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Associations between lameness and production, feeding and milking attendance of Holstein cows milked with an automatic milking system

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A longitudinal study involving 73 primiparous (PP) and 47 multiparous (MP) Holstein cows was conducted over an 8-month period to assess the associations between locomotion score (LCS) and milk production, dry matter intake (DMI), feeding behaviour, and number of visits to an automatic milking system (AMS). Twice weekly, all cows were locomotion scored (scale 1–5) by the same observer. Individual eating behaviour and individual feed consumption at each cow visit to the feed troughs, individual milk production, the time of milking, and the number of milkings for each cow were recorded for the day of locomotion scoring and the day before and after. Dependent variables, such as milk yield, DMI, etc. were modelled using a mixed-effects model with parity, LCS, days in milk (DIM), the exponential of −0·05 DIM, and the interaction between parity and LCS, as fixed effects and random intercepts and random slopes for the linear and the exponential of −0·05DIM effects within cow. LCS did not affect time of attendance at feed troughs, but affected the location that cows occupied in the feed troughs. The time devoted to eating and DMI decreased with increasing LCS. Milk production decreased with LCS>3. The number of daily visits to the AMS also decreased with increasing LCS. The cows with high LCS were fetched more often than the cows with low LCS. Overall, PP cows were more sensitive to the effects of increasing LCS than were MP cows. The decrease in milk production observed with increasing LCS seemed to be affected similarly by the decrease in DMI and by the decrease in number of daily visits to the AMS. A further economic loss generated by lame cows with AMS will be associated with the additional labour needed to fetch them.

Keywords: Lameness, milk loss, intake, behaviour, mixed model analysis.

Lameness is probably the most common affliction of dairy cattle. The average incidence of lameness is reported to be 9–50% (Barkema et al. 1994; Clarkson et al. 1996), and it is generally accepted that lameness incidence has increased over the past 45 years since Leech et al. (1960) reported an average incidence of lameness of about 4%. Lameness causes pain (Whay et al. 1997) and thus may reduce animal welfare, reproductive performance (Garbarino et al. 2004) and economic efficiency of affected herds (Whitaker et al. 1983; Kossaibati & Esslemont, 1997).

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However, reports on the impact of lameness on milk yield are inconsistent, with some reporting no change in milk yield (Cobo-Abreu et al. 1979) or an increase in milk production (Dohoo & Martin, 1984), but the majority reporting a decrease (Whitaker et al. 1983; Warnick et al. 2001; Green et al. 2002). One reason for this discrepancy may be that some types of lameness such as those arising from phelgmon have been associated with decreases in milk yield, but lameness produced by papillomatous digital dermatitis or claw lesions have not (Hernandez et al. 2002). Another reason for the discrepancy in reported effects of lameness on milk yield may be the difficulty in classifying cows as lame, but may also be due to the statistical methods used. Comparing milk yield differences between lame cows and their cohorts (Dohoo & Martin, 1984; Barkema et al. 1994) may be an appropriate method, but it may fail when the cows affected by lameness had initially a production level above the average milk yield of the control cows. The use of mixed-effects models, that account for the dependence of repeated measures on a same animal (Wilson et al. 2004) would be a preferred approach.

Feeding pattern of dairy cattle has been investigated using cows housed in tie-stalls (Dado & Allen, 1994) and under loose-housing conditions (DeVries & Von Keyserlingk, 2005; Shabi et al. 2005; Bach et al. 2006). However, to our knowledge, there are no studies that quantify changes in individual dry matter intake (DMI) as affected by locomotion score (LCS) or incidence of lameness in loose-housed dairy cattle. Furthermore, prevention of lameness is desirable for both economic and animal welfare reasons, but with automatic milking systems (AMS) lameness may pose an even greater problem than with conventional parlours because lame cows may not get milked (or will require additional labour to be fetched to the AMS). Therefore, the objectives of this study were to estimate changes in milk production, DMI, feeding pattern and number of visits to the AMS associated with LCS.

