Dairy cows use and prefer feed bunks fitted with sprinklers

Jennifer M. Chen,* Karin E. Schütz,† and Cassandra B. Tucker*¹

*Department of Animal Science, University of California, Davis 95616

†AgResearch Ltd., Hamilton 3240, New Zealand

ABSTRACT

Sprinklers reduce heat load in cattle, but elicit variable behavioral responses: cows readily use water in some studies, but in others either avoid it or show no preference. Nevertheless, on US dairies, a common way to cool cows is with nozzles mounted over the feed bunk that intermittently spray (i.e., 5 min on, 10 min off, as in this study) animals' backs while they feed. The objectives of this study were to determine how this type of sprinkler system affects behavior (single-treatment phase), and to assess preferences when cows were allowed to choose between feed bunks with or without sprinklers (choice phase). Data were collected 24 h/d for lactating Holsteins tested in groups of 3 cows ($n = 8$ groups) in warm ambient conditions [air temperature (mean $\pm$ standard deviation): 24-h average = $24.5 \pm 2.5^\circ\text{C}$, maximum = $36.0 \pm 3.5^\circ\text{C}$]. In the single-treatment phase, cows were fed from shaded bunks with or without sprinklers for 2 d/treatment, with order of exposure balanced in a crossover design. When sprinklers were present, cows spent more time at the bunk, both feeding [sprinkler vs. no sprinkler: 3.5 vs. 2.5 h/24 h, standard error (SE) = 0.12 h] and standing without feeding (4.3 vs. 2.3 h/24 h, SE = 0.32 h) than when no sprinklers were present. Sprinklers lowered the average 24-h core temperature (38.8 vs. 39.2°C , SE = 0.08°C), particularly on warmer days. Water cooling also mitigated the effects of weather on feeding time, which decreased with increasing heat load (air temperature and temperature-humidity index) when cows did not have sprinklers, but was unchanged when sprinklers were provided. In the choice phase, feed was provided ad libitum in both treatments for 5 d and preference was assessed. All groups preferred the feed bunk with sprinklers (78 vs. 22% of time spent near both feed bunks, SE = 3.9%), and the magnitude of this preference increased linearly with heat load. In both phases of the study, cows protected their heads from direct spray when head position was elective (i.e.,

standing without feeding): cows were more likely to put their heads through the head gates when the sprinklers were on than off (single-treatment phase: 78 vs. 59%, respectively, of time spent standing without feeding, SE = 2.8%; choice phase: 71 vs. 52%, SE = 2.0%). In conclusion, although cows avoided wetting their heads, this is the first study to demonstrate that cattle readily use and clearly prefer sprinklers mounted above the feed bunk, possibly due to the cooling provided by this resource.

Key words: heat load, sprinkler cooling, behavior

INTRODUCTION

Environmental conditions such as high air temperature and exposure to solar radiation can cause cattle to gain heat, affecting their physiology and behavior. Cows limit heat gain by seeking shade (Tucker et al., 2008; Schütz et al., 2011), lower heat production by reducing activity levels and feed intake (Ominski et al., 2002), and dissipate heat by sweating and panting to promote evaporation (Gebremedhin et al., 2008). In warm weather, cows also spend less time lying (Mader et al., 1997; Tucker et al., 2008; Schütz et al., 2010), which may expose more surface area for convective heat loss or reduce heat conducted from a warm lying surface. When these strategies are ineffective, accumulated heat load can increase body temperature and cause decreases in milk yield (Wheelock et al., 2010) and fertility (De Rensis and Scaramuzzi, 2003) and in some cases, result in mortality (Stull et al., 2008; Vitali et al., 2009).

To manage heat load, dairy producers can provide shade, fans, misters, sprinklers, or a combination of these resources: 94% of US dairies use at least one of these sources of heat abatement (USDA, 2010). Compared with shade alone, applying water more efficiently lowers body temperature (Igono et al., 1987; Kendall et al., 2007) and respiration rate (Mitlöhner et al., 2001), and can increase feed intake and milk yield in hot conditions (Keister et al., 2002). Because of their effectiveness, sprinklers are widely used on larger dairy operations in the United States (62% of lactating herds of 500 or more; USDA, 2010).

Received October 17, 2012.

Accepted April 30, 2013.

¹Corresponding author: cbtucker@ucdavis.edu

Although studies have shown sprinklers to be effective for reducing heat load in cattle, less is understood about the behavioral responses of cows to water cooling, which range from extensive voluntary use of showers (Legrand et al., 2011) to anecdotal evidence of spray avoidance (Marcillac-Embertson et al., 2009). In studies evaluating preferences for sprinklers, results have varied, with cattle preferring shade over sprinklers (Schütz et al., 2011), or preferring sprinklers primarily when lower volumes of water are applied, or only in warmer weather (Parola et al., 2012).

Some of the variation across studies may be explained by weather conditions. On cooler days ($<23^{\circ}\text{C}$) body temperature increased after spray treatments, perhaps due to vasoconstriction to minimize heat loss associated with sprinkling under those conditions (Kendall et al., 2007). This may explain why as air temperature decreases, cattle spend less time voluntarily using showers (Legrand et al., 2011) and their preference for sprinklers becomes less apparent (Parola et al., 2012), as well as why no preference for sprinklers was seen in a study conducted in milder weather [i.e., 18°C average 24-h air temperature in Schütz et al. (2011)].

Another behavioral response to spray that varies across studies is voluntary exposure of the head to water. When cows have full control over water application, they wet the head in addition to the body (Legrand et al., 2011), but when confined in a testing situation, they lower their heads (Kendall et al., 2007) or keep them out of the spray radius (Schütz et al., 2011). Similarly, cows lower their heads when exposed to sprinklers and fans in winter (Tucker et al., 2007). Such reactions could indicate that, depending on how much control cows have over the parts of the body that are sprayed, they may avoid wetting the head.

