JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

Strategies to reduce feedlot cattle heat stress: Effects on tympanic temperature,3

M. S. Davis, T. L. Mader, S. M. Holt and A. M. Parkhurst

J Anim Sci 2003. 81:649-661.

Strategies to reduce feedlot cattle heat stress: Effects on tympanic temperature[1,2,3]

M. S. Davis*, T. L. Mader†, S. M. Holt‡, and A. M. Parkhurst†

*Koers-Turgeon Consulting Services, Inc., Salina, KS; †University of Nebraska, Department of Animal Science, Concord, and Department of Biometry, Lincoln; and ‡South Dakota State University, Brookings, SD

ABSTRACT: Three experiments were conducted to evaluate the effect of different management strategies on body temperature of feedlot steers finished in the summer months. In Exp. 1, 24 crossbred steers were chosen to assess the effect of altered feed intake and feeding time on tympanic temperature (TT) response. Managed feeding (MF) treatments were applied for 22 d only and provided 1) ad libitum access to feed at 0800 (ADLIB), 2) feed at 1600 with amount adjusted so that no feed was available at 0800 (BKMGT), 3) feed at 1600 at 85% of predicted ad libitum levels (LIMFD). During heat stress conditions on d 20 to 22 of MF, LIMFD and BKMGT had lower ($P < 0.05$) TT than ADLIB from 2100 through 2400. A carryover effect of limit-feeding was evident during a severe heat episode (d 36 to 38) with LIMFD steers having lower ($P < 0.05$) TT than ADLIB. In Exp. 2, TT were obtained from 24 crossbred steers assigned to three treatments, consisting of no water application (CON), water applied to feedlot mound surfaces from 1000 to 1200 (AM) or 1400 to 1600 (PM). From 2200 to 0900 and 1200 to 1400, steers assigned to morning sprinkling treatment had lower ($P < 0.05$) TT than steers assigned to afternoon sprinkling treatment. In Exp. 3, 24 steers were utilized in a 2 × 2 factorial arrangement of treatments with factors of feeding time [0800 (AMF) and 1400 (PMF)] and sprinkling (WET and DRY). Tympanic temperatures were monitored under hot environmental conditions on d 30 to 32 and 61 to 62. A feeding time × sprinkling interaction ($P < 0.001$) was evident on d 30 to 32, although AMF/DRY steers had the highest ($P < 0.05$) TT. On d 61 to 62, TT of PMF steers was higher ($P < 0.05$) than AMF between 1500 to 1800. Use of sprinklers can effectively reduce TT of feedlot cattle, whereas shifting to an afternoon vs morning feeding time was most beneficial when bunks were empty several hours prior to feeding.

Key Words: Body Temperature, Cattle, Feedlots, Heat Stress, Management

 J. Anim. Sci. 2003. 81:649–661

Introduction

Environmental conditions during the summer can negatively impact feedlot cattle performance. Severe heat episodes occurred in 1992, 1995, 1997, and 1999 in which individual producers in the Great Plains alone lost in excess of 100 steers (Hahn and Mader, 1997; Hubbard et al., 1999). The heat waves of 1995 and 1999 were particularly severe with economic losses to cattle feeders in Iowa and Nebraska, respectively, estimated to exceed $20 million per state (Busby and Loy, 1996; Hahn and Mader, 1997; Mader et al., 2001). In order to prevent susceptibility to hyperthermia and improve overall summertime feedlot performance, management strategies designed to alter the peak and/or pattern of body temperature must be implemented. Examples of such strategies include altering feed consumption (Holt et al., 1999; Mader et al., 2002), feeding time (Brosh et al., 1998), dietary energy concentration (Mader et al., 1999), or provision of external cooling in the form of sprinklers (Monty and Garbareno, 1978). Lefcourt and Adams (1996) concluded that monitoring of thermoregulatory responses of steers requires frequent, if not continuous, measurement of body temperature.

The objectives of this study were to determine the effects of altered feeding time and/or feed consumption on hourly tympanic temperature measures of feedlot steers under varying summertime environmental conditions. In addition, the effect of water application to the mound area of the pen was assessed.

[1]Partial support for this study was provided through USDA-NRI Competitive Grants Program award number 9803525.

[2]Published as Journal series no. 13572, Agric. Res. Div., University of Nebraska.

[3]Correspondence: Haskell Agricultural Laboratory, 57905 866 Road, Concord, NE 68728 (phone: 402-584-2812; fax: 402-584-2859; E-mail: tmader@unlnotes.unl.edu).

Received June 21, 2002.

Accepted October 1, 2002.

Materials and Methods

All experiments reported herein were conducted at the University of Nebraska Northeast Research and Extension Center with the approval of the University of Nebraska-Lincoln Institutional Animal Care and Use Committee. Facility design has been previously reported by Mader et al. (1997). Facilities are located at 42° 23′ N latitude and 96° 57′ W longitude, with a mean elevation of 445 m above sea level.

In all experiments, prior to trial initiation, steers were vaccinated for viral diseases (Elite 4, Boehringer Animal Health, St. Joseph, MO), Clostridial sp. (Bar-Vac 7, Boehringer Animal Health, St. Joseph, MO) and treated for parasites (Tiguvon, Bayer Animal Health, Shawnee Mission, KS, and Cydectin, Fort Dodge Animal Health, Overland Park, KS, or Dectomax, Pfizer, Lee Summit, MO). In Exp. 1 and 2, steers were implanted with Synovex-Plus (Fort Dodge Animal Health, Overland Park, KS). In Exp. 3, steers were implanted with Revalor-S (Intervet, Millsboro, DE). Steers received implants on d 0 of the individual studies. Throughout the experiments steers were fed a dry-rolled corn-based, high-energy (NE_g = 1.43 mcal/kg) feedlot finishing diet. In Exp. 2 and 3, sprinklers were set to deliver 25 to 30 L/steer per day on the days sprinkling was performed. In addition, in all experiments, tympanic temperatures (**TT**) were obtained from a subset of steers within a pen. Additional cattle were provided to mimic cattle density and behavioral pattern of previous studies (Mader et al., 1997). With the exception of limit-fed cattle, DMI were typical and averaged between 9 and 11 kg/steer per day during these experiments.

Experiment 1. Seventy-two Angus × Charolais crossbred steers (BW = 433 ± 23 kg) within a coat color and weight block were randomly assigned to three treatments imposed among 12 pens of cattle (four pens/treatment; six steers/pen). Treatments provided 1) ad libitum access to feed at 0800 (**ADLIB**), 2) feed at 1600 with amount adjusted so that no feed was available at 0800 (**BKMGT**), and 3) feed at 1600 at 85% of predicted ad libitum intake (**LIMFD**). Treatments were imposed for 22 d (managed feeding; **MF**) at the end of which all cattle were provided feed ad libitum at 0800. The DMI of steers in the LIMFD treatment group was determined prior to starting the study and was based on projected gain and associated daily DMI of comparable cattle offered feed ad libitum using computer software (NRC, 1996), based on breed type, age, body condition, frame size, and diet.