Materials and Methods

Animals and their management

One-hundred-and-twenty lactating Holstein cows, 73 primiparous (PP) and 47 multiparous (MP), were monitored over an 8-month period, from October 2004 to May 2005. Animals were managed and handled under the guidance of the Animal Care Committee of Institut de Recerca i Tecnologia Agroalimentàries (IRTA). All cows were kept in loose-housing conditions on a farm split into two symmetrical pens with 28 feeding troughs, two waterers (200 × 60 and 140 × 45 cm) and an AMS (VMS, DeLaval, Sweden). Each pen held about 50 cows at any time of the study. As cows were dried off they left the study and as new cows calved they entered the study. Cows had free access to the AMS, and could be milked any time provided that >4 h had elapsed since the previous milking. Milking intervals for each cow were monitored four times a day at 7.00, 12.00, 15.00 and 19.00 approximately, and those cows with milking intervals >12 h were fetched and brought to the AMS. At any of these four times, only a maximum of 6 cows were fetched for each AMS to avoid an excessively long time in the waiting area. The time and date each cow was fetched was recorded. Each pen had 250 m^2 of a composting bedded pack (bedded with about 400 kg of straw every other day) and 550 m^2 for exercise (on concrete floors). All cows received the same basal ration (15·6% CP, 35·4% NDF, 20·7% ADF and 6·53 MJ net energy for lactation (NE_L)/kg, on a DM basis) *ad libitum* in the feed troughs twice daily at approximately 8.30 and 15.30 and, at each milking, 1·5 kg of a concentrate (25·8% CP, 21·7% NDF, 11·2% ADF and 7·91 MJ NE_L/kg, on a DM basis) during milking in the AMS. If cows were milked more than twice daily, they did not receive concentrate beyond the second milking (maximum concentrate allowance was 3 kg/d).

Measurements

All cows were locomotion scored (Sprecher et al. 1997) approximately twice weekly by the same observer, who had been trained before the start of the study. With the scoring system used (scale 1–5), cows assigned a score of 1 or 2 could be considered as not lame (because their gait is normal), whereas cows with scores equal or above 3 could be considered lame (Sprecher et al. 1997). According to this scoring system (Sprecher et al. 1997) cows with LCS = 1 stand and walk with a level-back posture; cows with a LCS = 2 stand with a level-back posture but arch their backs while walking although their gait is normal; cows with a LCS = 3 show an evident arched-back while both standing and walking and their gait is short-striding with one or more limbs; cows with a LCS = 4 have their back arched while standing and walking and they favour one or more limbs; and cows with LCS = 5 demonstrate an inability or extreme reluctance to bear weight on one or more limbs. Individual eating behaviour, including time, number and duration of visits to the feed troughs, as well as individual feed consumption at each visit, were recorded for the day of locomotion scoring and the day before and after using a computerized system (Bach et al. 2004). The system consisted of a scale below each feed trough and a proximity reader that detected a transponder that each cow was wearing in the ear. Data from the scales and the proximity readers were continuously recorded by a computer. Furthermore, the location on the feed trough chosen by each cow to eat was also recorded by the system. Moreover, on those 3 d, a grab sample of fresh total mixed ration (TMR) and a grab sample of refusals from the previous day were obtained to determine DM content of TMR and refusals. In addition, during the day of locomotion scoring and the day before and after, individual milk production, time of milking and number of visits to the AMS were recorded. Milk composition was determined once monthly in an official laboratory (Allic, Cabrils, Spain). All records corresponding to milk and intake were associated with a LCS assuming that the LCS did not change during the day before, the day after, and the day of the actual LCS recording. The use of 3-d records for milk and intake data, rather than observations corresponding only to the day that the LCS was assigned, was chosen owing to the large variation that exists in intake and milk production data.

Calculations and statistical analyses

The lowest number of observations per cow was 35, the maximum 136, and the average was 94. The dependent variables (milk yield, number of daily milks, DMI, etc.) were analysed with a mixed-effects model with random intercepts and random slopes for the linear and the exponential of −0·05 DIM (Wilmink, 1987) effects within cow, and parity (PP or MP), LCS, DIM, the exponential of −0·05 DIM, and the interaction between parity and LCS, as fixed effects. The random intercepts and slopes in this model assumed that the effects of the subject cow were random, and that these effects could have a different intercept and slope for each cow. The model had the following mathematical form:

$$Y_{ij}=\beta_{0i}+\beta_{1j}DIM_{ij}+\beta_{2j}e_{ij}^{(-0\cdot05DIM)}+\beta_{3j}LCS_{ij}+\beta_{4j}Parity_{ij}$$
$$+\beta_{5j}LCS_{ij}\times Parity_{ij}+(n_{0i}+\eta_{1j}DIM_{j}+\eta_{2j}e_{j}^{(-0\cdot05DIM)}+\varepsilon_{ij})$$

