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Behavior of dairy cows managed outdoors in winter: Effects of weather and paddock soil conditions

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ABSTRACT

Dairy cows are motivated to access dry lying surfaces and will seek protection from wind and rain, but winter conditions may limit these opportunities when cows are managed outdoors. The primary aim of this observational study was to determine the effects of weather and paddock soil conditions on lying behavior of dairy cows managed outdoors during winter and fed crop in situ, a practice occurring in New Zealand with year-round grazing of dairy cows. A secondary aim was to characterize eating and ruminating behaviors during winter weather and paddock soil conditions. Four groups (99 nonlactating, pregnant cows each) were managed on 4 outdoor paddock areas on the same farm; the groups were fed pasture silage and grazed either kale (2 groups) or fodder beet (2 groups). Behaviors were recorded using validated leg-based (lying behavior) and ear-based (eating and ruminating time) accelerometers on 30 focal cows in each group over 32 d. Soil depth and wetness were scored daily at 25 points along 4 transects within each paddock area using recognized technical measures (penetrometer, soil volumetric water content), which were compared with practical tools for farmer use (ruler, moisture meter, percentage of sites in paddock scored as dry, wet, sodden, or with surface water pooling). Rainfall occurred most days during the study (mean 1.6 mm/d; maximum 12.2 mm/d), resulting in wet and muddy paddocks (mud depth with ruler: mean 6 cm, maximum 18 cm; paddock sites scored as wet or sodden: mean 34%, maximum 100%; paddock sites with surface water pooling: mean 27%, maximum 100%). Group lying time was 9.6 ± 2.3 h/d (mean ± standard deviation); however, 21% of cows consistently lay less than 8 h/d (to a minimum of 4.9 h/d). A mixed regression model tested the effects of daily weather and paddock soil conditions on daily lying time, with group as the observational unit, day as repeated measure, crop type as a fixed effect, crop type interactions with explanatory variables, and random intercepts of group and paddock within group. Lying time was less on the day of and day after rainfall (24 and 29 min/d less for 1 mm increase in rainfall, respectively). Two days after rainfall, lying time rebounded to about 1 h longer than before the rainfall. On the day after the heaviest rainfall event, group average lying time was only 2.5 ± 1.9 h/d (mean ± standard deviation); in 2 groups, 30% and 38% of cows, respectively, did not lie down at all for 24 h. Lying time decreased with deteriorating paddock soil conditions, especially with increasing surface water pooling, suggesting that this may be a useful measure to estimate the quality of the lying surface. Descriptively, ruminating time appeared to decrease with increased surface water pooling, possibly due to decreased lying time. Our results demonstrated that dairy cows could experience periods of short or no lying time during inclement weather and muddy paddock soil conditions. Prior rainfall and surface water pooling may be useful measures to determine if lying time, and thus animal welfare, are compromised.

Key words: mud, inclement weather, crop feeding, lying behavior, feeding behavior

INTRODUCTION

Outdoor management of dairy cows during the winter on crop paddocks, such as kale or fodder beet, is a management strategy used in some parts of the world with pasture-based systems, such as New Zealand (Dalley and Geddes, 2012). Farmers practicing seasonal outdoor calving in late winter or spring (e.g., in New Zealand and Chile) can experience challenges with managing nonlactating, pregnant dairy cows under a range of environmental conditions that can include inclement, adverse weather. Winter grazing on crop paddocks typically involves daily allocation of fresh crop using temporary fencing, which is then grazed to ground level by the cows and results in bare ground

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left behind. These grazing practices at high stocking densities, in combination with high rainfall, make the soil susceptible to damage, saturation, and pugging. Consequently, muddy underfoot conditions can occur, resulting in little or no opportunity for the cows to access pasture or alternative lying surfaces. Keeping dairy cows in muddy outdoor areas has been raised as a potential animal welfare concern among New Zealand dairy industry stakeholders (MPI, 2021).

Dairy cows managed outdoors may seek protection from windy and rainy conditions (Schütz et al., 2010), and will spend the majority of their time under shelter when provided during winter (Cartes et al., 2021). This is likely related to the cow's motivation to access comfortable, dry, lying surfaces, which can be limited in winter conditions. For example, in both housed and pastured cattle, cows prefer to lie on dry, well-bedded, clean surfaces (Fregonesi et al., 2007; Reich et al., 2010; Schütz et al., 2019; Cartes et al., 2021). The amount of time that cows spend lying is an important welfare indicator. Longer lying times often suggest more comfortable lying surfaces (e.g., mattresses vs. concrete flooring; Haley et al., 2000), and even when restricted for just 3 h, cows are motivated to lie down when deprived of the opportunity (Metz, 1985; Munksgaard et al., 2005). If lying time is compromised, biological health and functioning can be negatively affected. For example, shorter lying times can be a risk factor for lameness in grazing cows (Sepúlveda-Varas et al., 2018) and can affect function of the pituitary-adrenal axis, leading to increased chronic stress (Fisher et al., 2002). Thus, it is important to understand how lying time of dairy cows is affected by different outdoor conditions (see review by Tucker et al., 2021).

Wet, cold, and muddy surface conditions affect the lying behavior of cattle. Experimental work has shown that cows managed in muddy pens show reduced lying time of up to 75% (Chen et al., 2017), and lying times may be less at cold temperatures due to thermoregulatory challenges (Fisher et al., 2003). When cows are deprived of the possibility to lie down, there often is a rebound effect with a large increase in lying time when the opportunity to lie on a comfortable surface arises. This was observed in dairy cows that were restricted to wet surfaces (Schütz et al., 2019) and also when cows were temporarily managed in a holding area with a deep-bedded wood chip surface stand-off pad (a practice common in parts of New Zealand in wet weather in winter to protect paddock soil structure; O'Connor et al., 2019). In addition, muddy conditions can result in poor walking surfaces that limit movement and can be energetically costly (Dijkman and Lawrence, 1997). These conditions occur in paddocks over winter in New Zealand, but there is limited understanding of how weather and paddock soil conditions affect the behaviors of dairy cows, such as lying, eating, and ruminating, when managed in outdoor winter crop paddocks.

The primary objective of this study was to determine how weather and paddock soil conditions affect the lying behavior of dairy cows managed outdoors in crop paddocks during winter; we predicted that lying time would be reduced during and following rainfall events and when paddock conditions became sodden. Additional secondary objectives of this study were to describe daily patterns of lying, eating, and ruminating behavior, and describe how eating and ruminating behavior are affected by weather and paddock soil conditions. We predicted that eating and ruminating time would be reduced during rainfall events and that eating time may be reduced with muddy paddock conditions. We measured paddock soil conditions each day using a series of simple and practical measures that could be used by farmers to assess the conditions of their paddock and suitability of the lying surface for dairy cattle. To determine their reliability, these practical measures were compared with gold-standard measures from technical equipment that characterized mud depth and wetness.

MATERIALS AND METHODS

This study was conducted from June 17 to July 21, 2020 (Southern Hemisphere winter), at the Southern Dairy Hub research facility in Wallacetown, Southland, New Zealand (latitude: −46.31072, longitude: 168.30314). All procedures were approved by the Ruakura Animal Ethics Committee in Hamilton, New Zealand (#14811) under the New Zealand Animal Welfare Act 1999.

Animal Management and Study Design

Four groups (99 cows each, totaling 396 cows) were managed on a single farm for the duration of the study (32 d). Two groups each were managed on kale or fodder beet paddocks, as part of a concurrent study examining different methods of crop feeding. Thus, before enrollment in this study, cows had been managed outdoors on kale or fodder beet paddocks for 3 wk. Group size was selected to allow for all cows on the research farm to be managed in 4 stable groups. More group replication, with fewer cows per group, was not possible due to availability of paddocks for rotational crop grazing. All cows were nonlactating and pregnant (mean ± SD; 76.9 ± 16.7 d prepartum), age of 5.3 ± 1.8 yr, BCS of 4.8 ± 0.4 on a 10-point scale (Roche et al., 2004), and crossbred (226 predominantly Friesian, 3 predominantly Jersey, and 167 equal cross of Friesian and Jersey). Allocation of cows to groups was based on age and winter BCS gain requirements, balancing groups for age, BCS, expected calving date, and breed. Allocation of groups to crop paddock type and paddock location on the farm was randomized.

Groups were allocated a fresh crop area at 0900 h each morning, except during a frost, when this was delayed to 1100 h. The back fence was moved up by the same space allowance as the new crop area to maintain a stocking density of 20 m^2/cow. The area offered was based on the individual paddock crop yield and the daily crop DM allocation. Groups were allocated 11.2 kg of DM/cow per day of kale, or 9.4 kg of DM/cow per day of fodder beet. Due to this difference in crop allocation and the lower DM yield of the kale crop, the kale groups received more untrodden "new ground" each day. All groups received 3.3 kg of DM/cow per day of perennial ryegrass and white clover baleage offered in bale feeders at the same time as the fresh crop area. Baleage was offered again at 1500 h if the group had consumed all their daily baleage allocation. Nutritional composition of feeds was measured every 2 wk (Hill Laboratories, near-infrared spectroscopy analysis) and are presented in Table 1.

