Sprinkler flow rate affects dairy cattle preferences, heat load, and insect deterrence behavior

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Abstract

Sprinklers provide benefits for cattle, such as reducing heat load and possibly deterring insects. However, the use of this resource by cows varies across studies. Some of this variation may, in part, be explained by sprinkler flow rate. Higher flow rates provide greater heat abatement (desirable in warmer conditions, but perhaps not in milder weather) and generate greater spray impact, which cattle may avoid. Our objective was to evaluate the effects of flow rate on dairy cows' preferences for sprinklers and shade. We tested cows ($n = 18$) in a shaded arena (air temperature = $29 \pm 3.8^{\circ}\text{C}$, mean $\pm$ SD). To ensure they made informed choices and to measure insect deterrence behavior, we exposed cows to each treatment (flow rate = 0, 0.4, and 4.5 L/min, spray impact = 0, 1.1, and 8.9 kPa, respectively) ≥ 10 times in 12-min sessions. We then offered pairwise choices between 12-min treatments once daily for 8 consecutive d/pair. Cows preferred 0.4 L/min over shade alone [probability of choosing 0.4 L/min = 0.87; 95% confidence interval (CI) = 0.53 to 0.98]. Although cows did not prefer 4.5 L/min overall (probability of choosing 4.5 vs. 0 L/min = 0.62, CI = 0.27 to 0.87; vs. 0.4 L/min = 0.37, CI = 0.11 to 0.73), their likelihood of choosing it over shade alone tended to increase with respiration rate, body temperature, air temperature, and Temperature Humidity Index (odds ratios = 1.04, 3.57, 1.13, and 1.16, respectively). Relative to shade alone, both 0.4 and 4.5 L/min sprinklers provided the benefits of reducing insect deterrence behavior (tail flicks by 28 and 35%, respectively, and skin twitches by 32 and 48%), localized air temperature (by 0.6 and 1.1°C, respectively, SE = 0.2°C), and respiration rate (by 11 and 14 breaths/min, respectively, SE = 1.6 and 1.5 breaths/min). In addition, when cows chose 4.5 over 0.4 or 0 L/min, body temperature decreased by an additional 0.14°C during treatment and stayed below starting values for 34 and 47 min longer afterward. Cows did not prefer 0.4 L/min over 4.5 L/min sprinklers, suggesting they do not avoid higher impact spray. Nonetheless, greater spray impact and heat loss may outweigh the benefits of 4.5 L/min in mild conditions, perhaps explaining why preference for this sprinkler flow rate over shade alone increased with heat load. As 0.4 L/min did not have these potential costs, this may explain why cows preferred the lower flow rate sprinkler to shade alone across all conditions tested.

Keywords: dairy cattle; heat abatement; insect deterrence, sprinklers; preference

1. Introduction

When dairy cows accumulate heat load, this results in production and welfare problems, including increased body temperature, decreased milk yield (Wheelock et al., 2010) and fertility (De Rensis and Scaramuzzi, 2003), and in extreme cases, mortality (Stull et al., 2008; Morignat et al., 2014). Compared to shade alone, water spray reduces body temperature, respiration rate, and localized air temperature (Kendall et al., 2007; Chen et al., 2013). Thus, this method of heat abatement is commonly used in U.S. dairies (62% of milking herds ≥ 500 head; USDA, 2010), and spray is often provided using sprinklers placed above the feed bunk that deliver sufficient water to wet through the hair coat to the skin. Spray cools the microclimate and dissipates heat from cows via evaporation when the water is turned off, similar to the mechanism of sweating. To allow for this evaporation, sprinklers for the entire pen of cattle are typically activated intermittently at preset intervals.

In most dairy housing systems (freestalls or drylots house three-quarters of U.S. cows; USDA, 2010) cows can choose whether or not to stand under spray. Thus, cattle behavior may moderate the heat abatement provided by sprinklers. In the literature, cattle responses to spray have been shown to vary considerably, ranging from voluntary usage (3.0 and 2.5 h/d, respectively, when water is on; Legrand et al., 2011; Chen et al., 2013) to anecdotal reports of avoidance (Marcillac-Embertson et al., 2009). A factor that may explain some of this variation across studies is sprinkler flow rate, which may influence cattle responses to spray through its effects on heat abatement, insect deterrence, and spray impact.

