Effect of shade on body temperature and performance of feedlot steers[1]

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ABSTRACT: A 120-d feedlot study using 164 Angus steers (BW = 396.7 ± 7.0 kg) was undertaken in Queensland Australia (24°84′ S, 149°78′ N) to determine the effect of shade on body temperature (T_B) and performance. Cattle were allocated to 20 pens: 16 with an area of 144 m^2 (8 steers/pen) and 4 with an area of 168 m^2 (9 steers/pen). Treatments (10 pens/treatment) were unshaded (NS) vs. shaded (SH). Shade (3.3 m^2/steer) was provided by 80% solar block shade cloth. Before the study (d −31), 63 steers were implanted (between the internal abdominal muscle and the peritoneum at the right side flank) with a T_B transmitter. Within each pen, 3 steers had a T_B transmitter. Individual T_B was obtained every 30 min. The cattle were fed a feedlot diet and had ad libitum access to water. Water usage and DMI were recorded daily on a pen basis. Average daily gain and G:F were calculated on a pen basis. Climatic variables were obtained from an on-site weather station every 30 min. Individual panting scores (PS) were obtained daily at 0600, 1200, and 1600 h. From these, mean PS (MPS) were calculated for each pen. At slaughter (d 121), individual HCW, loin muscle area (LMA), rump fat depth (P8), 12th-rib fat depth, and marbling score were obtained. Mean T_B was not affected ($P > 0.05$) by treatment (SH = 39.58°C; NS = 39.60°C). However, during a 21-d heat wave when cattle were exposed to a mean ambient temperature (T_{AM}) > 30°C for 8 h each d (T_{AM} between 0800 and 1800 h = 29.7°C, and 23.4°C between 1830 and 0730 h), the T_B of SH steers (40.41 ± 0.10°C) was less ($P < 0.01$) than the T_B of NS steers (41.14 ± 0.10°C). During this period, pen-MPS were greater ($P < 0.05$) for the NS cattle at all observation times. Over the first 6 d of the heat wave, MPS of NS steers at 1200 h was 2.47 ($P < 0.01$) vs. 1.39 for SH steers. Hip height, DMI, ADG, and G:F were greater ($P < 0.05$) for SH cattle. Exit BW (final BW) of SH steers (596.1 kg) was greater ($P < 0.05$) when compared with NS steers (578.6 kg). During the heat wave, DMI was 51% less for NS steers and 39% less for SH steers when compared with the pre-heat wave period ($P < 0.01$). The HCW of SH steers (315.4 ± 0.8 kg) was greater ($P < 0.05$) than for NS steers (321.4 ± 0.8 kg). No treatment differences ($P > 0.05$) were found for LMA, P8, or marbling score. Access to shade improved ($P < 0.05$) ADG and G:F, increased HCW, and decreased MPS; however, shade did not completely eliminate the impact of high heat load.

Key words: body temperature, *Bos taurus*, shade

J. Anim. Sci. 2010. 88:4056–4067
doi:10.2527/jas.2010-2987

INTRODUCTION

Temperate regions experience climatic conditions that at times may be stressful to *Bos taurus* cattle. Combinations of increased temperature, humidity, solar load, and low air movement can exceed the ability of an animal to cope, resulting in a loss of productivity and sometimes death (Lefcourt and Adams, 1996; Hahn and Mader, 1997). Shade ameliorates heat load of cattle (Bond et al., 1967; Valtorta et al., 1997; Gaughan et al., 1998; Brown-Brandl et al., 2005) and reduces mortality in extreme weather events (Busby and Loy, 1996; Entwistle et al., 2000); however, production results have been inconsistent. Mitlöhner et al. (2002) reported that ADG, DMI, and final BW were greater for shaded cattle than for unshaded cattle. In contrast,

[1]This study was funded by Meat & Livestock Australia P/L, Nth Sydney, New South Wales, Australia. The authors acknowledge the contribution of R. Howard, S. Fardell, R. Englebright, and the staff of Brigalow Research Station (Theodore, Australia) and Oakey Abattoir (Oakey, Australia).
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Received March 15, 2010.
Accepted August 10, 2010.

Clarke and Kelly (1996) reported that providing shade did not improve DMI, ADG, G:F, or carcass quality of feedlot cattle. Mader et al. (1997) and Brown-Brandl et al. (2005) reported inconsistent DMI for cattle with or without access to shade. Reductions in body temperature (**T_B**), respiration rate, and reduced incidence of open-mouthed breathing have been reported when shade is available (Valtorta et al., 1997; Mader et al., 1997, 1999a; Gaughan et al., 2004; Brown-Brandl et al., 2005).

Body temperature is a method of assessing the physiological response of an animal to the climatic environment, especially when cattle are exposed to hot conditions. Studies have been undertaken where T_B was obtained from cattle over a short time period (usually less than 10 d; Davis et al., 2003; Mader and Kreikemeier, 2006; Gaughan et al., 2009a), with very few studies undertaken in which T_B has been obtained over longer periods (Lefcourt and Adams, 1996; Brown-Brandl et al., 2005). There is a need to further explore T_B dynamics over periods longer than a few days.

The objective of this study was to investigate the effect of shade on performance, T_B, carcass characteristics, and welfare of feedlot steers in a subtropical environment during summer.

MATERIALS AND METHODS

The study was undertaken in Central Queensland, Australia, at the Queensland Department of Primary Industry and Fisheries (**DPI&F**) Brigalow Research Station feedlot (latitude 24°84′ S, longitude 149°78′ E, and 168 m above mean sea level), with the approval of the Queensland DPI&F Animal Ethics Committee.

The Central Queensland climate is classified as subtropical, with long-term ambient temperature averages for the months of the study (November to March; Australian summer) ranging from 31.6 to 33.7°C (maximum), and 17.7 to 21.0°C (minimum). Temperatures in excess of 39°C are not uncommon at this location during the summer. The long-term average rainfall at this location, for the period November to March, is 424.7 mm. The location of the study was selected on the basis that there was an increased probability that climatic conditions encountered would induce a heat stress response in *B. taurus* cattle.

One hundred sixty-four Angus steers, 12 to 15 mo of age (BW = 396.7 ± 7.0 kg), were used in a 120-d study to determine the effect of feedlot shade on T_B and performance. Cattle were obtained from a temperate region in southern New South Wales, Australia, and relocated to Central Queensland for the study; thus, they were not adapted to a subtropical climate.

Feedlot Description

Twenty earthen-floored pens with a north-south alignment were used. Sixteen pens had an area of 144 m^2 (**A-Pens**), and 4 pens had an area of 168 m^2 (**B-Pens**). The earthen floor had a 2% slope from the feed bunk (eastern end) to the rear of the pen (western end). Concrete feed bunks with a 3-m concrete apron were located at the front of each pen. Linear feed bunk and water trough space/steer were 583 and 279 mm/steer, respectively. The water trough was located at the rear of each pen. The stocking rate for the A-Pens was 18.0 m^2 (8 steers/pen) and 18.7 m^2 (9 steers/pen) for the B-Pens. Shade was provided in 8 of the A-Pens and 2 of the B-Pens. The shade (3.3 m^2 of shade available/animal at 1200 h) was provided by 80% solar block-out black shade cloth (Darling Downs Tarpaulins, Toowoomba, Australia). For the 8 shaded A-Pens, the shade was located 8.4 m from the front of the pen and covered an area of 7.4 m (width of pen) × 3.6 m, at a height of 4 m. In the 2 shaded B-Pens, the shade was located 8.4 m from the front of the pen and covered an area of 7.0 m (width of pen) × 4.2 m, at a height of 4 m. Due to the layout of the feedlot, pens were blocked (see Statistical Analysis below) so that there were 4 concurrent shaded pens (southern end of feedlot), then 4 concurrent unshaded pens, then 4 concurrent shaded pens, then 4 concurrent unshaded pens, and finally 2 shaded pens and 2 unshaded (northern end of feedlot). Previous observations of shade movement within the feedlot suggested that there would be no movement of shade from the shade structure over the shaded pens into the unshaded pens for the hottest months (December, January, and February). There was a possibility of minimal (<1.0 m) shade incursion into the NS pens in early November, at approximately 0600 h for 15 min and 1800 h for 15 min, and late March at approximately 0700 h for 20 min and at 1730 h for 20 min. This was monitored throughout the study.

