Lameness and lying behavior in grazing dairy cows

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ABSTRACT

Lameness is a serious welfare issue for dairy cows. To date, the majority of studies have focused on its effect on health and behavior at the herd level. The objectives of this study were to identify (1) between-cow and (2) within-cow changes in lying behavior associated with consistent and changing lameness status in grazing dairy cows. Previous studies of lying behavior in grazing dairy cows have not considered the effect of precipitation, so a third aim was to determine the effect of precipitation on lying behavior. A total of 252 dairy cows from 6 pasture-based farms in southern Brazil were gait scored weekly to assess lameness using a 5-point scale [1–5, numerical rating score (NRS)] for 4 consecutive weeks. Cows were considered to have consistent lameness if they were scored as lame (NRS ≥ 3) on each of the 4 visits and considered to have a changing lameness status if scored as being nonlame (NRS < 3) on at least 1 of the 4 visits. Cows classified as having a changing lameness status were further classified as developed, recovered, or inconsistent. Lying behavior (daily lying time, mean lying bout duration, and daily number of lying bouts) was recorded continuously for 3 wk using leg-mounted accelerometers. Cow-level variables included parity, days in milk, and body condition score. Regional precipitation and temperature were recorded hourly. Because only 1 primiparous cow was identified as lame at each of the 4 visits, the between-cow analysis of lameness was run on multiparous cows only. The overall prevalence of clinical lameness on the first visit was 39%, with development and recovery rates of 16 and 10% over the 4 visits, respectively. The between-cow effect of consistent lameness status on daily lying time and number of lying bouts was dependent on precipitation; consistently lame cows had reduced lying time and lying bouts on days with rain compared with days without rain. There was no within-cow effect of

changing lameness status on any of the lying behaviors. Precipitation was associated with decreased daily lying time, increased mean lying bout duration, and decreased daily number of lying bouts. The results of this research provide the first evidence that the effect of consistent lameness status on lying behavior is associated with rainfall in grazing dairy cows. Future work measuring lying behavior of grazing dairy cows should include precipitation as a covariate.

Key words: gait, locomotion, precision farming, animal welfare

INTRODUCTION

Lameness is the manifestation of one or more claw, leg, or nerve pathologies that can cause standing and walking to be uncomfortable or painful (Whay et al., 1997, 1998); it is typically presented and diagnosed by an abnormal gait (e.g., score 1–5, ≥ 3 being clinically lame; Sprecher et al., 1997; Flower and Weary, 2006). In addition to compromising the welfare of individual animals, lameness has negative effects on the productivity and longevity of dairy cattle. Previous work has shown that lame cows have lower milk yield and reduced reproductive performance, and, in some cases, have an increased risk of being culled (reviewed by Huxley, 2013). Lameness is also one of the most expensive production diseases that affect dairy cattle (Kossaihati and Esslemont, 1997). Despite the negative impact, lameness remains common in many commercial pasture-based dairy farms, with prevalence ranging from 8 to 31% (e.g., Fabian et al., 2014; Ranjbar et al., 2016; Bran et al., 2018).

Gait scoring is commonly used to identify lameness (Flower and Weary, 2009), with a variety of scoring systems used (e.g., Sprecher et al., 1997; Cook, 2003; Flower and Weary, 2006). Aside from changes in gait, lameness has also been shown to affect various behaviors in dairy cattle, such as lying (Ito et al., 2010; Sepúlveda-Varas et al., 2014; Weigle et al., 2018) and feeding (Weigle et al., 2018), which may serve as proxy measures for lameness detection.

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With increased automated recording of cow behavior (e.g., using wearable technology such as dataloggers), the use of these tools to explore the effects of lameness on behavior has gained popularity in research. The majority of research has focused on the relationship between lameness and daily lying time (Walker et al., 2008; Chapinal et al., 2010; Ito et al., 2010), as modulated by the number and duration of individual lying bouts (Ito et al., 2010; Sepúlveda-Varas et al., 2014). Most studies have measured the behavioral effects of lameness using cross-sectional studies, which only allow for between-group (i.e., lame versus nonlame) comparisons. To our knowledge, no research has investigated within-cow changes in lameness status and their effect on lying behavior.

