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APPLIED ANIMAL BEHAVIOUR SCIENCE
Applied Animal Behaviour Science 109 (2008) 141–154
www.elsevier.com/locate/applanim

Effect of solar radiation on dairy cattle behaviour, use of shade and body temperature in a pasture-based system

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Accepted 26 March 2007
Available online 21 May 2007

Abstract

Our aim was to understand how protection from solar radiation influenced the behaviour and physiology of Holstein Friesian dairy cattle. We compared the behaviour and body temperature of pastured dairy cattle kept in 1of 4 treatments: no shade or free access to shade that blocked either 25, 50 or 99% of solar radiation ($n = 3$ groups per treatment, 3 animals/group). Within each group, cows were categorized as predominantly black, black and white or white in colour ($n = 1$ of each coat colour per group). Shade use increased with higher levels of protection from solar radiation (total shade use, 25%: 1.3 h, 50%: 3.0 h, 99%: 3.3 h/15.5 day-time h, S.E.M.: 0.22 h, $P < 0.001$). As average ambient solar radiation increased, total use of the shade structures increased (26 of 27 cows had a positive relationship between solar radiation and total use of shade structures, $P < 0.001$). This pattern was particularity apparent for the 50 and 99% treatments ($P = 0.009$). Cows were more likely to use the shade structures when ambient solar radiation levels were highest within a day, highlighting the importance of providing enough shade for all cows to simultaneously use this resource. Standing was the most common behaviour under shade (25%: 1.1 h, 50%: 2.7 h, 99%: 2.9 h/15.5 day-time h, S.E.M.: 0.21 h, $P = 0.001$). Treatments had no effect on time spent lying or grazing over 24 h (lying: no shade: 9.0 h, 25%: 9.1 h, 50%: 9.5 h, 99%: 8.8 h/24 h, S.E.M.: 0.33 h, $P = 0.630$; grazing: no shade: 9.0 h, 25%: 9.4 h, 50%: 9.1 h, 99%: 9.3 h/24 h, S.E.M.: 0.19 h, $P = 0.231$). Cows with more protection from solar radiation had lower minimum body temperature (no shade: 37.9 °C, 25%: 37.9 °C, 50%: 37.9 °C, 99%: 37.7 °C, S.E.M.: 0.05 °C, $P = 0.004$). Together, these results demonstrate that the degree of protection from solar radiation is an important design feature of effective shade for dairy cattle.
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Keywords: Animal welfare; Behaviour; Body temperature; Dairy cattle; Heat stress; Shade

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0168-1591/$ – see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.applanim.2007.03.015

1. Introduction

Exposure to summer weather affects both the physiology and behaviour of dairy cattle. Respiration rate and core body temperature increase during heat exposure (differences in ambient temperature, 26 versus 40 °C, Wise et al., 1988; 20 versus 32 °C, Ominski et al., 2002). Cows provided with shade have significantly lower respiration rates and core body temperature than cattle without shade in warm summer conditions (Sethi and Nagarcenkar, 1981; Blackshaw and Blackshaw, 1994). Cattle will readily use shade when it is provided in summer (Widowski, 2001; Kendall et al., 2006) and provision of shade mitigates the production losses (milk production or weight gain) associated with high ambient temperatures or temperature–humidity indices (THI, e.g. Her et al., 1988; Muller et al., 1994a). For example, milk production is reduced when THI levels exceed 72 (e.g. Ravagnolo and Misztal, 2002). Based on changes in milk production, THI of 72 has been historically used as a threshold of thermal comfort for dairy cattle (THI of 72 equates to 25 °C and 50% relative humidity). More recently, a heat load index (HLI), which incorporates solar radiation and wind speed, has been used as an alternative to THI (Gaughan et al., 2004). We have found that shade and sprinklers reduce respiration rate and body temperature in dairy cattle when THI > 69 or HLI > 77 (Kendall et al., 2007).

The type of shade influences the microclimate created under the shadow cast. Agricultural engineers and foresters have evaluated the design characteristics of various shaded environments. For example, the amount of radiation emitted from shade structures made of aluminium siding can be manipulated with paint colour (Bond et al., 1954). Natural shade, such as trees and hedges, vary in their ability to reduce solar radiation, wind speed and temperature depending on the height, spacing and density of various species (e.g. Hawke and Wedderburn, 1994; for a review of trees as shelter see Gregory, 1995). Previous work has compared animal responses to specific types of shade (e.g. trees versus shade cloth or organic versus metal roofs, Gaughan et al., 1998; Ittner and Kelly, 1951; Valtorta et al., 1997). For example, Ittner and Kelly (1951) found that beef cattle preferentially used shade created with a combination of galvanized iron and hay roof and did not use a louver-type shade at all. This type of study provides information about how various designs compare, but often because of its specificity this information is not applicable across farming systems. Although there are many alternative ways to provide shade, little is known about the importance of various design features of shade (e.g. blockage of solar radiation, changes in wind speed, etc.).