Diets and Feeding

The diets used are presented in Table 1. Feed bunks were monitored at 1200 h each day using a modified "clean bunk at midday" feed intake management program (Lawrence, 1998). After a rainfall, wet feed was removed, weighed, and DM determined. The calculated dry weight was then subtracted from the weight of feed offered.

A starter diet was fed on d 0 to 3. An intermediate 1 diet was fed for 7 d, an intermediate 2 diet was fed for 6 d, and a finisher diet was fed for the remainder of the study.

Diet and refusal samples were air-dried subsamples ground to 1 mm, and DM was determined. Daily pen water usage was obtained using in-line water meters. In addition, rainfall and estimated evaporation from water troughs was accounted for each day, and these values were added to or subtracted from the meter reading.

Climatic Data

Climatic data were collected at 30-min intervals using an automated weather station (Easidata Mk 4, En-

Table 1. Composition of the 4 diets used in the study

Item	Starter	Intermediate 1	Intermediate 2	Finisher
Ingredient, kg/t (as-fed)				
Wheat, dry rolled	450	540	625	700
Molasses, cane	125	100	60	30
Cottonseed meal, solvent	55	55	25	—
Cottonseed high lint	70	80	80	90
Wheat straw	85	85	50	25
Sorghum silage	70	110	110	90
Alfalfa hay	120	—	—	—
Vegetable oil	—	—	10	20
Protein-mineral supplement[1]	25	30	40	45
Nutrient content (DM basis)				
NE_g, Mcal/kg	1.18	1.26	1.35	1.44
CP,%	14.3	13.9	13.5	13.2
Fat, %	3.42	3.67	4.85	6.18
Ca, %	0.78	0.69	0.80	0.83
P, %	0.40	0.42	0.42	0.42
NaCl, %	0.11	0.14	0.18	0.20
S, %	0.28	0.26	0.26	0.25
K, %	1.38	1.10	0.88	0.71
Monensin,[2] g/t	12.4	15.2	20.1	22.2

[1]Contained on a DM basis: 42.6% CP; 7,7423.3 IU/kg of vitamin A; 193.6 IU/kg of vitamin E; 14.4% Ca; 0.40% P; 3.91% salt; 0.72% K; 1.85% S; 0.81% Mg; 618.67 mg/kg of Zn; 1361.91 mg/kg of Fe; 139.92 mg/kg of Cu.

[2]Elanco Animal Health, West Ryde, Australia.

virondata, Warwick, Queensland, Australia) located 15 m behind (western side) the feedlot. The data collected were ambient temperature (**T_A**, °C), relative humidity (**RH**; %), wind speed (**WS**; $m{\cdot}s^{-1}$), wind direction, solar radiation ($w{\cdot}m^{-2}$), black-globe temperature (**BG**; °C), and daily rainfall (mm). From these data, the heat load index (**HLI),** which is an indicator of the environmental thermal load at any point in time, and the accumulated heat load units (**AHL**), which is an indicator of the accumulated thermal load on the animal, were calculated (Gaughan et al., 2008). The HLI consists of 2 parts based on a BG threshold of 25°C: $HLI_{BG > 25} = 8.62 + (0.38{\cdot}RH) + (1.55{\cdot}BG) - (0.5{\cdot}WS) + [e^{(2.4 - WS)}]$, and $HLI_{BG < 25} = 10.66 + (0.28{\cdot}RH) + (1.3{\cdot}BG) - WS$; where e = the base of the natural logarithm (approximate value of e = 2.71828). The interrelationship between HLI and AHL was determined by categorizing the HLI × AHL interaction into the following stress categories: low (HLI <70 and AHL <10), mild (HLI 70.1 to 77.0 and AHL 10.1 to 25.0), moderate (HLI 77.1 to 86.0 and AHL 25.1 to 50), severe (HLI 86.1 to 95.0 and AHL 50.1 to 100), and extreme (HLI >96 and AHL >100). The temperature humidity index (**THI**; $THI = (0.8{\cdot}T_A) + [(RH{\cdot}0.01){\cdot}(T_A - 14.4)] + 46.4$) was also calculated (modified from Thom, 1959) using the weather station data.

Animal Data

Thirty-three days before the study, rectal temperature, nonfasted BW, and hip height were obtained from 177 Angus steers. The steers were ranked by BW and rectal temperature with 10 outliers being removed due to increased rectal temperature. From the remaining 167 steers, 63 were randomly selected for surgical implantation of temperature transmitters. Three of the steers intended for surgery were to be used as spares in case a transmitter failed after surgery. These 3 steers remained within the selected group, but were removed from the study at induction.

Steers were vaccinated against tick fever (*Babesia bovis*, *Babesia bigemina*, and *Anaplasma marginale*; trivalent vaccine, Tick Fever Research Centre, Wacol, Queensland, Australia), bovine ephemeral fever (genus *Ephemerovirus*; Webster's Bovine Ephemeral Fever Vaccine – Live, Fort Dodge Australia P/L, Baulkham Hills, New South Wales, Australia), type C and D botulism (*Clostridium botulinum*; Longrange Botulinum Vaccine; Pfizer Australia P/L, West Ryde, New South Wales, Australia), and treated for internal and external parasites (Cydectin; Fort Dodge Australia P/L). Hormonal growth promotants were not used before or during the study.

Thirty-one days before trial initiation, 63 steers were surgically implanted [between the internal abdominal (abdominal oblique) muscle layer and the peritoneum at the right side flank] with a digital T_B transmitter (Sirtrack Ltd., Havelock North, New Zealand), which was sealed in an epoxy resin. After surgery the cattle were maintained in a grassed paddock and were inspected daily for any signs of ill health.

Before implantation, each transmitter was calibrated to a set temperature (40°C). Each transmitter (30 mm in diameter × 95 mm long) operated on a different radio frequency (150.10 to 151.36 MHz). Transmissions were detected and logged onto a radio receiver (TR-5

Receiver, Telonics, Mesa, AZ) that was programmed to acquire T_B data from each transmitter at 30-min intervals on a 24-h cycle. At the end of each 24-h cycle, temperature acquisitions from each transmitter were downloaded. Each transmitter was stopped for approximately 10 min while data were downloaded to a computer (TR-5 interface software; Telonics). After data downloads, T_B acquisition recommenced for the next 24-h period. This cycle continued for the duration of the study.

On d −1 the steers were moved from the paddock to the feedlot. Nonfasted BW, T_B, hip height, and BCS were obtained for each animal. On d 0 the steers were re-weighed, and an average BW determined from the d −1 BW and the d 0 BW. From within the 2 groups (63 steers with transmitters and 104 steers without transmittters), steers were randomly allocated to pen and treatment based on stratification of the average BW. There were 3 steers with transmitters in each pen. The 3 spare transmitter steers were removed from the study but were retained in the feedlot.

The cattle were weighed (nonfasted) at approximately 0900 h on feedlot induction (d 0), and then at d 30, 60, 90, 110, and 120 (exit). At each weighing, BCS was determined using a 1-to-9 scale (Herd and Sprott, 1996). Hip height was determined visually using a measuring grid (25-mm increments) attached to the inside of the scale. Also, the relationship between T_B, as measured by the digital T_B transmitters, vs. rectal temperature was determined by measuring rectal temperature of the 60 steers with temperature transmitters on d 30, 60, and 110.

