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Responses to short-term exposure to simulated rain and wind by dairy cattle: time budgets, shelter use, body temperature and feed intake

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Abstract

Our objective was to examine how short-term exposure to wind or rain, or the combination of wind and rain, influences behavioural and physiological responses and the motivation for shelter. Twenty-four, non-lactating, pregnant Holstein-Friesian cows were individually housed and allocated one of four treatments (control, wind, rain, wind and rain) created with fans and sprinklers. Feed intake and behavioural and physiological variables were recorded for 22 h. Motivation to use the shelter was assessed by creating a trade-off between time spent feeding while exposed to the weather treatments and time spent in the shelter. Feeding times were manipulated by placing frames with three different mesh sizes over the feed; the purpose of the smaller mesh was to increase the time spent feeding. However, shelter use was unchanged by these costs. Cows reduced their feed intake by 62% when exposed to rain and the combination of rain and wind. Cows spent approximately 50% of their time in the shelters in all weather treatments and spent little time lying, especially under wet conditions (5.9, 4.4, 2.8, and 1.1 [± 1.4 h] per 22 h for control, wind, rain, and wind/rain treatments, respectively; mean [± SED]). Rain alone, and in combination with wind, decreased skin temperature by 26%, on average. The short-term response to wet conditions was characterised by a marked decline in lying time, feed intake and skin temperature. Wind alone had little effect on these responses, but magnified the effect of simulated rain on feeding behaviour. These results indicate that protection from both rain and the combination of rain and wind is likely to be important for animal welfare, but future work is needed to understand when and how to provide protection to pastured dairy cattle.

Keywords: *animal welfare, behaviour, dairy cattle, motivation, physiology, rain and wind*

Introduction

Exposure to winter weather affects both the physiology (eg change in body temperature: Bergen *et al* 2001; Kennedy *et al* 2005) and the behaviour of cattle. If given the opportunity, cattle will change their behaviour in order to mitigate negative effects of inclement winter weather (Senft *et al* 1985; Olson & Wallander 2002). Behavioural responses to winter weather can be broken down into two main categories: seeking shelter or microclimates to mitigate weather and changes in time budgets if no shelter is available, including time spent lying and feeding. Cattle will seek shelter or microclimates that reduce the effects of inclement weather, particularly in strong winds and during heavy or persistent rain (Houseal & Olson 1995; Vandenheede *et al* 1995; Redbo *et al* 2001). Access to a shelter (natural or man-made) reduces the negative effects of wind and rain and can improve weight gain (Self *et al* 1963; Hidiroglou & Lessard 1971). Keeping cattle indoors mitigates the physiological responses to winter weather, including low body and skin temperature, compared to counterparts kept outdoors (Tucker *et al* 2007; Webster *et al* 2008). While it is clear that cattle will benefit from and seek shelter, there is little experimental evidence examining the motivation to use a shelter or the specific weather conditions that influence this behaviour.

A well-designed shelter may reduce the second type of behavioural response to winter weather: changes in time budgets. Cattle spend less time lying down on wet, muddy surfaces (Muller *et al* 1996; Fisher *et al* 2003). They eventually lie down on wet surfaces in cold weather, although lying postures that minimise the amount of surface area exposed to the surroundings are more common in these conditions (Tucker *et al* 2007). Cattle will increase the time spent lying if they are provided with a comfortable, dry substrate in cold climates, likely reducing heat loss to the environment (Gonyou *et al* 1979; Redbo *et al* 2001). Cattle also decrease time spent feeding in response to cold weather (Malechek & Smith 1976; Adams *et al* 1986), although this change is not consistent across studies (eg Redbo *et al* 2001; Tucker *et al* 2007). Changes in feeding times may be influenced by many factors, including the severity of the weather conditions, individual energy demand, feed availability, degree of acclimatisation, and type of microclimate (eg sheltered feeding areas).

In New Zealand, most dairy cattle are kept outdoors all year round. Keeping cattle on pasture is often perceived as beneficial for animal welfare because it allows the performance of natural behaviours, such as grazing. However, one consequence of pasture-based dairy farming is that the animals are exposed to cold and wet conditions throughout winter. For example, dairy cows decreased time spent lying, and showed a moderate activation of the hypothalamic-pituitary axis and changes in diurnal body temperature rhythm when exposed to a combination of simulated and natural rain and wind in winter in New Zealand (Tucker *et al* 2007; Webster *et al* 2008). From this work, it is unclear which aspect of winter weather is problematic: wind, rain or the combination. Understanding the role of each aspect of winter weather is important in order to design appropriate shelter and, ultimately, improve animal welfare.

The objective of this study was to understand how short-term exposure to components of winter weather (exposure to wind or rain, or the combination of wind and rain) influences the behavioural and physiological responses and the motivation for shelter. To measure the motivation, we created a trade-off situation where the cows could choose between feeding while exposed to inclement weather and using a shelter that provided protection from these weather treatments. Feeding time was manipulated by placing a rigid mesh with squares of different sizes on top of the feed. Smaller mesh sizes reduced the rate of feed intake and thus imposed a greater cost by requiring longer feeding times to maintain intake. We predicted that the importance of shelter could be estimated by the trade-off between the time taken to gather food and use of the shelter under different weather conditions. We also predicted that cows would spend less time feeding and lying and would spend more time in the shelter in aversive weather conditions and that skin and body temperature would decrease in response to winter weather. We expected that the response to the weather conditions would be, from greatest to least: wind/rain, rain only and wind only and, finally, the control.

Materials and methods

All procedures involving animals were approved by an independent Animal Ethics Committee as required under the New Zealand Animal Welfare Act 1999.