To date, it is clear that shade provides benefits for cattle in terms of behaviour, physiological responses and production. The next challenge is to make recommendations about the best way to provide shade for animals. The conclusions from comparisons of specific types of artificial (e.g. cloth or metal roofs) or natural (e.g. deciduous versus evergreen trees) shade are often limited to the range of materials tested. In contrast, our goal is to understand the importance of underlying physical features of shade for cooling cattle. In this experiment, our aim was to understand how a single design feature of shade, protection from solar radiation, influenced the physiological and behavioural responses of dairy cattle under a range of environmental conditions. Previous work has found that beef cattle show short-term preferences for shade that provided more protection from solar radiation (Bennett et al., 1984/1985). Thus, we predicted that cows would be more likely to use shade that provided more protection from solar radiation. We predicted that this pattern would be particularly apparent if cows had dark coats as these animals absorb more solar radiation than cattle with light coloured coats (Finch and Western, 1977; da Silva et al., 2003; Maia et al., 2005). Similarly, we predicted that cows provided with greater protection from solar radiation would have lower body temperatures, especially in the period between milkings (as reported previously by Kendall et al., 2006). We expected that both the behavioural and physiological responses would vary linearly with treatment and would be more marked on days with high levels of ambient solar radiation.

2. Materials and methods

2.1. Animals and treatments

All procedures involving animals were approved by the Ruakura Animal Ethics Committee under the New Zealand Animal Welfare Act. The study utilized 36 Holstein Friesian dairy cows in mid-lactation that ranged from 4 to 12 years of age and were, on average, 158 ± 21 days in milk (mean ± S.D.) at the beginning of the experiment. The animals had an average body weight of 499 ± 42 kg (mean ± S.D.) and body condition score between 3.5 and 6 on a 1–10 scale (Roche et al., 2004). The initial milk production at the start of the experiment was, on average, 20.8 ± 2.9 kg of milk per day (mean ± S.D.). Cows were categorized as predominantly black (96 ± 3% black hair, mean ± S.D.), black and white (60 ± 7% black hair) or white in colour (25 ± 8% black hair). The percentage of black hair was measured from digital photographs of both sides of each cow using image analysis software (Scion Image v.4.0.2).

The animals were grazed as 12 groups (3 cows/group) at the AgResearch farms near Hamilton, New Zealand (latitude 37°47′ S, longitude 175°19′ E). Groups were formed 2 d before the start of observations. A fresh sward of grass, on average 2707 ± 138 kg dry matter/ha, was provided every 24 h, immediately after the morning milking. Cows were milked twice daily (06:00 and 14:15) and the time away from the paddock averaged 171 ± 37 min/24 h, including time spent in the milking parlour. Estimates of time spent standing assume that cows did not lie down when they were away from the paddock. The groups of cows were balanced for coat colour category (1 black, 1 black and white and 1 white cow in each group) and were assigned 1 of 4 treatments: (1) no shade, (2) 25% solar radiation blocked, (3) 50% of solar radiation blocked and (4) 99% of solar radiation blocked ($n = 3$ groups per treatment, 3 cows/group). Cows always had visual and auditory contact with animals in the other treatments. Treatments were applied for 20 d during January and February 2006 (Southern hemisphere summer). Protection from solar radiation was provided to each shaded group with 2 wooden shade structures (2.3 m high, 4.0 m long, 3.0 m wide; giving 8.0 m^2 of shade/cow). The structures were all orientated in the same direction with the 3-m side facing north. The shade structures were covered with shade cloth (Donaghys Industries Ltd., Christchurch, NZ) that blocked out either 25, 50 or 99% of solar radiation. All groups had 2 mowed patches of grass (approximately 3.5 m × 4.5 m) that contained a painted rectangle measuring 3 m × 4 m. In the 3 treatments provided with shade, the painted rectangles were directly beneath the structures and in the no-shade treatment, the mowed patches and painted rectangles were in a comparable location to their shaded counterparts. These mowed patches improved visibility of the painted rectangle.

2.2. Sampling and measurement

2.2.1. Environmental variables

Air temperature and relative humidity (HMP45A humidity and temperature sensor, Vaisala, Helsinki, Finland), wind speed (# 40 Hall effect anemometer, NRG Systems, Hinesburg, VT, USA), rainfall (tipping spoon rain gauge, Pronamic Silkeborg, Denmark), solar radiation (Licor Li200x Pyranometer, Campbell Scientific Inc. Logan, UT, USA) and black globe temperature (CSI 107 temperature sensor in black ball, Campbell Scientific Inc., BGT) were recorded at 10-min intervals with a data logger (CR10X, Campbell Scientific Inc.) on weather stations located on the research farm. The microclimate (temperature, humidity, BGT) was measured in the painted rectangles with HOBO Pro Dataloggers (Onset Computer Corporation, Bourne, MA, USA). Four HOBO data loggers were used during the experiment and these were rotated between groups (1 HOBO in each treatment at a time). THI and HLI were used as indicators of thermal comfort for dairy cows and calculated as follows:

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

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

where T is the air temperature (°C), RH the relative humidity (%), BGT the black globe temperature and WS is the wind speed (m/s).