Individual panting scores were collected daily at approximately 0600, 1200, and 1600 h using the method of Mader et al. (2006). Panting score is a visual method (0 = no panting to 4 = excessive drooling, high respiration rate, open mouth, tongue out) used to assess the heat load status of cattle (Mader et al., 2006; Gaughan et al., 2008). Each animal was assessed and a mean panting score (**MPS**) was calculated for each pen for each observation time. Individuals with a panting score $\geq$2 were deemed to be heat stressed; those with scores 3 or 4 are considered to be under severe heat stress. Mean panting scores are categorized as follows: 0 to 0.4, minimal heat load; 0.4 to 0.8, moderate heat load; 0.8 to 1.2, high heat load; >1.2, extreme heat load.

At slaughter (d 121), HCW (kg), loin muscle area (**LMA**, cm^2), rump fat depth (**P8**, mm), fat depth on 12th rib, and USDA marbling score were obtained for each animal. The P8 fat depth was obtained by measuring the amount of fat over the gluteus muscle on the rump. The site is located at the intersection of a line through the pin bone parallel to the chine and is perpendicular through the third sacral crest (Reverter et al., 2000). Dressing percentage was calculated using the final BW obtained on d 120 and HCW obtained on d 121.

Statistical Analysis

Data were analyzed on the basis of the whole study (120 d), and also for a 21-d increased heat load period (d 71 to 91). The same models were used for the analysis of the data for the whole study and the increased heat load period. Pens were considered the experimental unit. All treatment effects (α = 0.05) were evaluated against a pen level variance term rather than an animal level sampling term.

The potential effects of the small amount of shade entering some of the unshaded pens and pen-arrangement block on feed efficiency, ADG, T_B, mean panting score, and carcass data were estimated allowing for differences in stocking density between A-Pens and B-Pens. There were no pen or block pen effects detected.

Dry matter intake and water usage were analyzed using a repeated measures model. The model included the effects of treatment (shaded, unshaded), day, and the interaction of day × treatment as fixed effects, with pen as a random effect.

Body temperature and mean panting score were analyzed using a repeated measures model (PROC MIXED, SAS Inst. Inc., Cary, NC) using REML estimation. The model included treatment (shaded, unshaded), observation time (0600, 1200, 1400 h), day, and the interaction of day × observation time as fixed effects, with animal included as a random effect. The model was run twice. For the first time the model was run, the specific term for the repeated measure was observation time, and for the second the specific term was day. Least squares means were estimated for the various treatment effects. In addition, residual diagnostics were examined, and the results for both the mean panting score and the average angular transformed panting score were compared.

Carcass data (HCW, LMA, P8 fat depth, marbling score, dressing percentage) and G:F were analyzed with ANOVA procedures (PROC GLM) appropriate for a completely random design. Independent variables were shade treatment and final BW. Least squares means were estimated for treatment effects. In addition, estimates and SE were derived for the average change due to shade. Means were separated using Tukey's Studentized range test.

RESULTS

Shade

Because there were no pen effects (P > 0.05) apart from shade or no shade, it is unlikely that the small amount of shade that was available in the unshaded pens for a few days at the start and end of the study had any impact on the results. In any case, it is impossible to fully remove shade from the pens. Cattle in the unshaded pens were observed accessing shade from other animals, the water trough, and fence posts throughout the study.

Table 2. The mean, maximum, and minimum values for ambient temperature (T_A, °C), black globe temperature (BG, °C), relative humidity (RH, %), heat load index (HLI), and temperature humidity index (THI) for the months of November to March

Item	Ambient temperature, °C	Black globe temperature, °C	Relative humidity, %	HLI[1]	THI[2]
November[3]					
Mean	23.9	26.9	58.4	67.7	71.1
Maximum	34.2	44.4	94.0	92.4	92.4
Minimum	14.4	13.3	23.0	48.6	54.9
December					
Mean	26.7	28.6	62.7	72.4	73.3
Maximum	35.1	47.4	96.0	100.4	81.9
Minimum	16.5	15.4	30.0	50.8	61.4
January					
Mean	25.6	28.5	69.0	74.2	74.1
Maximum	36.7	48.5	96.1	104.7	83.2
Minimum	18.3	17.6	30.0	56.0	64.7
February					
Mean	24.9	27.5	68.9	71.9	72.8
Maximum	38.7	50.9	97.0	105.7	84.5
Minimum	17.1	16.1	24.0	48.9	61.9
March[4]					
Mean	22.9	25.6	57.8	64.6	68.8
Maximum	31.3	41.3	93.0	89.9	77.1
Minimum	14.0	13.0	24.0	46.6	57.7

[1]$HLI_{BG > 25} = 8.62 + (0.38 \cdot RH) + (1.55 \cdot BG) - (0.5 \cdot WS) + [e^{(2.4 - WS)}]$, and $HLI_{BG < 25} = 10.66 + (0.28 \cdot RH) + (1.3 \cdot BG) - WS$, where WS = wind speed (m/s) and e = the base of the natural logarithm (approximate value of e = 2.71828).

[2]$THI = (0.8 \cdot T_A) + [(RH \cdot 0.01) \cdot (T_A - 14.4)] + 46.4$.

[3]Weather data collection commenced on November 13 at 0630 h.

[4]Weather data collection terminated on March 11 at 1200 h.

Relationship Between Body Temperature and Rectal Temperature

The T_B transmitters recorded greater ($P > 0.05$) temperatures compared with rectal temperatures. The mean differences (±SE) were d 30: 0.38 ± 0.03°C, r = 0.87; d 60: 0.38 ± 0.02°C, r = 0.90; d 110: 0.43 ± 0.03°C, r = 0.92. These data show that the differences between rectal temperature and T_B, as measured by the digital temperature transmitters, were consistent and repeatable.

Climatic Conditions

The summarized climatic data, HLI, and THI for the study period, are presented in Table 2. The greatest T_A recorded during each month was 34.2, 35.1, 36.7, 38.7, and 31.3°C for November, December, January, February, and March, respectively. Maximum T_A exceeded 30°C on d 74 of the 120-d study and exceeded 35°C on d 6. Maximum BG ranged from 41.3 to 50.9°C. Rainfall (≥0.2 mm) was recorded on d 44. Rainfall totals and the number of days per month when rain fell were 36.2 mm and 5 d, 103.0 mm and 10 d, 136.8 mm and 15 d, 96.6 mm and 13 d, and 0.8 mm and 1 d for November, December, January, February, and March, respectively. The greatest HLI and THI were recorded in February (105.7 and 84.5 units, respectively). The HLI ranged from 46.6 to 105.7 units and THI from 57.7 to 84.5 units over the duration of the study.

A 21-d period of increased heat load (d 71 to 91) induced significant heat stress in the cattle. Cattle were exposed to ambient temperatures in excess of 30°C for 8 to 10 h each day during the heat wave. The mean ambient temperature for the 21-d period was 29.7°C between 0800 h and 1800 h, and 23.4°C between 1830 h and 0730 h. Thus, there was only minimal nighttime cooling. Climatic data for this period are presented in Table 3. Generally the AHL returned to 0 each night and remained at 0 for at least 6 h. The exception was for d 74 and 75 where AHL was 0 for only 1 h (0600 to 0700 h; d 75). Cattle were therefore exposed to 39.5 h of continuous heat stress (0730 h on d 74 to 2300 h on d 75). Over a 9-h period on d 74, the mean HLI was 102.6 units, and the mean AHL was 81.3 units (severe category). The maximum AHL was 105.8 units on d 74 and 67.4 on d 75. The maximum HLI on d 74 was 102.8 and the maximum THI was 80.8. On d 75, BG increased from 22.7°C at 0600 h to 47.2°C by 1100 h; this was the largest increase per unit of time in BG encountered during the study. The effect of this increased solar load was reflected in the maximum HLI and the AHL, but not in the THI. During the 21-d period, the steers were exposed to moderate to severe conditions for 7 to 8 h each day based on the HLI × AHL categorization. The extreme categorization was not reached at any time during the study. The heat wave ended during the evening of d 91. A frontal system moved through from the west at approximately 1800 h. This was followed by an 8°C drop in T_B over a 2-h period. The abatement of the