Animals and treatments

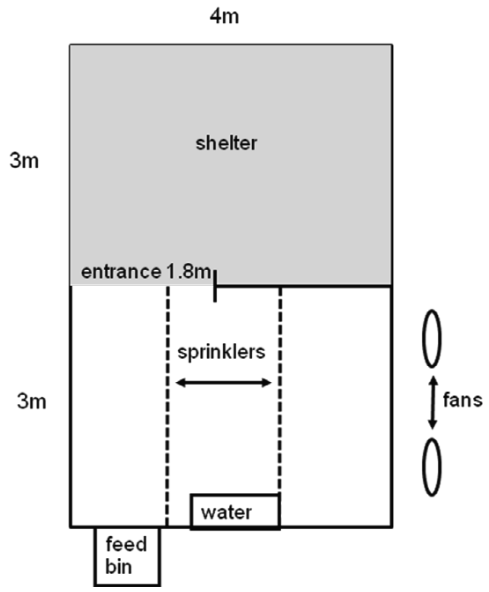
Twenty-four, non-lactating, pregnant, Holstein-Friesian dairy cows were studied at Ruakura Research Station in Hamilton (latitude 37º47' S, longitude 175º19' E), New Zealand in August 2006 (southern hemisphere winter). At the start of the experiment, cows were, on average, 5 (± 2) years of age, weighed 547 (± 54) kg, and were 242 (± 6) days pregnant (mean [± SD]). Each cow was allocated one of four weather treatments: i) wind only; ii) rain only; iii) wind and rain; and iv) no wind and no rain (control). The cows were divided into six treatment groups with four animals per group (one of each weather treatment). The treatment groups were balanced for bodyweight (n = 6 cows per treatment). The weather treatments were created indoors with fans and sprinklers (see below). Cows were exposed to the treatments individually. The four cows within a group were tested at the same time, one of each weather treatment, for approximately 22 h (1100–0900h). The six groups were further divided into two replicates (three groups or 12 cows per replicate) based on estimated calving date, in order to avoid exposing the cows to possible discomfort shortly before giving birth. The cows in the first replicate were tested for nine consecutive days before the testing was carried out on the second replicate. The cows were kept at pasture when not being tested.

To test the level of motivation for shelter, we created a trade-off: cows had to choose between feeding while exposed to the weather treatment and using a shelter. Feeding times (ie the cost) were altered by placing a 44 × 74 cm (length × width) steel mesh with squares within a wooden frame that were either large (14.5 × 15 cm), medium (5.0 × 5.0 cm), or small (3.5 × 4.0 cm), on top of the feed. By feeding through a smaller square within the frame, the cows had to spend more time in the weather in order to consume their daily feed intake. The size of the squares had been previously evaluated without any weather exposure to ensure that the cows were able to consume their daily intake through all mesh sizes, and that there was an increase in feeding time with decreasing mesh size; average feeding times were 9.7, 8.0 and 7.8 min per kg silage for the small, medium and large mesh size, respectively (SD: 1.0 min, n = 4). Each cow was tested three times, once every three days (nine days of testing per replicate, ie 18 days of testing in total) under the same weather treatment but with a different mesh size on each test day. The order of exposure to the different mesh sizes was balanced between weather treatments, during each replicate, and on each day. All cows were habituated to the experimental pens and the feeding system for a few hours per day, increasing the time of each exposure, during two weeks before the start of the experiment. During the habituation period, cows were initially kept in small groups with free access to feed before being kept individually with the different feeding conditions. They were only exposed to their assigned weather treatment in the last few days of habituation.

Each experimental pen measured 4.0 × 6.0 m (Figure 1) and had a 16.5-mm thick rubber Agri-mat (NuMat Industries, Timaru, New Zealand) on top of the concrete floor. Half of each pen consisted of a shelter made of wood (4.0 × 3.0 × 2.3 m; length × width × height) with a clear 1.0-mm plastic roof and 1.0-mm plastic sheeting on the sides. Clear plastic was used to allow light into the shelter during the day to facilitate behavioural observations when cows were in this area. The plastic was tightly attached to the wooden structures and did not make any noise or move. The entrance to the shelter was 1.8 × 1.75 m (width × height). A red light (80 W, one per pen) was installed to facilitate observations at night. All cows had auditory contact with the other test cows, but solid wooden walls separated the pens. Water was provided *ad libitum* in the non-sheltered area. Weather treatments were balanced across experimental pens.

Grass silage (42.2 [± 7.80]% dry matter [DM]; mean [± SD]) was provided in a feed bin on the outside of the non-sheltered half of each pen, opposite to the shelter

Figure 1



Experimental pen design. Different weather conditions were created by electric fans and sprinklers. The shelter consisted of a wooden structure covered in clear plastic.

(84 × 54 × 55 cm; length × width × height; Figure 1). The feed bins were located outside the test pens to facilitate refilling the feed with minimum disturbance and to keep the silage dry. Cows had to put their heads outside of the experimental pen in order to feed through the mesh. To ensure that the feed was available *ad libitum*, feed bins were refilled every two hours. If the bin did not require refilling, existing silage was moved around to ensure all cows received the same stimulus (human manipulating the food) at the same time.

The wind treatment was created with two pedestal fans (IMASU IFS65 650-mm Oscillating Pedestal Fans, Hamilton, New Zealand) located on one side of the pen (Figure 1). An electric fence separated the cow from the fans. Wind speed was 10 km per h when standing directly in front of the fan and 9 km per h in the middle of the pen. The rain treatment was created with two sprinkler lines fitted with 11 spray mist nozzles located 2.0 m above the floor. The sprinkler system was designed to simulate a constant light drizzle (756 [± 70] mm per 24 h; mean [± SD]). Water temperature (11.9 [± 0.7]°C) and flow rate (9.6 [± 0.9] ml per s) were recorded in the rain treatments at the beginning of the observations and at 7-h intervals throughout the test period. The wind and rain treatment was the combination of both the fans and sprinklers, while the control treatment (no wind and no rain) was subjected to neither. Air temperature in all pens fluctuated with outdoor conditions. All four test pens were drained such that water did not pool in the pens. All pens were cleaned after the 22 h of testing per cow with a high water pressure hose.