Each group was rotated to a new paddock of the same crop type when the current paddock was fully grazed (12 d after study start for kale paddocks, 20 and 21 d after study start for fodder beet paddocks). All groups began their grazing rotation on the lower terraced section of the farm with heavier soils and then were rotated to their new crop paddocks on the upper terraced section of the farm in the latter part of the study period. Each paddock contained 1 portable water trough that was always located close to the feeding face (<5 m). There was no shelter provided in any paddock.

Behavior Data Collection

Thirty focal cows from each group (total 120 cows) were selected pseudorandomly for behavior monitoring, balanced for age, BCS, breed, and days prepartum within each group. This sample size was selected to allow for sufficient variability in lying time among cows of a group; previous work that used between 18 and 32 cows found significant differences in lying time of nonlactating New Zealand dairy cows under different lying surface conditions (e.g., Al-Marashdeh et al., 2019; Schütz et al., 2019). To monitor daily eating and ruminating time, electronic ear tags [CowManager, Agis Automatisering BV; validated by Pereira et al. (2018) in cattle grazing pasture] were attached to the ear of the cow while restrained in a crush. Data were automatically downloaded from these devices to a server through readers installed near the paddocks. Lying behaviors were recorded using tri-axial accelerometer devices (HOBO Pendant G Acceleration Data Logger, Onset Computer Corp.; validated in dairy cattle by Ledgerwood et al., 2010) attached using Velcro pouches to the rear right leg of each cow while standing on the rotary dairy platform. Devices were removed from the cow 2 wk later to download data to the computer and replaced with a new device for the remaining 2 wk of the study. Accelerometers were set to record the *g*-forces of the x-, y- and z-axes at 1-min intervals, and data were processed using an adjusted version of the SAS algorithm developed by the UBC Animal Welfare Program (2013). The algorithm was adjusted for using histogram analysis of raw HOBO data, as described by Zobel et al. (2015; specific details on data handling described below). At the time of accelerometer attachment and changeover, cows were marked with a unique identifier number on their rump using tail paint (Tell Tail, FIL NZ Ltd.).

Animal Condition Measures

Each of the 30 focal cows per group was given a 3-point hygiene score weekly in the paddock and 3 times when the cows were on the rotary dairy platform (at study start during accelerometer attachment, during changeover of accelerometers, and finally at study end). This resulted in 7 hygiene scores per focal cow for the study period. Hygiene score followed the method used for Dairy Welfare Auditor Training (PAACO, 2020), where 1 = manure or mud covers less than A4 paper size in either of the belly or thigh areas, 2 = ma-

Table 1. Nutritional composition information (mean ± SD) of crop and baleage offered during the study to 4 groups of 99 pregnant, nonlactating dairy cows each; 2 groups were fed kale and 2 groups were fed fodder beet, all with supplementary perennial ryegrass and white clover baleage

Variable	Kale	Fodder beet leaf	Fodder beet bulb	Baleage
DM (% DM)	12.2 ± 1.3	9.5 ± 0.3	15.8 ± 1.0	37.8 ± 7.9
CP (% DM)	16.5 ± 3.1	20.3 ± 3.5	8.8 ± 1.3	13.1 ± 4.5
OMD (% DM)	78.1 ± 3.4	71.3 ± 3.6	90.7 ± 2.1	69.3 ± 3.2
ME (MJ/kg of DM)	11.5 ± 0.5	11.4 ± 0.6	14.6 ± 0.3	11.1 ± 0.6
NDF (% DM)	21.4 ± 1.6	27.8 ± 3.7	12.3 ± 2.5	49.7 ± 6.4
ADF (% DM)	17.0 ± 1.6	14.3 ± 3.7	6.3 ± 2.5	28.9 ± 6.4

nure or mud covers more than A4 paper size in either belly or thigh area, and 3 = manure or mud covers more than A4 paper size in both belly and thigh areas. Both sides of the cow were checked, and the worst side was scored. Agreement among observers was verified using the PAACO training module (series of 30 photos scored; considered trained with very good agreement of $\kappa > 0.80$). At each hygiene scoring, focal cows were identified using the unique identifier marked on the rump, and hygiene score was assessed by 2 observers.

Body condition of all 396 cows was scored 3 times during the study period using the BCS scoring system described by Roche et al. (2004). Cows were scored on the rotary dairy platform by the same certified BCS assessor at the time of accelerometer attachment, changeover, and removal.

Daily Paddock Measures

Soil conditions in each paddock were scored daily for mud depth, internal soil moisture, surface wetness, and surface water pooling. These measures were intended to be simple and practical methods to assess paddock soil conditions, especially during adverse weather; these methods were taken alongside gold-standard measures of soil conditions (described below). Interobserver reliability of these measures was verified at the beginning and end of the study ($\kappa > 0.86$) by having 2 observers independently score the same 25 sites within each paddock, resulting in 100 total sites scored by each observer for reliability assessment. All scores were taken at 25 sites per paddock, sampled in a double-W pattern covering the length and width of the paddock, resulting in 4 transects along the length of the paddock (Figure 1A). For example, sites 1, 7, 13, 19, and 25 were taken at the "tips" of the W nearest to the feed face and represented transect A. Sampling sites that were close to a baleage feeder or water trough were still scored but noted separately. Scoring always began at site 1, following the shape of the double W, and ended at site 25. One person conducted the measures, and another person recorded. Scores were taken beginning at 0900 h, regardless of weather conditions, and took approximately 30 to 45 min per paddock to complete scoring; order of paddock scoring each day rotated such that all paddocks were scored first (or last) every fifth day.

Mud Depth and Internal Soil Moisture. The mud depth of the soil site was measured using a standard 30-cm plastic ruler that was pushed through the soil by hand until it no longer moved, and depth was recorded in centimeters. Internal soil moisture was measured using a readily available garden soil moisture meter (Gardman Combination pH and Moisture Meter, Mitre10, Invercargill). The meter probe was embedded into the soil to 50% of the probe's length (10 cm), and a reading [from 0–10 (unitless), where 10 was highest moisture] was taken after the needle stabilized. When standing in rubber boots at each sampling site, mud depth and internal soil moisture readings were taken 3 times, 1 on either side of the person's boot and 1 at the tip of the boot. These 3 measures were then averaged to get a single measure of depth and internal soil moisture at each site.

Surface Wetness. The wetness of each site was scored using a boot score method adapted from O'Connor et al. (2019), who used this method to assess wetness of woodchip bedding. The researcher pressed the boot firmly into the soil at the site, removed the boot to leave a boot print, and then scored the appearance of the boot print as dry, wet, or sodden based on the criteria outlined in Figure 1B. This score was taken once at each sampling site.

Surface Water Pooling. If there was any visible liquid (water or urine) pooling in close vicinity of the sampling site (within a half-boot length), this was scored as a binary outcome, where "yes" indicated surface water pooling present. An example of surface water pooling is shown in Figure 1C. This score was taken once at each sampling site. Size of pooling needed to be at least the size of the palm of the hand to be scored as "yes."

Gold-Standard Paddock Measures

Soil conditions in each paddock were also scored weekly using technical equipment considered to be gold-standard measures of soil conditions. These weekly paddock measures were compared with the daily practical measures described above to determine if these were reflective of actual paddock soil conditions. Each week, in each paddock at the same sites as the daily practical measures described above, mud depth was measured in centimeters with a penetrometer (custom built by AgResearch Ltd., designed to deliver 200 kPa, equivalent to the pressure from a cow's hoof), and soil samples were collected for laboratory analysis of soil volumetric moisture (% vol/vol). Soil volumetric moisture was measured by oven drying (105°C for 24 h) a known weight of wet soil, calculating the gravimetric soil moisture [gravimetric soil moisture = (wet soil weight − dry soil weight)/dry soil weight)] and then multiplying by the soil bulk density (dry soil weight/total soil volume).