2.2.2. Behaviour

Behaviours were recorded with instantaneous scan sampling every 10 min during daylight hours (approximately 06:00–21:30) on all 20 d of data collection. Every other day, behaviour was recorded over 24 h (10 d in total) with the same 10-min sampling regime. We recorded the time spent lying, standing and grazing. Cows were considered lying if their flank was in contact with the ground (standing was defined as not lying). Cows were considered grazing if grass was being ingested or could be seen in the mouth. The use of the shade structures was measured in 2 ways. We recorded if at least 1 hoof was within the painted rectangle directly underneath the shade structure (variable called "directly underneath structure"). Secondly, we recorded if at least 1 hoof was within the shadow cast by the structure (variable called "in shade cast by structure"). This second measurement was only taken when the outline of the shadow was clearly defined on all 4 sides. Both measures were used because we felt that only recording the latter may underestimate shade use when the shadow was not clearly defined on all 4 sides. Finally, total time spent using the shade structures was calculated using a combination of the 2 measures of shade use: if cows had at least 1 hoof either directly underneath the structure or in the shadow cast by the structure (variable called "total use of structure"). Individual cows were identified with coloured collars and paint on the rump. A single observer watched 4 groups of cows (1 group from each treatment) at a time. Thus, multiple observers were used to collect the behavioural information. Inter-observer reliability, as measured by percentage agreement, was between 96 and 100% for all behaviours. Inter-observer agreement was lowest when assessing time spent grazing (96% agreement).

2.2.3. Body temperature

Internal body temperature was recorded every 10 min using a modified CIDR™ (InterAg, Hamilton, New Zealand) fitted with a microprocessor-controlled Minilog-TX data logger (Vemco Ltd., Shad Bay, Nova Scotia, Canada). Temperature loggers were inserted into the vaginal cavity on a 10-d in and 5-d out cycle to minimize irritation. This schedule resulted in 16 d of measurement of internal body temperature. A total of 7 cows had some amount of unusable data due to logger failure (from 1 to 13 d of data per cow and a total of 38 out of 576 d of data were not used). We examined 4 parameters for body temperature: mean (in all time periods, defined below), maximum, minimum and amplitude (maximum–minimum). The latter 3 parameters are only reported over 24-h periods.

2.3. Statistical analysis

Groups served as the experimental unit. All data were averaged across the collection period for each treatment (16 d for body temperature; 10 d for behaviours at night; 20 d for all other behaviours). For body temperature and behaviours measured over 24 h, data were divided into 3 categories: day-time (06:00–21:30 h daylight; 20 d), night-time (21:40–05:50 h darkness; 10 d) and full 24-h period (10 d). In addition, we examined body temperature during the period between milkings (10:00–14:00). The effect of treatment (linear, quadratic and cubic terms, 1 d.f. each) was tested against the group term (8 d.f.) and the effects of coat colour category (white, black or black and white; interactions between coat colour and linear effect of treatment, 2 d.f.) were tested against the cow term (16 remaining d.f.) in SAS (PROC GLM, v.9.1). This experiment was a dose–response trial and our objective was to describe the response to protection from solar radiation. Only the linear term is reported in the results, as this was our prediction about treatment differences. See Morris (1999) for further discussion about why dose–response trials should be analysed in this manner (as opposed to categorical comparisons of each treatment with a range test).

To assess the influence of weather on the response to treatment, we used daily information from each cow to calculate the slope of the relationship between the response variable (body temperature, time spent lying, standing, grazing and total use of shade structures) and THI, HLI and solar radiation, separately, during the treatment period. To test the interaction between treatment and weather we compared these slopes in the model described above. To assess the overall effects of weather, we summed the number of individuals with either positive or negative slope and compared these counts with a binomial test.

3. Results

3.1. Environmental conditions

Table 1 summarizes the weather variables recorded during the experiment during the day-time (06:00–21:30), night-time (21:40–05:50) and over 24 h. Air temperature, wind speed, solar radiation, THI and HLI were all higher during the day-time compared to night-time and 24-h mean records. Within each treatment, the average BGT, as measured by HOBO data loggers, for the no shade, 25, 50 and 99% treatments was, 26.0, 24.1, 22.9 and 22.1 °C, respectively over the 20 d of data collection (06:00–21:30). Over this same period, the average THI for the no shade, 25, 50 and 99% treatments were, respectively, 69.0, 68.4, 68.5, 68.4.