A challenge in using changes in lying behavior to identify lameness is accounting for other factors that affect lying. In outdoor systems, cows might be especially affected by environmental factors such as rain. Experimental work has shown that indoors, dairy cows prefer to lie down on dry bedding (Fregonesi et al., 2007; Reich et al., 2010) and outdoors, dairy cows decrease daily lying duration when lying surfaces are wet (Tucker et al., 2007; Schütz et al., 2010; Chen et al., 2017); this response is thought to help reduce conductive heat loss, which is potentially more important in cooler temperatures (Tucker et al., 2007). At temperatures below freezing, when precipitation turns to snow, Graunke et al. (2011) found that the proportion of beef cows lying down increased compared with periods with similar temperatures and no snow. To date, no studies have quantified the effect of precipitation on the lying behavior of dairy cows managed at pasture.

This study had 3 main objectives: (1) to describe differences in lying behavior between lame cows and nonlame cows to test the prediction that lame cows would spend more time lying down; (2) to describe changes in lying behavior when nonlame cows become lame and vice versa, to test whether lying behaviors would change in relation to changing lameness status; and (3) to document the effects of precipitation on lying behavior. Consistent with previous findings with wet lying surfaces, we predicted that rainfall would decrease daily lying time.

MATERIALS AND METHODS

This study was approved by the University of British Columbia Animal Care Committee (A15-0082) and the Federal University of Santa Catarina Ethics Committee of Research on Animals (PP00949). Between June and August 2015, we evaluated 252 lactating dairy cows from 6 pasture-based dairy farms with rotational grazing located in the west of Santa Catarina, Bra-

zil (26°43'51"S, 53°30'55"W). The farms were part of a larger study focused on risk factors associated with lameness, metritis, and ketosis in lactating dairy cows managed on pasture (see Daros et al., 2017; Bran et al., 2018a,b). On each farm, cows were milked twice daily at approximately 0600 and 1600 h and were allowed access to supplemental silage and concentrate (an average of 21.3 ± 10.1 and 6.8 ± 1.5 kg/cow per day, respectively; means $\pm$ SD) for approximately 30 min immediately after each milking. Both the milking and feeding areas had flat concrete flooring. Cows had access to pasture for the remainder of the day (a minimum of 16 h/d), under rotational grazing systems on paddocks of varying sizes. Pasture plant species consisted of primarily temperate grass species, such as oat (*Avena sativa*) and ryegrass (*Lolium* spp.), varying in age from juvenile to senescent. The use of trees to provide shade and shelter in the paddocks was minimal or absent.

Data Collection

Animal Measures. On the first farm visit, breed, parity, and DIM were retrieved from farm records or directly reported by the farmer. While cows were in the milking parlor, we assessed BCS (5-point scale with 0.25-point increments from 1 to 5; Ferguson et al., 1994). Data on milk yield per herd were obtained from dairy company records on the farm.

Gait Assessment. For 4 consecutive weeks, all lactating cows were gait scored by one of the researchers (J. A. Bran), a veterinarian with training in gait scoring. When cows exited the milking parlor and were walking along a straight, flat, hard surface, they were gait scored using a 5-point numerical rating score (NRS), where 1 = nonlame and 5 = severely lame (Flower and Weary, 2006). Cows were categorized as nonlame (NRS ≤ 2), clinically lame (NRS ≥ 3), or severely lame (NRS ≥ 4). Because farms were visited just once a week, reliability of gait scoring was estimated using inter-rater reliability rather than intra-rater reliability. To determine inter-rater reliability, a second observer (A. J. Thompson), who was trained using video and live-scoring, gait scored 48 lactating cows from one farm for each visit. The mean NRS values for each cow across all visits were used to generate intraclass correlation (ICC) estimates and their 95% confidence intervals (R version 3.4.3; R Core Team, 2017) based on single rater ($k = 2$), consistency, and 2-way random effects. The ICC estimate was 0.707 (95% CI: 0.531–0.824; $F_{(47, 47)} = 5.82$, $P < 0.001$).

Lame cows were frequently treated using antibiotics and topical hoof products, whereas few were treated with anti-inflammatories or analgesics or hoof trimming as remedies (see Bran et al., 2018a). Farmers in

this study did not have a systematic approach for diagnosing lameness or use regular preventative measures for lameness.