Higher flow rates (≥ 1.3 L/min) reduce respiration rate and body temperature more effectively than lower ones (0.4 L/min) when cows are restrained under spray (applied intermittently during 1 h; Chen et al., 2015). It is unknown whether the degree of heat abatement provided influences cattle use of spray, but weather does. When air temperature increases, cattle spend more time using spray (Legrand et al., 2011) and their preference for it over shade alone is more marked (Parola et al., 2012; Chen et al.,

2013). Given that spray use increases with need for heat abatement, we predicted that in warm summer conditions, cows would prefer higher flow rates, which reduce heat load more effectively.

Besides heat abatement, spray may provide the additional benefit of deterring insects, which may explain why visits to a shower were often brief (41% of visits were <1 min long; Legrand et al., 2011). In response to flies, cattle typically display tail flicks, hoof stamps, skin twitches, or ear flicks (Dougherty et al., 1993), but when cows are under spray, they show fewer tail flicks and hoof stamps (Kendall et al., 2007; Schütz et al., 2011). If spray repels insects, we predicted behaviors associated with their deterrence would be reduced under spray, and that cows would prefer this resource, regardless of flow rate, compared to shade alone.

In contrast, Schütz et al. (2011) observed more skin twitches when cows were under spray, and speculated this was a reaction to droplets hitting the skin. Spray impact is proportional to flow rate, and for this reason, higher flow rates could perhaps be less attractive to cattle. Consistent with this idea, heifers anecdotally avoided 30 L/min sprinklers altogether (Marcillac-Embertson et al., 2009) and some cows rarely used a 7.3 L/min shower (i.e., <1 h/d; Legrand et al., 2011). Likewise, steers did not prefer feed bunks with 2.6 L/min sprinklers compared to those without spray except in warmer weather, but clearly preferred 1.3 L/min to shade alone across weather conditions (Parola et al., 2012). If cattle respond to spray impact, we predicted skin twitches would increase with higher flow rates, and cows would prefer lower flow rates overall.

Our objective was to evaluate the effects of sprinkler flow rate on preferences, insect deterrence behavior, and heat load in dairy cattle.

2. Materials and methods

2.1 Animals and housing

The study was conducted during the summer (June to September, 2012) at the University of California-Davis (UC Davis) dairy facility, with all procedures approved by the Institutional Animal Care and Use Committee. Eighteen lactating, pregnant Holstein-Friesian dairy cows were used, with average

parity 1.8 ± 0.6 , days in milk 213 ± 55 , daily milk yield 42 ± 5.5 kg, and body weight 700 ± 80 kg (mean $\pm$ SD).

Cows were tested in two consecutive cohorts of nine cows each. Each cohort was kept in a concrete-floored home pen with three water troughs (automatically refilled to 378 L) and 16 shaded, sand-bedded freestalls with three fans (36-DMCH; Future Products Corp., Mosinee, WI, USA). The shaded feed bunk was fitted with six soaker nozzles (TF-VP7.5 Turbo FloodJet wide angle flat spray tip, 4.9 L/min; Spraying Systems Co., Wheaton, IL, USA) that delivered 3 min of continuous spray, followed by 10 min off. The bunk was replenished twice daily during milking at 07:00 and 18:00 h with total mixed ration formulated to National Research Council (1989) requirements using the PC Dairy system (Bath and Strasser, 1990).

Between 07:00 and 18:00 h daily, the home pen was divided into thirds with portable livestock fencing (Powder River, Provo, UT, USA) to separate the three groups (three cows each) within each cohort assigned to a different testing h (10:00, 12:00 and 14:00 h). Each group had one water trough and two sprinkler nozzles, which were turned off 3 h before and 3 h after each group's daily testing h (i.e., from 07:00 to 14:00 h, 09:00 to 16:00 h, and 11:00 to 18:00 h). This ensured that observed responses were due to the treatments, because sprinklers can lower body temperature for at least 2 h after a 1-h treatment (Chen et al., 2015). At night (18:00 to 07:00 h), each cohort of nine cows was allowed to intermingle, and had access to an additional 808 L water trough near the testing arena.