Table 3. The mean, maximum, and minimum values for ambient temperature (T_A, °C), black globe temperature (BG, °C), relative humidity (RH, %), heat load index (HLI), the accumulated heat load (AHL), and temperature humidity index (THI) for d 66 to 100

Item	Ambient temperature, °C	Black globe temperature, °C	Relative humidity, %	HLI[1]	AHL[2]	THI[3]
d 66 to 70						
Mean	24.8	27.3	76.5	74.5	18.2	73.8
Maximum	31.9	45.4	96.0	104.7	99.6	80.1
Minimum	21.0	20.4	44.0	58.8	0	69.5
d 71 to 76						
Mean	26.2	30.3	62.5	75.8	24.4	74.0
Maximum	35.0	47.2	90.0	102.8	105.8	80.8
Minimum	19.2	18.0	30.0	57.1	0	65.8
d 77 to 91						
Mean	25.8	28.9	66.9	74.2	12.6	74.1
Maximum	34.4	47.5	97.0	105.7	73.2	82.1
Minimum	17.1	16.1	29.0	48.9	0	61.9
d 92 to 100						
Mean	23.9	25.8	72.9	69.6	5.1	71.9
Maximum	34.7	46.7	95.0	101.9	100.6	80.3
Minimum	17.4	16.4	30.0	55.2	0	63.0

[1]$HLI_{BG > 25} = 8.62 + (0.38 \cdot RH) + (1.55 \cdot BG) - (0.5 \cdot WS) + [e^{(2.4 - WS)}]$, and $HLI_{BG < 25} = 10.66 + (0.28 \cdot RH) + (1.3 \cdot BG) - WS$, where WS = wind speed (m/s) and e = the base of the natural logarithm (approximate value of e = 2.71828).

[2]AHL = accumulated heat load (Gaughan et al., 2008).

[3]$THI = (0.8 \cdot T_A) + [(RH \cdot 0.01) \cdot (T_A - 14.4)] + 46.4$.

hot conditions was reinforced by 22 mm of rainfall on d 92, followed by an additional 15.6 mm on d 93.

Body Temperature

There were no rectal temperature differences ($P > 0.05$) between the shaded (39.7 ± 0.1°C) and unshaded (39.7 ± 0.1°C) cattle on d 0. Over the duration of the study, there were no differences ($P > 0.05$) in T_B between shaded and unshaded steers (39.58 ± 0.05°C and 39.60 ± 0.05°C, respectively). However, there were differences ($P < 0.01$) between shaded (1.20 ± 0.06°C) and unshaded steers (1.65 ± 0.06°C) in respect to the magnitude of change (i.e., the difference between maximum T_B and minimum T_B).

During the 21-d heat wave (d 71 to d 91), mean T_B (40.41 ± 0.10°C) of the shaded cattle was less ($P < 0.01$) than the unshaded cattle (41.14 ± 0.10°C), a difference of 0.73°C. The largest treatment differences for maximum T_B occurred on the first 2 d of the heat wave (Figure 1). The T_B of the unshaded cattle was 1.05 and 1.32°C greater ($P < 0.05$) than the shaded cattle on 71 and d 72, respectively. The only time that maximum T_B was not affected ($P > 0.05$) by treatment during this period was on d 87, which was characterized by cloud cover and light rain. Although the maximum T_B was greater for the unshaded steers during the heat wave, the minimum T_B for these steers (39.0 ± 0.07°C) tended to be less ($P > 0.10$) than the minimum for the shaded cattle (39.2 ± 0.07°C).

Table 4. Mean body temperature (°C) and mean panting score (MPS) of steers without access to shade (unshaded) and with access to shade (shaded) for d 66 to 100

Day (period)	Unshaded	Shaded	SEM	*P*-value
d 66 to 70 (5 d; period 1)[1]				
Body temperature, °C	39.77	39.83	0.06	0.24
MPS	1.03	0.95	0.06	0.04
d 71 to 76 (6 d; period 2)				
Body temperature, °C	41.48	40.52	0.10	0.01
MPS	2.47	1.39	0.08	0.001
d 77 to 91 (15 d; period 3)				
Body temperature, °C	41.01	40.37	0.10	0.01
MPS	1.99	1.88	0.08	0.001
d 92 to 100 (9 d; period 4)				
Body temperature, °C	39.97	39.95	0.07	0.16
MPS	1.33	1.07	0.09	0.001

[1]Periods means for body temperature and MPS differed ($P < 0.01$).

Table 5. Mean panting scores[1] at 0600 h (AM), 1200 h (MID), and 1600 h (PM)[2] for feedlot steers without access to shade (unshaded) and with access to shade (shaded), over 120 d on feed

		Mean panting score		
Period	Treatment	AM	MID	PM
d 0 to 30	Unshaded	0.82[a]	1.57[a]	0.96[a]
	Shaded	0.67[b]	1.15[b]	0.83[b]
	SEM	0.02	0.03	0.03
d 31 to 60	Unshaded	0.61[a]	1.61[a]	0.89[a]
	Shaded	0.54[b]	1.21[b]	0.75[b]
	SEM	0.02	0.03	0.03
d 61 to 90	Unshaded	0.60[a]	1.52[a]	0.77[a]
	Shaded	0.45[b]	1.04[b]	0.61[b]
	SEM	0.02	0.03	0.02
d 91 to 120	Unshaded	0.32[a]	1.42[a]	0.77[a]
	Shaded	0.22[b]	1.03[b]	0.62[b]
	SEM	0.01	0.02	0.02

[a,b]Within a column (i.e., within period), means without a common superscript differ ($P < 0.05$).
[1]Mean panting score = mean for all cattle within a treatment at a particular time over 120 d.
[2]Times are approximate (±15 min).

There were no differences ($P > 0.05$) between shaded and unshaded cattle for T_B over the 5 d (d 66 to 70) preceding the heat wave, or the 9 d (d 92 to 100) after the heat wave (Table 4). Over the first 6 d (d 71 to 76) of the heat wave, the T_B of the unshaded cattle was greater ($P < 0.01$) than the shaded cattle at 41.48 ± 0.1°C and 40.52 ± 0.10°C, respectively. Over the next 15 d (d 77 to 91), mean T_B of the unshaded cattle (41.01 ± 0.1°C) was greater ($P < 0.01$) than the T_B of the shaded cattle (40.37 ± 0.1°C; Table 4).

MPS

The MPS were greater ($P < 0.05$) for the unshaded cattle at the 3 daily observation times compared with the shaded cattle (Table 5). The largest differences were seen at 1200 h where the MPS of the unshaded cattle (1.53 ± 0.03) was greater ($P < 0.05$) compared with the shaded cattle (1.11 ± 0.02). At the 1200 h observation, the MPS of the unshaded cattle was in the extreme heat load category (MPS >1.2) for the periods d 0 to 30, d 31 to 60, d 61 to 90, and d 91 to 120. The MPS of the shaded cattle at 1200 h were only in the extreme category (MPS = 1.21) during the period d 31 to 60, and in the high category (MPS = 0.8 to 1.2) during the remaining periods. At 0600 and 1600 h, the MPS for cattle in both treatments were categorized as moderate to high.