A subset of two steers/pen was used to assess the effect of the imposed treatment on TT. On d 7, all of the steers in the 12 pens were removed from their pens, and data loggers (Stowaway XTI, Onset Computer Corporation) were placed in the ears of two steers/pen to measure TT, based on procedures outlined by Mader et al. (2002). Data loggers were placed in one black-haired and one white-haired steer/pen to assess potential differences as an effect of coat color. Placement of the data logger into the ear consisted of attachment of a thermistor to the data logger and inserting the thermistor approximately 13 cm down the ear canal until the tip was located near the tympanic membrane of the animal. The data logger was wrapped in gauze and secured to the ear using self-adhesive bandages (Vet-Wrap, 3M Corporation) and athletic tape (Andover Coded Products Inc., Salisbury, MA). Once data loggers were secured to the ear, all steers were returned to their respective pens where they remained until d 15. Tympanic temperatures were recorded at 5- to 10-min intervals and compiled into hourly readings. On d 15, pens containing steers with data loggers were returned to the processing facility, where data loggers were removed from the left ear and placed in the right ear. Steers were returned to their respective pens and remained there until d 23, when data loggers were removed. For the remainder of the trial, all cattle were managed similarly (fed at 0800). Data loggers were again placed in steers on d 35 to assess any carryover effects of previous feeding regimen on TT. Steers used for data logger placement were the same between the two times as were data logger placement procedures. Data loggers remained in the steers for 5 d.

Tympanic temperature data obtained during the MF and ad libitum feeding at 0800 were grouped for analysis into four distinctive heat stress periods, each consisting of three consecutive days. Criteria used to determine these grouping were based on the temperature-humidity index (**THI**). The THI was calculated as THI = (0.8 × ambient temperature) + ((% relative humidity/100) × (ambient temperature − 14.4)) + 46.4 (Thom, 1959; NOAA, 1976). Periods were deemed thermoneutral when average THI < 70, mild heat stress (**MHS**) when 70 ≤ THI < 74, heat stress (**HS**) when 74 ≤ THI < 77, and severe heat stress (**SHS**) when THI ≥ 77. During the MF period of Exp. 1, three distinct periods, which occurred on d 10 to 12, 13 to 15, and 20 to 22, were termed SHS, MHS, and HS, respectively. Data from the ad libitum feeding at 0800 consisted of tympanic temperatures on d 35 to 37. Based on mean THI, these days were classified as SHS. Climatic conditions for each of these periods are presented in Table 1. Black globe-humidity index was also calculated to characterize the climatic heat load (Buffington et al., 1981) by substituting black globe temperature for T_a in the THI equation. The same relative humidity value was used in calculating black globe humidity index as was used for THI.

Experiment 2. Ninety-six Angus crossbred steers (BW = 477 ± 33 kg) were utilized in an 82-d trial in a randomized complete block design. Steers were blocked by weight and randomly assigned to one of twelve pens (eight steers/pen). Treatments assigned to pens (four pens/treatment) consisted of 1) no water applied (**CON**), 2) water applied to mounds (pen surface) continuously between 1000 and 1200 (**AM**), and

Table 1. Environmental conditions during the selected periods for tympanic temperature analysis for the three experiments

	Environmental variable[a]					
Item	Temperature, °C	Relative humidity, %	Windspeed, km/h	Black globe, °C	THI	Black globe THI
Experiment 1						
d 10 to 12						
Mean	27.7 ± 3.1	70.7 ± 10.9	16.9 ± 5.4	30.6 ± 5.8	77.7 ± 3.6	81.8 ± 7.5
Minimum	20.5	52.2	4.3	20.0	66.9	66.1
Maximum	33.2	97.4	29.1	41.6	83.6	95.9
d 13 to 15						
Mean	23.6 ± 5.0	69.1 ± 16.6	9.9 ± 4.7	28.2 ± 9.1	71.0 ± 6.5	77.1 ± 11.2
Minimum	14.3	40.3	2.9	13.6	57.7	56.5
Maximum	34.43	92.2	18.6	42.97	83.15	94.6
d 20 to 22						
Mean	26.5 ± 4.3	66.0 ± 14.4	16.1 ± 5.7	29.7 ± 7.3	75.0 ± 4.9	79.4 ± 8.8
Minimum	18.4	39.34	8.3	17.9	64.4	63.6
Maximum	32.8	92.2	30.9	42.5	81.6	93.2
d 35 to 37						
Mean	28.1 ± 4.8	76.6 ± 16.7	7.4 ± 2.7	32.6 ± 9.4	78.6 ± 5.2	85.0 ± 11.6
Minimum	21.5	45.3	2.4	21.2	70.2	69.7
Maximum	36.8	98.6	14.4	48.0	86.9	104.2
Experiment 2						
d 30 to 33						
Mean	26.7 ± 3.5	82.4 ± 13.6	8.1 ± 3.6	30.9 ± 8.0	77.4 ± 4.1	83.7 ± 10.6
Minimum	20.9	54.4	2.2	20.4	69.5	68.5
Maximum	33.4	99.0	17.2	45.5	84.9	101.0
Experiment 3						
d 30 to 32						
Mean	27.8 ± 3.3	70.2 ± 12.8	13.7 ± 4.8	30.9 ± 6.5	77.6 ± 3.5	81.9 ± 7.8
Minimum	22.1	47.42	2.9	21.4	70.6	69.4
Maximum	32.9	92.1	22.4	40.8	82.4	93.2
d 61 to 62						
Mean	24.1 ± 4.2	74.0 ± 16.4	6.5 ± 3.5	28.4 ± 9.3	72.2 ± 5.2	78.3 ± 12.4
Minimum	17.6	41.7	1.8	16.8	63.4	61.9
Maximum	30.16	92.2	12.8	44.5	80.3	102.0

[a]Collected using a weather station located in the feeding facility. THI = temperature-humidity index, Blk globe = black globe temperature, Blk globe THI = temperature-humidity index using Blk globe temperature. THI = (0.8 × Temperature) + ((relative humidity/100) × (Temperature − 14.4)) + 46.4.