Environmental measurements

Air temperature and relative humidity (HMP45A humidity and temperature sensor, Vaisala, Helsinki, Finland), wind speed (# 40 Hall effect anemometer, NRG Systems, Hinesburg, VT, USA) were recorded at 10-min intervals with a data logger (CR10X, Campbell Scientific Inc, Logan, UT, USA) on a weather station located outside the test building. The microclimate (ambient air temperature and relative humidity) in each weather treatment (in the sheltered and non-sheltered areas, approximately 2.0 m above the floor) was measured with HOBO Pro Dataloggers (Onset Computer Corporation, Bourne, MA, USA). The wind chill factor was calculated using a modified equation from Environment Canada's Wind Chill Program (Environment Canada 2006):

$$W = 13.12 + 0.6215 \text{ x } T_{air} + (-11.37 + 0.3965 \times T_{air}) \times \text{Maximum } (2, V)^{0.16}$$

where W is the wind chill, T_{air} the air temperature (°C) and V is wind speed (km per h). This measure of environmental conditions was included to facilitate comparisons with other studies.

Behavioural and physiological measurements

Behavioural and physiological variables were recorded between 1100 and 0900h (approximately 22 h, start time varied slightly from day-to-day). At approximately 1700h on the day before testing, four cows were moved to a barn with a deep layer (approximately 1 m) of sawdust where they were kept as one group until they were moved into their treatments the next morning. Grass silage and water were freely available in this pen and this period ensured similar environmental conditions for all cows before exposure to weather and feed treatments.

Once testing began, the behaviour of the cows in each pen was recorded every 5 min with instantaneous scan sampling (Martin & Bateson 1993). Behaviours included: lying (flank in contact with ground, no weight supported by any of the legs); standing (any state where the cow was not lying); and feeding (head above/in feed bin, silage visible in mouth). If the cow was standing without feeding, it was recorded if the cow had its head above the feed bin without feeding (head above/in feed bin, no feed visible in mouth) or if the head was in a lowered position (chin was level with or below the brisket). Feeding rate was calculated by dividing feed intake by time spent feeding. The location of the cow (inside or outside the shelter) was recorded at each 5-min scan by counting the number of hooves that were within the shelter area (Figure 1). A cow was considered to be using the shelter if at least one hoof was inside the shelter. A white line was painted on the ground with spray paint to facilitate this measurement. Trained observers were used to collect behavioural information. One observer walked slowly down a corridor alongside the four pens in order to observe the animals (approximately 1 m away from the pens, in front of the feeders) and worked an 8-h shift. Inter-observer reliability, as measured by percentage agreement, was between 96 and 100% for all behaviours. Inter-observer agreement was lowest when assessing head above feed bin without feeding. The amount of silage consumed was recorded after each 22-h period.

Table 1 Summary of daily (22 h) weather recordings in outdoor conditions and in the weather treatments (control, wind, rain, and the combination of wind and rain) that contained a sheltered and a non-sheltered area.

	Outdoor		Control		Wind		Rain		Wind and rain	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Air temperature (°C)										
Non-shelter	10	–1–17	10	2–16	10	1–16	10	2–15	8	1–14
Shelter	–	–	10	3–16	10	2–16	10	3–16	10	2–16
Humidity (%)										
Non-shelter	81	36–93	90	46–100	84	37–100	93	59–100	95	63–100
Shelter	–	–	89	55–99	89	52–99	94	68–99	94	69–100
Wind chill (°C)										
Non-shelter	11	0–18	11	2–18	9	–1–16	11	3–17	7	–2–14
Shelter	–		12	3–17	11	3–17	11	4–17	11	3–17

Core body temperature was recorded every 10 min using a modified vaginal controlled internal drug release insert (CIDR™; InterAg, Hamilton, New Zealand) fitted with a microprocessor-controlled Minilog-TX data logger (Vemco Ltd, Shad Bay, Nova Scotia, Canada). Skin temperature was measured by infrared thermography (ThermaCam S60, FLIR Systems AB, Danderyd, Sweden). One day prior to the first test period, a 10 ×10 cm patch of hair was shaved off the scapula region of each cow. This clipped area was photographed immediately before and after each 22-h test period with the infrared camera (ThermaCam Researcher 2.7, FLIR Systems AB, Danderyd, Sweden) and the average temperature was calculated using the FLIR software. The clipped area was used because reflection from the wet hair could reduce the accuracy of this type of temperature measurement (McCafferty 2007).

Statistical analysis

The effects of the weather treatments (effect of rain, wind and their interaction) on behavioural and physiological variables and feed intake and feeding rate were assessed by fitting a mixed model (using residual maximum likelihood) with weather treatments (rain, wind), mesh size (and the interaction between weather treatments and mesh size) as fixed effects. Random effects in this model included replicate, cow within replicate, and day on trial (18 days in total) within replicate. This model used a uniform covariance structure to allow for the replicate structure and for the repeated observations for each animal. We report the overall effect of weather treatments ($P_{overall}$) and the factorial effects of wind (P_{wind}), rain (P_{rain}) and the interaction between the two ($P_{wind \times rain}$). For the variables feeding, head above feed bin without feeding, and standing with head down, a natural log-transformation was used to deal with clear departures from normality. A small correction factor (1/250th) was added to all values to facilitate transformation of zeros. The size of the mesh over the feed was always taken into account in the statistical analysis, but results in tables and figures are presented without it when no statistical differences were detected. The denominator degrees of freedom for the test statistics were estimated using the Kenward-Roger method (Kenward & Roger 1997). All statistical analyses were conducted using the statistical package GenStat version 10.2 (VSN International, Hemel Hempstead, UK).