where Y_{it} represented the dependent variable (DMI, milk yield, etc.) of the i^{th} cow at the j^{th} point in time, β_{0i} was the intercept and represented the average value of the dependent variable when $j=0$, β_{1j} and β_{2j} represented the change in the dependent variable for every one-unit increase in time (DIM), β_{3j} represented the change in the dependent variable for every 1-unit change in LCS, β_{4j} represented the change in the dependent variable with parity (PP *v.* MP), and β_{5j} modelled the interaction between LCS and parity. The part of the model within parenthesis describes the random effects with n_{0i} representing the random intercepts and η_{1j} and η_{2j} representing the slope of the random effects.

In addition, to assess the impact of lameness on milk yield and feeding behaviour a new categorical variable (DIMd) was used to divide DIM into four discrete classes (1: 0–95 d; 2: 96–165 d; 3: 166–240 d; 4: >240 d). This variable was then used in a model similar to the one mentioned above but including the interaction between LCS and the class variable DIMd:

$$Y_{ij}=\beta_{0i}+\beta_{1j}DIMd_{ij}+\beta_{2j}LCS_{ij}+\beta_{3j}Parity_{ij}+\beta_{4j}LCS_{ij}$$
$$\times Parity_{ij}+\beta_{5j}LCS_{ij}\times DIMd_{ij}+(n_{0i}+\varepsilon_{ij})$$

where Y_{it} represented the dependent variable (DMI, milk yield, etc.) of the i^{th} cow at the j^{th} point in time, β_{0i} was the intercept and represented the average value of the dependent variable when $j=0$, β_{1j} represented the change in the dependent variable for every 1-unit increase in lactation stage (DIMd), β_{2j} represented the change in the dependent variable for every 1-unit change in LCS, β_{3j} represented the change in the dependent variable with parity (PP *v.* MP), β_{4j} modelled the interaction between LCS and parity, β_{5j} modelled interaction between LCS and stage of lactation (DIMd), and n_{0i} represented the random effect of cow *i*.

In addition, to determine whether the incidence of lameness was different between MP and PP a contingency test was performed using a categorical variable coded 0 for LCS<3, and 1 for LCS⩾3. Similarly, to determine whether the lameness occurred earlier in lactation in MP than in PP, the average time elapsed between calving and the first occurrence of lameness for both parities was compared using a mixed-effects model, with cow as a random effect and parity as a fixed effect.

To group several visits to the feed troughs into single meals and determine the number of daily meals for each cow, individual meal criteria were determined as described by Bach et al. (2006).

To account for the dependence between determinations conducted on same animals throughout the study a compound-symmetry variance-covariance structure was used. The validity of the model was assessed plotting the standardized residuals to ensure that they followed a normal distribution. When the effect of LCS was significant, differences between the five levels were tested against zero adjusting for multiplicity based on Tukey's method (Montgomery, 1996).

To evaluate whether LCS could affect the location preferences of cows at the feed troughs, a mixed-effects model with feed trough as a continuous dependent variable, cow as a random effect, and LCS as a fixed effect was run. Moreover, a mixed-effects ordinal logistic regression, including cow as a random effect, was conducted between the LCS and the feed trough position chosen by each cow. Similarly, an ordinal logistic regression, including cow as a random effect, was run between the LCS and the time of voluntary visits to the AMS categorized into morning (6.00–12.00), afternoon (12.01–18.00), evening (18.01–24.00) and night (24.01–05.59) to assess whether lame cows had a time of the day at which they would prefer to be milked.

Finally, to determine whether the decrease in milk yield observed with LCS was more due to a decrease in DMI or to a decrease in the number of daily visits to the AMS, a mixed-effects multiple linear regression model with cow as random effect, milk yield as the dependent variable, and DMI and number of daily visits to the AMS plus DIM and the exponential of −0·05 DIM as independent variables was run, and the contributing semipartial correlations (the percent of variance in the dependent variable uniquely attributable to a given independent variable leaving the other variables in the equation fixed) of each of the two independent variables were calculated.

Results and Discussion

A practical limitation of the system proposed by Sprecher et al. (1997) is the distinction between LCS=2 (cows that arch their back while walking but stand with a flattened back) and LCS=3 (cows maintain an arch when walking and standing). It is not always easy for the investigator to score each cow while she is both standing and walking, making it difficult to make the distinction between LCS of 2 and 3. However, in the current study an effort was made to conduct all measurements on cows that were both walking and standing.