In US dairies, a common water delivery method that allows cows some degree of control over how they are sprayed is with sprinkler nozzles mounted over the feed bunk. Whereas the preference of steers for sprinklers above the feed bunk has been studied (Parola et al., 2012), only limited information is available on the time budgets of dairy cattle provided with this type of water resource (Perissinotto et al., 2006, in an unreplicated study). Thus, the objective of the current study was to characterize the behavioral responses of lactating dairy cows to sprinklers mounted over the feed bunk. This was addressed in 2 experimental phases. In the first, cows were given access to a single feed bunk, with or without sprinklers, and time spent near the feed bunk and body temperature were measured. In the second phase, cows were given access to both treatments, and preference was assessed. For both experimental phases, head position and the relationship between behavior and weather were also examined. It was predicted that

cows would spend more time near the feed bunk with sprinklers than the one without, and that they would prefer the sprinkler treatment when given a choice. Additionally, both usage and the magnitude of preference were expected to be higher overall with increasing heat load. The final prediction was that cows would avoid directly wetting their heads.

MATERIALS AND METHODS

Animals and Housing

The study was conducted during the summer and early fall (June to October, 2009) at the University of California dairy facility (Davis), with all procedures approved by the University of California Davis Institutional Animal Care and Use Committee (IACUC). Twenty-four lactating Holstein-Friesian dairy cows were divided into groups of 3 animals ($n = 8$ groups). The average BW was 681 ± 83 kg, BCS was 3.2 ± 0.4 on a 5-point scale (Ferguson et al., 1994), parity was 2 ± 0.9 , DIM was 98 ± 19 , and daily milk yield was 21 ± 3.6 kg (all preceding values: mean $\pm$ SD). Ten of the cows were pregnant, and these animals were balanced as evenly as possible across groups.

Each group of cows was acclimated to the pen (Figure 1) for 3 d. The pen included a bedded area (15-cm deep rice hull pack), shaded with a 3.0-m-high corrugated galvanized steel roof, with a fan (36-DMCH; Future Products Corp., Mosinee, WI) suspended from the shade structure and angled slightly downward. Twice daily at 0400 and 1600 h, cows were milked and fed TMR formulated using the PC Dairy system (Bath and Strasser, 1990) to NRC requirements (NRC, 1989). The TMR comprised 37% alfalfa hay, 36% grain mix, 12% almond hulls, 10% whole cotton seed, 3% mineral mix, and 2% soybean meal on a DM basis ($\text{DM} = 87 \pm 2.3\%$, mean $\pm$ SD), and was available to cows ad libitum.

Treatments

The 2 feed bunks (5 head gates each) were separated with plywood to prevent water drift, and covered with a 2.5-m-deep solid shade. Each feed bunk had 3 sprinkler nozzles (1/8K-5 FloodJet wide-angle flat-spray tips, 592- μm median droplet size; TeeJet Technologies, Springfield, IL), spaced 1 m apart; these were mounted 2.1 m high and angled to avoid wetting the feed, creating a spray radius extending approximately 3.8 m from the feed bunk.

At any given time, only a single feed bunk had active sprinklers (sprinkler treatment), whereas the other was dry (no-sprinkler treatment). Spray activation in the sprinkler treatment was controlled by a cycle timer

Figure 1. Configuration of pen (not to scale) that housed groups of 3 dairy cows. Both the bedded and feeding areas were shaded by solid roofing (shaded area). Plywood (hatched area) divided the feeding area into 2 feed bunks, each with 3 overhead sprinkler nozzles (*), with a spray radius extending 3.8 m.

(custom constructed by Chipponeri Electric Inc., Hilmar, CA) that triggered a solenoid (Meter-Man; Komelon USA Corp., Waukesha, WI). Sprinklers delivered 5 min of continuous spray, followed by 10 min without, 24 h/d. The 8 groups of cattle were tested sequentially, with the sprinklers rotated between sides of the pen between each group. Following acclimation (d 1 to 3), cows were fed from a single feed bunk (with or without sprinklers) for 2 d/treatment, with the order of exposure balanced across groups (single-treatment phase, d 4 to 7). Cows were then given unrestricted access to both treatment areas, with enough feed provided at both feed bunks such that the cows could obtain their entire daily feed requirement from a single bunk (choice phase, d 8 to 12).

During the choice phase, flow rate and water temperature (Fisherbrand traceable digital thermometer; Fisher Inc., Pittsburgh, PA) were measured hourly (from 1000 to 1800 h). The average water output for each nozzle was 3.3 ± 0.2 L/min (mean $\pm$ SD) at 207 kPa (30 psi), with an average water temperature of $26.2 \pm 2.1^\circ\text{C}$ (mean $\pm$ SD). Feed samples for DM analysis were collected from the original feed twice daily before each feeding, and from the sprinkler treatment every 2 h from 1000 to 1800 h.

Climatic Measures

A portable weather station (NovaLynx Corp., Auburn, CA) at the experimental site recorded air temperature (T , $^\circ\text{C}$), relative humidity (**RH**, %), wind speed (**WS**, km/h), rainfall (mm), black globe temperature (**BGT**, $^\circ\text{C}$), and solar radiation (W/m^2) at 5-min intervals. Along with air temperature, temperature-humidity index (**THI**) and heat-load index (**HLI**) were used as indicators of heat load, and were calculated according to the following equations developed by Berry et al. (1964) and Gaughan et al. (2008), respectively:

$$\text{THI} = (1.8 \times T + 32) - [(0.55 - 0.0055 \times \text{RH}) \times (1.8 \times T - 26)];$$

$$\begin{aligned} \text{HLI} = & \text{if } [\text{BGT} > 25, 8.62 + (0.38 \times \text{RH}) \\ & + (1.55 \times \text{BGT}) + \exp(-\text{WS} + 2.4) - (0.5 \times \text{WS}), \\ & 10.66 + (0.28 \times \text{RH}) + (1.3 \times \text{BGT}) - \text{WS}]. \end{aligned}$$

Additionally, the microclimate in the feed bunk areas was measured for 24 h after the choice phase for each group of cows, to prevent animals from damaging the equipment. Air temperature and RH were recorded in 30-s intervals by loggers (U23-002 HOBO external temperature and RH logger with RS3 solar radiation shields; Onset Computer Corp., Pocasset, MA) hung from the shade structure in front of the feed bunk at 1.1 m high.