Results

Weather recordings

A summary of daily (22 h) environmental recordings for both the weather treatments and outdoor conditions is presented in Table 1.

Effect of size of mesh over feed

Cows had lower feeding rates when the mesh placed over the silage was smaller (small: 0.05 kg, medium: 0.07 kg, large: 0.08 kg DM per h, SED: 0.0059, $P < 0.001$). Cows also consumed less silage when the mesh was smaller (small: 5.6 kg, medium: 6.3 kg, large: 7.1 kg DM per 22 h, SED: 0.83, $P < 0.001$, Figure 2). However, the effect of mesh size on time spent feeding was not statistically significant at the 5% level (small: 5.2 h, medium: 4.5 h, large: 4.8 h per 22 h, SED: 0.27, $P = 0.098$). Mesh size did not alter shelter use (small: 12.0 h, medium: 12.3 h, large: 11.6 h per 22 h, SED: 0.79, $P = 0.637$), nor was there an interaction between mesh size and weather treatment on shelter use ($P = 0.747$, Figure 3).

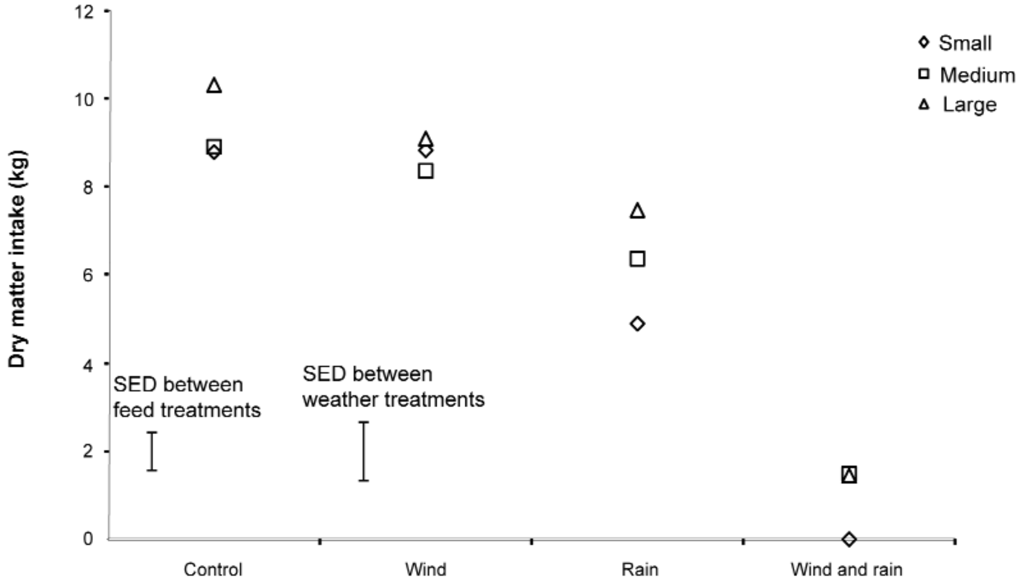
Cows in all treatment groups spent less time standing without feeding when the mesh size was small (small: 12.7 h, medium: 14.2 h, large: 14.1 h per 22 h, SED: 0.50, $P < 0.001$). No other effects of mesh size or the interaction between weather treatment and size of mesh over feed were significant at the 5% level ($P \geq 0.077$).

Effect of weather treatment

Behaviour and feed intake

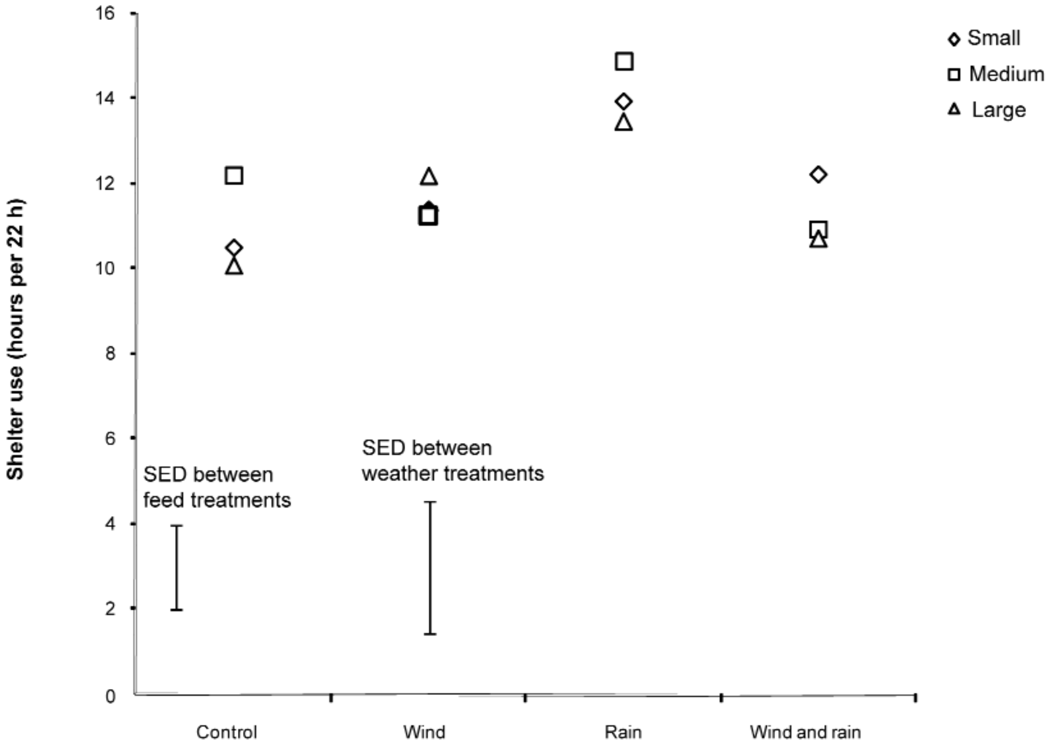
The behaviour of the cows in the different weather treatments are presented in Table 2. On average, cows spent