3.2. Behaviour

Cows spent more time using shade that blocked a greater percentage of solar radiation during day-time ($P_{linear} < 0.001$; Table 2). Over the 20 d of the experiment, cows spent, on average, 2.8 h per d using the shade structures that provided 99% protection compared to 1.0 h per d when only 25% protection was provided (Table 2). These treatment differences were also apparent during the period between milkings (10:00–14:00). The pattern of increasing shade use with higher levels of protection from solar radiation occurred regardless of the measuring shade use (standing in shadow cast by the structure, standing directly under the structure or the combination of these 2 measures; Table 2). All 4 sides of the shadow were clearly defined (requirement for

Table 1
Summary of daily (24 h), day-time (06:00–21:30) and night-time (21:40–05:50) meteorological records during the 20 d of the experiment in summer

Weather variable	Daily (24 h)		Day-time (06:00–21:30)		Night-time (21:40–05:50)	
	Mean	Range	Mean	Range	Mean	Range
Temperature (°C)	19.5	8.5–28.6	21.1	8.5–28.6	16.6	8.8–23.8
Relative humidity (%)	76.5	46.9–93.7	72.0	46.9–93.7	84.9	58.4–93.5
Wind speed (km/h)	4.6	0.0–31.7	6.1	0.0–31.7	1.8	0.0–18.7
Solar radiation (W/m^2)	227	0–1309	348	0–1309	0	0
Rainfall (mm/d)	6.2	0.0–49.0	5.7	0.0–49.0	0.6	0.0–6.0
THI[a]	65.6	47.8–77.7	67.8	47.8–77.7	61.5	48.2–72.4
HLI[b]	64.5	45.6–102.2	69.8	46.7–102.2	54.5	45.6–61.8

Both means and ranges (minimum to maximum) values are presented.
[a] Temperature–humidity index.
[b] Heat load index.

Table 2
Time spent lying, standing or grazing by dairy cattle while using shade (n = 12 groups, 3 groups per treatment) in response to cooling treatments provided at pasture in summer

Variable	Shade level				S.E.M.	*P*-value	
	No shade	25%	50%	99%		Treatment	Treatment × coat colour
In shade cast by structure							
Lying (h/15.5 day-light h)	–	0.0	0.1	0.1	0.02	0.108	0.049
Grazing (h/15.5 day-light h)	–	0.1	0.1	0.1	0.02	0.286	0.051
Standing, not grazing (h/15.5 day-light h)	–	0.6	1.5	1.6	0.12	0.001	0.064
Total time in shade (h/15.5 day-light h)	–	0.7	1.8	1.8	0.12	<0.001	0.047
Directly underneath structure							
Lying (h/15.5 day-light h)	0.0	0.0	0.1	0.1	0.02	0.010	0.003
Grazing (h/15.5 day-light h)	0.1	0.1	0.1	0.1	0.01	0.396	0.228
Standing, not grazing (h/15.5 day-light h)	0.2	0.9	2.3	2.6	0.18	<0.001	0.066
Total time underneath structure (h/15.5 day-light h)	0.2	1.0	2.5	2.8	0.19	<0.001	0.056
Total use of structure							
Lying (h/15.5 day-light h)	–	0.1	0.1	0.2	0.03	0.134	0.010
Grazing (h/15.5 day-light h)	–	0.1	0.2	0.2	0.02	0.137	0.135
Standing, not grazing (h/15.5 day-light h)	–	1.1	2.7	2.9	0.21	0.001	0.088
Total time of structure use (h/15.5 day-light h)	–	1.3	3.0	3.3	0.22	<0.001	0.072

Treatments included access to shade structures that blocked 25, 50, or 99% of solar radiation or no shade. Shade use was assessed in 3 ways: standing with at least 1 hoof in shade cast by structure, standing with at least 1 hoof directly underneath the structure, or at least 1 of these 2 (total use of structure). Coat colour was categorized as predominantly white, predominantly black, or black and white and these categories were balanced across treatment. *P*-values are presented for the linear effect of treatment and the interaction between treatment and coat colour. Behaviours are presented as h/15.5 day-light hours.

''standing in shadow cast by structure'' variable) in 24 ± 16% (mean ± S.D.) of the observations, with days ranging from a minimum of 0% to a maximum of 54% of observations.

Coat colour affected the response to the treatment, with black cows using the 99% treatment less than white or black and white cows ($P_{\text{linear}\times\text{coat colour}} = 0.072$). The linear trend between treatments or, increasing shade use with more protection from solar radiation, was less marked for black cows than for white or black and white cows (total use of structure; Fig. 1). Standing was the most common behaviour performed under or in the shade of the structures, although cows also spent a small amount of time lying and grazing in this area. There were no differences, however, in the activity patterns (lying, standing and grazing) of cows provided with differing levels of protection during the day-time, between milkings (10:00–14:00), night-time or over a 24-h period ($P_{\text{linear}} \geq 0.226$; Table 3).

As average ambient solar radiation increased, total use of the shade structures increased (26 of 27 cows had a positive relationship between solar radiation and total use of shade structures, $P_{\text{binomal}} < 0.001$; Fig. 2). This pattern was particularity apparent for the 50 and 99% treatments

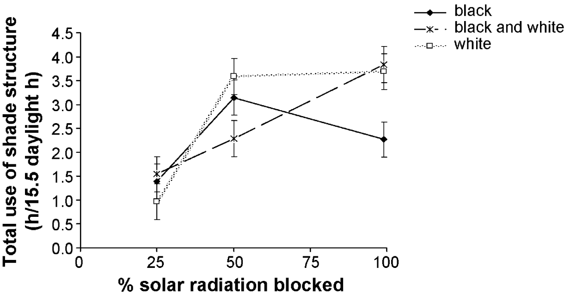

Fig. 1. Dairy cattle ($n = 12$ groups, with 3 cows per group, 1 of each coat colour category) that were predominantly black, white or black and white had free access to shade structures that blocked 25, 50 or 99% of solar radiation during 20 d of summer. The interaction between average use of the shade structures (total, h/15.5 h daylight) and the 3 coat colour categories is presented. Bars represent the least-squares S.E.M.