3) water applied to mounds between 1400 and 1600 (**PM**). Mounds were sprinkled only when predicted maximum temperature-humidity index (THI) ≥ 77. The decision for water application was made at 1000 based on local weather reports and current climatic conditions. Water was applied to mounds using impact sprinklers (Rainbird, Nelson, Peoria, IL) placed at ground level. One sprinkler was used to apply water to two pens. Sprinklers were placed along the dividing fence that bisected the mound of the pen lengthwise. Water application time was controlled using an electronic timer (Nelson, Peoria, IL). A semicircular area of the pen was wetted to provide 2.4 m^2/animal of wetted surface. Water was applied on 23 d of the 82-d study.

To assess the effects of treatment on steer TT, two steers/pen were chosen at random. Data loggers were placed in the ear of these steers on d 28 with data logger placement procedures similar to with those found in Exp. 1. Steers were returned to their pen where they remained until removal of the data loggers on d 34. Data from d 30 to 33 were used for analysis. On these 4 d, sprinklers were operational in all treatment pens.

Experiment 3. Ninety-six British × Continental steers (BW = 424 ± 26 kg) were used in an 83-d trial, in a completely randomized design to evaluate the effects of altered feeding time and water sprinkling on TT of feedlot cattle during the summer. Feeding times of 0800 (**AMF**) or 1400 (**PMF**) and sprinkling (**WET**) vs nonsprinkling (**DRY**) were used in a 2 × 2 factorial arrangement. Steers were randomly assigned to one of 12 pens. Animals were given ad libitum access to feed.

Method of water application was identical to Exp. 2 except sprinklers were positioned on top of the posts (height = 1.7 m). Water was applied to pens when THI at 0900 was ≥ 68. This threshold value was determined using regression equations with THI at 0700, 0800, and 0900 as the independent variable and daily maximum THI as the dependent variable. The database for the equation consisted of THI values compiled by a weather station located in the center of the feedlot facility for the months of July and August. The correlation coefficients for daily maximum THI vs hourly THI at 0700, 0800, and 0900 were 0.62, 0.71, and 0.77, respectively; thus, THI at 0900 was used as the threshold. When sprinklers were set to come on, they ran for 20 min every 1.5 h from 1000 to 1750.

Individual steers within 12 of the 24 pens (two steers/pen; six steers/treatment) were used to assess the effect of the imposed treatment on TT. Steers within pen were chosen at random for TT collection. Tympanic data loggers were placed in the same steers for three periods (d 0 to 4, 29 to 33, and 56 to 63) during the trial. Data logger placement procedures were similar to those described for Exp. 1.

Statistical Analysis

In Exp. 1, analysis of TT was performed using PROC MIXED of SAS (SAS Inst., Inc., Cary, NC) for repeated measures. The model for each environmental period included the fixed effects of feeding regimen, day, coat color, time of day, feeding regimen × time of day, and coat color × time of day. The Satterthwaite option was used to calculate degrees of freedom. The model also included the random effect of pen within feeding regimen × day, which was used as the error term for the effect of feeding regimen. Time of day was included in the repeated statement, and the subject effect was individual animal within day with compound symmetry used for covariant structure. Animal within day was used as the error term to assess differences in TT as an effect of coat color. Differences were determined using PDIFF option with a protected ***F***-test.

In Exp. 2, TT data on d 30 to 33 were chosen for analysis. This allowed for TT to be compared at a time in which sprinklers were operational on all days. Based on the criteria used in Exp. 1 for describing environmental conditions, this 4-d period consisted of SHS (Table 1).

Statistical analyses of TT were conducted using PROC MIXED analysis of SAS for repeated measures. The model including the fixed effects of sprinkling treatment, day, time of day, and sprinkling treatment × time of day interaction. Pen within day was included as a random variable with time of day included in the repeated statement. Pen within day served as the subject with compound symmetry covariance structure. When the treatment × time of day interaction was significant ($P < 0.05$), differences among treatments were compared within a time of day using Fisher's Protected LSD and the PDIFF option.

In Exp. 3, TT were also grouped according to environmental conditions and sprinkler operation. The 3-d period consisting of d 30 to 32 was chosen for analysis. Environmental conditions (Table 1) at this time would be classified as SHS based on the above mentioned criteria. Sprinklers were operational during this 3-d period. During TT collection from d 56 to 62, sprinklers were only operational on d 59, 61, and 62. Thus, d 61 and 62 were chosen for analysis and were classified as MHS.

Analysis of TT in Exp. 3 was done using PROC MIXED of SAS for repeated measures. The model for TT in Exp. 3 consisted of the effects of feeding time, sprinkling, day, time of day, feeding time × sprinkling, feeding time × time of day, sprinkling × time of day, and feeding time × sprinkling × time of day. Pen within day was included as a random effect and served as the subject with compound symmetry covariant structure. When interactions with time of day were significant, differences among treatments were determined within a time of day using Fisher's Protected LSD and the PDIFF option.

Results

Experiment 1. Daily DMI between ADLIB and LIMFD treatment groups differed ($P < 0.05$) during d 10 to 12 and d 13 to 15 only. Daily DMI stayed constant for the LIMFD group and declined for the ADLIB group during the MF period (Table 2). Daily DMI was more variable for the BKMGT group. A feeding regimen × time of day interaction ($P < 0.05$) was found for TT during SHS (d 10 to 12) of the MF period. Figure 1 shows TT of steers according to feeding regimen and time of day. All steers had similar ($P > 0.05$) TT from 0800 to 1400. However, at 1500, BKMGT steers had greater TT ($P < 0.05$) than LIMFD with ADLIB being intermediate (38.87, 39.02, and 38.81 ± 0.06°C, for ADLIB, BKMGT, and LIMFD, respectively). Differences among these treatments were maintained through 1800. At 1800, TT of BKMGT steers were higher ($P < 0.05$) than LIMFD (39.08 vs 38.86°C) with ADLIB intermediate (38.98°C). Differences were not evident among feeding regimen ($P > 0.05$) from 1900 to 0700. The final assessment of TT during the MF period was made during an HS episode on d 20 to 22 (Figure 2). Steers on the LIMFD treatment had lower ($P < 0.001$) overall TT than steers ADLIB (38.72 vs 39.22 ± 0.10°C) and tended ($P < 0.10$) to be lower than BKMGT steers (39.00 ± 0.10°C). At 1800 and from 2100 through 2400, TT of LIMFD and BKMGT steers were lower ($P < 0.05$) than TT of ADLIB steers. The TT of LIMFD was lower than TT of both BKMGT and ADLIB steers during much of the morning (0200 through 1000) and during much of the early evening (1600, 1700, 1900, and 2000).