Weather Measures

Rainfall and ambient temperature were recorded every 15 min with a weather-monitoring system (HALO

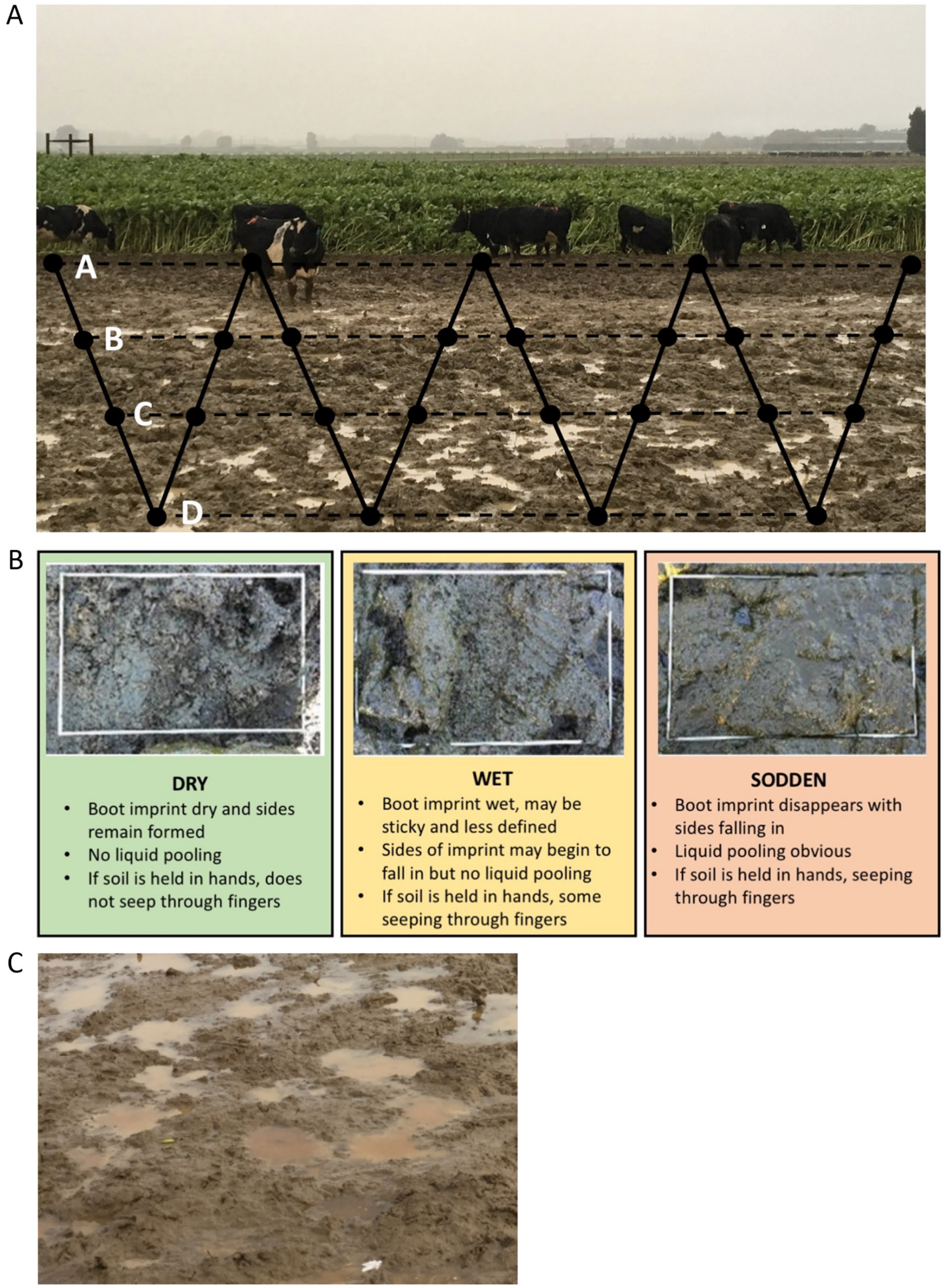

Figure 1. Sampling methodology for daily paddock scoring. (A) Example of location of site samples in each paddock, following a superimposed double-W shape over the entire length and width of the paddock. Each filled circle represents a sampling site (total 25 sites). Each horizontal dotted line represents a sampling transect: transect A, nearest the current (today's) feed face; transect B and C, respectively, at middle of paddock; transect D, nearest the current (today's) back fence, which was previously (yesterday's) the front fence line. (B) Scoring method for surface wetness using a "boot score"; images depict soil conditions scored as dry, wet, or sodden after depressing the site with a boot. (C) Scoring method for surface wetness using presence of surface water pooling, as demonstrated in this image.

Systems) located approximately 200 m away from the study paddocks. Measures were summarized into daily total rainfall (mm), and minimum, average, and maximum daily ambient temperature (°C). As a comparison with the weather conditions experienced during the study period, we extracted the 5-yr average rainfall and ambient temperature from 2 National Climate Database (https://cliflo.niwa.co.nz) stations located 11 km from the study site (station 11104 for rainfall, and station 12444 for temperature; NIWA, 2021).

Data Handling

Some of the accelerometers were lost in the paddock during the first half of the study (June 19–July 8); of the 30 devices applied per group, 1 and 13 devices from the 2 kale groups were not recovered, and 15 and 13 devices from the 2 fodder beet groups were not recovered. We suspect these losses were related to deep and sticky mud conditions during a heavy rain event that caused the devices to come off when cows walked in the mud. In the second half of the study (July 9 –20), 1 device from 1 kale group was not recovered. Raw 1-min data from the accelerometer devices were first visualized as daily frequency distributions of the adjusted x- and z-axis values [see UBC Animal Welfare Program (2013) for description and cut-points used] for each study day for each cow to identify erroneous data, such as incorrect recording frequency, inverted axes (due to upside down device), slipped device (resulting in incorrect axis values), or device lost from the cow that was later recovered (resulting in constant axis values for extended period). Errors were corrected for 1 device that was attached upside down (axes were inversed for analysis) and 6 devices where data were recorded at 30-s frequency (the first recording was retained for analysis). For 2 devices, data were recorded at 10-s frequency, resulting in rapid battery loss (data excluded). For devices with incomplete data sets (8 devices that were recovered from the paddock due to detachment from the leg when in the field), data were truncated to exclude all days after which the device was first noted to have slipped from position. Days on which devices were attached and removed, and the 2-d changeover period, were excluded from the data set; this resulted in a total of 30 study days for analysis. Due to logger losses described above, there were 75 cows with all 30 study days available for analysis, 1 cow each with 20, 22, and 23 study days available for analysis, and 42 cows with 11 study days available for analysis. Daily (24 h) summaries for lying time, number of lying bouts, and lying bout duration were calculated separately from the 1-min recordings for each focal cow. Lying bouts that occurred across midnight were not split but rather considered as number of lying bouts that began within the 24-h period. Daily values from focal cows were then averaged for each paddock per day. Hourly summaries of lying time were also generated from the 1-min recordings, first for each cow, and then averaged for each group, to examine diurnal patterns of lying time.

Data from the electronic ear tags (reported as total min/h for each of eating and ruminating behavior) were available beginning on d 6 of the study due to a data-acquisition period required by the company. Daily eating and ruminating behaviors were examined for biologically unlikely measurements (such as zero, or more than 3 SD above or below the mean) and days that had less than 1,440 data points, which were excluded from analysis (2% of all data). Data from d 6 to 31 of the study were summarized into hourly and daily durations of eating and ruminating for each focal cow and then summarized into group averages.

Paddock measures from each site in the paddock were either averaged across the 25 sites for a single measure per paddock per day (for mud depth and soil moisture) or were summed for a total number of sites per paddock and then calculated as a percentage of sites scored per paddock (for percentage of sites scored as dry and percentage of sites with surface water pooling). The same procedure was conducted for each transect within a paddock (measures averaged or summed across the 5, 8, 8, and 4 sites for transect A, B, C, and D, respectively).

Statistical and Descriptive Analyses

All statistical analyses were performed with SAS (Studio University Edition, SAS Institute). All lying behavior outcome variables (lying time, lying bouts, and lying bout duration) were assumed to be normally distributed (assessed using PROC UNIVARIATE and model residuals). In our reporting of lying times, we make reference to 2 thresholds of adequate lying times for dairy cattle managed outdoors in winter as follows: 8 h/d, which is the historical industry minimum recommended lying time in New Zealand (DairyNZ, 2021), and >10 h/d, which has been demonstrated by non-lactating pregnant New Zealand dairy cows in winter when they have access to comfortable off-paddock lying surfaces (e.g., Schütz and Cox, 2014; Schütz et al., 2015, 2019). Results are reported as model estimates ± standard error, and significance is reported at $P \leq 0.05$.

Gold Standard Versus Practical Paddock Measures. The relationships between the gold standard and practical measures of paddock soil conditions were assessed. Agreement between the 2 measures of mud depth (penetrometer vs. ruler, units in cm) and the 2 measures of soil moisture (laboratory analysis versus moisture meter, units in volumetric water content) were assessed following Grinter et al. (2019). First, a Pearson correlation (PROC CORR) measured the association between the gold standard and practical measures, and then accuracy of the measurements was calculated using linear regression with a restricted zero intercept to calculate the slope of the relationship between the 2 measures (PROC REG) and using Bland-Altman plots of the difference in the 2 measures against their mean, following Bland and Altman (1986). Bland-Altman plots were created in Microsoft Excel (Excel 2016 v.16.3, Microsoft Corp.) by calculating the difference in measures (practical − gold-standard) at each time point to determine average bias. Standard deviation of the difference in measures was used to calculate the upper and lower limits of agreement (± 1.96 × SD). Mud depth and soil moisture were considered accurate if the linear regression slope did not differ significantly from 1, and if the 95% interval of agreement included 0 for mean bias from the Bland-Altman plots. A Pearson correlation (PROC CORR) was used to measure association between the gold-standard measure of soil moisture (volumetric water content) and the indirect measures of soil wetness as follows: the percentage of sites in the paddock scored as wet or sodden, and the percentage of sites in the paddock with surface water pooling.