Lying Behavior. For 3 consecutive weeks, beginning immediately after the initial gait scoring session and ending immediately before the final gait scoring session, lying behavior was recorded at 1-min intervals using dataloggers (Hobo Pendant G, Onset Computer Corp., Bourne, MA) attached to the hind leg of each cow. Dataloggers were attached using a self-adherent bandage (Co-Flex, Andover Healthcare Inc., Salisbury, MA) and padded to minimize risk of chafing. Once a week, loggers were removed and replaced with new ones so that data could be downloaded. Standing or lying data were extracted following the methods outlined by Ledgerwood et al. (2010), using a 2-event filter to correct for bouts of standing or lying that lasted less than 3 min (UBC Animal Welfare Program, 2013).

Environmental Measures. This study took place between June and August, during the winter season in southern Brazil, a period when rain is frequent and temperatures are mild. Hourly regional temperature (°C) and precipitation (mm) were retrieved from the Automatic Meteorological Station in São Miguel do Oeste, Santa Catarina (National Institution of Meteorology, Ministry of Agriculture; 26°46'S, 53°30'W). All farms were within 40 km of this weather station.

Statistical Analysis

Statistical analyses were performed in R (version 3.4.3; R Core Team, 2017) with linear mixed-effects models using R packages lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2016). A *P*-value of <0.05 was considered statistically significant. Cows with incomplete datalogger recordings (missing more than 1 week, either because they were lost or stopped recording due to moisture) were not included in the analysis. Thus, data from 51 cows were excluded, leaving 201 cows in the final analyses.

Between-Cow Analysis: Consistent Lameness Status. This analysis included cows that were scored as nonlame (NRS ≤2) or lame (NRS ≥3) in each of the weekly gait scoring sessions over the 3-wk study period. For these cows (n = 103), daily lying time, mean lying bout duration, and the daily number of lying bouts were summarized individually.

Unconditional linear mixed-effects models with cow nested within farm as a random effect were used to screen the fixed effects of parity (categorical: primiparous and multiparous), DIM (continuous), BCS (continuous: 5-point scale with 0.25-point increments between 1 and 5), and total daily precipitation (continuous: mm/d),

one variable at a time. Mean lying bout duration (min/bout) and total daily precipitation (mm/d) were transformed using the ln function to better normalize their distributions. Variables with *P*-values ≤0.2 were considered potential explanatory variables; precipitation, DIM, BCS, and parity were identified as potential explanatory variables. These variables were checked for collinearity with lameness status using unconditional logistic regression models with cow nested within farm as a random effect. Explanatory variables were considered collinear if the odds ratio was >10 (Dohoo et al., 2012). Parity was found to be highly collinear with lameness status (odds ratio = 55), so the effect of lameness was considered separately for primiparous and multiparous cows. However, only 1 primiparous cow was classified as lame in our study, thus only the multiparous model was considered (nonlame: n = 35 cows; lame: n = 32 cows). For multiparous cows, a linear mixed-effects model including cow nested within farm as random effect was used to test for the main effect of lameness on each lying behavior. The effect of parity on lying behavior for nonlame cows was also considered (primiparous: n = 24; multiparous: n = 35). For nonlame cows, a linear mixed-effects model including cow nested within farm as a random effect was used to test for the main effect of parity on each lying behavior. Normality and homoscedasticity of model and random effect residuals were assessed graphically. All possible 2-way interactions were tested and reported if significant.

Within-Cow Analysis: Changing Lameness Status. All cows that did not have consistent lameness status were considered to have changing lameness status (n = 98). Cows were considered to have developed lameness if their weekly gait score changed from nonlame (NRS ≤2) to clinically lame (NRS ≥3) and remained clinically lame for the remainder of the observational period. Cows were considered to have recovered from lameness if their weekly gait score changed from clinically lame (NRS ≥3) to nonlame (NRS ≤2) and they remained nonlame for the remainder of the observational period. Cows were considered to have an inconsistent lameness status if their weekly lameness status was not consistent.

Only cows that developed or recovered from lameness on the first, second, or third visit were considered in final analyses (n = 76). Cows that developed or recovered from lameness on the fourth and final visit to the farm were omitted from final analyses because lying data were unavailable following the final gait score (n = 22). Daily lying time, mean lying bout duration, the daily number of lying bouts, and total daily precipitation for these cows were summarized by cow and day [n = 1,340 observations (76 cows with 18 d of observation each

Table 1. The number of cows, prevalence of clinical and severe lameness, and percentage of cows that had consistent and changing lameness status on 6 farms in southern Brazil (n = 201 cows)