Figure 3 shows changes in TT with respect to coat color and time (coat color × time of day; $P < 0.01$) on d 10 to 12. Black-haired steers had higher ($P < 0.05$) TT than white-haired steers from 1000 through 1900 and at 2100 and 0600. Differences between 1000 and 1900 ranged from 0.16°C at 1000 and 1900 to 0.26°C at 1300. Black-haired steers had a 0.14°C higher ($P < 0.01$) overall TT (38.87 vs 38.73 ± 0.04°C). A coat color × time of day interaction ($P < 0.001$) was found for TT during MHS on d 13 to 15 of the MF period. The interaction was such that TT of all steers increased

Table 2. Mean daily DMI (kg) of pens of steers corresponding to time tympanic temperatures were obtained in Exp. 1

	Treatments[a]			
Item	ADLIB	BKMGT	LIMFD	SE
d 10 to 12	9.95[c]	9.51[c]	8.29[b]	0.18
d 13 to 15	9.72[c]	8.41[b]	8.27[b]	0.25
d 20 to 22	9.06[b]	10.23[c]	8.28[b]	0.35
d 35 to 37	7.22[c]	6.20[b]	7.44[c]	0.22

[a]Treatments provided ad libitum access to feed at 0800 (ADLIB), feed at 1600 with amount adjusted so that no feed was available at 0800 (BKMGT), or feed at 1600 at 85% of predicted ad libitum intake (LIMFD). Treatments were imposed for 22 d at the end of which all cattle were provided feed ad libitum at 0800.

[b,c]Means within day with unlike superscripts differ ($P < 0.05$).

similarly over time ($P < 0.05$) from 0800 to 1600. Black-haired steers had higher ($P < 0.05$) TT than white-haired steers from 1800 to 1900 with differences of 0.17 and 0.16°C, respectively. No differences were detected for TT between 2000 and 0100, but black-haired steers had lower ($P < 0.05$) TT than white-haired steers at 0200 (38.84 vs 39.02 ± 0.07°C) and lower ($P < 0.05$) TT from 0300 through 0500 with differences of 0.22, 0.18, and 0.19°C. Feeding regimen had no effect ($P < 0.10$) on TT during the MHS period (d 13 to 15). During the HS period (d 20 to 22), black-haired steers had 0.27°C higher ($P < 0.05$) TT than white-haired steers (39.12 vs 38.85 ± 0.08°C).

The final assessment of TT was made from d 35 to 37 at a time when all cattle were given ad libitum access to feed during a SHS episode. Differences in TT between black and white-haired steers averaged around 0.5°C at 1900 and 2000 (Figure 4). A feeding regimen by time of day interaction ($P < 0.001$) was found in TT of steers during SHS on d 35 to 37 (13, 14, and 15 d, respectively, after ad libitum access was given to all steers). Steers previously on the LIMFD treatment had lower ($P < 0.05$) TT than ADLIB steers at all times of the day. Differences between these treatments ranged from 0.76°C at 0600 (39.05 vs 38.29 ± 0.15°C) to 0.50°C at 2000 (39.98 vs 39.48 ± 0.15°C).

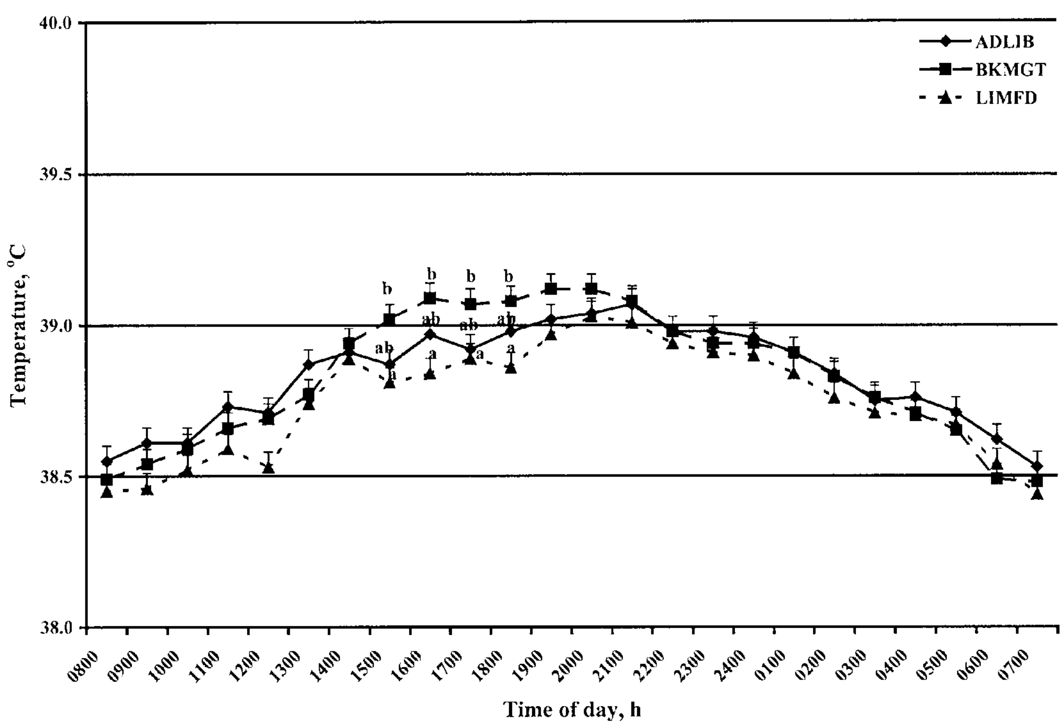

Figure 1. Effect of altered feeding regimen on tympanic temperature of steers during severe heat stress conditions (mean daily temperature-humidity index > 77) on d 10 to 12 in Exp. 1 with ADLIB steers given ad libitum access to feed at 0800; bunk management (BKMGT) steers fed at 1600 with bunks empty at 0800; and limit-fed (LIMFD) steers fed 85% of predicted ad libitum intake at 1600. Time of day effect ($P < 0.001$). Feeding regimen × time of day interaction ($P = 0.03$). [a,b]Means within a time with unlike superscripts differ ($P < 0.05$).