Weather and Paddock Soil Conditions Over the Study. Pearson correlations between daily rainfall and paddock soil conditions were examined (PROC CORR). The areas of the paddock (transect A, B, C, or D; see Figure 1a) that were most likely to be scored as wet or sodden were tested in a logistic mixed regression model (PROC GLIMMIX). Crop type (fodder beet or kale) was included as a fixed effect, with the random effect of paddock within group (1 or 2). Degrees of freedom method was specified as Satterthwaite.

Daily Behavior Patterns. Diurnal patterns of lying, eating, and ruminating time were examined descriptively. Daily lying time of each cow was categorized as <8 h/d or ≥8 h/d. In a logistic regression model, (PROC GLIMMIX) we examined if cow age, BCS, or number of days prepartum increased the likelihood of daily lying time below 8 h/d. Group (1, 2, 3, or 4) was included as a random effect, with degrees of freedom method specified as Satterthwaite.

Effects of Weather and Paddock Soil Conditions on Lying Behavior. The effects of weather conditions (day of rainfall, day after rainfall, 2 d after rainfall, and ambient temperature) and paddock soil conditions (percent of paddock scored as dry, percent of paddock with surface water pooling, and mud depth) on daily lying behaviors (lying time, number of lying bouts, and lying bout duration) were tested using a mixed regression model (PROC MIXED). Group was the observational unit with day as repeated measure, and random effects of group (1, 2, 3, or 4) and paddock within group (1 or 2). Crop type (fodder beet or kale) was included as a fixed effect in all models; the small sample size of 2 groups per crop type prevented testing its effect on outcome variables. The interaction of crop with each weather and paddock explanatory variable was tested and retained in the model if $P < 0.20$ because crop type is known to affect soil stability. Degrees of freedom method was specified as Satterthwaite. We expected the weather and paddock measures to have causal relationships (see causal diagram, Figure 2); for instance, mud depth will be affected by greater rainfall, but it also will be affected when there is more surface water pooling, which will also increase when the paddock becomes wetter. Thus, paddock and weather measures are not expected to independently influence lying behavior.

Hygiene Score and Lying Time. The relationship between lying time and weekly hygiene score was tested using a logistic mixed regression model (PROC GLIMMIX). Average daily lying time of each cow corresponding to each date of hygiene score was categorized as <8 h/d or >10 h/d (cows with intermediate lying times were not considered for analysis). The number of cows in each lying time category differed at each date of hygiene scoring (minimum to maximum: 9–40 cows <8 h/d; 10–72 cows >10 h/d). There were few occurrences of the highest hygiene score (score = 3) for cows under 8 h/d; therefore, hygiene scores 2 and 3 were combined and compared against hygiene score 1 as the outcome variable. Fixed effects in the model were lying time category, crop type, cumulative rainfall in the previous 7 d (to align with weekly hygiene score), and the interaction of cumulative rainfall and lying time category, with a random intercept of week and group. Degrees of freedom method was specified as Satterthwaite.

Eating and Ruminating Time. Descriptive analyses were used to examine if weather and paddock soil conditions affected eating and ruminating time. We chose this approach given that the electronic ear tags have only been validated for use in dairy cattle grazing pasture (Pereira et al., 2018), and we anecdotally noted behavioral differences in how dairy cattle eat crop, which could have affected how the technology recorded eating and ruminating behaviors. Total time spent eating and ruminating per hour for each group and crop type (fodder beet or kale) were graphically displayed and the diurnal patterns examined.

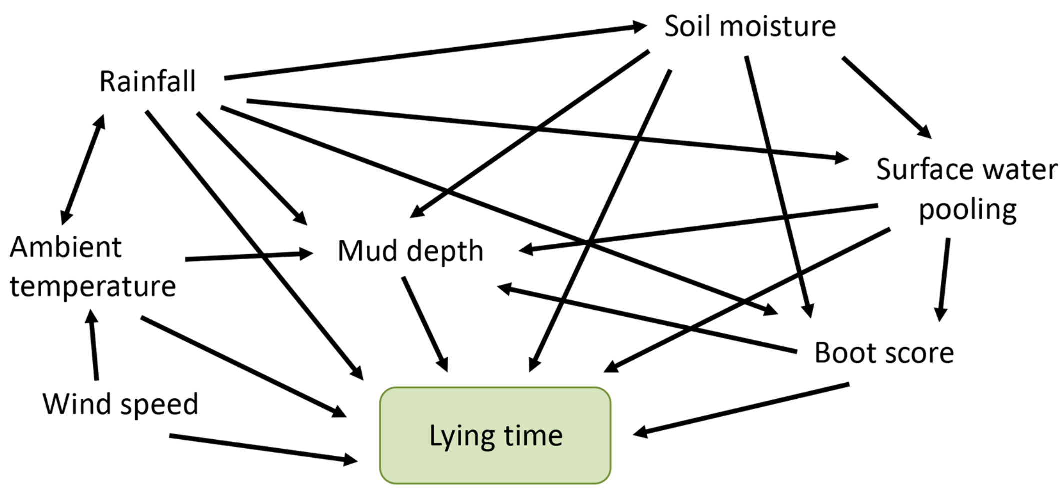

Figure 2. Causal diagram depicting pathways relevant for determining the effects of weather and paddock soil conditions on lying time of dairy cattle. Direction of the solid lines describes the predicted effect direction of one variable upon another. The complexity of the relationships among the weather and paddock variables guided our modeling approach.

RESULTS

Gold Standard Versus Practical Paddock Soil Measures

Mud depth measured with the ruler was precise (r = 0.85; $P < 0.001$), but not accurate, compared with using a penetrometer as the gold standard for mud depth. The ruler underestimated the actual mud depth by approximately 2-fold [slope of regression: 1.96 ± 0.14 (95% CI: 1.67–2.26); $R^2 = 0.92$], but this bias was consistent throughout the range of mud depth measures collected in this study (mean ± SD difference: −7.7 ± 4.1 cm; Supplemental Figure S1a; https://data.mendeley.com/datasets/svc3s7n7wc/1; Neave et al., 2022). Soil moisture using the store-bought moisture meter was neither precise (r = 0.36; $P = 0.13$) nor accurate compared with laboratory analysis of volumetric water content. The moisture meter underestimated actual soil moisture by 7-fold [slope of regression: 7.09 ± 0.17 (95% CI: 6.73–7.45); $R^2 = 0.99$], and there was a clear ceiling effect due to a maximum of 10 on the moisture meter (mean ± SD difference: −59.8 ± 12.7 volumetric water content; Supplemental Figure S1b). Therefore, we do not report further results from the soil moisture meter. Other indirect, practical methods of estimating the wetness of the soil were positively associated with actual soil moisture (Supplemental Figure S2; https://data.mendeley.com/datasets/svc3s7n7wc/1; Neave et al., 2022; percentage of sites scored as wet or sodden: r = 0.58, $P < 0.01$; percentage of sites with surface water pooling: r = 0.60, $P < 0.01$).

Weather and Paddock Soil Conditions Over the Study

A range of weather conditions was experienced over the 32-d study period, which was drier than typically experienced over the previous 5 yr during the same period (Table 2). Rainfall occurred on 27 of the 32 study days; <1 mm of rain occurred on 14 study days, between 1 and 5 mm of rain occurred on 12 study days, and over 10 mm of rain occurred on 1 study day. Paddock soil conditions did not differ between fodder beet and kale groups, apart from fodder beet groups that had greater mud depth compared with kale groups when measured with the gold-standard penetrometer (Table 3). Because crop type did not have an overall effect on paddock soil conditions, we report the statistical results as averages for all 4 groups.

Paddock soil conditions deteriorated with increased rainfall, especially 1 to 2 d after rainfall. Mud depth using a ruler and percent of paddock with surface water pooling were positively, but weakly, correlated with daily rainfall (mud depth: r = 0.18; $P = 0.03$; pooling: r = 0.22; $P = 0.01$), whereas percent of paddock scored as dry was negatively correlated with daily rainfall (r = −0.31; $P < 0.001$).