Physiological Measures

Internal body temperature was recorded at 5-min intervals using a microprocessor-controlled Minilog12-TX data logger (accuracy: $\pm 0.1^\circ\text{C}$, resolution: $\pm 0.015^\circ\text{C}$, 1.6-cm diameter $\times$ 7-cm length; Vemco Ltd., Shad Bay, Nova Scotia, Canada) attached to a shortened, hormone-free controlled internal drug release (CIDR) insert (InterAg, Hamilton, New Zealand) with a clevis rod end. These loggers were inserted into the vaginal cavity of all cows on d 3 after entering the pens and were removed the day data collection ended (d 12). Logger data were screened for transient, atypical valleys, and in the final analysis, values below 37.6°C were excluded.

During the 5 d of data collection in the choice phase, 3 trained observers recorded respiration rate hourly from 1000 to 1800 h by counting the flank movements of each animal for 30 s; these counts were converted to breaths/min to facilitate comparison with other studies. Interobserver reliability for pairs of observers

ranged from 0.972 to 0.975, as calculated with Pearson correlation.

Behavioral Measures

The pen was recorded continuously 24 h/d with video cameras (WV-BP334 black-and-white CCTV video cameras; Panasonic Corp. of North America, Secaucus, NJ) with 13VG2812ASII lenses (Tamron, Commack, NY) positioned as follows: 5 cameras (3 at 2.4 m high and 2 at 3.4 m high) and 2 red lights (2.4 m high) recorded the treatment areas and the unshaded portion of the pen, and 4 cameras (2.4 m high) and 2 red lights (3.0 m high) were positioned above the bedded area. The cameras were connected to a digital video recorder with a GV-1120/1240/1480 Combo card (USA Vision Systems Inc., Irvine, CA) and digital surveillance software (IPD-NVR16; ClearVision Inc., Wheeling, IL). All cameras were set to record at medium quality and 15 frames/s. Individual cows were identified by markings made with hair dye (L'Image MaxiBlonde and Nice 'n Easy Natural Black #122; Clairol, Stamford, CT).

Eight observers (4 in each phase of the study) scored the video recordings. Each cow was observed using instantaneous scan sampling (Martin and Bateson, 1993) in 5-min intervals 24 h/d, with days beginning at 0400 h. Location was demarcated by white painted lines in 2 portions of the pen: the bedded area and within 3.8 m of the feed bunks. A cow was considered to be within either of these locations if at least one of its front hooves was on or over these lines. In addition to location, cow behavior was also recorded; observers determined whether each cow was lying (flank in contact with the ground) or standing. If the cow was near (within 3.8 m) the feed bunk, observers scored head position (ears and poll through the head gate or not) and whether the cow was feeding or standing without feeding. Feeding behavior was defined as when a cow had its head through the head gate, lowered, and actively manipulating the feed. In the single-treatment phase, observers watched 5 s of continuous video at 5-min intervals to assess feeding; this was extended to 10 s for the choice phase, as using only 5 s of video may have underestimated feeding behavior by $10.8 \pm 3.4\%$ (mean $\pm$ SD) compared with using 10 s in a subset of data. Interobserver reliability for each pair of observers was determined by the kappa coefficient of concordance (Hollenbeck, 1978; Martin and Bateson, 1993). For each behavior, the ranges of reliability scores for pairs of observers in the single-treatment phase were as follows: lying: $\kappa = 0.990$ to 1.0 , head position: $\kappa = 0.988$ to 1.0 , feeding: $\kappa = 0.815$ to 0.860 , and location: $\kappa = 0.988$ to 0.995 . For the choice phase, the ranges were as follows: lying: $\kappa = 0.997$ to 1.0 , head position: $\kappa = 0.981$ to

0.996 , feeding: $\kappa = 0.899$ to 0.932 , and location: $\kappa = 0.981$ to 0.991 .

Statistical Analysis

Statistical analyses are summarized in Table 1; unless specified otherwise, all analyses were conducted using SAS software (SAS Institute, 2011), with group as the experimental unit ($n = 8$).

Single-Treatment Phase. Dependent variables were averaged across days and behavioral responses were converted to hours per 24 h per cow; for selected variables, analyses were repeated separately for each hour of the day, or for the 5- and 10-min intervals in which the sprinklers were on and off, respectively.

Choice Phase. Overall preference for the sprinkler treatment was measured as percentage time spent near the sprinkler feed bunk compared with total time spent near both feed bunks, for either 24-h periods or the entire 5-d testing period; preference for the sprinkler treatment for feeding and for standing without feeding were determined in the same manner. To examine the consistency of preference across individual cows, a binomial test was also conducted for the number of cows with an overall preference for sprinklers over 50% ($n = 24$; Stat Trek, 2012).

RESULTS

Environmental Conditions

Weather. Climatic data for both phases of the experiment are summarized in Table 2; in the single-treatment phase, weather conditions were comparable between treatments ($P > 0.57$ for air temperature, THI, and HLI).