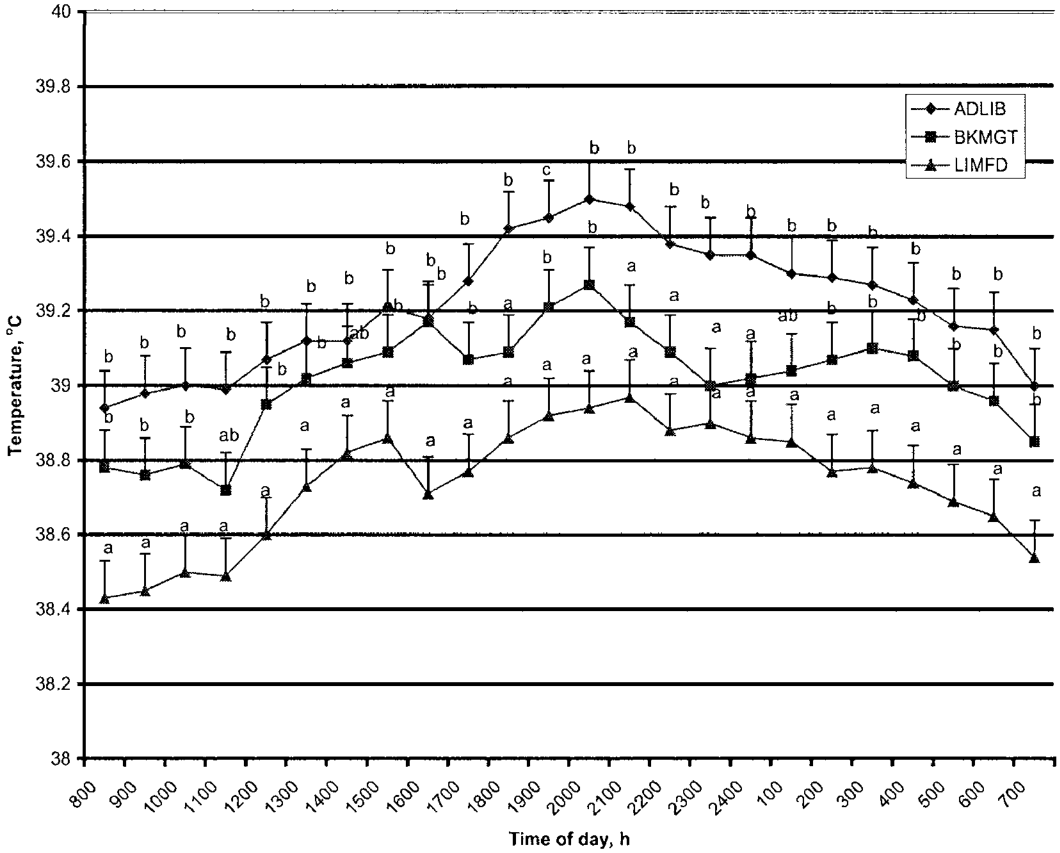

Figure 2. Tympanic temperature of steers during heat stress conditions (mean daily temperature-humidity index > 74) on d 20 to 22 of Exp. 1, with ADLIB steers given ad libitum access to feed at 0800; bunk management (BKMGT) steers fed at 1600 with bunks empty at 0800; limit-fed (LIMFD) steers fed 85% of predicted ad libitum intake at 1600. Treatment effect ($P < 0.01$). Time of day effect ($P < 0.001$). [a,b,c]Means within a time with unlike superscripts differ ($P < 0.05$).

Temperatures of steers previously on the BKMGT treatment were intermediate to the LIMFD and ADLIB steers. This was the hottest sequence of days that TT were obtained, resulting in lower DMI (Table 2) for all treatment groups.

Experiment 2. During the time TT were obtained, DMI did not differ ($P > 0.05$) among treatments and averaged 7.33, 6.99, and 7.58 kg/d, respectively, for the CON, AM, and PM treatment groups. Tympanic temperatures of steers in Exp. 2 during SHS on d 30 to 33 are shown in Figure 5. Steers in pens where mounds were sprinkled between 1000 and 1200 had lower ($P < 0.05$) TT than PM steers from 2300 through 0800 with CON being intermediate. Tympanic temperatures of all steers declined ($P < 0.05$) from 2300 through 0800 with CON, AM, and PM decreasing 0.93, 0.81, and 0.92°C, respectively. The differences in TT during this time were not a result of a change in the rate of decline during this period but were the result of the decline in TT between 1900 and 2300. During this time TT for all steers decreased ($P < 0.05$); however, AM and CON steers decreased 0.90 and 1.09°C, respectively, whereas PM decreased 0.57°C. After the initiation of sprinkling the AM mounds (1000), TT of all steers were similar. By 1200, TT tended to be lower ($P < 0.10$) for AM vs PM steers (39.06 vs 39.45 ± 0.14°C) with CON being intermediate (39.24 ± 0.14°C). Following cessation of AM sprinkling (1200), TT of AM steers at 1300 were similar to 1200 TT, whereas TT of CON and PM steers increased ($P < 0.05$) 0.31 and 0.33°C, respectively, and were higher than AM. Differences between AM and PM were maintained through 1400 with CON being intermediate. Although sprinkling was initiated at 1400 in PM pens, TT was not affected and was similar ($P < 0.05$) among treatments at 1500. Tympanic temperatures of AM and CON steers numerically increased from 1500 to 1600, whereas those of PM steers decreased ($P < 0.05$) 0.35°C. Steers in AM and CON reached peak TT of 40.23 and 40.33 ± 0.14°C at 1800, whereas peak temperature of PM steers was 40.26 ± 0.14°C and occurred at 2000.

Experiment 3. As in Exp. 2, DMI did not differ ($P > 0.05$) among treatment groups. During the time TT were obtained, DMI averaged 8.41, 8.94, 8.98, and 9.27 (d 30 to 32) and 8.54, 8.32, 8.34, and 8.32 k/d, respectively, for AMF/DRY, AMF/WET, PMF/DRY, and PMF/WET treatment groups. Tympanic temperatures in Exp. 3 were measured during SHS on d 30 to