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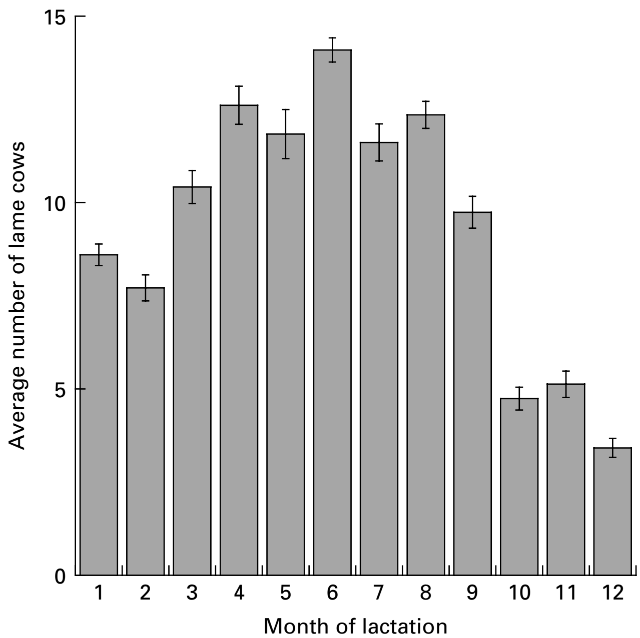

Fig. 1. Average number of lame cows (locomotion score ⩾3) by month of lactation.

The study was conducted between October 2004 and May 2005, which coincides with the seasons where the largest incidence of lameness was reported by Hirst et al. (2002). There were 111, 76, 58, 78 and 38 cows scored, at least once, with a LCS of 1, 2, 3, 4, and 5, respectively. Overall, there were 2571, 412, 234, 714, and 251 observations with LCS of 1, 2, 3, 4, and 5, respectively. The total number of lame observations (LCS⩾3) was 1199, which was equivalent to 28·7% of the total observations. The incidence of lameness was more frequent ($P<0·05$) in MP (44·8% of MP observations were ⩾3) than in PP (19·7% of PP observations were ⩾3) cows. This result agreed with earlier studies (Warnick et al. 2001; Hirst et al. 2002).

The greatest incidence of lame cows occurred between 4 and 8 months in milk (Fig. 1). Former reports (Green et al. 2002) describe a greater incidence of lame cows in earlier months of lactation. The average elapsed time between calving and a first case of lameness (excluding the cows that calved already lame) was overall 120·9± 10·83 d, and tended ($P=0·09$) to be shorter in MP (99·5±16·27 d) than in PP cows (137·2±14·19 d). Cases with LCS=3 lasted a median (distribution was not normal) of 7·9±0·43 d, cases of LCS=4 lasted a median of 10·0±0·45 d and cases of LCS=5 lasted a median of 12·0±1·09 d.

Feed intake and feeding pattern

Cows with high LCS, regardless of their difficulties in walking, attended the feed troughs at similar times as their companions. However, the preference shown by cows for specific locations of the feed troughs seemed to change with LCS. The change in the visit location was more evident for those cows with a LCS=5, and was similar in both pens. Lame cows avoided the feed troughs that were furthest from the exit of the AMS as the number of visits to those feed troughs by cows with LCS=5 was lower than the rest. In fact, the average feed trough position decreased ($P<0·001$) by 0·11±0·03 units for every increase in LCS in pen 1 (thus getting closer to the AMS as feed trough 1 was closest to the AMS) and it increased ($P<0·001$) by 0·21±0·03 units in pen 2 (thus getting also closer to the AMS as feed trough 56 was closest to the AMS). Furthermore, the results from the ordinal logistic regression analyses conducted between the LCS and each feed trough, showed significantly ($P<0·001$) increasing odds ratios for the feed troughs closest to the AMS. For example, location number 2 (close to the AMS) in pen 1, had 1·57±0·07 as great odds ($P<0·001$) of receiving a visit by a cow with a high LCS as location number 28 (the furthest from the AMS). Similarly, location 56 (close to the AMS) of pen 2, had 1·35±0·06 greater ($P<0·001$) odds of receiving a visit from a cow with a high LCS than location number 31 (furthest from the AMS).