The sites nearest the back fence (along transect D; see Figure 1a) were 3 times as likely to be scored as wet or sodden (using the boot score) compared with the sites nearest the feed face [transect A; odds ratio 3.0, confidence limits (**CL**): 1.6 − 5.6, $P < 0.01$]. The sites in the middle of the paddock (along transects B and C) were twice as likely to be scored as wet or sodden compared with transect A (transect A vs. B: odds ratio

Table 2. Daily weather conditions experienced over the duration of the 32-d study period (June 17 to July 20, 2020) and the previous 5-yr average for the same study period (June 17 to July 20 for years 2015–2019)[1]

Weather variable	Mean	SD	Minimum	Maximum
Daily average ambient temperature (°C)				
Study period	5.4	1.8	1.2	8.7
Previous 5 yr[2]	4.3	1.2	2.5	5.0
Daily minimum ambient temperature (°C)				
Study period	1.0	2.9	−5.4	7.4
Previous 5 yr	1.3	1.5	−6.9 to −2.2	5.2 to 7.7
Daily maximum ambient temperature (°C)				
Study period	11.0	2.1	7.8	17.3
Previous 5 yr	10.8	0.5	5.3 to 7.7	14.6 to 18.3
Daily rainfall (mm)				
Study period	1.6	2.4	0	12.2
Previous 5 yr	2.5	0.5	0	11.8 to 18.4

[1]Values are means ± SD, and daily minimum and maximum. For the previous 5-yr period, the range in minimum and maximum rainfall and temperature are provided.

[2]Data extracted from weather station located 11 km from study site (NIWA, 2021). Ambient temperature was recorded at 0900 h.

= 2.2, CL: 1.3 – 3.7, $P < 0.01$; transect A vs. C: odds ratio = 2.6, CL: 1.5 – 4.5, $P < 0.01$).

Daily Behavior Patterns

The behaviors observed in each group over the study period are reported in Table 4. All groups averaged more than 8 h/d of lying time (the historical industry minimum recommended lying time in New Zealand), with only 1 group exceeding 10 h/d of lying time (the expected lying time for nonlactating pregnant New Zealand dairy cows in winter with comfortable lying surfaces). However, there was large individual variation in daily lying time among cows within groups as follows: 21% (25 of 120 focal cows) lay for less than 8 h/d, and 40% (48 of 120 focal cows) lay for longer than 10 h/d. The cows with less than 8 h/d of lying time were more likely to be younger cows ($F_{1,116} = 13.3$; $P < 0.001$), but BCS and days prepartum did not affect overall average lying time ($F_{1,116} < 3.3$; $P > 0.07$).

The diurnal patterns of time spent lying, eating, and ruminating are shown for descriptive purposes in Figure 3. Numerical differences were observed between kale and fodder beet groups for eating time, where cows in kale paddocks spent more time eating between the daytime hours of about 1000 and 1800 h. In contrast,

Table 3. Soil conditions in the paddock measured weekly using gold-standard methods and measured daily using practical methods for the duration of the 32-d study period[1]

	Fodder beet		Kale		Difference between crop type	
Paddock variable	Group 1	Group 2	Group 1	Group 2	*F*-value	*P*-value
Gold-standard measure						
Mud depth using penetrometer (cm)	19.9 ± 4.5 (9.9–32.7)	18.6 ± 3.6 (10.6–29.0)	15.9 ± 3.6 (5.0–27.0)	17.1 ± 4.4 (8.7–31.0)	$23.6_{1,2.1}$	0.04
Soil moisture (volumetric water content)	70.9 ± 13.2 (25.1–100.3)	64.5 ± 11.6 (36.0–104.5)	72.6 ± 12.6 (34.2–112.5)	71.0 ± 14.2 (30.3–100.3)	$0.65_{1,4.05}$	0.46
Practical measure						
Mud depth using ruler (cm)	8 ± 4 (2–19)	7 ± 2 (2–13)	5 ± 2 (1–13)	6 ± 3 (1–13)	$4.8_{1,2.0}$	0.16
Paddock[2] scored as "dry" using boot score (%)	69 ± 30 (0–100)	61 ± 28 (0–92)	70 ± 28 (0–100)	61 ± 34 (0–100)	$0.13_{1,2.0}$	0.75
Paddock[2] scored as "wet" using boot score (%)	69 ± 28 (0–100)	36 ± 25 (8–92)	27 ± 23 (0–76)	32 ± 28 (0–92)	$0.49_{1,1.96}$	0.56
Paddock[2] scored as "sodden" using boot score (%)	3 ± 5 (0–20)	3 ± 8 (0–40)	3 ± 11 (0–48)	8 ± 16 (0–80)	$0.29_{1,4.25}$	0.62
Paddock[2] scored with surface water pooling present (%)	18 ± 19 (0–76)	36 ± 22 (12–100)	23 ± 24 (0–88)	33 ± 26 (0–100)	$0.01_{1,2.0}$	0.95

[1]Values are raw means ± SD for each group, with group average minimum to maximum in parentheses. Groups were fed either fodder beet or kale (2 groups each) supplemented with perennial ryegrass and white clover baleage. Subscripts refer to numerator and denominator degrees of freedom.

[2]Percent of sites out of 25 sites scored across the full length and width of the paddock.

Table 4. Daily behaviors over the duration of the 32-d study period for each group (raw means ± SD, group average minimum to maximum in parentheses)[1]

	Fodder beet		Kale	
Behavior	Group 1	Group 2	Group 1	Group 2
Lying time (h/d)	10.6 ± 2.1 (3.0–14.0)	9.4 ± 2.4 (1.1–12.9)	9.6 ± 2.0 (5.1–13.0)	8.6 ± 2.3 (1.1–12.9)
Lying bouts (no./d)	9.1 ± 1.9 (3.8–12.2)	7.9 ± 2.0 (2.7–10.4)	9.2 ± 1.8 (3.9–12.2)	7.9 ± 2.0 (2.7–10.4)
Lying bout duration (min/bout)	79.0 ± 18.7 (34.9–140.2)	82.5 ± 23.6 (16.1–146.9)	70.8 ± 15.5 (49.6–135.7)	72.1 ± 25.6 (10.4–164.8)
Eating time (h/d)	4.1 ± 0.5 (3.1–5.3)	3.9 ± 0.8 (2.9–5.8)	6.2 ± 0.8 (4.7–8.4)	5.4 ± 0.9 (4.3–7.4)
Ruminating time (h/d)	6.5 ± 0.9 (4.5–8.3)	5.8 ± 0.9 (4.4–7.5)	5.3 ± 0.9 (4.0–7.0)	5.2 ± 1.2 (3.2–8.0)

[1]Groups were fed either fodder beet or kale (2 groups each) supplemented with perennial ryegrass and white clover baleage. Behavior data are from 30 focal cows per group of 99 pregnant, nonlactating cows. Behavioral differences between fodder beet and kale groups were not statistically analyzed due to small sample size.

cows in the fodder beet paddocks spent numerically more time ruminating in the evening and early morning hours from about 2300 to 0500 h.

Effect of Weather on Lying Behavior

The relationships between lying behaviors, rainfall, and ambient temperature over the study period are shown in Figure 4. Lying time decreased on the day of rainfall (estimate: −0.48 ± 0.09 h/d; $F_{1,19.3} = 31.1$; $P < 0.001$) and the day after rainfall (estimate: −0.40 ± 0.09 h/d; $F_{1,27.9} = 18.2$; $P < 0.001$), with some individuals reducing their lying time by more than 40% on the day of rainfall. Two days after rainfall, lying time increased (estimate: 0.23 ± 0.11 h/d; $F_{1,35.5} = 9.9$; $P < 0.01$), rebounding to about 1 h longer than before the rainfall event (Figure 4a). Most notably, 2 of the highest rainfall days occurred in succession (4.6 mm on study d 15, and 12.2 mm on study d 17), resulting in a decrease in group average lying time from 10 h/d (d 14 before rainfall) to 6 and 7 h/d (day of rainfall on d 15 and 17), and group average lying time dropped to just 2 h/d (a decrease of about 70%) on the day after the heaviest rainfall (d 18). Two groups (1 each in kale and fodder beet paddocks) had 30% and 38% of cows, respectively, that did not lie down at all during the 24-h period after this heavy rainfall event. Lying time also decreased with lower ambient temperature (estimate: 0.36 ± 0.12 h/d; $F_{1,20.4} = 9.9$; $P < 0.01$).

The number of lying bouts decreased on the day of rainfall (estimate: −0.53 ± 0.08 bouts/d; $F_{1,18.2} = 45.1$; $P < 0.01$; Figure 4b), whereas lying bout duration increased (estimate: 3.7 ± 0.89 min/bout; $F_{1,23.8} = 17.2$; $P < 0.001$; Figure 4c). The day after rainfall, lying bout duration decreased (estimate: −4.8 ± 1.0 min/bout; $F_{1,33.8} = 22.8$; $P < 0.001$). The number of daily lying bouts decreased at lower ambient temperatures, but this was driven by cows on kale paddocks (estimate: 0.24 ± 0.11 bouts/d; $F_{1,73} = 4.8$; $P = 0.03$).