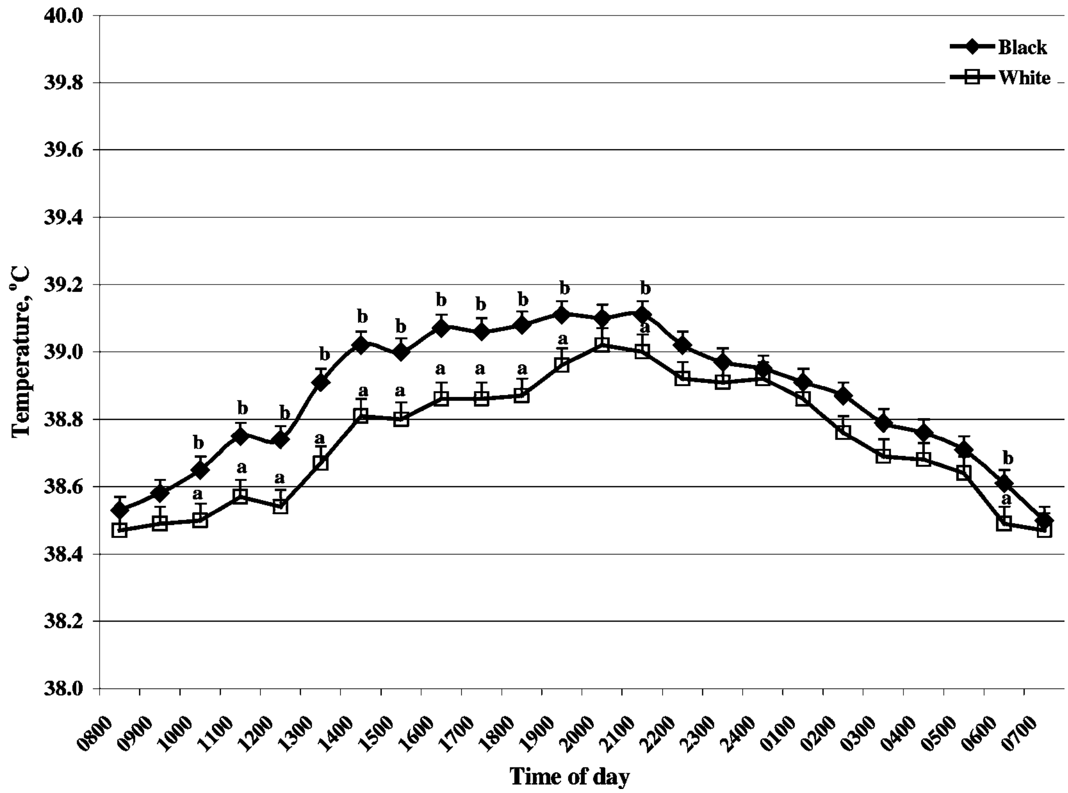

Figure 3. Effect of coat color on tympanic temperatures of steers during severe heat stress conditions (mean daily temperature-humidity index > 77) on d 10 to 12 in Exp. 1. Coat color effect ($P < 0.01$). Time of day effect ($P < 0.001$). Coat color × time of day interaction ($P < 0.01$). [a,b]Means within a time with unlike superscripts differ ($P < 0.05$).

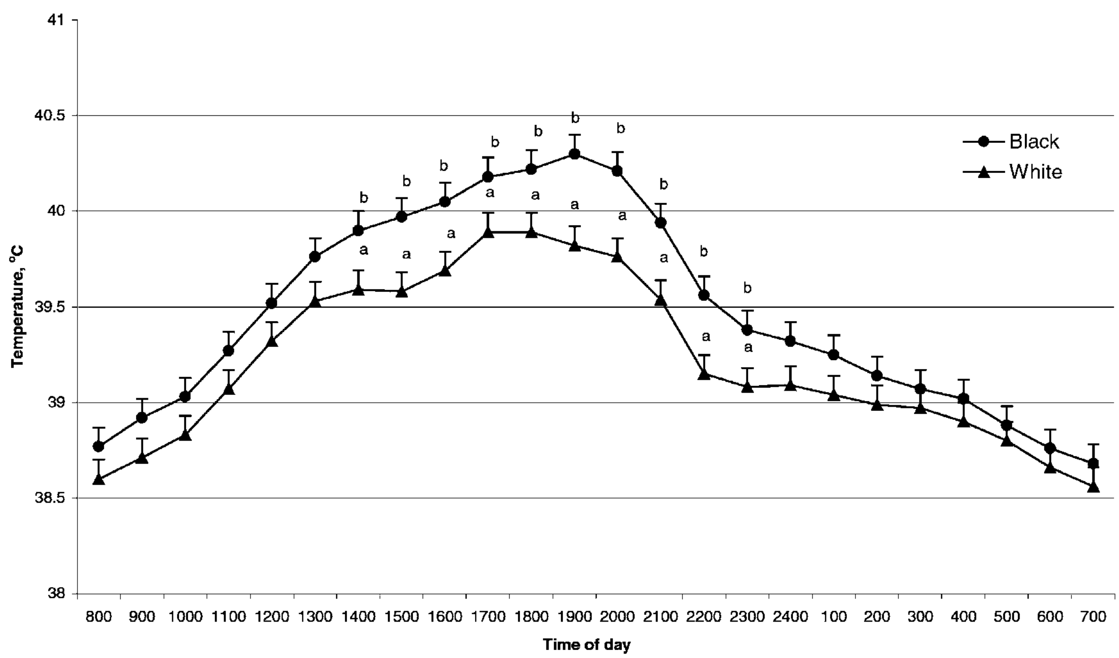

Figure 4. Tympanic temperature of steers during severe heat stress conditions (mean daily temperature-humidity index > 77) on d 35 to 37 of Exp. 1. All steers were given ad libitum access to feed at 0800. Coat color effect ($P < 0.05$). Time of day effect ($P < 0.001$). [a,b]Means within a time with unlike superscripts differ ($P < 0.05$).