Farm	No. of lactating cows ¹	Prevalence of clinical lameness ² (%)	Prevalence of severe lameness ² (%)	Consistent lameness status		Changing lameness status		
				Nonlame (%)	Consistently lame (%)	Developed (%)	Recovered (%)	Inconsistent (%)
1	42	25.7	7.1	20.0	8.6	22.9	11.4	37.1
2	35	44.0	20.0	48.0	16.0	0	12.0	24.0
3	47	60.6	25.5	11.8	44.1	23.5	8.8	11.8
4	29	30.8	6.9	34.6	11.5	23.1	7.7	23.1
5	57	39.6	8.8	39.6	20.8	8.3	14.6	16.7
6	42	34.4	0	39.4	12.1	15.2	6.1	27.3

¹Based on total number of cows surveyed (252 cows).
²Calculated using gait scores from the first visit to each farm.

= 1,368 possible observations)]. Linear mixed-effects models including farm, cow, and week as random effects were used to test the main effect of lameness on each lying behavior for cows that changed lameness status.

RESULTS

Animal Measures

The average lactating herd size was 42 ± 10 cows (±SD; range: 29–57 cows) with 83.5% Holstein, 9.0% Jersey, and 7.5% Holstein-Jersey crossbred cows. Across farms, mean parity was 2.6 ± 1.4 (range: 1–6), mean DIM was 192 ± 123 d (range: 7–737 d), mean BCS was 3.17 ± 0.45 (range: 2.25–4.50), and estimated mean daily milk yield was 19.8 ± 4.7 L/d (range: 13–25 L/d) during the summer months.

Environmental Measures

The average daily temperature throughout this study was 18.1 ± 4.6°C (±SD; range: 2.9–29.8°C). It rained for 31 of 70 d during the study (average rainfall 17.7 ± 27.0 mm/d with rain; range: 0.2–132.8 mm/d).

Lameness

At the first visit, the average prevalence of clinical lameness was 39.2% across the 6 farms (range:

25.7–60.6%), including 11.4% severe lameness (range: 0–25.5%). No cows were scored as NRS 5. In total, 32.2% of cows were never scored as lame, 18.9% of cows were consistently clinically lame, and 23.3% of cows were inconsistent in their lameness status throughout the study. The mean proportions of cows in each herd that developed and recovered from lameness were 15.5% (range: 0–23.5%) and 10.1% (range: 6.1–14.6%), respectively. Of the cows that recovered from lameness, 27.8% were scored as severely lame on at least one of the visits (see Table 1).

Lying Behavior

Overall, cows in this study had a mean daily lying time of 10.9 ± 1.4 h/d (±SD), a mean lying bout duration of 80.8 ± 16.8 min/bout, and a mean daily number of lying bouts of 9.6 ± 1.8 bouts/d (Table 2).

Between-Cow Results: Consistent Lameness Status

Model outputs for the association between lameness and lying behavior in multiparous cows can be found in Table 3. Model outputs for the association between parity and lying behavior in nonlame cows can be found in Table 4.

Daily Lying Time. For nonlame and lame multiparous cows, there was an interaction between lameness

Table 2. The average lying behavior of primiparous cows (n = 44), multiparous cows (n = 139), and all cows considered together (n = 201) across the 6 farms included in this study (mean ± SD [range])

Lying behavior	Primiparous cows	Multiparous cows	All cows
Daily lying time (h/d)	10.7 ± 1.1 [9.0–13.1]	10.8 ± 1.6 [7.0–15.8]	10.9 ± 1.4 [7.0–15.8]
Lying bout duration (min/bout)	81.7 ± 16.7 [48.0–121.0]	78.6 ± 15.9 [46.8–132.7]	80.8 ± 16.8 [46.8–132.7]
Daily number of lying bouts (no./d)	9.4 ± 1.7 [5.7–14.1]	9.7 ± 1.8 [5.4–15.2]	9.6 ± 1.8 [5.4–15.2]

Table 3. The effect of consistent lameness status (nonlame: n = 35; lame: n = 32) on the daily lying time (min/d), natural logarithm (ln) of mean lying bout duration (min/bout), and daily number of lying bouts (no./d) of multiparous cows modeled using linear mixed-effects models with cow nested within farm as random effects