Figure 2



Mean (± SED) daily intake of grass silage dry matter (kg) of 24 non-lactating, pregnant dairy cows exposed to different simulated weather conditions: control, wind, rain, and the combination of wind and rain (n = 6 cows per treatment). Each cow was tested on three occasions with the same weather treatment but under different feeding treatments. Feeding treatments consisted of a mesh with squares of different sizes (small, medium, large) placed over the silage to slow feeding activity.

Figure 3



Mean (± SED) shelter use (h per 22 h) of 24 non-lactating, pregnant dairy cows exposed to different simulated weather conditions: control, wind, rain, and the combination of wind and rain (n = 6 cows per treatment). Each cow was tested on three occasions with the same weather treatment but under different feeding treatments. Feeding treatments consisted of a mesh with squares of different sizes (small, medium, large) placed over the silage to slow feeding activity.

Table 2 **Behaviour (in sheltered and non-sheltered areas) of 24 non-lactating, pregnant dairy cows exposed to a 22-h period of simulated weather conditions (control, wind, rain, and the combination of wind and rain, n = 6 cows per treatment). *P*-values are presented for the effects of weather treatment; between all four weather treatments (overall), and the factorial effects of wind, rain, and the interaction between wind and rain (wind × rain). Values are mean values (untransformed or back-transformed) and the standard error of the difference between weather treatments (SED).**

	Weather treatment					*P*-value			
Behaviour (h per 22 h)	**Control**	**Wind**	**Rain**	**Wind and rain**	**SED**	**Overall**	**Wind**	**Rain**	**Wind × Rain**
Non-sheltered area									
Feeding*	6.0	4.8	5.3	3.2	2.08	0.641	0.328	0.475	0.713
Feeding rate** (kg DM per h)	1.8	2.3	1.4	0.4	0.13	< 0.001	0.325	< 0.001	0.007
Head above feed bin without feeding*	2.2	0.9	0.5	2.8	0.43	0.046	0.394	0.751	0.015
Standing without feeding**	4.4	4.7	3.3	5.9	1.04	0.140	0.064	0.906	0.144
Standing with head down*	0.23	0.20	0.23	0.18	0.07	0.957	0.605	0.857	0.888
In shelter									
Standing**	6.1	7.9	11.3	10.6	1.13	0.007	0.066	0.002	0.947
Standing with head down*	0.5	0.6	1.1	1.0	0.30	0.523	0.810	0.151	0.990
Lying**	4.9	3.7	2.8	0.7	1.14	0.007	0.068	0.002	0.939
Total shelter use**	10.9	11.6	14.1	11.3	2.82	0.668	0.600	0.483	0.393

* Back-transformed means; ** Untransformed means.

Table 3 **Skin and body temperature of 24 non-lactating, pregnant dairy cows exposed to a 22-h period of simulated weather conditions (control, wind, rain, and the combination of wind and rain, n = 6 cows per treatment). *P*-values are presented for the effects of weather treatment; between all four weather treatments (overall), wind versus no wind (wind), rain versus no rain (rain), and the interaction between wind and rain (wind × rain). Values are mean values and the standard error of the difference between weather treatments (SED).**

	Weather treatment					*P*-value			
	Control	**Wind**	**Rain**	**Wind and rain**	**SED**	**Overall**	**Wind**	**Rain**	**Wind × Rain**
Skin temperature (°C)									
Before weather exposure	32.5	32.8	32.5	32.6	0.51	0.901	0.573	0.795	0.705
After weather exposure	31.0	30.8	24.6	23.9	0.93	< 0.001	0.462	< 0.001	0.736
Before–after exposure	–1.4	–2.1	–7.7	–8.7	0.97	< 0.001	0.256	< 0.001	0.806
Body temperature (°C)									
Mean	38.6	38.7	38.6	38.7	0.10	0.542	0.170	0.847	0.818
Minimum	38.3	38.4	38.2	38.1	0.11	0.242	0.808	0.089	0.354
Maximum	39.0	39.1	39.0	39.2	0.14	0.625	0.236	0.768	0.688
Amplitude	0.8	0.8	0.8	1.0	0.16	0.214	0.350	0.135	0.303

approximately 50% of their time in their shelters. The remainder of the time was primarily spent feeding or standing without feeding. Both rain and the combination of rain and wind reduced feeding rate by 50%, on average (Table 2). Cows that were exposed to wind and rain simultaneously spent more time with their heads above the feed bin without feeding than the control, wind, and rain treatments, respectively (Table 2). Cows ate less when exposed to rain ($P_{\text{rain}} < 0.001$), wind ($P_{\text{wind}} = 0.002$) and the combination of rain and wind exacerbated this response (control: 9.3 kg, wind: 8.8 kg, rain: 6.2 kg, wind and rain: 0.9 kg DM per 22 h, SED: 1.14, $P_{\text{wind} \times \text{rain}} = 0.009$, Figure 2). There were no effects of weather on time spent feeding, standing with head down, or total time spent in the shelter (Table 2).