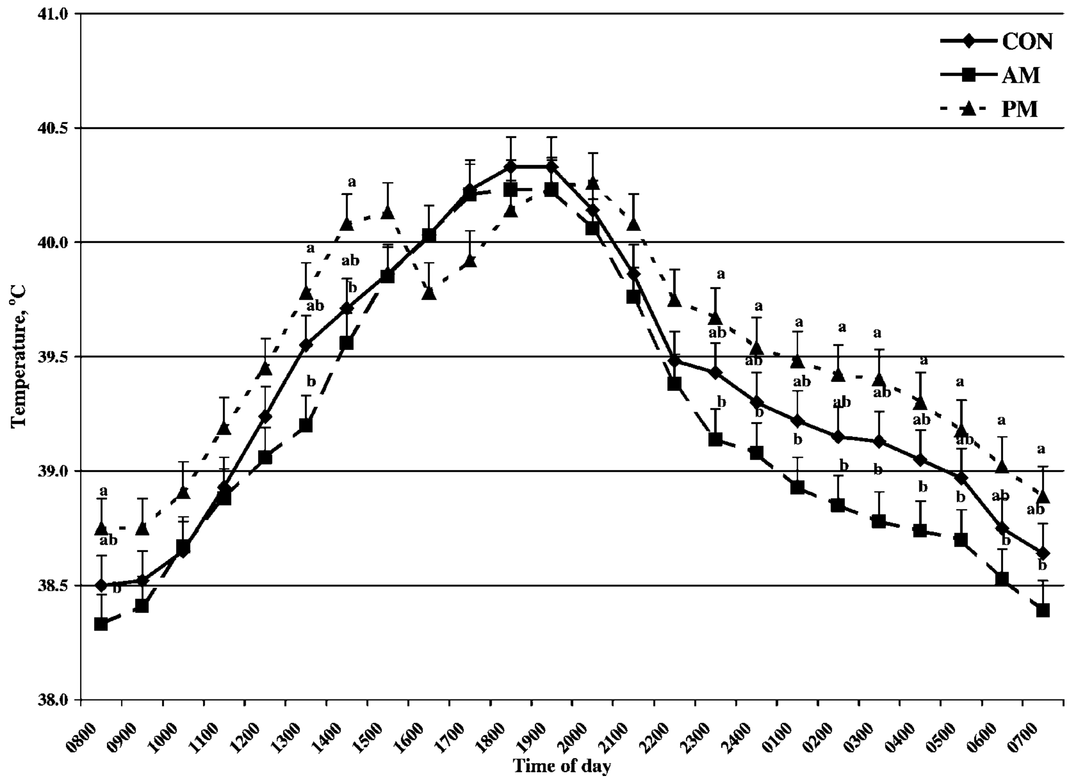

Figure 5. Tympanic temperatures of steers on d 30 to 33 during severe heat stress (mean daily temperature-humidity index > 77) in Exp. 2. No water was applied to control mounds, whereas AM and PM mounds were sprinkled between the hours of 1000 and 1200 and 1400 and 1600, respectively. Treatment effect ($P = 0.09$). Time of day effect ($P < 0.001$). Treatment × time of day interaction ($P < 0.01$). [a,b]Means within a time with unlike superscripts differ ($P < 0.05$).

32 of the experiment (Figure 6). This was 10, 11, and 12 d after treatments were initiated. Main effects of feeding time were not significant ($P > 0.05$). However, sprinkling × time of day ($P < 0.01$) and feeding time × sprinkling interactions ($P < 0.001$) were apparent. In addition, steers in pens with WET tended to have lower TT than those in DRY pens at 1400 and 1600, and were significantly lower ($P < 0.05$) between 1700 and 1900 (Figure 7). The elevated TT of DRY steers over time was due to the greater mean daily TT of AMF/DRY (39.80 ± 0.12°C) steers, which differed ($P < 0.01$) from the TT of AMF/WET, PMF/DRY, and PMF/WET (39.17, 39.09, and 39.43 ± 0.12°C, respectively) steer groups.

On d 61 to 62, a feeding time × time of day interaction ($P < 0.001$) was found in TT (Figure 8). Steers in the PMF treatment group had higher ($P < 0.05$) TT than AMF steers from 1600 to 1900. The differences ranged from 0.55°C at 1600 to 0.58°C at 1900. On d 30 to 32, the TT of the AMF group averaged over 0.2°C less than TT of the PMF group.

Discussion

Controlling intake of feedlot cattle under thermoneutral conditions has resulted in similar or improved overall feed efficiency compared to ad libitum fed controls (Sainz et al., 1995; Loerch and Fluharty, 1998; Carstens et al., 1991). Reducing overall feed intake or energy intake has been explored to reduce susceptibility to HS (Brosh et al., 1998; Mader et al., 1999; Holt et al., 1999). Brosh et al. (1998) reported rectal temperature, pulse rate, respiration rate, heart rate, and oxygen consumption were all reduced in heifers consuming an all forage diet vs those fed an 80:20 concentrate to forage diet. Mader et al. (1999) fed a high-energy diet (1.36 Mcal/kg NE_g) at 100 and 90% ad libitum in addition to a low-energy diet (1.15 Mcal/kg NE_g) fed ad libitum. Steers were housed in a controlled environment facility. Pulse rate of heifers fed the 90% and low energy diets were lower than ad libitum heifers under both thermoneutral and HS conditions. Additionally, rectal temperatures of these animals were also reduced 0.5°C under hot environmental conditions. This reduction is identical to that documented for d 20 to 22 of the present study where steers on the restricted feeding regimen had 0.5°C lower mean body temperature than those with ad libitum access to feed.

Mader et al. (2002) restricted feed intake of steers by 70 to 80% for either 21 or 42 d and compared tympanic temperatures of these steers to ad libitum fed controls. The 0.5°C reduction in TT between ADLIB and LIMFD steers on d 20 to 22 of the current study is similar

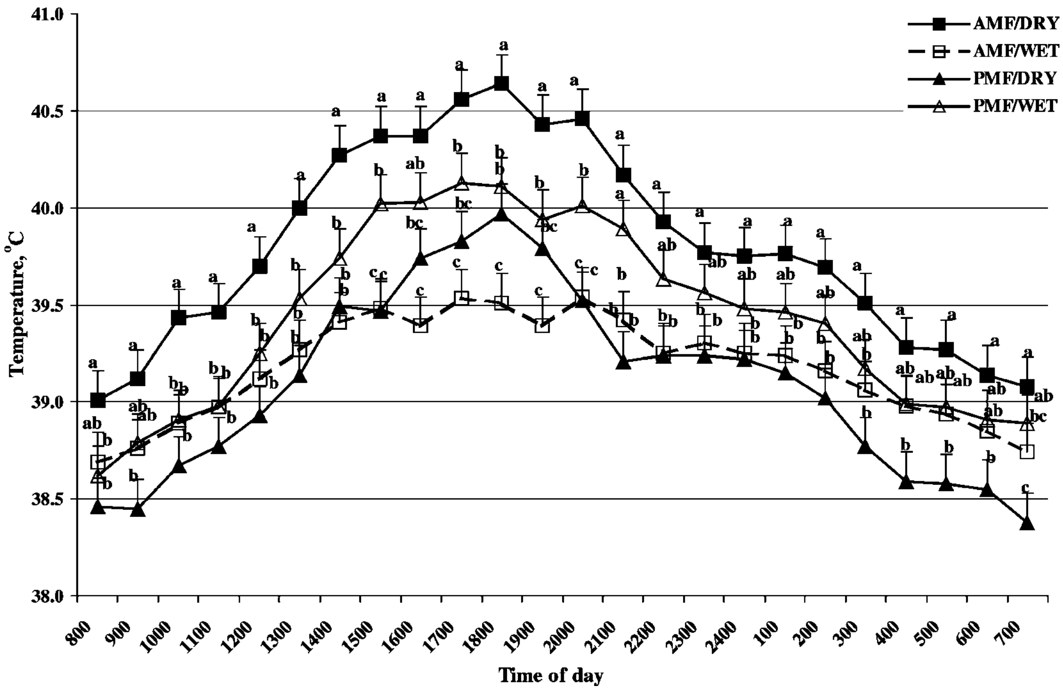

Figure 6. Effect of feeding time (0800 [AMF] vs 1400 [PMF]) and with (WET) and without (DRY) sprinkling on tympanic temperature of steers during severe heat stress (mean daily temperature-humidity index > 77) on d 30 to 32 of Exp. 3. Feeding time effect ($P = 0.12$). Time of day effect ($P < 0.001$). Feeding time × sprinkling interaction ($P < 0.002$). Sprinkling × time of day interaction ($P < 0.02$). Feeding time × sprinkling × time of day interaction ($P = 0.09$). [a,b,c]Means within a time with unlike superscripts differ ($P < 0.05$).