Feed Bunk Microclimate. Air temperature was lower and RH was higher in the sprinkler treatment than in the no-sprinkler treatment [air temperature: 23.5 vs. 25.7°C , respectively (SE = 0.09°C , $P < 0.001$); RH: 50.0 vs. 42.3% , respectively (SE = 0.39% , $P < 0.001$)]. Furthermore, when the spray was on in the sprinkler treatment, the air temperature was slightly lower and RH was higher than when the water was off [air temperature: 23.3 vs. 23.6°C , respectively (SE = 0.07°C , $P = 0.026$); RH: 53.3 vs. 48.4% , respectively (SE = 0.45% , $P = 0.004$)]. Dry matter for the feed in the sprinkler feed bunk was $80.7 \pm 2.8\%$ (mean $\pm$ SD).

Body Temperature and Respiration Rate

In the single-treatment phase, body temperature was lower from 1100 to 2100 h daily when cows had access to sprinklers, compared with when they did not ($P < 0.025$; Figure 2). Consequently, in the sprinkler

Table 1. Statistical models¹ used to evaluate dairy cattle behavior when fed from a single feed bunk with or without sprinklers for 2 d each (single-treatment phase), or given access to both treatments for 5 d (choice phase)

Question and dependent variable(s)	Procedure	Model (df)	Error df
Single-treatment phase			
Differences in weather ² between treatments	GLM	Group (7), day (3), treatment (1)	20
Differences in behavior ³ and body temperature ⁴ between treatments	GLM	Group (7), treatment (1), order (1)	6
Effect of weather on behavior and body temperature, depending on treatment	GLM	Group (7), day (3), treatment (1), weather (1), weather × treatment (1)	18
Differences in head-wetting ⁵ when spray was on or off	GLM	Group (7), spray on/off (1)	7
Choice phase			
Preference ⁶ for sprinkler treatment	UNIVARIATE	1-Sample <i>t</i> -test	8
Differences in preference when spray was on or off	GLM	Group (7), spray on/off (1)	7
Relationship between preference and weather ⁷	GLM	Group (7), weather (3)	29
Differences in head-wetting when spray was on or off	GLM	Group (7), spray on/off (1)	7
Feed bunk microclimate			
Differences in air temperature and RH ⁸ between treatments	GLM	Group (7), treatment (1)	7
Differences in air temperature and RH when spray was on or off	GLM	Group (7), spray on/off (1)	7

¹All analyses were performed using SAS software (SAS Institute, 2011).

²Weather variables assessed were air temperature, temperature-humidity index, and heat-load index.

³Behaviors included time spent lying, standing in the bedded area of the pen, and near (within 3.8 m) the feed bunk overall, feeding, and standing without feeding.

⁴Measures of body temperature were 24-h average, maximum, and minimum body temperature.

⁵To assess whether cows avoided wetting their heads, the percentage of time spent with the head through the head gates when standing (without feeding) near the feed bunk was compared between intervals when the spray was on versus off.

⁶Preference was measured as the percentage of time spent near the sprinkler treatment divided by total time spent near both feed bunks for the 5-d testing period. Percentage preference for the sprinkler treatment overall, for feeding, and for standing was compared with chance (50%).

⁷For each weather variable, linear, quadratic, and cubic terms were included. Preference was calculated for each group of cows for 24-h periods.

⁸RH = relative humidity.

treatment, 24-h average body temperature was lower than in the no-sprinkler treatment (38.8 vs. 39.2°C, respectively; SE = 0.08°C, $P = 0.011$) as was average 24-h maximum body temperature (39.6 vs. 40.2°C, respectively; SE = 0.08°C, $P = 0.002$). A trend was observed for average 24-h minimum body temperature to be lower in the sprinkler treatment as well (38.1 vs. 38.3°C, respectively; SE = 0.1°C, $P < 0.057$).

Table 2. Summary of daily ambient conditions during 72 experimental days from June to October 2009^{1,2}

Weather variable	24-h average			24-h maximum		
	Mean	SD	Range	Mean	SD	Range
Single-treatment phase ³						
Air temperature (°C)	24.5	2.5	20.1–28.9	36.0	3.5	28.6–42.1
Relative humidity (%)	45.0	7.6	30.2–60.7	77.4	6.2	64.3–87.1
Solar radiation (W/m ²)	278	49.2	203–352	853	83.4	721–981
Black globe temperature (°C)	29.1	2.4	24.9–34.2	48.3	4.0	40.8–55.9
Wind speed (km/h)	0.8	0.3	0.4–1.7	3.6	0.5	1.2–3.6
Rainfall (mm)	0	0	0–0	0	0	0–0
THI	69	2.5	65–74	79	2.8	73–85
HLI	68	3.4	61–76	96	5.6	85–106
Choice phase						
Air temperature (°C)	23.7	2.9	18.3–32.0	34.4	4.1	24.7–43.7
Relative humidity (%)	48.0	8.5	26.2–59.4	77.4	9.3	46.5–89.2
Solar radiation (W/m ²)	266	56.1	122–342	851	92.2	703–1,098
Black globe temperature (°C)	28.0	3.3	20.2–36.9	46.6	4.9	33.3–57.1
Wind speed (km/h)	1.0	0.3	0.5–2.5	2.2	0.6	1.3–4.4
Rainfall (mm)	0	0	0–0	0	0	0–0
THI	69	3.1	62–77	78	3.6	68–86
HLI	67	6.4	45–79	94	8.1	67–107

¹Each group of 3 cows ($n = 8$ groups) was fed from a single feed bunk with or without sprinklers for 2 d each (single-treatment phase), and then given unrestricted access to both feed bunks for 5 d (choice phase)

²Means, SD, and range (minimum to maximum of mean daily values) are given for 24 h.

³In the single-treatment phase, weather conditions were comparable between treatments [$P > 0.57$ for air temperature, temperature-humidity index (THI), and heat-load index (HLI)] and, thus, all environmental conditions are combined.