During the heat wave (d 71 to 91), the MPS of the unshaded cattle (1.88) were greater ($P < 0.01$) than for

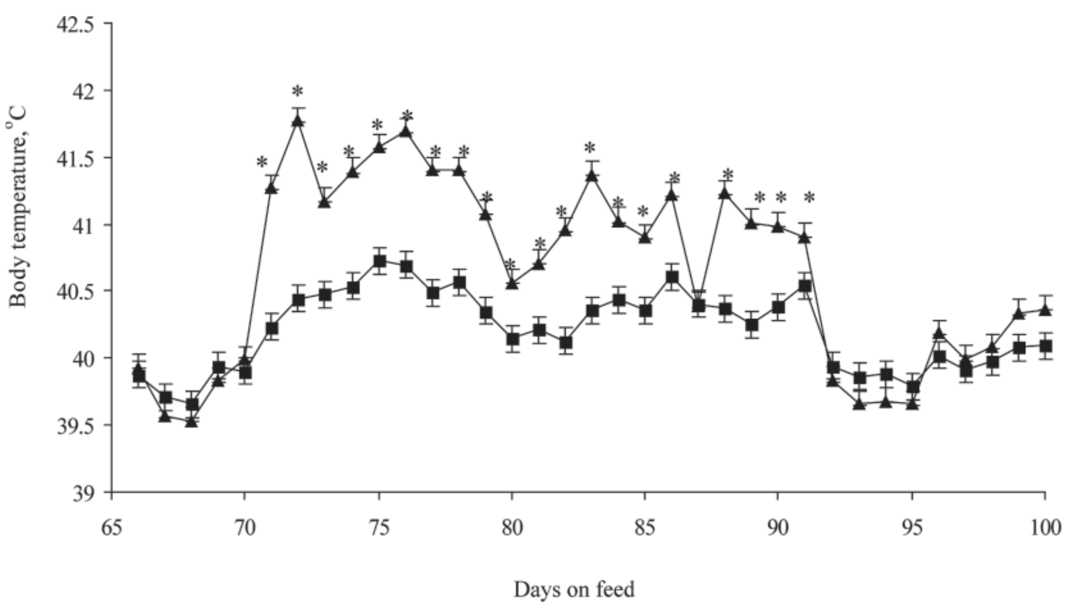

Figure 1. Maximum body temperature of feedlot steers with (■) and without (▲) access to shade over a 45-d period, which includes a 21-d period (d 71 to 91) of increased heat load. *Indicates a significant difference among treatments within a day ($P < 0.01$).

Table 6. Initial (d 0) and final (d 120) BW, hip height, and BCS; and ADG, DMI, G:F, and water intake for steers without access to shade (unshaded) or with access to shade (shaded)

Item	Unshaded	Shaded	SEM
n	82	82	—
Initial BW, kg	396	398	2.3
Final BW, kg	578[a]	596[b]	2.4
Initial hip height, mm	1,264	1,262	3.0
Final hip height, mm	1,348[a]	1,356[b]	3.0
Initial BCS	5.2	5.2	0.0
Final BCS	7.3	7.4	0.1
ADG, kg/d	1.51[a]	1.65[b]	0.02
DMI, kg/d	10.0[a]	10.3[b]	0.1
G:F	0.152[a]	0.160[b]	0.002
Water intake, L·d^{-1}	53.1	49.3	1.5

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

the shaded cattle (1.28), except on d 80 and 87 (Figure 2). The MPS of the shaded (0.36) and unshaded steers (0.45) were in the high category during the 5 d (d 66 to 70) before the 21-d heat wave (Table 4). Over the first 6 d (d 71 to 76) of the heat wave, the MPS of the shaded steers (1.39) was less ($P < 0.01$) compared with the unshaded steers (2.47); however, both were in the extreme stress category. The MPS of the unshaded steers (MPS = 1.99) was less ($P < 0.01$) from d 77 to 91 compared with d 71 to 76 when MPS was 2.47. In contrast, the MPS of the shaded steers for d 77 to 91 was 1.88, which was greater ($P < 0.01$) than the MPS (1.39) observed on d 71 to 76. The MPS of both treatments reduced to 0 after the rain events on d 92 and 93, and then increased sharply after d 95.

DMI and Water Usage

The DMI of the shaded cattle was greater ($P < 0.05$) than the unshaded cattle over the duration of the study (Table 6). There were no treatment differences ($P > 0.05$) for water usage. During the heat wave, DMI was affected ($P < 0.05$) by climatic conditions from d 72 for the unshaded cattle and from d 73 for the shaded cattle (Figure 3). The daily DMI (mean for d 66 to 70) fell from 11.70 kg·steer^{-1} and 11.81 kg·steer^{-1} for the unshaded and shaded cattle, respectively, to 5.68 kg·steer^{-1} (unshaded) and 7.17 kg·steer^{-1} (shaded) on d 77. Daily DMI increased from d 77 and peaked on d 81 (11.8 kg·steer^{-1}). From this point on, DMI was erratic. The daily DMI of the unshaded cattle was greater ($P < 0.01$) than that of the unshaded group on d 70 and 71 (12.2 vs. 11.6 kg·steer^{-1}, respectively, and less ($P < 0.01$) on d 73 to 78 (8.3 vs. 9.2 kg·steer^{-1}), respectively.

Water usage increased as heat load increased for both the shaded and unshaded cattle (Figure 4). In the 5 d before the heat wave, daily water usage was 41.3 ± 1.8 and 39.1 ± 1.8 L·steer^{-1}, respectively, for unshaded and shaded cattle. Water usage was greater ($P < 0.05$) for

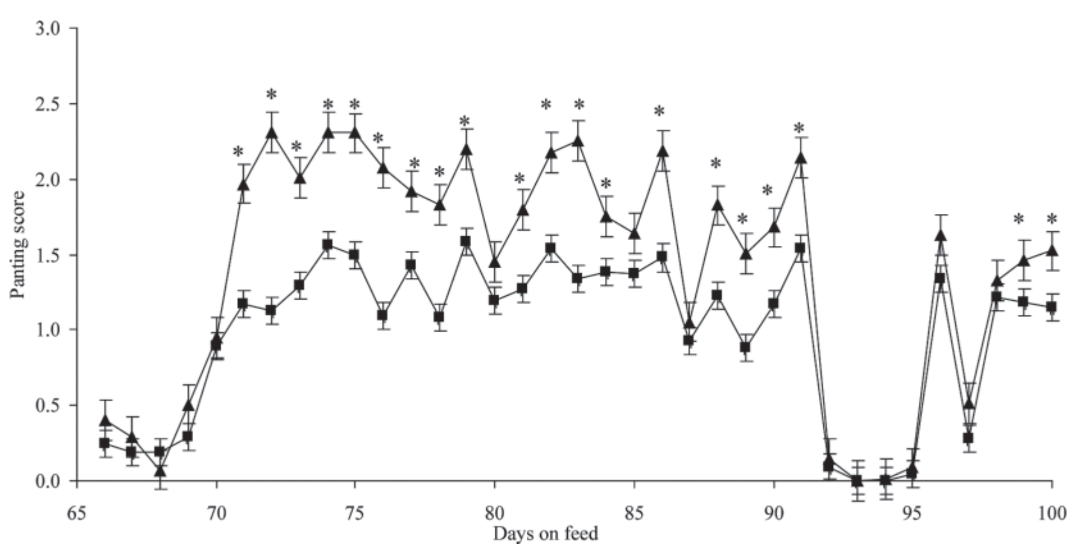

Figure 2. Panting scores at 1200 h of feedlot steers with (■) and without (▲) access to shade over a 45-d period, which includes a 21-d period (d 71 to 91) of increased heat load. *Indicates a significant difference among treatments within a day ($P < 0.05$).