Weather did, however, influence how cows used the shelter. Standing was the most common behaviour in the shelter, especially when it was wet (56, 68, 80, and 94% of total time spent in shelter for the control, wind, rain, and wind and rain treatments, respectively, Table 2). There was a significant effect of weather treatment on total lying behaviour (control: 5.9 h, wind: 4.4 h, rain: 2.8 h, wind and rain: 1.1 h per 22 h, SED: 1.40, $P_{\text{overall}} = 0.004$,

$P_{wind} = 0.124$, $P_{rain} = 0.005$, $P_{wind \times rain} = 0.849$). Eighty-five percent of all lying behaviour was observed in the shelter (Table 2). Lying times in all treatments were relatively low, but were particularly low in the rain and rain/wind treatments (2.0 h per 22 h on average in treatments with rain vs 5.9 h per 22 h in control). Time spent standing with the head below the brisket did not differ either inside or outside the shelter (Table 2). Time spent standing with their heads below the brisket in the non-sheltered area was 4.0, 2.7, 11.3, and 4.3% of total time standing for the control, wind, rain, and wind and rain treatments, respectively (SED: 4.0, $P \geq 0.131$).

Skin and body temperature

Skin temperature was lower for cows exposed to wet conditions (Table 3). The change in skin temperature (before-after treatment) was also more marked after exposure to the wet conditions. There was no effect of weather treatment on any core body temperature variable (Table 3).

Discussion

The dairy cattle in the present study showed behavioural and physiological changes in response to simulated rain, including reduced lying times, feeding rate, feed intake and skin temperature. In contrast to our predictions, cows did not seek shelter more in response to rain and/or wind, and nor were we able to manipulate the trade-off between shelter use and feeding rate as intended.

Cows in the current study decreased feed intake as a short-term response to rain, particularly when wet conditions were combined with wind. In the wind and rain treatment, cows consumed only 10% of the amount of feed eaten by control cows. The amount of silage consumed by control cows is in line with appropriate feeding levels for non-lactating, pregnant dairy cattle (approximately 8–9 kg DM per day; AFRC 1993), indicating that when exposed to wind and rain, cows were not eating enough to meet their daily requirements. Other studies have reported higher thyroxine and non-esterified fatty acid concentrations in cows exposed to both wind and rain likely because of higher metabolic requirements in these conditions (Tucker *et al* 2007; Webster *et al* 2008). Although measures of metabolic demands were not included in the present study, the combination of likely higher metabolic requirements and insufficient feed intake induced by wet and windy conditions could result in hunger in the short term and loss of body condition over the long term, if conditions persisted and animals were unable to adapt.

Despite the change in feed intake, weather did not affect time spent feeding. This result is in agreement with some studies (Tucker *et al* 2007), but disagrees with others that report a reduction in feeding time when cows were exposed to cold conditions (grazing times positively correlated with minimum temperature ranging from 0 to −34°C; Adams *et al* 1986: 1 min decrease in grazing time per ºC when mean temperature was between 7.8 to −13.0°C; Prescott *et al* 1994) or moderate temperatures in combination with rain (9 min decrease in feeding times per 16 h at mean temperature of 5.0 compared to 5.8°C in simulated rain and wind and indoor conditions, respectively; Webster *et al* 2008). However, none of these previous studies recorded feed intake for individual animals, making it difficult to reconcile their findings with all of our results. Despite no difference in feeding time, cows exposed to rain had a slower feeding rate compared to the cows in the control and wind treatments. It is unclear why rain would slow feeding rate and there is no clear pattern in the literature about which aspect of winter weather influences feeding behaviour. These mixed results highlight the need for future studies to include a suite of measures, including intake, feeding time and feeding rate in order to fully understand how feeding behaviour changes in response to winter weather.

Cows showed the expected higher feeding rates and consumption with increasing mesh size. However, in contrast with our predictions, the mesh size did not influence feeding time or shelter use. Indeed, feeding times of cows not exposed to wind or rain and with the largest mesh size (5.3 h per 22 h) were similar to other experiments with *ad libitum* access (5.9 h per 24 h; Tucker *et al* 2007). The mesh sizes were tested before the experiment under control conditions without any weather exposure, and it is unclear why the changes seen in this testing were not replicated in the larger sample. It is possible that the exposure to the weather treatments may have resulted in an unexpected change in feeding rate rather than feeding time. Alternative methodology is required to ask questions about the motivation to use shelter.

Shelter use, approximately 50% of the time, was similar in all weather treatments. The reason for this is unclear. In terms of the wind-chill factor, the weather conditions were always more favourable in the shelters except in the rain treatment. Despite this, shelter use was highest in this treatment. One possible explanation for this may be that the cows were motivated to use the shelters for other reasons than protection from the weather, possibly as a response to social isolation. Very little is known about appropriate shelter design and this is an important area for future research.