Figure 2. Differences (shaded bars) between time spent near a feed bunk with or without overhead sprinklers (difference = sprinkler – no sprinkler); dashed (sprinkler) and solid (no sprinkler) lines show body temperature over time. Cows were milked at 0400 and 1600 h daily. Group averages ($n = 8$ groups) for the 2 d/treatment are shown. Error bars represent SE. † $P < 0.10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Sprinklers modulated the relationship between body temperature and climatic conditions (interactions between treatment and weather, for both 24-h average and maximum body temperature: air temperature and THI: $P < 0.002$; but not for HLI: $P > 0.15$). In the no-sprinkler treatment, both 24-h average and maximum body temperature increased with ambient heat load, whereas when sprinklers were provided, this pattern was much less marked (Figure 3A). In the choice phase, 24-h average body temperature was $38.8 \pm 0.13^\circ\text{C}$ (mean $\pm$ SD), and the average respiration rate from 1000 to 1800 h was 49 ± 7.1 breaths/min (mean $\pm$ SD).

Behavioral Responses

In the single-treatment phase, cows were observed near the feed bunk 1.6 times more often when sprinklers were available than when they were not, regardless of whether the water was on or off (Figure 4). The increase in time spent at the feed bunk occurred primarily during the daytime (1000 to 1400 h) and again later in the day (1800 and 2000 h; $P < 0.047$; Figure 2). In the choice phase, cows preferred the sprinkler treatment both when feeding (69 vs. 31%; SE = 5.4%, $P = 0.009$) and standing without feeding (84 vs. 16%; SE = 2.7%, $P < 0.001$). This preference was apparent whether the water was on or off (77 vs. 78%, respectively, of time spent near both feed bunks; SE = 0.4%, $P = 0.185$), and was most marked from 0900 to 1800 h ($P < 0.004$; Figure 5). The preference for sprinklers was consistent across individuals, with all 24 cows showing an overall preference for the sprinkler treatment over 50% ($P < 0.001$; Figure 6).

Sprinklers moderated the relationships between environmental conditions and cattle behavior at the feed bunk (interactions between treatment and weather, for both feeding and overall time at the feed bunk: air temperature and THI: $P < 0.001$; but not for HLI: $P > 0.084$). When cows did not have access to sprinklers, feeding time decreased as heat load increased (Figure 3B). In contrast, weather did not affect feeding time when cows had access to either a single feed bunk with sprinklers, or to both feed bunks in the choice phase ($P > 0.572$ for linear relationships with all weather variables). Also, when sprinklers were available in the single-treatment phase, cows spent more time near the feed bunk overall as heat load increased, but this pattern was not apparent in the no-sprinkler treatment (Figure 3C). In the choice phase, the magnitude of preference for sprinklers increased with heat load: a linear relationship existed between preference and ambient conditions (THI and air temperature: $P < 0.008$; HLI: $P = 0.071$; all quadratic and cubic relationships: $P > 0.15$); however, the preference for sprinklers was apparent even in the coolest conditions experienced during the study (18.3°C ; Figure 7).

Environmental conditions also affected lying and standing behavior. In both phases of the study, lying time decreased as heat load increased (choice phase: linear relationships with all weather variables: $P < 0.002$; single-treatment phase: air temperature and THI: $P < 0.004$). In the single-treatment phase, the amount of time cows spent lying did not differ between treatments (sprinkler vs. no sprinkler: 11.3 vs. 11.0 h/24 h; SE = 0.26 h, $P = 0.46$), and no interactions were observed between weather conditions and treatment ($P > 0.22$).

Figure 3. Relationship between ambient temperature and (A) 24-h average body temperature, (B) time spent feeding, and (C) overall time near the feed bunk, when 8 groups of dairy cattle had access to a feed bunk either with (open squares) or without (solid squares) overhead sprinklers; points represent group averages for 24-h periods (2 d/treatment).

Differences were observed, however, in where the cows stood in the pen: when no sprinklers were present, cows spent more time standing in the shaded bedded area of the pen (no sprinkler vs. sprinkler: 4.7 vs. 2.6 h/24 h; SE = 0.26 h, $P = 0.001$), but the addition of sprinklers over the feed bunk almost doubled the time that cows spent standing at the bunk without feeding compared with when no sprinklers were present (Figure 4B). Likewise, when cows had access to both feed bunks in the choice phase, they preferred the sprinkler treatment when standing without feeding (84 vs. 16%; SE = 2.7%, $P < 0.001$).

When cows were standing without feeding at the bunk with sprinklers, they put their heads past the head gates, thus protecting their heads from spray, more when the sprinklers were on; this pattern was evident in both the single-treatment (on vs. off: 78 vs. 59% of time spent standing without feeding; SE = 2.8%, $P = 0.002$) and choice phases (71 vs. 52%; SE = 2.0%, $P < 0.001$).

DISCUSSION

When cows had access to a single feed bunk, they spent more time both feeding and standing near the feed bunk in the sprinkler treatment, regardless of whether the spray was on or off. The difference between treatments in time spent at the feed bunk was most apparent during the midday hours. Body temperature was also lower during this time and remained lower well into the evening and across weather conditions, compared with when no sprinklers were at the feed bunk. Without sprinklers, feeding time decreased as ambient heat load increased, but provision of sprinklers eliminated this relationship: feeding time was maintained, even in the warmest conditions. Consistent with these benefits of sprinklers, when cows were allowed to choose between feed bunks with and without this resource, they preferred to spend time at feed bunks with water cooling. Although this preference was apparent even in the coolest conditions, the magnitude of preference increased with ambient heat load.