Effect of Paddock Soil Conditions on Lying Behavior

The relationships between lying time and measures of paddock soil conditions over the study period are shown in Figure 5. Lying time decreased with increasing percentage of surface water pooling, especially for cows in fodder beet paddocks (estimate: −0.026 ± 0.009 h/d; $F_{1,77.2} = 7.6$; $P < 0.01$). The number of lying bouts decreased with increasing mud depth (estimate: −0.16 ± 0.07 bouts/d; $F_{1,99.5} = 4.5$; $P = 0.04$), and for cows in fodder beet paddocks, number of lying bouts also decreased with increasing percentage of surface water pooling (estimate: −0.032 ± 0.02 bouts/d; $F_{1,75.8} = 4.6$; $P = 0.04$). For cows in kale paddocks, lying bout duration increased as the paddock became less dry (estimate: −0.031 ± 0.20 min/bout; $F_{1,82} = 4.3$; $P = 0.04$).

Hygiene Score and Lying Time

Cows became dirtier over the study period (higher hygiene score; $F_{1,374} = 95.5$; $P < 0.01$). When rainfall was greater in the previous week, cows with lower lying time (less than 8 h/d) were scored as cleaner than cows lying more than 10 h/d (estimate: 0.16 ± 0.05; $F_{1,308.1} = 10.5$; $P < 0.01$).

Effect of Weather and Paddock Soil Conditions on Eating and Ruminating Time

Descriptively, daily rainfall did not appear to affect daily eating time or ruminating time, except during the wettest day of the study on d 17 (Supplemental Figure

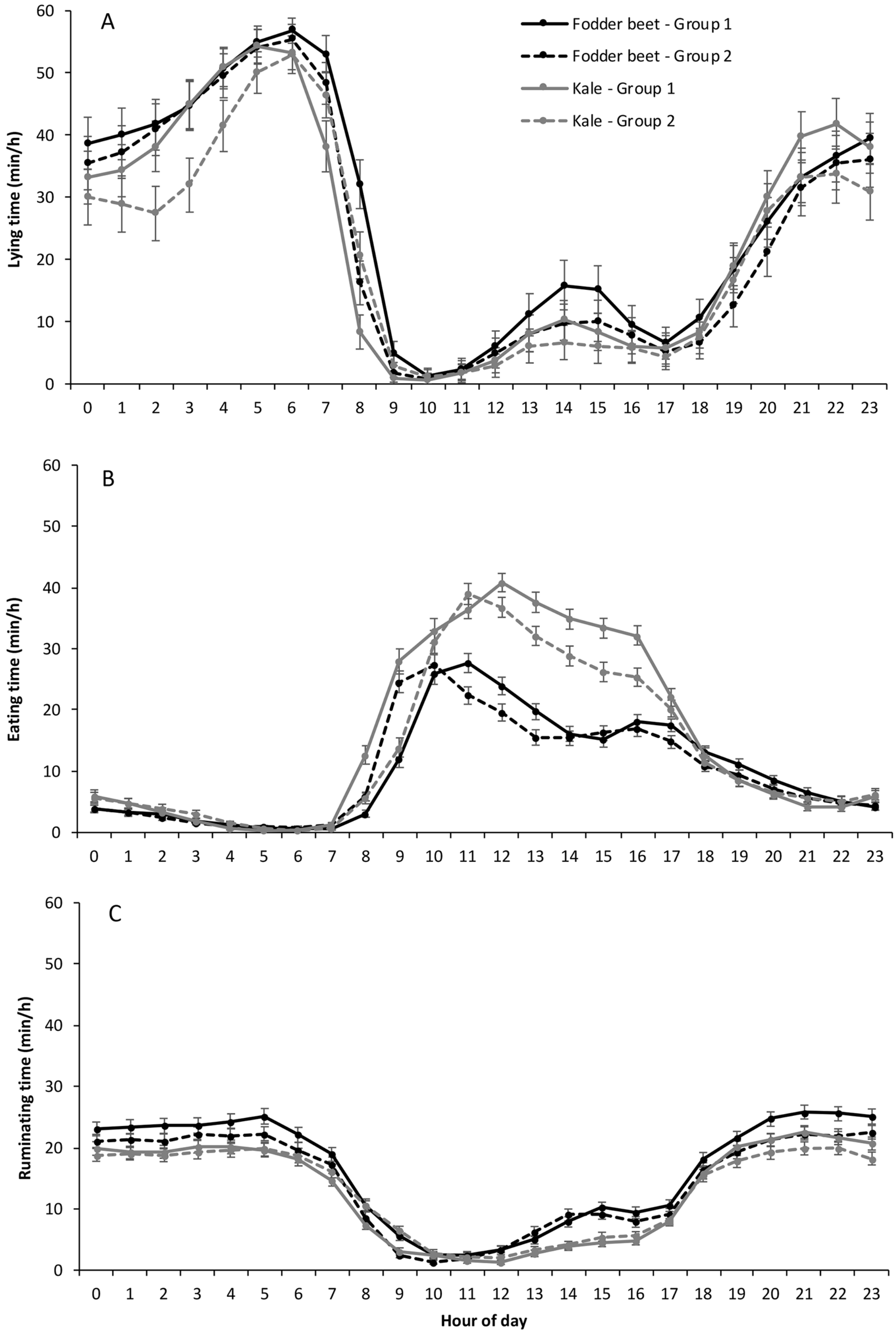

Figure 3. Diurnal behavior patterns of 30 focal cows in each of the 4 groups; 2 groups were managed on fodder beet paddocks and 2 groups were managed on kale paddocks, with each group containing 99 pregnant, nonlactating cows. Values represent raw means ± SE of time spent performing each of the following behaviors (min/h) over the 32-d study period: (A) lying time, (B) eating time, and (C) ruminating time. Data are presented for fodder beet and kale groups for descriptive purposes only; inferential statistics were not performed on effect of crop type.

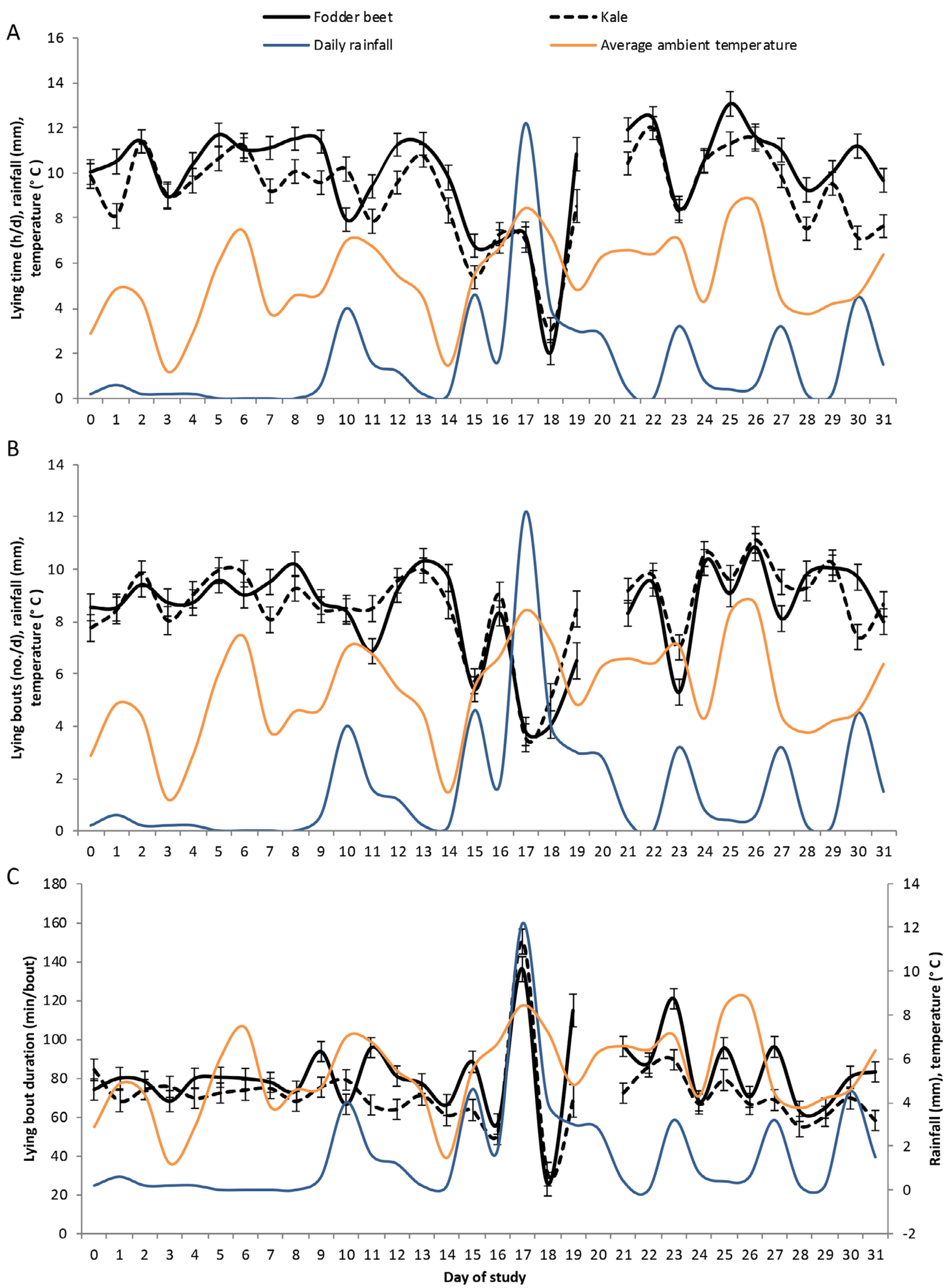

Figure 4. Raw means ± SE of lying behavior of 30 focal cows (pregnant, nonlactating) over the 32-d study period and relationship with rainfall and ambient temperature. The black lines represent the daily group averages of (A) lying time (h/d), (B) number of lying bouts (no./d), and (C) lying bout duration (min/bout per day). Two groups were managed on fodder beet paddocks (solid line), and 2 groups were managed on kale paddocks (dashed line), with each group containing 99 cows. Data are presented for fodder beet and kale groups for descriptive purposes only; inferential statistics were not performed on effect of crop type. Missing data on d 20 were due to device changeover for all cows.