Behavior	Variable	Estimate	SEM	95% CI		P-value
				Lower	Upper	
Daily lying time (min/d)	Intercept	512.28	70.85			
	DIM	0.22	0.09	0.04	0.39	0.017
	BCS	27.49	20.82	−13.31	68.30	0.192
	Lame	12.92	21.63	−29.47	55.30	0.553
	ln(Precipitation)	−34.61	4.83	−44.09	−25.14	<0.001
	Lame × ln(Precipitation)	−19.89	6.59	−32.81	−6.98	0.003
	Random effect	Variance	SD			
ln(Lying bout duration [min/bout])	Cow:Farm	4,983	70.59			
	Farm	5,105	71.45			
	Intercept	4.18	0.05			
	DIM	0.0007	0.002	0.0003	0.001	<0.001
	Lame	0.06	0.04	−0.02	0.14	0.160
	ln(Precipitation)	0.06	0.01	0.04	0.08	<0.001
	Random effect	Variance	SD			
Daily number of lying bouts (no./d)	Cow:Farm	0.02	0.13			
	Farm	0.004	0.06			
	Intercept	10.00	0.44			
	DIM	−0.003	0.002	−0.006	0.00009	0.062
	Lame	−0.26	0.39	−1.02	0.50	0.498
	ln(Precipitation)	−0.81	0.13	−1.06	0.57	<0.001
	Lame × ln(Precipitation)	−0.38	−0.17	−0.72	−0.04	0.027
	Random effect	Variance	SD			
	Cow:Farm	1.72	1.31			
	Farm	0.18	0.42			

status and precipitation on daily lying time ($P = 0.01$). Overall, precipitation reduced total daily lying time; however, the magnitude of this change was dependent on lameness status: lame cows decreased their lying time more than nonlame cows on days with rainfall (Figure 1A). Similarly, for nonlame primiparous and multiparous cows, there was an interaction between the main effects of parity and precipitation on daily lying time ($P = 0.003$). Again, precipitation reduced daily lying time overall, but multiparous animals decreased their lying time less than primiparous animals on rainy days (Figure 2A).

Lying Bout Duration. For nonlame and lame multiparous cows, lameness status did not affect mean lying bout duration ($P = 0.160$) but precipitation increased mean lying bout duration regardless of lameness status ($P < 0.001$; Figure 1B). Similarly, for nonlame primiparous and multiparous cows, parity did not affect mean lying bout duration ($P = 0.432$) but precipitation increased mean lying bout duration regardless of parity ($P < 0.001$; Figure 2B).

Number of Lying Bouts. For nonlame and lame multiparous cows, there was an interaction between the main effects of lameness and precipitation on number of lying bouts ($P < 0.05$). Overall, precipitation decreased lying bouts in both nonlame and lame cows ($P < 0.001$), but this effect was greater for lame cows (Figure 1C). For nonlame primiparous and multiparous cows, there was no effect of parity on the number of lying bouts ($P = 0.502$), but precipitation decreased the number of lying bouts ($P < 0.001$; Figure 2C).

Within-Cow Results: Changing Lameness Status

There was no difference in daily lying time ($P = 0.11$), mean lying bout duration ($P = 0.986$), or the daily number of lying bouts ($P = 0.874$) for cows that changed their lameness status (i.e., developed or recovered from lameness; Table 5). Precipitation was associated with decreased total daily lying time ($P < 0.001$), increased mean bout duration ($P < 0.001$), and decreased daily number of lying bouts ($P < 0.001$).

Table 4. The effect of parity (primiparous: $n = 24$; multiparous: $n = 35$) on the daily lying time (min/d), natural logarithm ($\ln$) of mean lying bout duration (min/bout), and daily number of lying bouts (no./d) of nonlame cows modeled using linear mixed-effects models with cow nested within farm as random effects

Behavior	Variable	Estimate	SEM	95% CI		P-value
				Lower	Upper	
Daily lying time (min/d)	Intercept	473.49	58.75			
	DIM	0.14	0.08	−0.01	0.28	0.076
	BCS	35.31	16.84	2.31	68.31	0.041
	Multiparous	20.48	15.70	−10.30	51.25	0.198
	$\ln(\text{Precipitation})$	−59.05	4.84	−68.54	−49.55	<0.001
	Multiparous $\times \ln(\text{Precipitation})$	24.06	6.68	10.97	37.16	<0.001
$\ln(\text{Lying bout duration [min/bout]})$	Random effect	Variance	SD			
	Cow:Farm	2,561	50.61			
	Farm	3,747	61.21			
	Intercept	4.23	0.06			
	DIM	0.0006	0.0002	0.0002	0.001	0.006
	Multiparous	−0.03	0.04	−0.12	0.05	0.432
Daily number of lying bouts (no./d)	$\ln(\text{Precipitation})$	0.05	0.01	0.03	0.08	<0.001
	Random effect	Variance	SD			
	Cow:Farm	0.02	0.14			
	Farm	0.01	0.09			
	Intercept	9.80	0.48			
	DIM	−0.004	0.002	−0.007	−0.0004	0.036
	Multiparous	0.28	0.41	−0.53	1.08	0.502
	$\ln(\text{Precipitation})$	−0.94	0.09	−1.12	−0.76	<0.001
	Random effect	Variance	SD			
	Cow:Farm	2.06	1.43			
	Farm	5.59	2.36			