In the single-treatment phase, average and maximum 24-h body temperature was lower in the sprinkler treatment than in the no-sprinkler treatment, despite comparable weather conditions. This reduction in body temperature was likely attributable to the 1.6-fold increase in time spent at the feed bunk with sprinklers, which occurred mainly during the daytime (1000 to 1400 h). Consistent with other studies, when no sprinklers were available, body temperature showed a diurnal pattern, with peak evening values more than 1°C higher than early morning measurements (e.g., Araki et al., 1985; Gaughan et al., 2004; Kendall et al., 2007). In contrast, this pattern was flattened in the sprinkler treatment,

Figure 4. Average time each dairy cow spent (A) feeding and (B) standing without feeding near a feed bunk with or without overhead sprinklers. Sprinklers were activated in cycles of 5-min on (shaded areas) and 10-min off (areas with diagonal lines), 24 h/d; equivalent time intervals were compared between the sprinkler and no-sprinkler treatments. Error bars represent SE ($n = 8$ groups).

with body temperature lower than in the no-sprinkler treatment from 1100 to 2100 h. Other studies have similarly found that sprinklers help reduce the diurnal rise in body temperature late in the day. In studies with water cooling administered in a discrete session,

body temperature remained lower for several hours afterward (Araki et al., 1985; Flamenbaum et al., 1986; Kendall et al., 2007). Also, cows that could activate a shower showed 85% of daily voluntary usage of water from 1000 to 1900 h, and body temperature was 0.2°C

Figure 5. Air temperature (line) and preference (shaded bars) by hour when dairy cattle were given the choice between feed bunks with and without sprinklers for 5 d (preference is expressed as the percentage of time spent near the sprinkler treatment divided by total time spent near both feed bunks). † $P < 0.10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Figure 6. Average preference for 8 groups of 3 dairy cows, each given the choice between feed bunks with or without sprinklers for 5 d, with individual preferences (x) superimposed (+ indicates overlapping individuals). Preference is expressed as the percentage of time spent near the sprinkler treatment divided by total time spent near both feed bunks; dashed line marks 50% (expected by chance).

lower than controls from 1800 to 2100 h (Legrand et al., 2011). Our study is the first to demonstrate that cows with access to feed bunk sprinklers, as commonly found in production settings, have lower body temperature following the peak in usage. Similarly, the provision of sprinklers in this study modulated the effect of climatic

conditions on body temperature: when no sprinklers were present, average and maximum 24-h body temperature increased with ambient heat load, whereas in the sprinkler treatment, body temperature was much less affected by weather.

The provision of sprinklers was beneficial not only for lowering body temperature, but also for moderating the effects of weather conditions on feeding behavior. When no sprinklers were present, feeding time decreased as ambient heat load increased, consistent with feed intake reductions associated with heat load (Ominski et al., 2002). In contrast, when cows had access to sprinklers, they spent 40% more time feeding overall, and this behavior did not change with weather. This interaction between weather and the provision of sprinklers agrees with previous work indicating that sprinklers and shade can mitigate the reduction in feed intake seen in warmer weather (Strickland et al., 1989; Gaughan et al., 2004). Indeed, because lowered feed intake can lead to decreases in milk production (Wheelock et al., 2010), the ability of sprinklers to moderate heat-related reductions in feeding time (and likely intake) could be a mechanism by which water cooling can minimize production losses in the summer.

Weather also affected lying and standing behavior in this study: as heat load increased, cows spent less time lying, a pattern that has been observed across numerous studies (e.g., Zähler et al., 2004; Parola et al., 2012). The reasons for a shift in the time budget

Figure 7. Relationship between ambient temperature and preference when dairy cattle were given the choice between feed bunks with and without sprinklers for 5 d (preference is expressed as the percentage of time spent near the sprinkler treatment divided by total time spent near both feed bunks). Each marker indicates the 24-h average for 1 group of cows, with different symbols for each group.

from lying to standing have not been explicitly examined, but may include increasing convective heat loss by exposing a greater surface area of the body to air movement, reducing heat conducted from a warm lying surface, or increasing the efficiency of respiration. In the current study, the availability of sprinklers did not change the overall amount of time cows spent lying or standing, but rather shifted standing time from the shaded bedded area with fans to the area in front of the feed bunk that had both shade and sprinklers. This locational switch suggests that standing near sprinklers provided greater cooling benefits, in agreement with other studies that have found that this combination of cooling resources reduces body temperature and respiration rate more effectively than shade alone (Correa-Calderon et al., 2004; Avendaño-Reyes et al., 2006). Indeed, the microclimate in the feed bunks differed: although both bunks were shaded, sprinklers reduced air temperature by 2.2°C, on average.

Although past studies have shown considerable agreement on the benefits of water cooling, the few studies that have examined behavioral responses to spray have found variability: some have shown that individual animals readily use water, whereas others suggest avoidance, either altogether or by moving the head away from spray. When cows are unable to fully control what parts of the body are wetted by sprinklers, they hold their heads out of the spray radius (Schütz et al., 2011) or lower them (Kendall et al., 2007), similarly to when they are exposed to wet winter conditions (Tucker et al., 2007). In contrast, when cows can freely decide how to use water, they sometimes voluntarily wet their heads (Legrand et al., 2011). In this study, cows could control where they were wetted, and overall willingly used and preferred sprinklers; yet, evidence existed that they protected their heads from direct spray. In the sprinkler treatment, the nozzles were angled to spray only the cows' backs if they stood with their heads through the head gates, and when cows were standing without feeding, they were more likely to put their heads through the head gates when the sprinklers were on than when they were off. Further study is needed to understand how control over the areas of the body and head that are sprayed relates to sprinkler usage by cattle.

