locations in New Zealand (Jago et al., 2003).

The greater MI of PRE cows explained their lower MF. A lack of difference in MF was observed for cows in different SOL, together with the MF obtained that was lower than the typical MF generally maintained with the research herd (around 1.8 milking events/cow per day with an even spread of SOL resultant of the year-round calving pattern; N. A. Lyons, un-

published data). Possible reasons for this are (1) the level of feeding was in line with greater levels of milk production than the milk level harvested in this study, which could have reduced the value of feed incentives used to encourage voluntary cow traffic; (2) the dairy layout associated with a prototype RR retrofitted to an existing dairy facility; and (3) the fact that PRE and POST cows were managed together means we cannot eliminate the possibility that the less motivated PRE cows restricted the path of the POST cows through the premilking waiting yard. Furthermore, in our study, MF was lower than the 2.5 milking event/cow per day reported for free cow-traffic indoor AMS (Nixon et al., 2009), and lower than the 3 milking events/cow per day (Halachmi, 2004) for cows in an indoor AMS that only had access to concentrates after milking.

Although PRE cows had higher MY, they also had lower MF, this resulted in no difference in DY. The lack of treatment effect on DY indicates that the effect on MI, although significant, was small and inconsequential in affecting yield. This would also suggest that cows in both treatments had similar total daily DMI. The difference in CC, despite being significant, was small and would be unlikely to reflect a significant increase in DY.

Another aim of this study was to evaluate the effect of location of supplementary feed on the number of MI exceeding 16 h. These MI are considered excessively long and have been shown to adversely affect milk production (N. A. Lyons, unpublished data) and udder health (Hammer et al., 2012). In our study, feeding cows before milking caused no reduction in the incidence of milking events with intervals exceeding 16 h. The incidence was even greater than the 30% that has been found previously (N. A. Lyons, unpublished data). Part of the reason could be due to the difference in milking system per se, which could have an effect on cow traffic in the system. In this study, animals were milked with a RR, whereas single box units were used previously (DeLaval VMS).

The proportion of cows entering the premilking waiting yard as a result of being fetched from previous allocations was comparable to the 27% obtained in an experiment conducted in an indoor loose housing system analyzing the effect of different amount of concentrates offered in the AMS (Bach et al., 2007). It is possible that a further reduction in MI could be obtained from a combination of feeding location options, by which some feed is offered before and other after milking. To encourage cows to volunteer from the paddock for feeding before milking has an advantage (reduced RT), although traffic through the dairy facility was improved feeding after milking (reduced FT and WT). Certainly a layout that allows the flexibility of both systems could allow for management to be optimized

during different seasons and under different conditions. Feeding high amounts of pasture in spring may lead to a reduced MF, however if concentrate feeders are available to cows as soon as they get to the dairy facility, a reduction in RT may become evident. During periods of high feed supplementation (e.g., during periods of reduced pasture growth, such as dry summer or cold winter periods) a need may exist to encourage cows to eat more supplementary feed per cow per day, which could be achieved through providing cows access to the feeding area both before and after milking. Such conditions can also contribute to large queues of cows at the dairy facility at certain times of day. If this is the case, a form of priority drafting may be an ideal solution; for example, cows that are close to or have exceeded a settable MI threshold (say a 12 or 16 h MI) could be drafted directly to the premilking waiting yard, whereas cows who have not reached that MI threshold could be offered feed before being drafted to milking. Feeding after milking is also a common practice incorporated into conventional milking systems and has the added advantage of reducing the risk of clinical environmental mastitis infections, given that cows are more likely to remain standing for a longer period after milking when the teat sphincter remains open. The best results are reportedly obtained when feed is provided within 30 min before or 60 min after the milking event (DeVries et al., 2010). The potential also exists for an unlimited number of options for targeted management for individual cows or for categorized groups of cows. For example, it is conceivable that feeding before milking could be used for late-lactation cows that have an MI too high to comfortably release the cow to the paddock but, whereby, milk harvesting efficiencies could be gained by adding another hour or 2 to the MI.

Results could be different if supplementation levels changed. Proportion of pasture in the diet is known to have an effect on MI (N. A. Lyons, unpublished data). The level of supplementation in this study (almost 40% of daily DMI) is representative of a low to moderate pasture growth time of the year in a pasture-based system. It is likely that lower levels of feed on offer at the dairy facility would not have acted as a strong incentive for cow movement. Moreover, greater levels comparable to those of indoor systems could have had an even stronger effect, with a further reduction in the time to return from the pasture. Different levels of concentrates on offer in the feed stations could also have had an effect on cows, yet previous studies, although conducted in indoor systems, have reported no difference in concentrate allowance in number of voluntary milking events or milk production (Halachmi et al., 2005; Bach et al., 2007).

CONCLUSIONS

In comparison to POST cows, PRE cows milked in a pasture-based AMS had a reduced RT to the dairy facility, although FT and WT were greater, resulting in a greater overall MI, but without affecting DY. This study demonstrated the potential of feeding management strategies to influence cow behavior and traffic in voluntary milking systems. Design of dairy facilities and feeding layout for AMS installations should consider the allowance for flexible management for different supplementary feeding strategies.

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