($P_{linear} = 0.009$). Cows were also more likely to use the shade structures when solar radiation levels were highest within a day. This use of the shade structure during the peak in solar radiation was dependent on the weather conditions on a given day. We selected the day (06:00–21:30) with the highest (532 W/m^2) and lowest (48 W/m^2) average ambient solar radiation in the experiment to illustrate this effect (Fig. 3). Overall activity patterns were also influenced by weather. As HLI

Table 3
Day-time, night-time and 24-h activity patterns of dairy cows ($n = 12$ groups, 3 groups per treatment) in response to cooling treatments provided at pasture in summer

Variable	Shade level				S.E.M.	*P*-value	
	No shade	25%	50%	99%		Treatment	Treatment × coat colour
Day-time (h/15.5 daylight h)							
Lying	1.6	1.9	1.7	1.6	0.19	0.778	0.664
Grazing	8.4	8.4	8.6	8.5	0.17	0.722	0.637
Standing, not grazing	5.5	5.2	5.2	5.4	0.23	0.987	0.915
Between milkings (h/4 h between 10:00 and 14:00)							
Lying	0.3	0.3	0.3	0.3	0.07	0.881	0.949
Grazing	1.6	1.5	1.4	1.5	0.07	0.226	0.723
Standing, not grazing	2.1	2.2	2.3	2.3	0.08	0.260	0.696
Night-time (h/8.5 darkness h)							
Lying	6.8	6.7	7.1	6.5	0.17	0.529	0.186
Grazing	0.7	1.0	0.6	1.0	0.12	0.601	0.237
Standing, not grazing	1.0	0.9	0.8	1.0	0.13	0.874	0.811
24-h period (h/24 h)							
Lying	9.0	9.1	9.5	8.8	0.33	0.630	0.407
Grazing	9.0	9.4	9.1	9.3	0.19	0.231	0.559
Standing, not grazing	6.0	5.5	5.4	5.9	0.32	0.988	0.736

Treatments included access to shade structures that blocked 25, 50, or 99% of solar radiation or no shade. Coat colour was categorized as predominantly white, predominantly black, or black and white and these categories were balanced across treatment. *P*-values are presented for the linear effect of treatment and the interaction between treatment and coat colour.

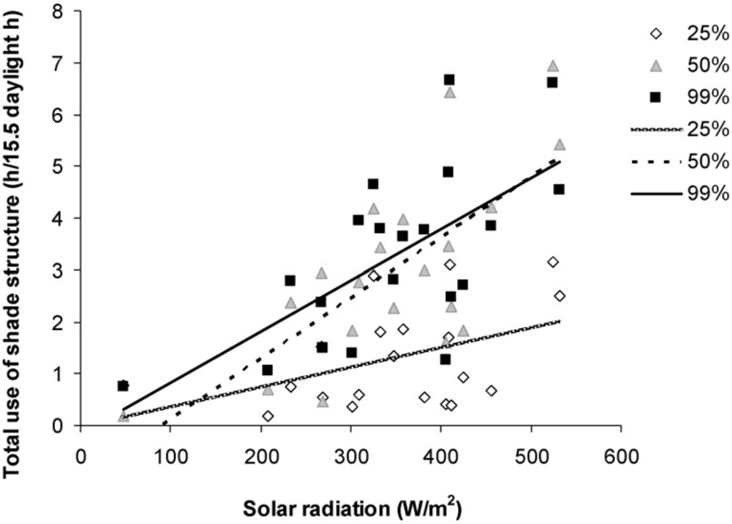

Fig. 2. Relationship between daily average solar radiation and total use of the shade structures. The shade structures blocked 25, 50 or 99% of solar radiation and were freely available to dairy cattle ($n = 9$ groups, 3 groups per treatment) during 20 d of summer.