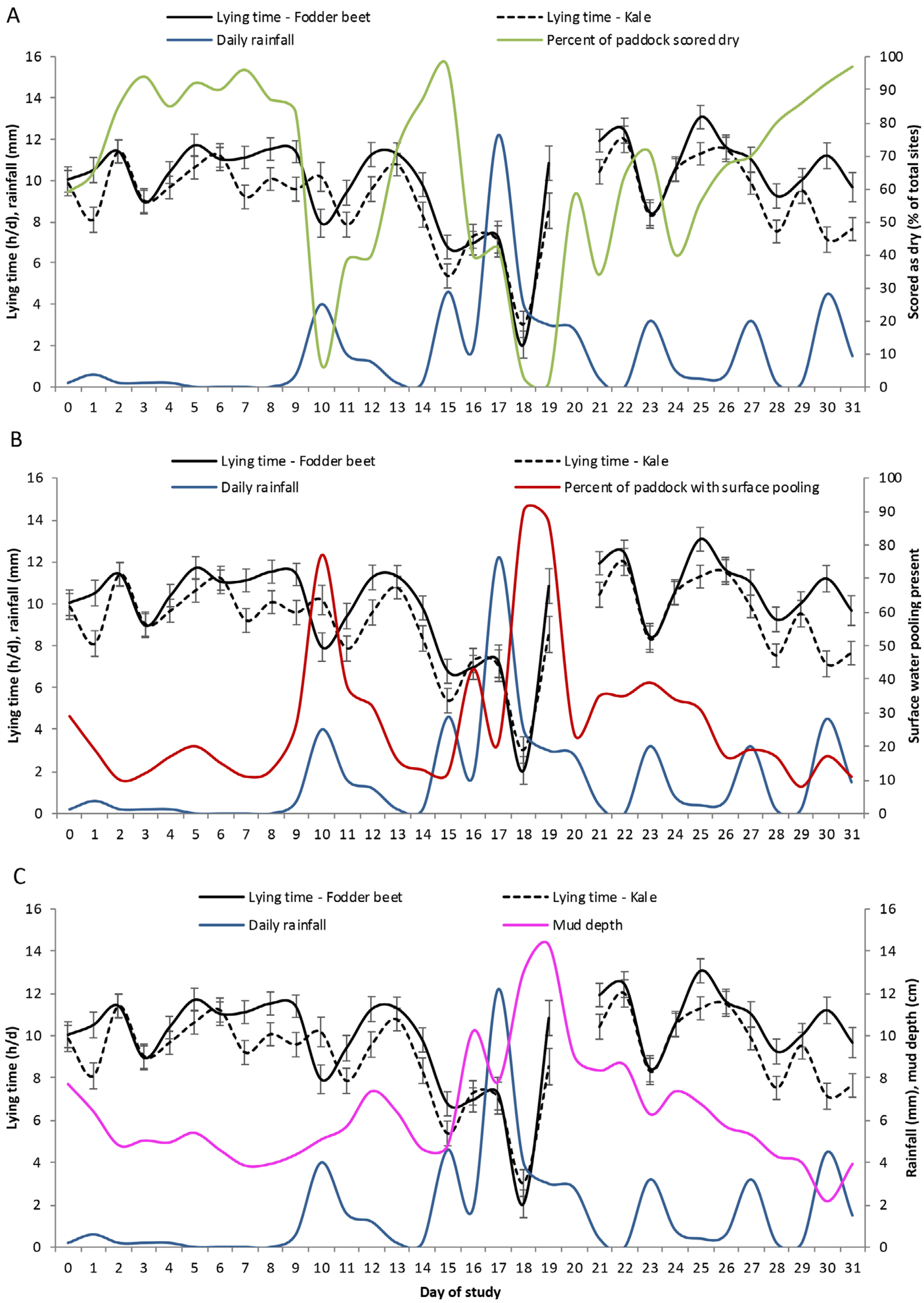

Figure 5. Raw means ± SE of lying time of 30 focal cows (pregnant, nonlactating) over the 32-d study period and relationship with daily paddock soil conditions. The black lines represent the daily group average lying time of the 2 groups managed on fodder beet paddocks (solid line) and the 2 groups managed on kale paddocks (dashed line), and the blue line represents the daily rainfall. (A) Percent of paddock sites scored as dry (using boot score), (B) percent of paddock sites with surface water pooling, and (C) mud depth (cm on ruler). Data are presented for fodder beet and kale groups (2 groups each) for descriptive purposes only; inferential statistics were not performed on effect of crop type. Missing data on d 20 were due to device changeover for all cows.

S3; https://data.mendeley.com/datasets/svc3s7n7wc/1; Neave et al., 2022). Percentage of sites with surface water pooling emerged as the most important paddock condition that affected lying time, so we chose to focus on this variable to determine if it also affected other behaviors. Eating time did not appear to decrease when surface water pooling increased, except when pooling reached over 80% of sites on the wettest study day (d 17). Ruminating time appeared to decrease by about 1 h on days when surface water pooling increased.

DISCUSSION

This study examined the effect of weather and paddock soil conditions on the behavior of prepartum (pregnant, nonlactating) dairy cows managed outdoors on crop paddocks during the winter in New Zealand. A major finding was that lying time became compromised with deteriorating paddock soil conditions, which were closely linked with rainfall events. Descriptively, eating and ruminating behaviors may also be negatively affected when paddock soil conditions are especially poor. Notably, measures of soil conditions using practical tools for farmer use were found to be precise, but they did not accurately measure true mud depth or soil wetness. These practical measures of mud depth and soil wetness (using a ruler, boot score, and presence of surface water pooling) were correlated with rainfall amount, but only weakly. Therefore, the practical measures used in our study can be indicators of paddock soil conditions and thus quality of the lying surface, but caution is necessary if thresholds for mud depth or soil wetness are to be developed using these tools.

Lying Behavior

Historically, a minimum lying time of 8 h/d has been considered adequate for pregnant, nonlactating dairy cows in New Zealand (DairyNZ, 2021), based on the limited research available at the time (Fisher et al., 2002, 2003). However, in recent years, research has demonstrated that nonlactating pregnant dairy cows in New Zealand will lie down for more than 10 h/d when they have access to comfortable off-paddock lying surfaces (Schütz and Cox, 2014; Schütz et al., 2015, 2019). All of our groups achieved average lying times of longer than 8 h/d, but only 1 group exceeded 10 h/d during the entire study period. Well-fed lactating dairy cows grazing pasture in summer in New Zealand spend between 8 and 10 h/d lying (Kendall et al., 2006; Tucker et al., 2007, 2008; Fisher et al., 2008; Schütz et al., 2013). Thus, we should expect longer lying times in nonlactating cows managed on crop because their daily feed requirements are less. In our study, we noted that cows spent about 5 h/d eating crop and pasture baleage, although we caution the technology was only validated for dairy cows grazing pasture, not crop (Pereira et al., 2018). Several studies have demonstrated that the shortest lying times occur when feeding time is greatest (e.g., under 9.3 h/d of lying time and over 7.9 h/d of grazing in pastured cows; see review by Tucker et al., 2021). Thus, the shorter eating times observed in our study should allow for longer lying times than seen in lactating cows grazing pasture, due to more available time to do so. When not lying or eating, the remainder of the day is spent standing idle or engaged in other activities including social behavior or grooming (although previous work suggests that time spent social grooming on pasture is limited; Tresoldi et al., 2015). Longer periods of standing have been linked with greater odds of developing claw horn lesions in pastured dairy cattle (Sepúlveda-Varas et al., 2018), and wet conditions (created by manure, cow cooling systems, and humidity in confinement systems) especially contribute to lameness (Sanders et al., 2009). Presumably, cows chose not to lie down more often due to the lying surface conditions, discussed below.