Overall, the time devoted to eating was greater ($P<0·001$) in MP than in PP cows (263·8±20·38 *v.* 249·0± 20·43 min/d, respectively) and decreased ($P<0·001$) as LCS increased, especially with LCS>3 (Table 1). However, the decrease was more pronounced for PP than for MP cows as indicated by the significant ($P<0·001$) interaction between LCS and parity. Time devoted to eating by PP ranged from 265±20·38 to 226±20·81 min/d, whereas in MP it ranged from 272±20·35 to 255±20·64 min/d for LCS 1–5, respectively. Cook et al. (2004) could not establish significant differences in total eating times between non-lame cows (277 min/d) and cows with mild (254 min/d) and moderate (229 min/d) lameness, although the trend was the same as the one reported in the current study. Thus, it can be concluded that increasing LCS in lactating dairy cattle will result in decreasing time devoted to eating.

The number of daily meals tended ($P<0·08$) to be greater in PP (4·56±0·31 meals/d) than in MP cows (4·40±0·31 meals/d) and decreased with increasing LCS (Table 1). The decrease in the number of daily meals was more pronounced ($P<0·001$) in MP than in PP cows. PP cows with LCS=1 had 4·75±0·31 of meals/d, and this number decreased to 3·79±0·35 meals/d with LCS=5, whereas MP cows with LCS=1 had 5·02±0·31 meals/d but MP cows with LCS=5 had 3·56±0·35 meals/d.

As expected, DMI was also greater ($P<0·001$) in MP than in PP cows (22·2±0·67 *v.* 17·8±0·68 kg/d, respectively). DMI was similar for LCS 1–3, but decreased ($P<0·001$) with LCS>3 (Table 1) and the decrease was more important ($P<0·001$) in PP (from 18·3±0·67 to 17·3±0·74 kg/d, for LCS=1 to LCS=5, respectively) than in MP cows (from 22·1±0·68 to 21·8±0·70 kg/d, for

Table 1. Feeding behaviour and feed intake of dairy cattle as affected by their locomotion score

	Locomotion score						*P* value†		
	1	2	3	4	5	SE	LCS	LCS × Parity	Parity
Total eating time, min/d‡	268·1^{a}	264·0^{a}	262·0^{ab}	247·7^{b}	240·0^{d}	20·24	<0·001	<0·005	<0·001
Primiparous	264·6^{a}	258·6^{a}	255·6^{ab}	240·5^{b}	225·9^{b}	20·38	<0·001	—	—
Multiparous	271·6^{a}	269·4^{ab}	268·3^{ab}	254·8^{b}	254·8^{b}	20·39	<0·001	—	—
Number of meals, d^{-1}‡	4·89^{a}	4·60^{b}	4·66^{b}	4·61^{b}	3·69^{c}	0·22	<0·001	<0·001	<0·001
Primiparous	4·75^{a}	4·54^{a}	4·62^{a}	4·72^{a}	3·79^{b}	0·31	<0·001	—	—
Multiparous	5·02^{a}	4·78^{b}	4·69^{b}	4·34^{b}	3·56^{c}	0·31	<0·001	—	—
Total DMI, kg/d	20·2^{a}	20·1^{a}	20·5^{a}	19·6^{b}	19·5^{b}	0·48	<0·001	<0·003	<0·001
Primiparous	18·3^{a}	18·0^{a}	17·9^{a}	17·4^{b}	17·3^{b}	0·70	<0·001	—	—
Multiparous	22·1^{a}	22·2^{a}	22·5^{a}	21·8^{b}	21·8^{b}	0·70	<0·001	—	—

† LCS: Effect of locomotion score; LCS × Parity: Interaction between locomotion score and parity (primiparous or multiparous)
‡ Excluding concentrate consumption during milking
[a,b,c] Values within the same row without a common superscript letter are significantly different at $P<0{\cdot}05$

Table 2. Milk yield and number of daily milkings with an automatic milking system of lactating cows as affected by their locomotion score