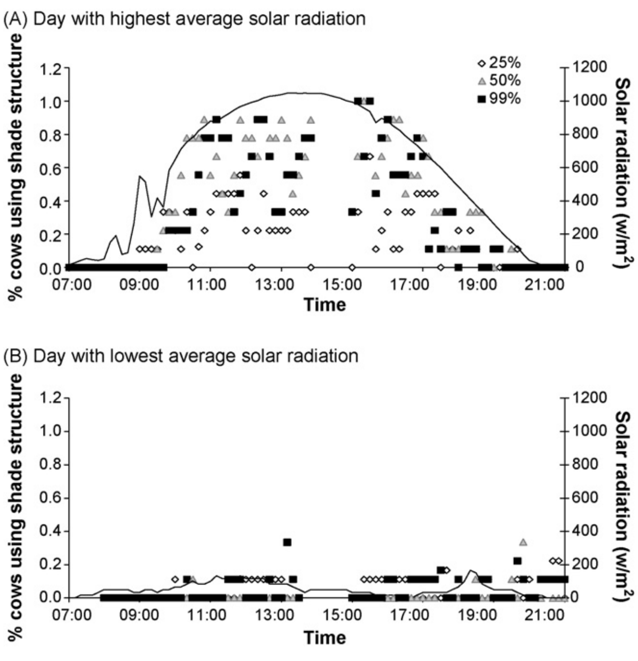

Fig. 3. Percentage of cows ($n = 9$ groups, 3 cows per group) using shade structures on the day with the highest (panel A) or lowest (panel B) average ambient solar radiation. Dairy cows had access to shade structures that blocked 25, 50, or 99% of solar radiation in summer. Solar radiation (—) is plotted on the second *y*-axis. In this figure, total shade use (at least 1 hoof directly under or in the shadow cast by the shade structure) is presented.

Table 4
Average mean (24 h, day-time, night-time and 24-h mean), minimum and maximum body temperature of dairy cows ($n = 12$ groups, 3 groups per treatment) in response to cooling treatments provided at pasture in summer. The earliest time that minimum and maximum body temperatures occurred in 24-h periods are also reported

Variable	Shade level				S.E.M.	*P*-value	
	No shade	25%	50%	99%		Treatment	Treatment × coat colour
Mean							
24 h (°C)	38.6	38.6	38.6	38.5	0.06	0.512	0.746
Day-time (°C in 15.5 h daylight)	38.7	38.7	38.7	38.6	0.07	0.576	0.450
Night-time (°C in 8.5 h darkness)	38.4	38.4	38.5	38.4	0.05	0.378	0.717
Minimum							
24 h (°C)	37.9	37.9	37.9	37.7	0.05	0.004	0.081
Time of minimum	08:28	07:34	07:57	07:54	00:36	0.882	0.938
Maximum							
24 h (°C)	39.5	39.5	39.5	39.5	0.12	0.807	0.225
Time of maximum	16:03	16:03	15:58	16:00	00:16	0.897	0.877

Treatments included access to shade structures that blocked 25, 50, or 99% of solar radiation or no shade. Coat colour was categorized as predominantly white, predominantly black, or black and white and these categories were balanced across treatment. *P*-values are presented for the linear effect of treatment and the interaction between treatment and coat colour.

increased, cows spent less time lying and grazing and more time standing, regardless of treatment ($P_{binomal} \leq 0.004$).

3.3. Body temperature

Cows with more protection from solar radiation had lower minimum body temperature ($P_{linear} = 0.004$; Table 4). Cows with access to the 99% treatment had a minimum temperature of 37.7 °C while cows in the no-shade treatment had a minimum temperature of 37.9 °C. There was no evidence that the treatments influenced the diurnal rhythm of the body temperature: the timing of both minimum and maximum body temperature was similar between treatments and there was no difference in the amplitude of these curves ($P_{linear} = 0.434$). There were also no treatment differences in the mean or maximum body temperatures during the day-time, night-time or over a 24-h period ($P_{linear} \geq 0.378$; Table 4). We expected the greatest treatment differences in body temperature during the period between milkings (10:00–14:00). There were, however, no treatment differences in the mean body temperature between milkings (no shade: 38.6 °C, 25%: 38.6 °C, 50%: 38.5 °C, 99%: 38.5 °C, S.E.M.: 0.06 °C; $P_{linear} = 0.263$).

As average daily ambient solar radiation increased, average body temperature increased (33 of 36 cows had a positive relationship between solar radiation and mean body temperature over 24 h, $P_{binomal} < 0.001$). This pattern was also apparent for body temperature between milkings (10:00–14:00; $P_{binomal} = 0.029$), during the day-time ($P_{binomal} < 0.001$), maximum ($P_{binomal} < 0.001$) and minimum ($P_{binomal} < 0.001$) body temperature. Coat colour influenced the relationship between ambient conditions and body temperature. For example, white cows had a smaller increase in maximum body temperature at higher levels of HLI, compared to black or black or black and white cows ($P = 0.024$, Fig. 4). However, this response was only associated with HLI, not THI or solar radiation ($P \geq 0.113$ for the latter two weather variables).