About 20% of the cows consistently lay less than 8 h/d, and these cows were more likely to be younger. The reasons why these individuals lay less may be due to social factors. For example, younger cows may be outcompeted for suitable lying areas (as observed in indoor-housed cattle; Friend and Polan, 1974), or dominant cows gain priority access to resources when they are motivated (Val-Laillet et al., 2008). These situations could result in younger cows standing when only wet lying surfaces are available. Daily stocking density was low at 20 m^2/cow; therefore, all cows theoretically had ample area to lie down. However, following wet weather events, surface water pooling was high (over 80% of sites), and thus available drier space to lie down was diminished considerably (e.g., less than 4 m^2 per cow). Under these conditions, competition for lying in the drier areas nearest the feed face may have occurred. Alternatively, younger cows may have lower lying time requirements than older cows, resulting in lower lying times for these individuals (e.g., Munksgaard et al., 2020). It is also possible that some cows may have individual preferences to spend less than 8 h/d lying; thus, shorter lying times may not be a concern for them, but this remains to be investigated.

Our results are similar to those from several previous studies showing that lying times of dairy cows are reduced in response to rainfall in winter (Schütz et al., 2010; O'Connor et al., 2019; Thompson et al., 2019). Cows in our study lay less on the day of and the day after rainfall, but 2 d after rainfall, lying time was greater than before the rainfall event. Prolonged periods of standing are known to result in compensatory (or "rebound") lying behavior; for instance, cows reduced their lying time when kept on wet, muddy, or hard surfaces, and they showed a rebound in lying time when they were released to pasture (Schütz and Cox, 2014; Schütz et al., 2019). This rebound in lying is likely due to the high motivation of cows to access comfortable lying surfaces when deprived of the opportunity; cows will pay a cost by pushing on a weighted gate to reach a deep-bedded lying area when forced to stand for 4 h/d (Tucker et al., 2018). This suggests that cows in our study experienced a period of lying deprivation during rainfall events, and the cows compensated for this by lying down for longer 2 d later. Some cows were more affected by heavy rainfall periods; a third of cows did not lie down for an entire 24-h period. This is likely due to a lack of a comfortable lying surface, leading to prolonged lying deprivation and possibly fatigue. We found air temperature was also a mediating factor; lying time decreased at cooler temperatures, as shown by others for pastured dairy cattle (Tucker et al., 2007; Webster et al., 2008; Hendriks et al., 2020) and beef cattle in winter (Graunke et al., 2011). This may relate to thermoregulation, in which heat loss may be more rapid in colder temperatures when underfoot conditions are wet (Bøe, 1990). Neither rainfall nor ambient temperature visibly affected eating and ruminating time, which further supports that lying time in this study was most likely affected by the condition of the lying surface.

Paddock soil conditions, and thus the quality of the lying surface, deteriorated during and after rainfall, resulting in a wetter surface that cows were less likely to lie down on. This is consistent with other work, confirming that cows spend less time lying down when the surface is wet compared with dry outdoor New Zealand conditions (Fisher et al., 2003; Tucker et al., 2007; Schütz et al., 2010, 2019) and dry indoor conditions (Fregonesi et al., 2007; Reich et al., 2010). Experimental work in cows exposed to muddy conditions (housed in pens indoors without inclement weather) found that cows spent 3.2 h lying down in the muddiest condition compared with 12.5 h lying down in the driest condition on the first day of exposure and were more likely to choose to lie down on a concrete surface instead of the muddy surface (Chen et al., 2017). Other work has demonstrated that the wetness of the surface over dirtiness is most undesirable for cows (Schütz et al., 2019).

In addition to lying time, the number of lying bouts and lying bout duration were affected by rainfall and poor paddock soil conditions. Previous studies with pastured dairy cows also found fewer and longer lying bouts with greater rainfall (Thompson et al., 2019) and when the lying surface was dirty or wet compared with a clean and dry surface (Schütz et al., 2019). This may be due to cow preference to remain lying once they have chosen to do so, perhaps because other lying areas are less desirable if they were to leave the current lying area. Alternatively, poor lying surface conditions during and after rainfall may physically limit the cow from transitioning from lying to standing, or may be energetically costly (e.g., due to mud depth).

Of the paddock measures used in this study, the percentage of the paddock sites with surface water pooling emerged as having a significant effect on lying time. Therefore, we suggest that surface water pooling could be a useful measure for farmers or assessors to estimate the quality of the lying surface. If paddock measures are not possible, or for farms where soil is prone to pugging and poor drainage, rainfall amount could be used as a guide for farmers in making decisions about whether paddock soil conditions may be (or could become) unsuitable for cows. However, the amount of rainfall at which paddock soil conditions begin to deteriorate will depend on several factors, including crop type, soil type, topography, and stocking density.

Cow hygiene score is often used as an indicator of the quality of the lying surface and cow comfort in off-paddock facilities (McPherson and Vasseur, 2020; Robles et al., 2021). The cows in our study became dirtier over the duration of the study, similar to previous experimental work where cows provided a dirty (contaminated with manure) or muddy (wet soil) surface had higher hygiene scores than when provided a clean surface (Chen et al., 2017; Schütz et al., 2019), and cows became dirtier as bedding material deteriorated (O'Connor et al., 2019). We found hygiene score was related to lying time; the dirtiest cows spent more time lying down, whereas cows that spent less time lying down were cleaner. These results suggest that dirty cows can be a general indicator that lying surface conditions are dirty or wet, but a clean cow is not necessarily an indication of good individual animal welfare—this could mean the cow was able to find a clean, dry area to lie down, or it could mean she did not lie down, which is similar to when cows are managed on concrete surfaces (Schütz and Cox, 2014).

Overall, this observational study supports experimental work indicating that cow comfort is compromised when the lying area is wet. This study maintained the size of the paddock area available to the cows each day regardless of paddock or weather conditions, but farmers often provide more feed during inclement weather and thereby increase access to potentially drier or more comfortable lying areas. If inclement weather follows a period of fine weather, farmers may also provide cows with access to the area behind the back fence, which could include more comfortable lying areas. Provision of artificial shelter with dry bedding for prepartum dairy cows in winter has also been shown to increase lying times (Cartes et al., 2021). These practices may improve lying times under poor conditions and deserve further investigation. Our study was limited to a small sample size of 4 groups managed on the same research farm, due to the availability of paddocks for rotational crop grazing. However, unlike other experimental work examining lying behavior of pastured dairy cows, our groups contained 99 cows each, which more closely resembles the nature of a commercial farm operating under similar winter conditions. Our results may differ depending on the type of crop that is offered; common winter crops such as fodder beet, kale, or swedes have different root structures that could affect soil stability and thus lying surface quality. We were unable to examine if fodder beet and kale crops differentially affected lying time due to limited sample size, but this deserves future work.

Eating and Ruminating Behavior

The ear-attached accelerometer devices used to measure eating and ruminating time were validated in dairy cows when grazing pasture (Pereira et al., 2018), but head and ear movements when eating crop and baleage from feeders may differ from those when grazing pasture. It is possible that the algorithm for eating and rumination classification under- or overestimated the durations reported in this study; therefore, we chose to only examine relationships descriptively. We observed that ruminating time appeared to decrease with increased percentage of sites with surface water pooling. Rumination often occurs when lying down (Schirmann et al., 2012), which may explain why ruminating time was lower during wet paddock soil conditions when lying time was also lower. Eating time did not appear to be consistently affected to the same extent as rumination time, but there was a decrease on the wettest day of the study when surface water pooling reached 90% of sites. This could relate to poorer crop utilization in wet conditions as feed is more likely to be trampled into the soil and therefore not available for eating. There was visually a longer eating time by cows on kale paddocks, but a longer ruminating time by cows on fodder beet paddocks. Further work with more groups is necessary to verify these potential behavior differences between crop types and whether the effect of poor paddock soil conditions on eating and ruminating behavior is dependent on crop type. Overall, although validation in crop-fed dairy cattle is needed, this precision technology device showed changes in eating and ruminating time that appeared to coincide with changes in paddock soil conditions. Therefore, this technology may be useful for farmers to identify when paddock soil conditions become poor, and thus also the quality of the lying surface.

CONCLUSIONS

Dairy cattle managed outdoors in winter on crop paddocks experienced reduced lying time when paddock soil conditions deteriorated, especially on the day of and day after a rainfall event, leading to a rebound in lying time 2 d later. The majority of cows had under 10 h/d of lying time, and some below 8 h/d, suggesting that these cows may not have had access to comfortable lying surfaces. The percentage of sites in the paddock with surface water pooling may be the most useful of the 4 paddock measures to estimate the quality of the lying surface. Our results suggest that the welfare of dairy cows becomes compromised when the paddock area becomes muddy, especially when it is wet. These conditions are likely to occur when groups are managed outdoors on crop paddocks in winter and the majority of the group is unlikely to achieve 10 h/d of lying time.

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