	Locomotion score						*P* value†		
	1	2	3	4	5	SE	LCS	LCS × Parity	Parity
Milk yield, kg/d	30·7^{a}	29·9^{ab}	30·3^{a}	29·2^{b}	28·3^{b}	1·03	<0·001	<0·001	<0·01
Primiparous	27·5^{a}	27·5^{a}	26·1^{a}	25·1^{b}	23·8^{b}	1·05	<0·001	—	
Multiparous	33·8^{ab}	33·9^{ab}	34·5^{a}	33·3^{bc}	32·9^{c}	1·04	<0·001	—	—
Total milkings, d^{-1}	2·64^{a}	2·36^{c}	2·48^{b}	2·24^{d}	1·93^{e}	0·10	<0·001	<0·001	<0·001
Primiparous	3·24^{a}	2·69^{c}	2·88^{b}	2·69^{c}	2·20^{d}	0·11	<0·001	—	—
Multiparous	2·04^{a}	2·04^{a}	1·95^{a}	1·70^{b}	1·67^{b}	0·11	<0·001	—	—
Voluntary milkings, d^{-1}	2·09^{a}	1·80^{c}	1·92^{b}	1·63^{d}	1·19^{e}	0·13	<0·001	<0·001	<0·001
Primiparous	2·79^{a}	2·18^{c}	2·60^{b}	2·20^{c}	1·55^{d}	0·14	<0·001	—	—
Multiparous	1·38^{a}	1·41^{a}	1·25^{b}	1·07^{b}	0·84^{d}	0·14	<0·001	—	—

† LCS: Effect of locomotion score; LCS × Parity: Interaction between locomotion score and parity (primiparous or multiparous)
[a,b,c,d,e] Values within the same row without a common superscript letter are significantly different at $P<0{\cdot}05$

LCS=1 to LCS=5, respectively). Therefore, it appears that MP were less sensitive to locomotion problems with respect to their DMI than were PP cows, who showed a more important decrease in DMI with increasing LCS. The greater sensibility to lameness of PP compared with MP cows could be linked to the more severe decrease in the time devoted to eating as LCS increased in PP than in MP cows. Furthermore, MP cows were able to compensate the decrease in the number of daily meals, without incurring in a decrease in total eating time as pronounced as the one showed by PP cows.

Milk production and milking visits

Average milk production throughout the study was 29·7±0·1 kg/d with an average DIM of 169·1±0·9 d, and an average milk fat of 3·74±0·08 and milk protein of 3·23±0·03. As expected, milk production was greater ($P<0{\cdot}001$) in MP than in PP cows (33·7±0·9 *v.* 26·1±0·7 kg/d).

Milk production decreased for LCS>3 (Table 2). The decrease in milk production was more severe ($P<0{\cdot}001$) in PP than in MP cows. This is contrary to the observations of Warnick et al. (2001) and Hernandez et al. (2005), but agrees with the conclusions of Rajala-Schultz (2004). PP cows with LCS=1 produced 27·5±1·02 kg/d whereas PP cows with LCS=5 produced 23·8±1·08 kg/d. On the other hand, MP with LCS=1 produced 33·8±1·02 and MP with LCS=5 produced 32·9±1·06 kg. Therefore PP cows appeared to be more sensitive to high LCS than MP cows, as was also indicated by the drop in DMI and time devoted to eating.

Milk production of cows that became lame at the beginning (<95 DIM) or at the end of lactation (>240 DIM) was most impaired ($P<0{\cdot}001$), with a reduction from 34·1±0·59 to 30·9±0·87 kg/d at DIM <95 and from

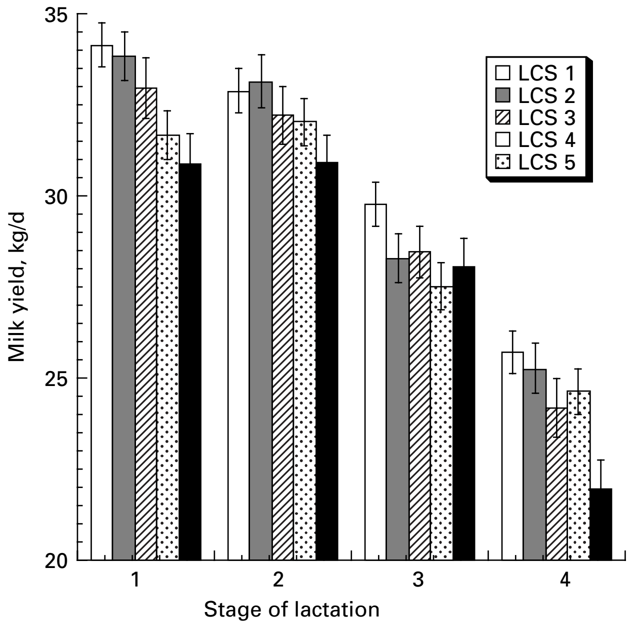

Fig. 2. Milk yield as affected by locomotion score and stage of lactation. Stage of lactation: 1, 0–95 days in milk; 2, 96–165 days in milk; 3, 166–240 days in milk; and 4, >240 days in milk.