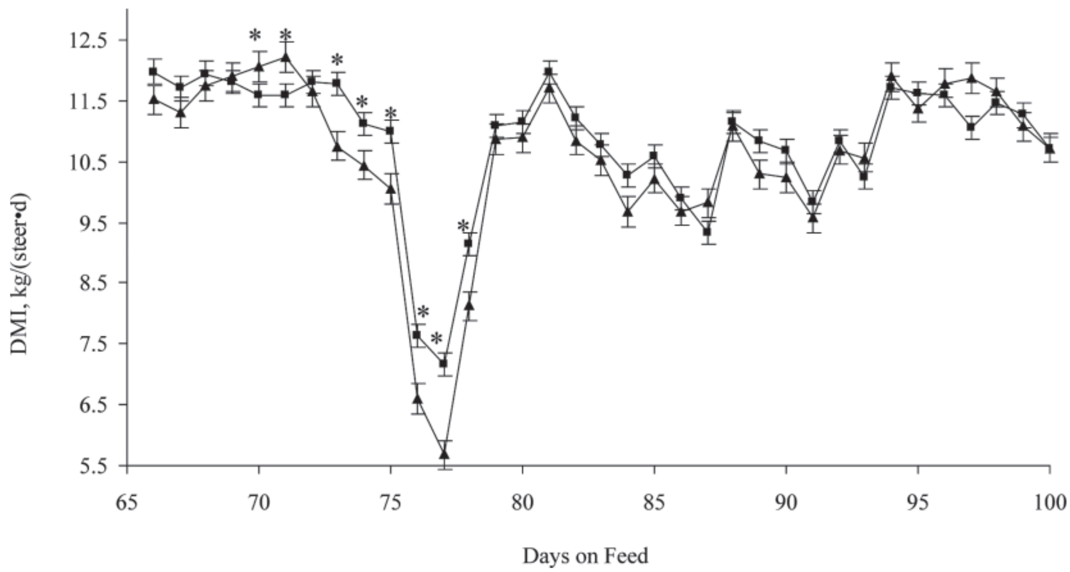

Figure 3. Dry matter intake of feedlot steers with (■) and without (▲) access to shade over a 45-d period, which includes a 21-d period (d 71 to 91) of increased heat load. *Indicates a significant difference among treatments within a day ($P < 0.01$).

the unshaded cattle (66.8 ± 2.7 L·steer^{-1}) compared with the shaded steers (56.8 ± 2.7 L·steer^{-1}) from d 71 to 90. Water usage peaked during d 77 to 90, at 71.2 L·steer^{-1} (unshaded) and 57.7 L·steer^{-1} (shaded). The unshaded cattle had greater ($P < 0.05$) water usage on d 76 to 84, and d 88 to 90 than the shaded cattle. On d 91, the last day of the heat wave, water usage was 22.5 L·steer^{-1} (unshaded) and 18.9 L·steer^{-1} (shaded), a 40 to 50 L/steer reduction. This was due to cooler conditions that occurred during the evening of d 91.

Animal Performance and Carcass Data

The unshaded steers weighed less ($P < 0.05$) and were shorter (hip height) than cattle with access to shade on exit (d 120; Table 6). Average daily gain and G:F were greater ($P < 0.05$) for the shaded cattle (1.65 kg·d^{-1}, 0.160) than for the unshaded cattle (1.51 kg·d^{-1}, 0.152). Final BCS was not ($P > 0.05$) influenced by treatment (7.3 and 7.4 for unshaded and shaded cattle, respectively).

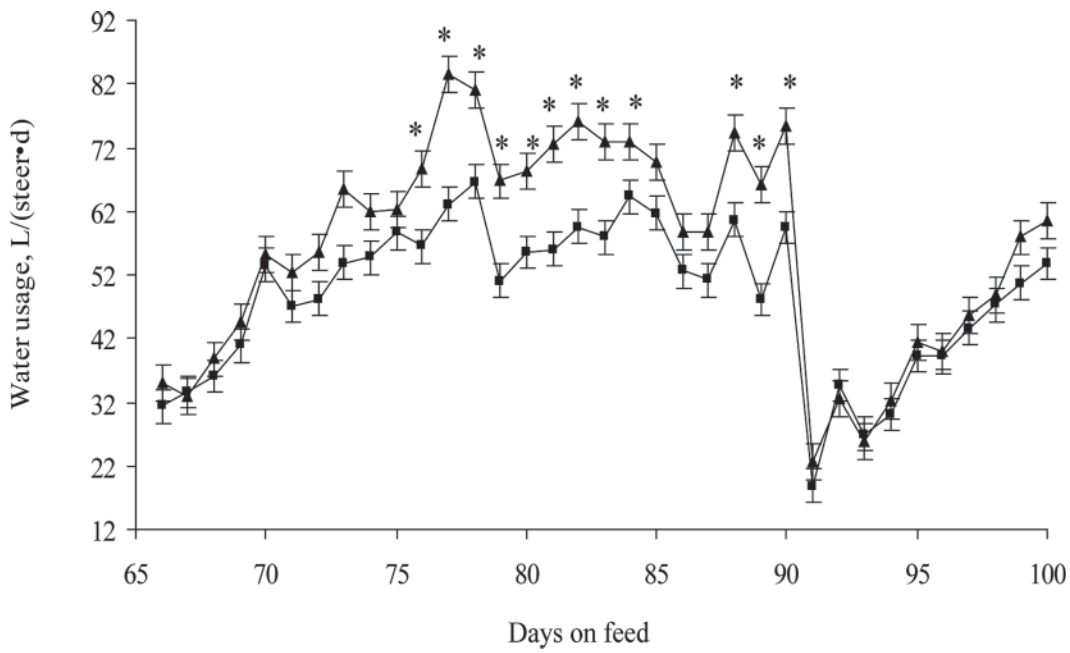

Figure 4. Effect of shade on water usage of feedlot steers with (■) and without (▲) access to shade over a 45-d period, which includes a 21-d period (d 71 to 91) of increased heat load. *Indicates a significant difference among treatments within a day ($P < 0.05$).

Table 7. Hot carcass weight (kg), dressing percentage, loin muscle area (LMA, cm^2), P8[1] fat depth (mm), rib[2] fat depth (mm), and marbling score[3] for feedlot steers (120 d on feed) without access to shade (unshaded) and with access to shade (shaded)

Item	Unshaded	Shaded	SEM
HCW, kg	315[a]	321[b]	0.8
Dressing percentage, %	54.5[a]	53.9[b]	0.2
LMA, cm^2	70.7	70.8	0.3
P8 fat, mm	14.5	15.5	0.4
Rib fat, mm	10.5	11.5	0.3
Marbling score	471.1	493.2	15.0

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[1]P8 fat depth is obtained by measuring fat depth over the gluteus muscle on the rump, at the intersection of a line through the pin bone parallel to the chine and perpendicular through the third sacral crest (Reverter et al., 2000).

[2]Fat depth over the 12th rib.

[3]USDA marbling score: 450 = slight 50, 500 = small 0, 550 = small 50, 600 = modest 0.

The greater BW of the shaded steers at d 120 resulted in a heavier ($P < 0.05$; 321.4 kg) HCW (d 121) compared with the unshaded cattle (315.4 kg; Table 7). However, the dressing percentage of the shaded steers (53.9%) was less ($P < 0.05$) compared with the unshaded steers (54.5%). There were no treatment differences ($P > 0.05$) for LMA, P8 fat depth, rib fat depth, or marbling score.

DISCUSSION

Previous studies (Mitlöhner et al., 2001, 2002) have shown a positive production response if feedlot cattle had access to shade. However, little is known about the effect of shade on core T_B and respiratory dynamics (panting) of feedlot cattle. The current study builds on the earlier studies by the inclusion of T_B and panting data of Angus steers fed for 120 d. These data also permit an assessment of the welfare benefits of shade.

The location of the current study was selected on the basis of climate. The summer weather conditions at the study site were deemed sufficient to elicit a heat stress response in Angus cattle. The climatic conditions encountered during the study were milder than expected, especially the minimum temperatures. Nevertheless, sufficient hot days were encountered to observe heat stress responses (i.e., increase in T_B and MPS) in the cattle.