2.2 Treatments

Treatments were administered to individual cows in an area separated from the home pen, shaded by a portable structure (9.8 x 6.1 m x 3.4-m-high) with a waterproof polyethylene cover that blocked $88.4 \pm 1.2\%$ (mean $\pm$ SD) of solar radiation (**SR**). Portable livestock fencing was used to construct three treatment locations (left, center, right), separated from a starting lane by a chain (Fig. 1), and abutting an unshaded concrete feed bunk, 35 m from the home pen feed bunk. The treatments were separated with 2.4-m-wide x 2.4-m-tall plywood partitions to prevent spray drift from the nozzles, which were controlled manually with a ball valve, mounted on water line 1.9-m-high, and angled such that the spray wetted the

entire floor of each treatment.

There were three treatments: a shade-only control in which no water was applied (0 L/min), and two sprayed options. The sprayed treatments were delivered by soaker nozzles (TK-FloodJet wide angle flat spray tips; Spraying Systems Co., Wheaton, IL, USA) differing in flow rate: 0.4 L/min [model TK-0.75, 138 kPa (20 psi, 1.4 kg/cm²) operating water pressure, 370 µm average droplet size], and 4.5 L/min [model TK-12, 69 kPa (10 psi, 0.7 kg/cm²) operating water pressure, 975 µm average droplet size]. We selected these two from the six nozzles evaluated in a previous study (Chen et al., 2015), to maximize the chance cows could discriminate between the options based on theoretical total spray impact (F_i), which was 1.1 and 8.9 kPa for 0.4 and 4.5 L/min, respectively. These were determined with the equation $F_i = Q \times \sqrt{P} \times K$, where Q is the volumetric flow rate in L/min, P is the liquid operating pressure in kg/cm², and K is the constant 2.354 to convert to kPa (Spraying Systems Co., 2015).

The treatments were presented in three paired comparisons: 0 vs. 0.4 L/min, 0 vs. 4.5 L/min, and 0.4 vs. 4.5 L/min, with access to the unused treatment location blocked by a portable livestock fencing panel. All cows had 4 d of exposure and 8 d of preference testing for one paired comparison at a time, and received all three pairs in a crossover design. The time and location of treatments was consistent for each cow, and, along with order of exposure to paired comparisons, was balanced across cows using a repeated Graeco-Latin square design. Treatments were applied for 12 min; this duration was selected based on the average bout length of voluntary shower usage by dairy cows (14.6 ± 9.5 min, excluding bouts < 1 min; Legrand et al., 2011), and the cumulative spray duration (3 min x four applications = 12 min) that lowered respiration rate using ≥ 0.4 L/min compared to no spray in previous work (Chen et al., 2015).

2.3 Treatment exposure and insect deterrence measures

To ensure cows were making informed choices during preference testing, they were exposed to each treatment option at least five times per paired comparison, for a total of ≥ 10 times/treatment, during 4 d (d 2 to 5, 14 to 17, and 26 to 29). Before each 12-min session, about 1 kg of total mixed ration topped with grain was placed in the feed bunk at each treatment location, the floor was wetted completely, and the spray was turned on in the sprinkler treatments. On the first d (d 2, 14, and 26) cows had two sessions

in which they were required to visit both treatment options, moved by a handler if necessary, and were then allowed to move freely between them. For the next 3 d (treatment exposure phase, d 3 to 5, 15 to 17, and 27 to 29), cows were exposed to each option once daily, returning to the home pen between treatments, which were balanced for order. During 10 min of each 12-min exposure, observers continuously recorded four different insect deterrence behaviors (Table 1). Five to eight observers were trained on each behavior. Inter-observer reliability was measured using Pearson correlation by comparing each observer to J. M. Chen as the gold standard. For each behavior, the range of r-values for pairs of observers was: skin twitches = 0.947 to 0.979, tail flicks = 0.940 to 1.000, ear flicks = 0.943 to 0.980, and hoof stamps = 0.901 to 0.988. Cows were not treated with insect repellent during the study.