DISCUSSION

The daily lying time of cows in our study was similar to lying times reported in previous studies with grazing dairy cows (Krohn and Munksgaard, 1993; Legrand et al., 2009; Olmos et al., 2009; Sepúlveda-Varas et al., 2014), as well as to that of cows kept in loose-housed indoor systems with either automated milking systems (DeVries et al., 2011; Deming et al., 2013) or parlor milking systems (Wechsler et al., 2000; Ito et al., 2009). The daily number and duration of lying bouts reported here are similar to results reported previously for indoor-housed and outdoor-managed cows (Ito et al., 2010; Navarro et al., 2013; Weigele et al., 2018).

In contrast to previous findings, we did not detect a direct association between lameness status and lying time in this study (Navarro et al., 2013; Sepúlveda-Varas et al., 2014). Previous cross-sectional studies have reported that lame cows spend an additional 24 to 126 min/d lying down indoors (Ito et al., 2010; Navarro et al., 2013; Weigele et al., 2018) and an additional 91 to 105 min/d lying down outdoors compared with

nonlame cows (Walker et al., 2008; Navarro et al., 2013; Sepúlveda-Varas et al., 2014). Similarly, we did not detect a direct association between consistent lameness status and the number or duration of lying bouts. Other work has shown that lameness influences lying bouts, but the effect differs depending on both the severity of lameness and the type of lying surface (Ito et al., 2010; Sepúlveda-Varas et al., 2014; Weigele et al., 2018). To understand how lying bouts are affected by lameness in grazing systems, further research is needed to consider the quality of pasture as a lying surface.

To our knowledge, no previous research regarding lameness and lying behavior in grazing herds has accounted for precipitation (Olmos et al., 2009; Navarro et al., 2013; Sepúlveda-Varas et al., 2014). Our findings indicate that precipitation reduces lying time in cows regardless of lameness status, but the reduction in lying time is greater in lame cows. This decline in lying time was likely driven by lame cows reducing their number of lying bouts more than nonlame cows during periods of rainfall. Rain may also increase the chance that cows lie on wet, muddy, and slippery surfaces, which may in

Figure 1. Bar plots showing consistent lameness status (light gray: nonlame; dark gray: lame) in relation to (A) mean daily lying time (min/d), (B) mean lying bout duration (min/bout; untransformed), and (C) mean daily number of lying bouts (no./d) of multiparous cows on days with and without precipitation. Error bars represent ± 1 SEM ($n = 67$ cows).

turn compromise transitions from lying to standing and vice versa, perhaps especially affecting lame cows. Further research addressing how well lame and nonlame cows transition from lying to standing and vice versa is warranted.

Despite having similar average daily lying times, nonlame multiparous cows reduced their lying time less than nonlame primiparous cows on days with rain. This result is in contrast to previous work that reported greater reductions in lying time in dry cows than in heifers when exposed to a muddy lying surface (Chen et al., 2017). As mentioned above, multiparous cows may also be affected by wet, muddy, and slippery surfaces

more than primiparous cows. Previous work has found that other behaviors (e.g., social and feeding behavior) differ between primiparous and multiparous cows (Neave et al., 2017). Unfortunately, we were not able to measure social or feeding behavior in this study. These mixed results suggest that more work is required to understand the effect of rain and wet lying surfaces on the lying behavior of grazing cows of different parities.

In contrast to our prediction, we did not find within-cow differences in lying time or the number or duration of lying bouts associated with changes in lameness status (i.e., whether the same cow changed her lying behavior before and after being scored as lame). In our study,

Figure 2. Bar plots showing parity (light gray: primiparous; dark gray: multiparous) in relation to (A) mean daily lying time (min/d), (B) mean lying bout duration (min/bout; untransformed), and (C) mean daily number of lying bouts (no./d) of nonlame cows on days with and without precipitation. Error bars represent ± 1 SEM ($n = 59$ cows).