Increased heat load, leading to heat stress, resulted in loss of production and death of feedlot cattle (Busby and Loy, 1996; Hahn and Mader, 1997; Entwistle et al., 2000). Strategies to reduce the impact of increased heat load on feedlot cattle include dietary manipulation (White et al., 1992; Brosh et al., 1998; Mader et al., 1999b; Mader and Davis, 2004), water application (Morrison et al., 1973; Mitlöhner et al., 2001, 2002; Mader et al., 2007), and housing (Mader et al., 2008; Gaughan et al., 2009a), including shade structures (Bennett et al., 1985; Clarke and Kelly, 1996; Mader et al., 1999a; Mitlöhner et al., 2001, 2002; Gaughan et al., 2004; Brown-Brandl et al., 2005; Sullivan et al., 2008).

Cattle will seek shade in increased temperatures, particularly when it is combined with increased solar radiation (Buffington et al., 1983; Bennett et al., 1985). The provision of shade for dairy cows has shown consistent positive results (Roman-Ponce et al., 1977; Davison et al., 1988; Muller et al., 1994a,b; Gaughan et al., 1998; Kendall et al., 2006). However, results have not been as consistent for beef feedlot cattle. In the current study, access to shade improved steer ADG, G:F, and HCW, all of which are important economic traits. Improved DMI and ADG for shaded compared with unshaded heifers were reported by Mitlöhner et al. (2001). They also reported that the provision of shade reduced the incidence of dark-cutting beef. In contrast, Clarke and Kelly (1996) reported that provision of shade gave no improvement in DMI, ADG, G:F, or meat characteristics of feedlot cattle. Mader et al. (1997) and Brown-Brandl et al. (2005) found inconsistent results in terms of DMI when cattle had access to shade.

In the study presented herein, greater HCW, ADG, and G:F of steers with access to shade resulted in a greater carcass value for these steers compared with unshaded steers. The improved ADG (140 $g\cdot d^{-1}$) of the shaded steers was, however, less than the 200 $g\cdot d^{-1}$ reported by Mitlöhner et al. (2001). The reduced response in the current study compared with Mitlöhner et al. (2001) may be because growth-promoting implants were not used in the current study. Climate × growth-promotant interactions have been reported (Ray et al., 1969; Hunter and Vercoe, 1987; Gaughan et al., 2005). However, Kreikemeier and Mader (2004) reported a climate × growth-promotant interaction for DMI, but no interactions for ADG, G:F, water intake, or carcass characteristics. Although there are inconsistencies in performance, there are consistent results showing reductions in core body temperature, panting score, and respiration rate, as well as reduced incidence of open-mouthed breathing when cattle have access to shade (Clarke and Kelly, 1996; Mader et al., 1997; Valtorta et al., 1997; Gaughan et al., 2004; Brown-Brandl et al., 2005).

Access to shade reduced the impact of heat load, specifically solar load. As a result, mean T_B of steers with access to shade was less than for steers without access to shade. Brown-Brandl et al. (2005) reported that cattle with access to shade had a decreased mean tympanic temperature (**TT**; 38.5°C) than those without access to shade (38.9°C) when maximum THI ≥84. The maximum difference between shaded and unshaded cattle in the Brown-Brandl et al. (2005) study was 0.6°C, which was less than differences (0.73°C) between shaded and unshaded cattle during the heat wave in the current study. In a different study, Gaughan et al. (2009a) reported a maximum TT difference of 0.76°C during 2 heat waves (mean daily THI ≥74). In that study, the differences between the maximum and minimum T_B were 2.4°C for unshaded steers, and 1.7°C for steers with access to shade.

In the current study, the reduced night time T_B of steers without access to shade, compared with those with access to shade, is in agreement with Mader et al. (1999a, 2009), Gaughan et al. (2004), and Brown-Brandl et al. (2005). Brown-Brandl et al. (2005) suggested that the reason for this may be that the cattle without access to shade are exposed to an open sky at night and, therefore, dissipate more heat at night, resulting in a reduced T_B. Mader et al. (2009) grouped cattle based on their diurnal variation in T_B. Mader et al. (2009) reported that cattle that had the greatest maximum TT during the day also had the least TT at night. The decrease in T_B at night for cattle housed outside may also be a result of the cattle overcorrecting T_B at night in an attempt to reach homeothermy. A better understanding of T_B dynamics of cattle exposed to increased heat load may improve selection of heat-tolerant *B. taurus* cattle.

The change in panting scores from 0 to 4.5 as the animal is heat challenged is a good indicator of the changing heat load status of the animal (Mader et al., 2006). When a group is assessed, the MPS can be used as an indicator of the severity of climatic induced stress: 0 to 0.4 minimal heat load, no stress; 0.4 to 0.8 moderate heat load, slight stress; 0.8 to 1.2 high heat load, moderately stressed; >1.2 extreme heat load cattle, highly stressed (Gaughan et al., 2008). The importance of solar load on panting score of Angus cattle was reported by Mader et al. (2006). The effect of shade in reducing panting scores of feedlot cattle has been reported for several *B. taurus* breeds (Gaughan et al., 2009b). In the current study, cattle with access to shade had smaller panting scores at all times compared with unshaded cattle. The unshaded cattle were under extreme heat load at 1200 h daily throughout the study, whereas the shaded cattle were in the moderately stressed category at the same observation time. During the heat wave period, the MPS of both shaded and unshaded cattle reached the extreme heat load category. However, the MPS of the unshaded cattle was double that of the shaded cattle. This does not, however, indicate that there was a 2-fold increase in stress. The data from the current study demonstrate that access to shade ameliorated, but did not eliminate, heat stress in Angus cattle. Similar results were reported by Gaughan et al. (2009b), who found that access to shade reduced the severity of heat load (based on MPS) of Angus steers. In that study, 26.9% of steers without access to shade had a MPS ≥2.5 compared with 5.2% for steers with access to shade.

In conclusion, these results suggest that access to shade reduces the effects of increased heat load and thereby improves the welfare of cattle. However, shade will not completely eliminate the impact of harsh, heat-related climatic conditions. Furthermore, there appears to be a production benefit associated with shade based on improved G:F and HCW.

LITERATURE CITED

Bennett, I. L., V. A. Finch, and C. R. Holmes. 1985. Time spent in shade and its relationship with physiological factors of thermoregulation in three breeds of cattle. Appl. Anim. Behav. Sci. 13:221–236.

Bond, T. E., C. F. Kelly, S. R. Morrison, and N. Pereira. 1967. Solar, atmospheric, and terrestrial radiation received by shaded and unshaded animals. Trans. ASAE 10:622–627.

Brosh, A., Y. Aharoni, A. A. Degen, D. Wright, and B. A. Young. 1998. Effects of solar radiation, dietary energy, and time of feeding on thermoregulatory responses and energy balance in cattle in a hot environment. J. Anim. Sci. 76:2671–2677.

Brown-Brandl, T. M., R. A. Eigenberg, J. A. Nienaber, and G. L. Hahn. 2005. Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, Part 1: Analyses of indicators. J. Biosyst. Eng. 90:451–462.

Buffington, D. E., R. J. Collier, and G. H. Canton. 1983. Shade management system to reduce heat stress for dairy cows in hot, humid climates. Trans. ASAE 26:1798–1802.

Busby, D., and D. Loy. 1996. Heat stress in feedlot cattle: Producer survey results. Pages 108–110 in 1996 Beef Research Report. Iowa State University AS Leaflet R1348.

Clarke, M. R., and A. M. Kelly. 1996. Some effects of shade on Hereford steers in a feedlot. Anim. Prod. Aust. 21:235–238.

Davis, M. S., T. L. Mader, S. M. Holt, and A. M. Parkhurst. 2003. Strategies to reduce feedlot cattle heat stress: Effects on tympanic temperature. J. Anim. Sci. 81:649–661.