2.4 Preference testing and measures of heat abatement

Following treatment exposure, each cow chose between a pair of treatments once daily for 8 consecutive d (preference testing phase, d 6 to 13, 18 to 25, and 30 to 37). The arena was prepared in the same manner as it was the previous d. After a cow was moved to the starting lane, the chain separating her from the treatment locations was removed; if the cow did not move forward voluntarily within 30 s, she was encouraged with increasing amounts of handling pressure following a standardized scale (Table 2; modified from Schwartzkopf-Genswein et al., 1997; Pajor et al., 2000). Choice was recorded when both of the cow's front hooves crossed the entrance to one of the two accessible treatment locations. The cow was then shut into the chosen treatment location for 12 min, and the unchosen sprinkler option was turned off.

Respiration rate was recorded by counting 10 flank movements (converted to breaths/min to facilitate comparison with other studies), twice during each testing trial: when the cow was in the starting lane, and at the end of the 12-min treatment before the cow was released from its chosen location. Three observers recorded this measure over the course of the study; inter-observer reliability for each observer compared to J. M. Chen as the gold standard ranged from $r = 0.994$ to 0.996 , as measured by Pearson correlation. Body temperature was recorded intra-vaginally at 2-min intervals by a data logger (Minilog12-TX, accuracy: $\pm 0.1^{\circ}\text{C}$, resolution: $\pm 0.015^{\circ}\text{C}$, 1.6-cm diameter x 7-cm length; Vemco Ltd.,

Bedford, Nova Scotia, Canada) attached to a shortened, hormone-free controlled internal drug release insert (InterAg, Hamilton, New Zealand).

2.5 Environmental and spray measures

2.5.1 Weather conditions

A portable weather station (WS-16; NovaLynx Corp., Auburn, CA, USA) onsite recorded air temperature (**T**, °C), black globe temperature (**BGT**, °C), SR (W/m^2), relative humidity (**RH**, %), wind speed (**WS**, m/s), and rainfall (mm), at 5-min intervals. Additional measures of heat load were Temperature Humidity Index (**THI**) and Heat Load Index (**HLI**), calculated according to the following equations from Kelly and Bond (1971) and Gaughan et al. (2008), respectively:

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

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

2.5.2 Water temperature

Sprinkler water temperature was measured at 11:00, 13:00, and 15:00 h on all preference testing d by submerging the probe of a digital thermometer (Fisher Inc., Pittsburg, PA, USA) into about 170 mL of spray collected in a bottle placed around the 4.5 L/min nozzle.

2.5.3 Treatment area microclimate

Microclimate data (T and RH) were collected for 5 d after the experiment was completed, to prevent cattle interference with equipment. These variables were recorded at 1-min intervals from 10:00 to 11:00 h, 12:00 to 13:00 h, and 14:00 to 15:00 h by loggers (U23-002 HOBO logger with RS3 solar radiation shields; Onset Computer Corp., Pocasset, MA, USA) hung from the shade structure in each treatment location at 1.4 m high and 1.4 m away from the feed bunk.

2.6 Statistical analysis

Analyses were conducted using SAS software (Version 9.4; SAS Institute Inc., 2014) and R software (Version 2.14.2; R Development Core Team, 2012). For all animal-based measures, cow (n = 18)

was the experimental unit.

2.6.1 Treatment area microclimate

Differences in microclimate (T, RH) were evaluated using ANOVA (PROC GLM; SAS) with fixed terms for h of testing ($df = 2$), location ($df = 2$), and treatment ($df = 2$), and an error term with 20 df. When main effects of treatment were significant ($P < 0.05$), comparisons were conducted between all pairs of treatments using the PDIFF function.

2.6.2 Insect deterrence behavior

For the four insect deterrence behaviors recorded during the treatment-exposure phase, differences among treatments in the number of bouts/min were evaluated using ANOVA (PROC GLM; SAS) with fixed terms for cow ($df = 17$) and treatment ($df = 2$), and an error term with 34 df. These measures were Winsorized at the fifth and ninety-fifth percentiles to improve the fit of the residuals to the assumption of normality, as determined by the Shapiro-Wilk statistic. When main effects of treatment were significant ($P < 0.05$), comparisons were conducted between all pairs of treatments using the PDIFF function.