Several factors may explain why cows in this study showed more consistent usage of and preference for sprinklers than in other experiments. First, evidence from this study and others indicates that as environmental conditions become warmer, cows make greater use of water cooling (Legrand et al., 2011) and the degree of preference increases (Parola et al., 2012). In a study that found no preference for sprinklers, the weather was cooler overall (average 24-h air tempera-

ture: 18°C in Schütz et al., 2011) than in studies that have found evidence of preference for (24.5°C in the current study; 23°C in Parola et al., 2012) and voluntary usage of spray (25.3°C in Legrand et al., 2011). Second, both treatments in the current study were shaded; thus, these cows did not face a tradeoff between sprinklers and shade—a valuable resource that cows are motivated to use (Schütz et al., 2008)—whereas in previous studies cows have had to make this choice (Legrand et al., 2011; Schütz et al., 2011). Lastly, cows in the current study were housed in groups, which may have led to social facilitation of sprinkler usage. Previous studies with individually tested cows found either no preference for sprinklers (Schütz et al., 2011) or wide individual variation in shower usage (Legrand et al., 2011), whereas group-tested steers preferred sprinklers mounted over the feed bunk (1.3 L/min treatment in Parola et al., 2012). In the latter study, aggressive interactions were rarely observed in group-housed steers, and no relationship existed between social success and individual preference for sprinklers (Parola et al., 2012). In the current study, agonistic behaviors were not measured, but competition was unlikely to have been a major factor, as the preference for sprinklers was consistent across all cows. Overall, lactating dairy cows in the current study readily used and preferred sprinklers mounted above the feed bunk.

CONCLUSIONS

Dairy cows spent more time at feed bunks with sprinklers compared with those without this resource, particularly during the daytime and on warmer days. With the provision of sprinklers, body temperature stayed lower into the evening hours and was generally lower than when no sprinklers were available. Additionally, sprinklers moderated the effects of warm weather on body temperature and feeding time. When given access to both feed bunks with and without water cooling, cattle preferred feed bunks with sprinklers, and the magnitude of preference increased with ambient heat load. Overall, despite evidence that cows avoided wetting their heads, this is the first study to find that dairy cattle readily use and clearly prefer to spend time at feed bunks with sprinklers.

ACKNOWLEDGMENTS

The authors are grateful for the help of the following individuals, all affiliated with the University of California (UC) Davis at the time this experiment was conducted: David Ledgerwood, Amanda Grout, Eranda Rajapaksha, Erin Mintline, Benjamin Kasl, Amy Fochetti, Brittany Greenberg, and Kacie Minamide. Many

thanks also to the managers, staff, and interns of the UC Davis Dairy Teaching and Research Facility, the Animal Science Farm Crew, the Department of Animal Science, and the UC Davis College of Agricultural and Environmental Sciences. This research was funded by the Animal Compassion Foundation (Austin, TX).