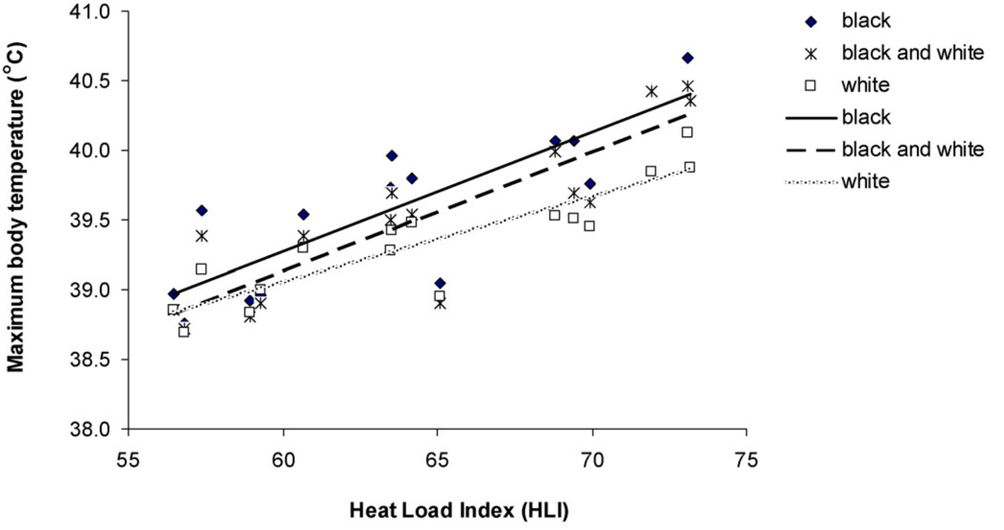

Fig. 4. Maximum body temperature (°C) in relation to average HLI (heat load index). Pastured dairy cows were categorized as predominantly black, white or black and white ($n = 12$, 3 cows per group, 1 of each coat colour) and body temperature was monitored during 16 days of the experiment in summer. Daily averages and trend lines are shown for each coat colour.

4. Discussion

Cows were more likely to use shade that provided more protection from solar radiation. These differences were likely due to the cooler microclimates created by this additional protection from solar radiation. Our results agree with the short-term preferences shown by beef cattle for shade that blocked more solar radiation (Bennett et al., 1984/1985). In addition, the total amount of time spent in the shade was similar to other studies with pastured cattle (1–3 h per d, e.g. Bennett et al., 1984/1985; Widowski, 2001). In this experiment, coat colour influenced the behavioural response to treatments. Cows with a predominantly black coat used the 99% treatment less than cows with either predominantly white or black and white coats, in contrast to our prediction that black cows would spend more time in the shade. We speculate that this result could be due to differences in the effectiveness of the shade for cooling black cows. Cows with dark coloured coats both absorb more solar radiation and have higher rates of heat loss than cattle with light coloured coats (Finch and Western, 1977; da Silva et al., 2003; Maia et al., 2005). Because of these differences, it is possible that the patterns of shade use differed with coat colour. For example, black cows may have visited the shade more often, but stayed for a shorter period of time than white cows. Unfortunately, the sampling method we used to estimate the time spent in the shade, instantaneous scans every 10 min, was too infrequent to calculate the number of visits to the shade structures. Alternatively, cows with predominantly white coats may be more motivated to seek shade than their darker counterparts, perhaps to avoid sunburn.

Standing was the most common behaviour performed under or in the shadow cast by the structures, although cows also spent a small amount of time lying and grazing in this area. There were no differences, however, in the overall activity patterns (lying, standing and grazing) of cows with access to shade of various levels of solar radiation during the day-time, night-time or over 24 h. These results differ from previous work that found that cattle shifted their time budgets in order to use shade (shade cloth that blocked > 93% of solar radiation) during the day and spent more time grazing at night (Kendall et al., 2006). Low grass quality or availability may affect how cows make the trade-off between shade use and grazing. In our study, cows had ad libitum access to high-quality grass and may have been able to meet their metabolic needs by grazing in the mornings and evenings.

The pattern of increasing shade use with more protection from solar radiation occurred regardless of method of measuring shade use (standing in shadow cast by the structure, standing directly under the structure or a combination of these 2 measures). Previous papers have measured shade use by recording if any part of the body was in shade (e.g. ‘‘50% body in shade’’, Kendall et al., 2006). We had several concerns about this definition of shade use. Firstly, estimates of the percentage of body in shade could be affected by coat colour, as it would be more difficult to distinguish the outline of the shadow on a black cow compared to a white cow. We also doubted our ability to reliably assess 50% of the cows' surface area. To address these concerns, we measured the location of the hooves in relation to shade and the shade structure, rather than the overall body. Secondly, measuring the time spent in the shadow cast by the structure could underestimate shade use when shade was not readily distinguished, as was the case in 76% of our observations. The differences between treatments, however, were readily characterised by both of our measures of shade use. As we expected, the estimates of shade use were slightly higher when based on time spent underneath the structure, as this definition could be applied regardless of the visibility of shadow cast by the structure. The time spent under the structure was also a valuable measurement because we could estimate the amount of time spent in the area comparable to the shaded sections in the no-shade treatment (about 20 min/d).