2.6.3 Preference

To determine overall treatment preferences within each paired comparison, the probability of cows choosing a given treatment was determined using an intercept-only generalized linear mixed model (GLMM in the LME4 package; R) with a binomial distribution and a logit link, with a random term for cow. To evaluate whether cows were biased toward choosing particular treatment locations, this analysis was repeated using left, center, and right instead of treatments. To examine whether cows chose differently when they voluntarily selected a treatment with no coaxing, the analysis was repeated using only the 80% of preference testing trials for which handling pressure score was 0.

To examine how heat load affected preference, a GLMM was created with a fixed term for measure of heat load (as a continuous predictor) and a random term for cow. For each paired comparison, this analysis was performed separately for respiration rate, body temperature, T, THI, HLI, BGT, SR, RH, and WS.

2.6.4 Heat abatement

Respiration rate and body temperature were evaluated using the difference between starting values and the end of the 12-min treatment that cows chose. Within each paired comparison, a mixed model (PROC MIXED; SAS) was used with a fixed term for treatment chosen ($df = 1$) and random terms for cow and cow x treatment chosen (total error $df = 7$ to 9). To determine whether heat abatement continued after the 12-min treatment ended, this model was used to compare the amount of time that body temperature stayed below starting values.

3. Results

3.1 Environmental and spray characteristics

Table 3 summarizes weather conditions in the preference phase. Rainfall was 0 mm throughout the study. The average sprinkler water temperature was $29.6 \pm 2.9^{\circ}\text{C}$ (mean $\pm$ SD; range = 23.3 to 34.2°C). In the treatment area, microclimate T was lower and RH was higher as a result of spray compared to shade alone, as well as when flow rate was higher (T: 0, 0.4, and 4.5 L/min = 29.3, 28.7, and 28.2°C , respectively, SE = 0.2°C ; overall: $P < 0.001$, all pairwise differences: $P \leq 0.037$; RH: 0, 0.4, and 4.5 L/min = 40, 42, and 44%, respectively, SE = 0.5%; overall: $P < 0.001$, all pairwise differences: $P \leq 0.006$).

3.2 Preference

Overall, cows preferred 0.4 L/min over shade alone (probability = 0.87, 95% confidence interval (CI) = 0.53 to 0.98; $P = 0.037$). Cows had no preference for 4.5 L/min compared to the other options (probability of choosing 4.5 vs. 0 L/min = 0.62, CI = 0.27 to 0.87; 4.5 vs. 0.4 L/min = 0.37, CI = 0.11 to 0.73; $P \geq 0.497$).

Handlers used encouragement in only 20% of trials, and little pressure was needed [score 1 = 15%, 2 = 4%, 3 and 4 < 1% (one cow only), 5 and 6 = 0%]. When evaluating only the trials in which no handling pressure was used, the results were similar to when including all trials: cows preferred 0.4 L/min over shade alone [probability = 0.95, CI = 0.67 to 0.99; $P = 0.010$], and did not prefer 4.5 L/min

compared to the other options (probability of choosing 4.5 vs. 0 L/min = 0.65, CI = 0.24 to 0.92; 4.5 vs. 0.4 L/min = 0.27, CI = 0.06 to 0.66; $P \geq 0.237$).

Cattle preference for 4.5 L/min over shade alone tended to increase with heat load (respiration rate: odds ratio = 1.04, $P = 0.052$; body temperature: odds ratio = 3.57, $P = 0.089$; T: odds ratio = 1.13, $P = 0.065$; THI: odds ratio = 1.16, $P = 0.051$; Fig. 2). There were no effects of HLI, BGT, SR, RH, or WS ($P \geq 0.160$). In the paired comparisons with 0.4 L/min, preferences did not depend on heat load (0.4 vs. 0 L/min: $P \geq 0.445$; 0.4 vs. 4.5 L/min: $P \geq 0.314$).

Cows had no preference between the left and right treatment locations (probability of choosing left = 0.52, CI = 0.24 to 0.79; $P = 0.909$), but preferred the center treatment location over the sides (probability of choosing center vs. left = 0.97, CI = 0.81 to 0.99; center vs. right = 0.92, CI = 0.75 to 0.98; $P \leq 0.001$).