Davison, T. M., B. A. Silver, A. T. Lisle, and W. N. Orr. 1988. The influence of shade on milk production of Holstein-Friesian cows in a tropical upland environment. Aust. J. Exp. Agric. 28:149–154.

Entwistle, K., M. Rose, and B. McKiernan. 2000. Mortalities in feedlot cattle at Prime City Feedlot, Tabbita, New South Wales, February 2000. A Report to the Director General, New South Wales Agriculture, Sydney, Australia.

Gaughan, J. B., P. J. Goodwin, T. A. Schoorl, B. A. Young, M. Imbeah, T. L. Mader, and A. Hall. 1998. Shade preferences of lactating Holstein-Friesian cows. Aust. J. Exp. Agric. 38:17–21.

Gaughan, J. B., S. M. Holt, and R. H. Pritchard. 2009a. Assessment of housing systems for feedlot cattle during summer. Prof. Anim. Sci. 25:633–639.

Gaughan, J. B., W. M. Kreikemeier, and T. L. Mader. 2005. Hormonal growth-promotant effects on grain-fed cattle maintained under different environments. Int. J. Biometeorol. 49:396–402.

Gaughan, J. B., T. L. Mader, and S. M. Holt. 2008. A new heat load index for feedlot cattle. J. Anim. Sci. 86:226–234.

Gaughan, J. B., T. L. Mader, S. M. Holt, M. L. Sullivan, and G. L. Hahn. 2009b. Assessing the heat tolerance of 17 beef cattle genotypes. Int. J. Biometeorol. doi:10.1007/s00484-009-0233-4.

Gaughan, J. B., L. A. Tait, R. A. Eigenberg, and W. L. Bryden. 2004. Effect of shade on respiration rate and rectal temperature of Angus heifers. Anim. Prod. Aust. 25:69–72.

Hahn, G. L., and T. L. Mader. 1997. Heat waves in relation to thermoregulation, feeding behavior and mortality of feedlot cattle. Pages 563–571 in Proc. 5th Int. Livest. Environ. Symp., Bloomington, MN. Am. Soc. Agric. Eng., St. Joseph, MI.

Herd, D. B., and L. R. Sprott. 1996. Body condition, nutrition and reproduction of beef cows. Texas Agricultural Extension Service. No. B-1526.

Hunter, R. A., and J. E. Vercoe. 1987. Reduction of energy requirements of steers fed on low-quality roughage diet using trenbolone acetate. Br. J. Nutr. 58:477–483.

Kendall, P. E., P. P. Nielsen, J. R. Webster, G. A. Verkerk, P. P. Littlejohn, and L. R. Matthews. 2006. The effects of providing shade to lactating dairy cows in a temperate climate. Livest. Sci. 103:148–157.

Kreikemeier, W. M., and T. L. Mader. 2004. Effects of growth-promoting agents and season on yearling feedlot heifer performance. J. Anim. Sci. 82:2481–2488.

Lawrence, R. J. 1998. A comparison of feedlot bunk management strategies and their influence on cattle performance and health. Anim. Prod. Aust. 22:177–180.

Lefcourt, A. M., and W. R. Adams. 1996. Radiotelemetry measurement of body temperatures of feedlot steers during summer. J. Anim. Sci. 74:2633–2640.

Mader, T. L., J. M. Dahlquist, G. L. Hahn, and J. B. Gaughan. 1999a. Shade and wind barrier effects on summertime feedlot cattle performance. J. Anim. Sci. 77:2065–2072.

Mader, T. L., and M. S. Davis. 2004. Effect of management strategies on reducing heat stress of feedlot cattle: Feed and water intake. J. Anim. Sci. 82:3077–3087.

Mader, T. L., M. S. Davis, and T. Brown-Brandl. 2006. Environmental factors influencing heat stress in feedlot cattle. J. Anim. Sci. 84:712–719.

Mader, T. L., M. S. Davis, and J. B. Gaughan. 2007. Effect of sprinkling on feedlot microclimate and cattle behaviour. Int. J. Biometeorol. 51:541–551.

Mader, T. L., L. R. Fell, and M. J. McPhee. 1997. Behavior response of non-Brahman cattle to shade in commercial feedlots. Pages 795–802 in Proc. 5th Int. Livest. Environ. Symp., Bloomington, MN. Am. Soc. Agric. Biol. Engineers, St. Joseph, MI.

Mader, T. L., J. B. Gaughan, L. J. Johnson, and G. L. Hahn. 2009. Tympanic temperature in confined beef cattle exposed to excessive heat load. Int. J. Biometeorol. doi:10.1007/s00484-009-0229-0.

Mader, T. L., J. B. Gaughan, and B. A. Young. 1999b. Feedlot diet roughage level for Hereford cattle exposed to excessive heat load. Prof. Anim. Sci. 15:53–62.

Mader, T. L., L. J. Johnson, T. M. Brown-Brandl, and J. B. Gaughan. 2008. Climate conditions in bedded confinement buildings. Pages 395–402 in Proc. 8th Int. Livest. Environ. Symp., Iguassu Falls, Brazil. Am. Soc. Agric. Biol. Engineers, St. Joseph, MI.

Mader, T. L., and W. M. Kreikemeier. 2006. Effects of growth-promoting agents and season on blood metabolites and body temperature in heifers. J. Anim. Sci. 84:1030–1037.

Mitlöhner, F. M., M. L. Galyean, and J. J. McGlone. 2002. Shade effects on performance, carcass traits, physiology and behaviour of heat stressed feedlot heifers. J. Anim. Sci. 80:2043–2050.

Mitlöhner, 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 effects on behaviour, physiology, performance, and carcass traits of heat stressed feedlot cattle. J. Anim. Sci. 79:2327–2335.

Morrison, S. R., R. L. Givens, and G. P. Lofgreen. 1973. Sprinkling cattle for relief from heat stress. J. Anim. Sci. 36:428–431.

Muller, C. J. C., J. A. Botha, W. A. Coetzer, and W. A. Smith. 1994b. Effect of shade on various parameters of Friesian cows in a Mediterranean climate in South Africa: 2. Physiological responses. S. Afr. J. Anim. Sci. 24:56–60.

Muller, C. J. C., J. A. Botha, and W. A. Smith. 1994a. Effect of shade on various parameters of Friesian cows in a Mediterranean climate in South Africa: 3. Behaviour. S. Afr. J. Anim. Sci. 24:61–66.

Ray, D. E., W. H. Hale, and J. A. Marchello. 1969. Influence of season, sex, and hormonal growth stimulants on feedlot performance of beef cattle. J. Anim. Sci. 29:490–495.

Reverter, A., D. J. Johnston, H. U. Graser, M. L. Wolcott, and W. H. Upton. 2000. Genetic analyses of live-animal ultrasound and abattoir carcass traits in Australian Angus and Hereford cattle. J. Anim. Sci. 78:1786–1795.

Roman-Ponce, H., W. W. Thatcher, D. E. Buffington, C. J. Wilkax, and H. H. Van Horn. 1977. Physiological and production responses of dairy cattle to a shade structure in a subtropical environment. J. Dairy Sci. 60:424–430.

Sullivan, M. L., J. B. Gaughan, and A. J. Cawdell-Smith. 2008. Impact of shade on the panting score of feedlot cattle. Page 34 in Proc. Aust. Soc. Anim. Prod. 2008. Vol. 27, Brisbane, Australia.

Thom, E. C. 1959. The discomfort index. Weatherwise 12:57–59.

Valtorta, S. E., P. E. Leva, and M. R. Gallardo. 1997. Effect of different shades on animals well being in Argentina. Int. J. Biometeorol. 41:65–67.

White, T. W., L. D. Bunting, L. S. Sticker, F. G. Hembry, and A. M. Saxton. 1992. Influence of fish meal and supplementary fat on performance of finishing steers exposed to moderate or high ambient temperature. J. Anim. Sci. 70:3286–3292.