25·7±0·60 to 22·0±0·8 kg/d at DIM >240 for cows with LCS=1 and LCS=5, respectively (Fig. 2). In contrast, lameness between 96 and 240 DIM resulted in lower milk losses (from 30·1±0·70 to 29·7±0·65 kg/d for LCS=1 and LCS=5, respectively).

The number of daily visits to the AMS also decreased ($P<0·001$) with increasing LCS (Table 2). The decrease in the number of daily milkings was more pronounced ($P<0·001$) in PP than in MP cows. The number of daily milkings in PP decreased from 3·24±0·10 of those with a LCS=1 to 2·20±0·13 of those with a LCS=5, whereas MP with LCS=1 visited the AMS 2·04±0·10 and decreased to 1·67±0·11 with LCS=5. The number of voluntary visits to the AMS followed the same pattern (Table 2) as the total daily visits but the difference between voluntary visits and total daily milkings was greater ($P<0·05$) in cows with LCS⩾4 than the rest (0·55 *v.* 0·74 for LCS=1 and LCS=5, respectively) illustrating that cows with high LCS were fetched more often than cows with low LCS.

As observed with feeding attendance, the time pattern of voluntary visits to the AMS was similar in both pens and did not seem to be affected by the LCS except for those cows with a LCS=5 that showed a lower number of voluntary visits to the AMS during the night. In fact, the ordinal logistic regression analysis (Table 3) indicated that cows with high LCS avoided visiting the AMS at night and preferred visiting it during the mornings, because the odds of being milked between 06.00 and 12.00 for lame cows was 1·38-times as great ($P<0·001$) as the odds of being milked during the night (24.01–5.59).

Table 3. Adjusted ordinal odds ratios (OR) for the time of the day that cows voluntarily visited the automatic milking system according to their locomotion score†

Time	OR	Confidence interval	*P* value
6.00–12.00	1·38	1·29–1·47	<0·001
12.01–18.00	1·28	1·20–1·37	<0·001
18.01–24.00	1·15	1·08–1·23	<0·001
24.01–5.59	1·0	Reference	—

† Ordinal odds ratios indicate the odds change for each unit increment in LCS

Intake, decreased milking frequency and milk loss

Milk production is mainly driven by DMI, and thus a decrease in DMI due to a high LCS should result in a decrease in milk production. However, increases in LCS also elicit a decrease in the number of daily milkings, and this decrease in milking frequency may also have negative consequences on milk production because increased milking frequency is associated with increases in milk yield (Wagner-Storch & Palmer, 2003) and there are several studies (Rennison et al. 1993; Peaker & Wilde, 1996) that suggest that milk accumulation in the udder has a negative autocrine effect on milk secretion.

To separate the effects of DMI and milking frequency on the decrease in milk production observed with increasing LCS, semipartial correlations for these two independent variables were calculated. The semipartial correlation between DMI and milk yield was 0·26 and between the number of visits to the AMS and milk yield was 0·25. Therefore, the decrease in milk production observed with increasing LCS seemed to be affected similarly by the decrease in DMI and by the decrease in number of daily visits to the AMS. It can be concluded that with AMS, lame cows will result in a greater milk loss (compared with their cohorts) than in traditional milking parlours, as a consequence of a reduced milking frequency. In addition, a further economic loss generated by lame cows with AMS will be associated with the additional labour needed to fetch them.

It is concluded that the time devoted to eating, DMI and the number of daily meals decreased with increasing LCS. Cows with high LCS approached the feed troughs at similar times than non-lame cows, but they avoided those feed troughs that were the furthest from the AMS. The number of visits to the AMS decreased with increasing LCS, and cows with high scores needed to be fetched more often than non-lame cows. Moreover, cows with high LCS avoided visiting the AMS during the night and preferred visiting it during the mornings. The decrease in feed consumption and in milking attendance were equally responsible for the decrease in milk yield, and thus with AMS, lameness poses a further economic problem associated with the increased labour needed to fetch cows and the poor milking frequency.

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