Table 5. The effect of changing lameness status (developed and recovered; $n = 30$ cows) on the daily lying time (min/d), natural logarithm (ln) of mean lying bout duration (min/bout), and daily number of lying bouts (no./d) of grazing cows modeled using linear mixed-effects models with farm, cow, and week as random effects

Behavior	Variable	Estimate	SEM	95% CI		<i>P</i> -value
				Lower	Upper	
Daily lying time (min/d)	Intercept	641.29	25.63			
	Lameness status	−1.58	6.61	−14.55	11.38	0.811
	ln(Precipitation)	−48.64	2.84	−54.21	−43.07	<0.001
	Random effect	Variance	SD			
	Week:Cow:Farm	945.6	30.75			
	Cow:Farm	4,483.5	66.96			
	Farm	3,452.9	58.76			
ln(Lying bout duration [min/bout])	Intercept	4.35	0.04			
	Lameness status	0.0004	0.02	−0.04	0.04	0.986
	ln(Precipitation)	0.05	0.009	0.03	0.06	<0.001
	Random effect	Variance	SD			
	Week:Cow:Farm	0.01	0.07			
	Cow:Farm	0.03	0.17			
	Farm	0.004	0.07			
Daily number of lying bouts (no./d)	Intercept	9.25	0.27			
	Lameness status	0.03	0.18	−0.32	0.37	0.874
	ln(Precipitation)	−0.94	0.07	−1.09	−0.80	<0.001
	Random effect	Variance	SD			
	Week:Cow:Farm	0.72	0.85			
	Cow:Farm	2.34	1.53			
	Farm	4.92	0.4			

cows were gait scored weekly, whereas lying behavior was recorded every minute and summarized daily. Thus, a cow's daily lying behavior may not have accurately reflected her most recent gait score if she changed her lameness status in the days following the most recent assessment. Furthermore, there may have been error in the weekly gait estimates; in this study, animals were live-scored, unlike in Flower and Weary (2006), when scorers had multiple opportunities to review video of each cow walking before scoring. Future research should consider including more frequent scoring for lameness, ideally daily, and for longer periods to allow for more meaningful comparisons between the lying behavior of the same individual when nonlame and lame. Identifying whether lying behavior changes before a change in gait would be an important first step. Furthermore, a greater number of cows should have been assessed to allow for a comparison of changes in lying behavior separately for cows that developed lameness and those that recovered from lameness. There may be differences in how lying behavior changes (e.g., magnitude and rate of change) for cows that develop and recover from lameness. We modeled developing and recovering lameness cases separately in previous analyses with no

differences detected, likely due to the low number of animals in each category.

This study is the first to quantify the effect of precipitation on lying behavior in grazing dairy cows. Daily lying time decreased with rainfall, consistent with previous work that has shown reductions in daily lying duration associated with wet lying surfaces indoors (Fregonesi et al., 2007) and outdoors on wet dirt packs (Chen et al., 2017). Similarly, in agreement with the effect of muddy ground conditions found elsewhere (Chen et al., 2017), rainfall increased individual lying bout duration and decreased the number of lying bouts in this study. The results of this study show that precipitation is clearly an influential covariate with lying behavior in grazing dairy cattle.

The prevalence of lameness found in this study was similar to estimates previously reported for dairy cattle housed indoors (Cook et al., 2016; Solano et al., 2016; Adams et al., 2017; Costa et al., 2018) and at pasture (Olmos et al., 2009; Costa et al., 2013; Fabian et al., 2014; Ranjbar et al., 2016; Bran et al., 2018b). This research provides further evidence that lameness remains a pertinent issue in outdoor housing systems. We were able to measure the development of and recovery from

lameness where no treatment for lameness was applied to the herds (for details, see Bran et al., 2018a, and Omos et al., 2018). To our knowledge, no studies to date have reported incidence and cure rate in grazing cows; future studies should follow cows for longer periods to understand lameness dynamics in grazing systems.

CONCLUSIONS

Lame cows and nonlame cows differ in their lying behavior, thus lying time has the potential to be an effective indicator of lameness in grazing systems; however, more research is needed to identify key factors (e.g., precipitation) that also influence the lying behavior of cows at pasture. Given the strong effect of precipitation on lying behavior in this study, we recommend that future research include rainfall as a covariate when working with grazing cattle.

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