3.3 Heat abatement

Before cows chose a treatment, respiration rate was 69 ± 16.6 breaths/min and body temperature was $38.9 \pm 0.5^\circ\text{C}$ (mean $\pm$ SD). When cows selected the option that delivered more water (i.e., sprinklers vs. shade alone, or 4.5 vs. 0.4 L/min), respiration rate decreased more during the 12-min treatment in all paired comparisons ($P \leq 0.002$; Fig. 3A). When cows selected 4.5 L/min, body temperature decreased more during treatment than when cows chose 0 or 0.4 L/min ($P < 0.001$, Fig. 3B), and this measure also remained below starting values for longer afterward (mean $\pm$ SE: 4.5 vs. 0 L/min = 38 ± 5 vs. 5 ± 6 min, respectively, $P = 0.002$; 4.5 vs. 0.4 L/min = 56 ± 5 vs. 9 ± 5 min, respectively, $P < 0.001$). When cows chose between 0 and 0.4 L/min, there was no difference in how much body temperature changed during the 12-min treatment ($P = 0.338$, Fig. 3B), nor was there any difference in how long this measure remained below starting values (mean $\pm$ SE: 0 vs. 0.4 L/min = 15 ± 8 vs. 16 ± 5 min, respectively; $P = 0.914$).

3.4 Insect deterrence behavior

During the treatment exposure phase, there were fewer bouts of skin twitches (overall $P < 0.001$; Fig. 4A) under spray relative to shade alone, and this effect tended to be greater for 4.5 compared to 0.4

L/min. There were fewer tail flicks (overall $P = 0.005$; Fig. 4B) in both sprinkler treatments compared to shade alone, regardless of flow rate. Bouts of ear flicks and hoof stamps did not differ among treatments (overall $P \geq 0.616$; Fig. 4C and 4D).

4. Discussion

Previous studies found that cattle varied in their behavioral responses to spray, which may be attributable, in part, to the effects of different sprinkler flow rates on spray impact, insect deterrence, or heat load. In this study, we found that, compared to shade alone, cows preferred 0.4 L/min overall, and they tended to prefer 4.5 L/min when they were warmer (i.e., body temperature, respiration rate, air temperature, or THI were higher). Cows did not choose between sprinkler treatments based on spray impact, as they did not prefer lower-impact (0.4 L/min) over higher-impact (4.5 L/min) spray, and skin twitches decreased when spray impact increased. Their preferences for sprinklers over shade alone were likely explained by the insect deterrence and heat abatement benefits of spray. Sprinklers reduced insect deterrence behavior (skin twitches and tail flicks) and cooled the microclimate and the cows (lower respiration rate) relative to shade alone. The higher sprinkler flow rate affected these variables to a greater degree than the lower flow rate, and when cows chose 4.5 L/min over the other treatments, body temperature decreased more during the 12-min treatment and stayed below starting values for longer afterward.

4.1 Insect deterrence behavior

Previous studies showed cows performed fewer hoof stamps and tail flicks under spray than when given shade alone (Kendall et al., 2007; Schütz et al., 2011). We also found a reduction in the latter measure, regardless of flow rate. We did not detect treatment differences in hoof stamps or ear flicks. For hoof stamps, this is perhaps because we observed this behavior less frequently than in other studies due to a narrower behavioral definition: to exclude walking, we counted only when the hoof landed within one hoof-length of where it left the ground. For ear flicks, the lack of difference is unsurprising given our anecdotal observation that cows nearly always stood with their heads outside the spray radius.

Another insect deterrence behavior, skin twitches, increased under spray in a previous study (Schütz et al., 2011), and the authors speculated this was a reaction to droplets landing on the cattle. Spray impact is a function of flow rate (Spraying Systems Co., 2015). Thus, we predicted that skin twitches would increase with flow rate. On the contrary, we observed fewer skin twitches under spray compared to shade alone. Furthermore, 4.5 L/min tended to result in fewer skin twitches than 0.4 L/min, despite having eight-fold greater theoretical total spray impact (1.1 vs. 8.9 kPa, respectively). Thus, we found no evidence that skin twitches occurred in response to spray impact. Future studies should quantify actual impact from these spray treatments compared to flies landing, and should also measure insect load to evaluate whether spray repels insects.