Weather conditions influenced activity patterns and shade use. As weather became warmer (HLI increased) cows spent less time lying and grazing, in agreement with previous research (Overton et al., 2002; Wagner-Storch et al., 2003; Zähner et al., 2004). Also, as HLI increased, cows had higher maximum body temperature, especially if they were black or black and white. These differences associated with coat colour were in line with our predictions that darker cows would absorb more heat. However, this response was only associated with HLI, not THI or solar radiation. It is unclear why only HLI would influence the body temperature of darker cows, particularly when no other behaviours (time spent lying, standing or grazing) were influenced by coat colour in this manner. As average ambient solar radiation increased, shade use increased in all treatments. Others have also found that shade use increased as ambient temperature, THI or HLI increased (e.g. Brown-Brandl et al., 2005; Kendall et al., 2006). Previous research has identified thresholds for heat stress in dairy cattle based on reduction in milk production (e.g. heat stress occurs over THI = 72, Ravagnolo and Misztal, 2002). However, there is a growing body of evidence that providing shade or other methods of cooling is beneficial for cattle based on changes in respiration rate and body temperature. Work by Kendall and others suggests that shade and other cooling methods reduce respiration rate and body temperature at thresholds lower than those based on milk production, THI > 69 or HLI > 77 (Kendall et al., 2007). In addition, provision of shade effectively reduced rectal temperature of beef cattle when HLI exceeded 78 (Gaughan et al., 2004). In our current experiment, shade use was apparent even on days when ambient levels of solar radiation were low, indicating that shade is likely to be an important resource on most summer days. Indeed, treatment differences were apparent on all days except the coolest and wettest day of the experiment when average solar radiation was 48 W/m^2.

In addition to variation of shade use between days, cows were more likely to use the shade when solar radiation levels were highest within a day. In our study, on the day with the highest level of ambient solar radiation, shade use began around 10:00 and started to decline around 18:00. Because shade use is concentrated at specific times of day, it is important that all cows have simultaneous access to this resource. We provided 2 shade structures per group of 3 cows because, at times, 1 cow would defend a single structure and not allow other cows to use it. Although this experiment was not explicitly designed to answer questions about group size and amount of shade, these limitations clearly influence the ability to access shade at the appropriate time. Further research into the questions of shade quantity for a given group size is required.

We had predicted that body temperature between milkings would be lower with more protection from solar radiation, based on differences reported in previous literature (Muller et al., 1994b; Kendall et al., 2006). However, we found no treatment differences in body temperature between milkings, averages over a 24-h period or maximum temperature. We also found no evidence of phase shifts or changes in the amplitude of the diurnal rhythm of body temperature, in agreement with previous research on pastured dairy cows (Kendall et al., 2006). Previous research indicated that cows with access to shade had lower afternoon body temperature than cows without shade on warmer days (Kendall et al., 2006); the weather during our experiment may have been relatively mild compared to other studies. Indeed, other studies have also found no differences in average body temperature even when shade is readily used and weather conditions were between 21 and 27 °C (Mitlöhner et al., 2001). We did, however, find lower minimum body temperature with higher levels of protection from solar radiation, particularly with the 99% treatment. Other authors have reported no differences in average body temperature, but have reported lower minimum temperatures in shaded cattle when THI levels were below 74 (Brown-Brandl et al., 2005). We speculate that cows without access to effective shade were able to prevent their day-time body temperature from rising with other cooling methods (e.g. evaporative, drinking). Perhaps cows that were able to use shade to regulate body temperature during the day had greater energy for cooling at night, thus resulting in lower minimum temperatures in the early morning. Regardless, in the current study, the mechanisms underlying the differences in lower minimum body temperature between treatments remain unclear. We recommend that future studies include respiration rate as a dependent variable as it is a more sensitive indicator of heat stress than body temperature (Brown-Brandl et al., 2005).

5. Conclusions

Cows were more likely to use shade that provided more protection from solar radiation in summer conditions. Cattle were more than twice as likely to use shade that provided 99% compared to 25% protection from solar radiation. We found a positive relationship between shade use and ambient solar radiation in all treatments, especially the 50 and 99% treatments. Shade use occurred even on days with relatively low levels of solar radiation, indicating that shade should be provided on most summer days. Similarly, shade use in all treatments peaked during hours of the day when solar radiation was highest, highlighting the importance of providing enough shade for all cows to simultaneously access this resource. Cows provided with more protection from solar radiation had lower minimum body temperature and had less marked increases in average body temperature on days with higher levels of ambient solar radiation. Together, these results demonstrate that protection from solar radiation is an important design feature of effective shade.

Acknowledgements

The authors gratefully acknowledge the technical assistance from AgResearch staff: Tania Blackmore, Kaye Bremner, Kate Brown, Jennie Burke, Katie Carnie, Daniel Cullen, Antonia Davies, Debbie Davison, Suzanne Dowling, Cara Hansen, Frankie Huddart, Paul Kendall, Dai Morgan, Gavin Ng, Kim Preston, Renee Railton, Sally Robinson, Haley Shepherd, Helen Simons and Ananda Wickramasuriya. We also thank the staff at AgResearch No. 1 and 2 Dairies, Ron Clarke, Bob Smith and Kevin Orr. This work would not have been possible without funding from Dairy InSight and the Foundation for Research, Science and Technology.

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