REFERENCES

- Araki, C. T., R. M. Nakamura, L. W. G. Kam, and N. L. Clarke. 1985. Diurnal temperature patterns of early lactating cows with milking parlor cooling. *J. Dairy Sci.* 68:1496–1501.
- Avendaño-Reyes, L., F. D. Alvarez-Valenzuela, A. Correa-Calderón, J. S. Saucedo-Quintero, P. H. Robinson, and J. G. Fadel. 2006. Effect of cooling Holstein cows during the dry period on postpartum performance under heat stress conditions. *Livest. Sci.* 105:198–206.
- Bath, D. L., and S. J. Strasser. 1990. A computer program for formulating nutritional and economical rations for dairy operations. *Vet. Med.* 85:1334,1336–1340,1342.
- Berry, I. L., M. D. Shanklin, and H. D. Johnson. 1964. Dairy shelter design based on milk production decline as affected by temperature and humidity. *Trans. ASAE* 7:329–331.
- Correa-Calderon, A., D. Armstrong, D. Ray, S. DeNise, M. Enns, and C. Howison. 2004. Thermoregulatory responses of Holstein and Brown Swiss heat-stressed dairy cows to two different cooling systems. *Int. J. Biometeorol.* 48:142–148.
- De Rensis, F., and R. J. Scaramuzzi. 2003. Heat stress and seasonal effects on reproduction in the dairy cow—A review. *Theriogenology* 60:1139–1151.
- Ferguson, J. D., D. T. Galligan, and N. Thomsen. 1994. Principal descriptors of body condition score in Holstein cows. *J. Dairy Sci.* 77:2695–2703.
- Flamenbaum, I., D. Wolfenson, M. Mamen, and A. Berman. 1986. Cooling dairy cattle by a combination of sprinkling and forced ventilation and its implementation in the shelter system. *J. Dairy Sci.* 69:3140–3147.
- Gaughan, J. B., M. S. Davis, and T. L. Mader. 2004. Wetting and the physiological responses of grain-fed cattle in a heated environment. *Aust. J. Agric. Res.* 55:253–260.
- Gaughan, J. B., T. L. Mader, S. M. Holt, and A. Lisle. 2008. A new heat load index for feedlot cattle. *J. Anim. Sci.* 86:226–234.
- Gebremedhin, K. G., P. E. Hillman, C. N. Lee, R. J. Collier, S. T. Willard, J. D. Arthington, and T. M. Brown-Brandl. 2008. Sweating rates of dairy cows and beef heifers in hot conditions. *Trans. ASABE* 51:2167–2178.
- Hollenbeck, A. R. 1978. Problems of reliability in observational research. Pages 79–98 in *Observing Behavior*, Vol. II, Data Collection and Analysis Methods. G. P. Sackett, ed. University Park Press, Baltimore, MD.
- Igono, M. O., H. D. Johnson, B. J. Steevens, G. F. Krause, and M. D. Shanklin. 1987. Physiological, productive, and economic benefits of shade, spray, and fan system versus shade for Holstein cows during summer heat. *J. Dairy Sci.* 70:1069–1079.
- Keister, Z. O., K. D. Moss, H. M. Zhang, T. Teegerstrom, R. A. Edling, R. J. Collier, and R. L. Ax. 2002. Physiological responses in thermal stressed Jersey cows subjected to different management strategies. *J. Dairy Sci.* 85:3217–3224.
- Kendall, P. E., G. A. Verkerk, J. R. Webster, and C. B. Tucker. 2007. Sprinklers and shade cool cows and reduce insect-avoidance behavior in pasture-based dairy systems. *J. Dairy Sci.* 90:3671–3680.
- Legrand, A., K. E. Schütz, and C. B. Tucker. 2011. Using water to cool cattle: Behavioral and physiological changes associated with voluntary use of cow showers. *J. Dairy Sci.* 94:3376–3386.
- Mader, T. L., L. R. Fell, and M. J. McPhee. 1997. Behavior response of non-Brahman cattle to shade in commercial feedlots. *Livest. Environ.* 5:795–802.
- Marcillac-Embertson, N. M., P. H. Robinson, J. G. Fadel, and F. M. Mitloehner. 2009. Effects of shade and sprinklers on performance, behavior, physiology, and the environment of heifers. *J. Dairy Sci.* 92:506–517.
- Martin, P., and P. Bateson. 1993. *Measuring Behavior: An Introductory Guide*. 2nd ed. Cambridge University Press, Cambridge, UK.
- Mitloehner, F. M., J. L. Morrow, J. W. Dailey, S. C. Wilson, M. L. Galyean, M. F. Miller, and J. J. McGlone. 2001. Shade and water misting effects on behavior, physiology, performance, and carcass traits of heat-stressed feedlot cattle. *J. Anim. Sci.* 79:2327–2335.
- NRC. 1989. *Nutrient Requirements of Dairy Cattle*. 6th rev. ed. National Academy of Sciences, Washington, DC.
- Ominski, K. H., A. D. Kennedy, K. M. Wittenberg, and S. A. Moshtaghi Nia. 2002. Physiological and production responses to feeding schedule in lactating dairy cows exposed to short-term, moderate heat stress. *J. Dairy Sci.* 85:730–737.
- Parola, F., E. Hillmann, K. E. Schütz, and C. B. Tucker. 2012. Preferences for overhead sprinklers by naïve beef steers: Test of two nozzle types. *Appl. Anim. Behav. Sci.* 137:13–22.
- Perissinotto, M., D. J. Moura, S. V. Matarazzo, A. S. Mendes, and I. A. Naas. 2006. Behavior of dairy cows housed in environmentally controlled freestall. *Agric. Eng. Int. Vol. VIII. Manuscript BC 05 016*. International Commission of Agricultural Engineering, Beijing, China.
- SAS Institute. 2011. *SAS/STAT 9.3 User's Guide*. SAS Institute Inc., Cary, NC.
- Schütz, K. E., N. R. Cox, and L. R. Matthews. 2008. How important is shade to dairy cattle? Choice between shade or lying following different levels of lying deprivation. *Appl. Anim. Behav. Sci.* 114:307–318.
- Schütz, K. E., A. R. Rogers, N. R. Cox, J. R. Webster, and C. B. Tucker. 2011. Dairy cattle prefer shade over sprinklers: Effects on behavior and physiology. *J. Dairy Sci.* 94:273–283.
- Schütz, K. E., A. R. Rogers, Y. A. Poulouin, N. R. Cox, and C. B. Tucker. 2010. The amount of shade influences the behavior and physiology of dairy cattle. *J. Dairy Sci.* 93:125–133.
- Stat Trek. 2012. Binomial calculator: Online statistical table. Accessed Sep. 13, 2012. <http://stattrek.com/online-calculator/binomial.aspx>.
- Strickland, J. T., R. A. Bucklin, R. A. Nordstedt, D. K. Beede, and D. R. Bray. 1989. Sprinkler and fan cooling system for dairy cows in hot, humid climates. *Appl. Eng. Agric.* 5:231–236.
- Stull, C. L., L. L. McV. Messam, C. A. Collar, N. G. Peterson, A. R. Castillo, B. A. Reed, K. L. Andersen, and W. R. VerBoort. 2008. Precipitation and temperature effects on mortality and lactation parameters of dairy cattle in California. *J. Dairy Sci.* 91:4579–4591.
- Tucker, C. B., A. R. Rogers, and K. E. Schütz. 2008. Effect of solar radiation on dairy cattle behaviour, use of shade and body temperature in a pasture-based system. *Appl. Anim. Behav. Sci.* 109:141–154.
- Tucker, C. B., A. R. Rogers, G. A. Verkerk, P. E. Kendall, J. R. Webster, and L. R. Matthews. 2007. Effects of shelter and body condition on the behaviour and physiology of dairy cattle in winter. *Appl. Anim. Behav. Sci.* 105:1–13.
- USDA (US Department of Agriculture). 2010. Facility characteristics and cow comfort on U.S. dairy operations, 2007. No. 524.1210.
- USDA-Animal and Plant Health Inspection Service-Veterinary Services, Centers for Epidemiology and Animal Health (USDA-APHIS-VS, CEAH), Fort Collins, CO.
- Vitali, A., M. Segnalini, L. Bertocchi, U. Bernabucci, A. Nardone, and N. Lacetera. 2009. Seasonal pattern of mortality and relationships between mortality and temperature-humidity index in dairy cows. *J. Dairy Sci.* 92:3781–3790.
- Wheelock, J. B., R. P. Rhoads, M. J. VanBaale, S. R. Sanders, and L. H. Baumgard. 2010. Effects of heat stress on energetic metabolism in lactating Holstein cows. *J. Dairy Sci.* 93:644–655.
- Zähner, M., L. Schrader, R. Hauser, M. Keck, W. Langhans, and B. Wechsler. 2004. The influence of climatic conditions on physiological and behavioural parameters in dairy cows kept in open stables. *Anim. Sci.* 78:139–147.