Cows spent very little time lying down, particularly in the rain and rain and wind treatments. Lying times in the control treatment were also much lower than values reported for dairy heifers housed indoors (12–15 h per day; Jensen *et al* 2005) or for cows on pasture (10–11.8 h per day; Krohn & Munksgaard 1993; Ketelaar-de Lauwere *et al* 1999). A reduction in lying time is a common response of cattle to wet and cold conditions in winter (59–67% reduction; Tucker *et al* 2007; Webster *et al* 2008) and to wet bedding (36% reduction; Fregonesi *et al* 2007). The flooring was moist in all treatments because the entire test environment was very humid and the rubber mats never dried completely after the daily cleaning routine of the pens. It is possible that the cows were reluctant to lie down on the wet surface in the shelters in order to minimise heat loss to the environment and the additional water in the rain and rain/wind treatment exacerbated this behavioural response. The reduction of lying time in response to wet conditions is more marked than other manipulations of the lying area (eg additional bedding only changes lying time by 1 to 2 h per day; Tucker *et al* 2009), and is associated with other physiological changes, such as activation of the hypothalamic-pituitary axis (Munksgaard *et al* 1999; Fisher *et al* 2002). In addition, dairy cows are highly motivated to spend approximately 50% of their day lying down (Jensen *et al* 2005; Munksgaard *et al* 2005), thus rainy conditions that result in prolonged reductions in lying times are likely to compromise animal welfare.

Standing was the most common behaviour performed in the shelter (control: 56%, wind: 68%, rain: 80%, wind and rain: 94% of total time spent in the shelter), especially for the cows that were exposed to rain, alone or in combination with wind. In addition to exploring time spent standing, we also examined standing posture, as we have previously found that cows exposed to wind and rain spend more time standing with their heads low to the ground compared to animals kept indoors (17 vs 3% of standing time, respectively; Tucker *et al* 2007). Cows may stand with their heads low in order to protect their head from wind and rain. In the current study, we found no effect of weather on head position while standing in the non-sheltered area. However, the cows in this study had access to shelter and were also able to position themselves facing away from the fans, thereby obtaining some protection from the weather. Indeed, others have shown that cattle orientate themselves in relation to environmental conditions to minimise effects of the weather (Gonyou & Stricklin 1981).

Two measures of body temperature were used in this study. Core body temperature was measured using vaginal temperature loggers. Infrared thermography, previously used in cattle (Zähner *et al* 2004; Webster *et al* 2008), was used to measure the skin temperature. Cows that had been exposed to rain, and rain in combination with wind, had lower skin temperatures compared to the other treatments. Similar results were demonstrated by Webster *et al* (2008) who found that skin temperature in cows exposed to windy and rainy conditions was 5°C lower than in cows housed indoors. Wind and rain increases the heat loss to the environment by reducing the insulative properties of the coat (Webster 1974; Ames & Insley 1975) and it is possible that the cows responded to the rain and wind by shunting blood away from peripheral tissues in order to thermoregulate. Indeed, the results indicate that all cows were able to maintain their core body temperature during the 22 h, regardless of weather. Minimum air temperature and windchill factor were relatively mild in the present study (1 and –2°C, respectively) and the cows were always able to use the shelter for protection. Therefore, we did not see changes in core body temperature that have previously been found in cows exposed to wind and rain without shelter, including lower minimum body temperature (38.0 vs 37.6°C for thin cows, for animals kept indoors vs outdoors, respectively; Tucker *et al* 2007). Finally, cattle, as endotherms, will do their best to defend core temperature, thus skin temperature or temperature of any peripheral tissue may be a more sensitive and, therefore, a promising way to assess the response to winter weather.

In addition to understanding the behavioural and physiological short-term response to winter weather, this study aimed to understand the relative importance of wind and rain for cattle. Wind exacerbated the response to simulated rain in terms of both feed intake and feeding rate. Exposure to wind alone did not considerably change behaviour or physiology, except for a minor reduction in feed consumption. One possible explanation for this is that exposure to wind only at mild air temperatures does not increase the metabolic heat production to the same extent as exposure to wet conditions (Degen & Young 1993) or to wind in combination with cold weather (Houseal & Olson 1995). Indeed, high wind velocities in combination with low temperature have been shown to increase lying times (Redbo *et al* 2001). Thus, protection from wind may become important in more extreme conditions. In contrast, protection from rain is likely to be important even in relatively mild temperatures.

Animal welfare implications and conclusion

The response of dairy cattle to short-term exposure to wet conditions was characterised by a clear decline in lying time, feed intake and skin temperature. Wind exaggerated the effect of rain on feeding behaviour, but wind alone had little effect on behaviour or physiology. These results indicate that protection from both rain and the combination of rain and wind is likely to be important for animal welfare, but future work is needed to understand when and how to best provide this type of protection to pastured dairy cattle.

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References

Adams DC, Nelsen TC, Reynolds WL and Knapp BW 1986 Winter grazing activity and forage intake of range cows in the northern great plains. *Journal of Animal Science 62*: 1240-1246

AFRC 1993 *Energy and Protein Requirements of Ruminants. An advisory manual prepared by the AFRC Technical Committee on Responses to Nutrients.* CAB International: Wallingford, UK

Ames DR and Insley LW 1975 Wind-chill effect for cattle and sheep. *Journal of Animal Science 40*: 161-165

Bergen RD, Kennedy AD and Christopherson RJ 2001 Effects of intermittent cold exposure varying in intensity on core body temperature and resting heat production of beef cattle. *Canadian Journal of Animal Science 81*: 459-465

Degen AA and Young BA 1993 Rate of metabolic heat production and rectal temperature of steers exposed to simulated mud and rain conditions. *Canadian Journal of Animal Science 73*: 207-210

Environment Canada 2006 Wind Chill Program. http://www.msc.ec.gc.ca/education/windchill (accessed 1 July 2006)

Fisher AD, Stewart M, Verkerk GA, Morrow CJ and Matthews LR 2003 The effects of surface type on lying behaviour and stress responses of dairy cows during periodic weather-induced removal from pasture. *Applied Animal Behaviour Science 81*: 1-11

Fisher AD, Verkerk GA, Morrow CJ and Matthews LR 2002 The effects of feed restriction and lying deprivation on pituitary-adrenal axis regulation in lactating cows. *Livestock Production Science 73*: 255-263