4.2 Heat abatement

Spray cooled both the microclimate and the cows, and this effect increased with flow rate. Consistent with previous work, we found that compared to shade alone, spray resulted in lower localized air temperature and higher relative humidity (Kendall et al., 2007; Chen et al., 2013), and 4.5 L/min did so more than 0.4 L/min. Also in agreement with other studies (e.g., Mitlöhner et al., 2001), spray lowered respiration rate: when cows chose shade alone, this measure increased by 1 to 4 breaths/min from the start to the end of the 12-min treatment, but when cows chose spray, it decreased by at least 7 breaths/min. Furthermore, heat abatement was greater when cows chose 4.5 over 0.4 L/min: respiration rate decreased by an additional 8 breaths/min, and body temperature decreased by an additional 0.14°C and remained below starting levels for 47 min longer afterward. Our study is the first to show that higher flow rates improve heat abatement when cows choose to use spray. These patterns agree with previous observations of cows that were required to use unshaded spray: relative to 0.4 L/min, ≥ 1.3 L/min lowered respiration rate and body temperature from the start to the end of a 1-h intermittent spray treatment by an additional 9 breaths/min and 0.2°C, and the latter measure remained below starting levels for 24 min longer after spraying ended (Chen et al., 2015).

4.3 Preference

Cows preferred 0.4 L/min to shade alone overall. They tended to choose 4.5 L/min over shade alone when the weather was warmer or when their body temperature or respiration rate was higher. Previous studies using at least 1.3 L/min likewise found that as air temperature increased, preference for sprinklers over shade alone became more marked (Parola et al., 2012; Chen et al., 2013), and cows spent more time using showers (Legrand et al., 2011). Relative to shade alone, both 0.4 and 4.5 L/min provided benefits in terms of reduced insect deterrence behavior, localized air temperature, and respiration rate. Nevertheless, because preference patterns for the two flow rates differed, perhaps cattle associated 4.5, but not 0.4 L/min, with a cost. One possibility is the reduction in body temperature that 4.5 L/min provides may be undesirable in cooler weather. Cows that were tested when average 24-h air temperature was 18°C did not prefer sprinklers compared to shade or ambient conditions overall (Schütz et al., 2011). Physiological responses to spray in milder weather also indicate attempts to conserve heat. When cows are sprayed in the morning (Araki et al., 1985) or on days with air temperature <23°C (Kendall et al., 2007) body temperature temporarily increases afterward. Also, when the torso is sprayed, skin temperature on the extremities decreases, consistent with vasoconstriction (Chen et al., 2015).

Another possible cost may be incurred when spray is directed toward the head. Cows often stood with their heads outside of the spray radius, which others have also reported (Schütz et al., 2011; Chen et al., 2013). The head may be particularly sensitive to droplets; indeed, the ear responds to stimulation from von Frey monofilaments at one sixth the level of force compared to the shoulder (Chen et al., 2016). When flow rates are higher, cows show greater avoidance of wetting their heads, which may reflect differences in spray impact: when required to walk through 4.5 L/min spray, they lowered their heads four times more often than when approaching 0.4 L/min spray (Chen et al., 2016). However, cows in the current study had no preference between 0.4 and 4.5 L/min, despite the difference in theoretical total spray impact (1.1 vs. 8.9 kPa, respectively), and regardless of weather conditions. In all, we found no evidence that spray impact affected overall preference when cows were offered pairwise choices.

Aspects of experimental design may also play a role in cattle preference. Location is a salient cue for cattle (Grandin et al., 1994), and thus we kept treatment-location assignments consistent for each cow.

However, perhaps because the starting lane had a more direct line of sight to the center treatment location than the two outer ones, cows chose the former more frequently than the others. We accounted for this possibility by balancing treatment-location assignments across cows, but in future an improved arena design would include treatment locations equidistant from the starting lane.

5. Conclusions

The insect deterrence and cooling benefits of 0.4 L/min sprinklers likely explain why cows preferred this treatment to shade alone overall. The 4.5 L/min sprinkler treatment provided greater reductions in heat load, but although this may be beneficial in warmer weather, it is perhaps detrimental in milder conditions. This potential cost, along with greater spray impact, may explain why cows did not prefer 4.5 L/min to shade alone overall, but were more likely to choose this type of spray in warmer weather.