Fregonesi JA, Veira DM, von Keyserlingk MAG and Weary DM 2007 Effects of bedding quality on lying behavior of dairy cows. *Journal of Dairy Science 90*: 5468-5472

Gonyou HW and Stricklin WR 1981 Orientation of feedlot bulls with respect to the sun during periods of high solar radiation in winter. *Canadian Journal of Animal Science 61*: 809-816

Gonyou HW, Christopherson RJ and Young BA 1979 Effects of cold temperature and winter conditions on some aspects of behaviour of feedlot cattle. *Applied Animal Ethology 5*: 113-124

Hidiroglou M and Lessard JR 1971 Some effects of fluctuating low ambient temperatures on beef cattle. *Canadian Journal of Animal Science 51*: 111-120

Houseal GA and Olson BE 1995 Cattle use of microclimates on a northern latitude winter range. *Canadian Journal of Animal Science 75*: 501-507

Jensen MB, Pedersen LJ and Munksgaard L 2005 The effect of reward duration on demand functions for rest in dairy heifers and lying requirements as measured by demand functions. *Applied Animal Behaviour Science 90*: 207-217

Kennedy AD, Bergen RD, Christopherson RJ, Glover ND and Small JA 2005 Effect of once daily 5-h or 10-h cold-exposures on body temperature and resting heat production of beef cattle. *Canadian Journal of Animal Science 85*: 177-183

Kenward MG and Roger JH 1997 Small sample inference for fixed effects from restricted maximum likelihood. *Biometrics 53*: 983-997

Ketelaar-de Lauwere CC, Ipema AH, van Ouwerkerk ENJ, Hendriks MMWB, Metz JHM, Noordhuizen JPTM and Schouten WGP 1999 Voluntary automatic milking in combination with grazing of dairy cows: milking frequency and effects on behaviour. *Applied Animal Behaviour Science 64*: 91-109

Krohn CC and Munksgaard L 1993 Behaviour of dairy cows kept in extensive (loose housing/pasture) or intensive (tie stall) environments. II. lying and lying-down behaviour. *Applied Animal Behaviour Science 37*: 1-16

Malechek JC and Smith BM 1976 Behavior of range cows in response to winter weather. *Journal of Range Management 29*: 9-12

Martin P and Bateson P 1993 *Measuring Behaviour. An Introductory Guide, 2nd Edition*. Cambridge University Press: Cambridge, UK

McCafferty DJ 2007 The value of infrared thermography for research in mammals: previous applications and future directions. *Mammal Review 37*: 207-223

Muller CJC, Botha JA and Smith WA 1996 Effect of confinement area on production, physiological parameters and behaviour of Friesian cows during winter in a temperate climate. *South African Journal of Animal Science 26*: 1-5

Munkgsgaard L, Ingvartsen KL, Pedersen LJ and Nielsen VKM 1999 Deprivation of lying down affects behaviour and pituitary-adrenal axis responses in young bulls. *Acta Agriculturae Scandinavica Section A, Animal Science 49*: 172-178

Munkgsgaard L, Jensen MB, Pedersen LJ, Hansen SW and Matthews L 2005 Quantifying behavioural priorities: effects of time constraints on behaviour of dairy cows, *Bos taurus*. *Applied Animal Behaviour Science 92*: 3-14

Olson BE and Wallander RT 2002 Influence of winter weather and shelter on activity patterns of beef cows. *Canadian Journal of Animal Science 82*: 491-501

Prescott ML, Havstad KM, Olson-Rutz KM, Ayers EL and Petersen MK 1994 Grazing behavior of free-ranging beef cows to initial and prolonged exposure to fluctuating thermal environments. *Applied Animal Behaviour Science 39*: 103-113

Redbo I, Ehrlemark A and Redbo-Torstensson P 2001 Behavioural responses to climatic demands of dairy heifers housed outdoors. *Canadian Journal of Animal Science 81*: 9-15

Self HL, Summers CE, Roth F, Hull D and Zmolek WG 1963 Environmental influence on rate and economy of gains in yearling steers. *Journal of Animal Science 22*: 1111-1112 (Abstract)

Senft RL, Rittenhouse LR and Woodmansee RG 1985 Factors influencing selection of resting sites by cattle on shortgrass steppe. *Journal of Range Management 38*: 295-299

Tucker CB, Rogers AR, Verkerk GA, Kendall PE, Webster JR and Matthews LR 2007 Effects of shelter and body condition on the behaviour and physiology of dairy cattle in winter. *Applied Animal Behaviour Science 105*: 1-13

Tucker CB, Weary DM, von Keyserlingk MAG and Beauchemin KA 2009 Cow comfort in tie-stalls: Increased depth of shavings or straw bedding increases lying time. *Journal of Dairy Science 92*: 2684-2690

Vandenheede M, Nicks B, Shehi R, Canart B, Dufrasne I, Biston R and Lecomte P 1995 Use of shelter by grazing fattening bulls: effect of climatic factors. *Animal Science 60*: 81-85

Webster AJF 1974 Heat loss from cattle with particular emphasis on the effects of cold. In: Monteith JL and Mount LE (eds) *Heat Loss From Animals and Man. Assessment and Control* pp 205-231. Butterworths: London, UK

Webster JR, Stewart M, Rogers AR and Verkerk GA 2008 Assessment of welfare from physiological and behavioural responses of New Zealand dairy cows exposed to cold and wet conditions. *Animal Welfare 17*: 19-26

Zähner M, Schrader L, Hauser R, Keck M, Langhans W and Wechsler B 2004 The influence of climatic conditions on physiological and behavioural parameters in dairy cows kept in open stables. *Animal Science 78*: 139-147