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Fig. 1. Dairy cow ($n = 18$) preferences for heat abatement resources were tested in a shaded arena (diagram not to scale) with three treatment locations abutting a feed bunk, which were separated with solid barriers to minimize spray drift. During preference testing, cows began in the starting lane (as depicted) behind a chain, then chose between two locations; access to the third location was blocked using portable livestock fencing (not shown).

Fig. 2. Model predictions for the average probability of cows ($n = 18$) choosing the higher flow rate in a given paired comparison (i.e., 0.4 vs. 0 L/min, 4.5 vs. 0 L/min, or 4.5 vs. 0.4 L/min), as a function of (A) respiration rate, (B) body temperature, (C) air temperature, and (D) Temperature Humidity Index at the time when the choice between treatments was offered.

Fig. 3. Mean change in (A) respiration rate and (B) body temperature from start to end of a 12-min treatment chosen by cows in each paired comparison; error bars represent SE ($n = 18$ cows). Within each comparison, treatment differences for change in physiological measure are indicated: ** $P < 0.01$; *** $P < 0.001$.

Fig. 4. Mean number of (A) skin twitches, (B) tail flicks, (C) ear flicks, and (D) hoof stamps that were observed per min when cows were exposed repeatedly to each of three sprinkler flow rates; error bars represent SE ($n = 18$ cows). Treatment differences in mean bouts/min are indicated: † $P < 0.09$, ** $P < 0.01$, *** $P < 0.001$.

Chen et al. Fig. 1

Chen et al. Fig. 2

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Table 1. Definitions for four insect deterrence behaviors that observers continuously recorded for 10 min

Behavior	Definition
Skin twitch	Rapid, repeated twitching or shivering on the shoulder or flank of the focal side of the body; distinct pause of movement required before recording new bout
Tail flick	Muscle-powered tail movement causing the tail to swing
Ear flick	Rapid movement (i.e., flap, flick, twitch, or fast rotation) of focal ear; distinct pause of movement required before recording new bout
Hoof stamp	A hoof is lifted, raised, or kicked, such that it leaves the ground and is replaced at least partially within the original hoof print (i.e., within one hoof-length)

Table 2. Standardized scale^a used by handlers to encourage forward movement when dairy cows chose between a pair of treatments

Score	Description
0	If cow moves forward on its own within 30 s, apply no pressure
1	Whistle, use gentle vocal encouragement, and raise arm behind cow
2	Whistle, use gentle vocal encouragement, and prod cow's rump with fingers
3	Whistle, use gentle vocal encouragement, and use plastic tip of mechanical pencil to scratch cow's rump
4	Whistle, use loud vocal encouragement, and use plastic tip of mechanical pencil to prod cow's rump
5	Use loud vocal encouragement and push cow from behind with both hands
6	Use loud vocal encouragement and push cow from behind with one hand while grasping tail with the other

^aWhen scores 1 to 5 are reached, each step is repeated up to three times, until the cow moves; if the cow does not move after three repetitions, the handler escalates to next score.

Table 3. Summary of daily weather conditions on preference testing d^a in June through September, 2012

Weather variable	Preference testing session ^b			24 h ^c		
	Mean	SD	Range	Mean	SD	Range
Air temperature (T, °C)	29.2	3.8	15.5 – 41.0	23.4	2.6	17.7 – 29.2
Temperature Humidity Index (THI)	74	3	60 – 83	68	3	62 – 73
Heat Load Index (HLI)	88	7	56 – 102	68	4	56 – 74
Black globe temperature (BGT, °C)	41.2	4.6	19.6 – 53.7	28.0	2.9	20.9 – 33.8
Solar radiation (SR, W/m ²)	761	75	177 – 919	281	35	170 – 324
Relative humidity (RH, %)	34	8.7	12 – 74	50	7.0	36 – 64
Wind speed (WS, m/s)	1.2	0.5	0 – 4.3	1.1	0.4	0.5 – 2.7

^aCattle preferences were tested for 8 consecutive d per paired comparison, following 4 d of exposure to each pair of treatments.

^bMeans, SD, and range (minimum to maximum of observed values) are given for 10:00 to 11:00 h, 12:00 to 13:00 h, and 14:00 to 15:00 h combined; each cow (n = 18) was tested for preference during the same h daily.

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