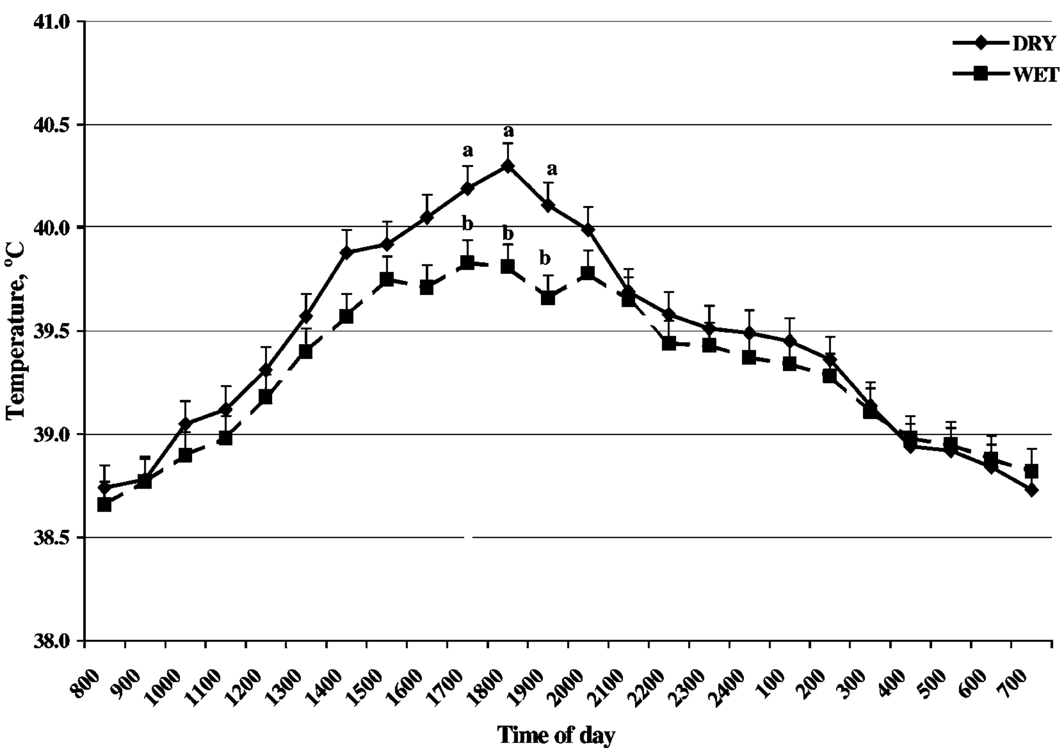

Figure 7. Effect of water sprinkling on tympanic temperatures of steers during severe heat stress (mean daily temperature-humidity index > 77) on d 30 to 32 of Exp. 3. Dry steers were in pens with mounds not receiving water sprinkling, whereas mounds in the pens of Wet steers were sprinkled 20 min/1.5 h from 1000 to 1750 h. Time of day effect ($P < 0.001$). Sprinkling × time of day interaction ($P < 0.02$). [a,b]Means within a time differ ($P < 0.05$).

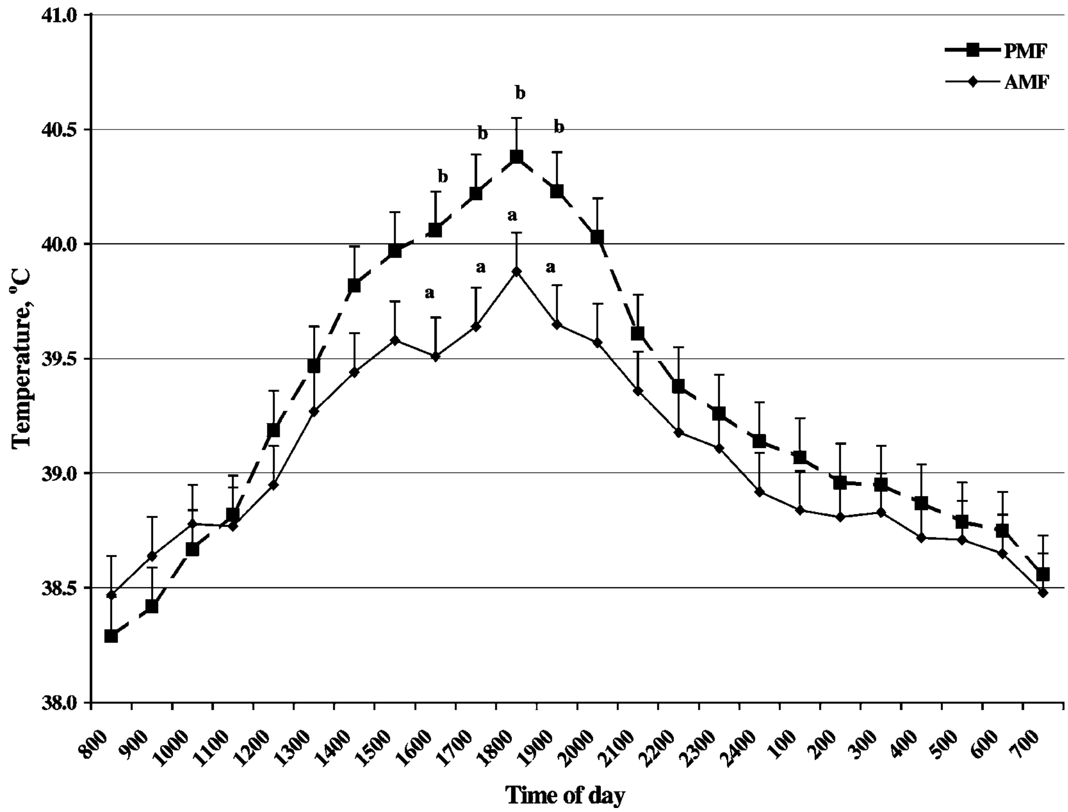

Figure 8. Effect of altered feeding time on tympanic temperatures of steers during mild heat stress conditions (mean daily temperature-humidity index between 70 and 74) on d 61 to 62 in Exp. 3. Treatments consisted of AMF (fed ad libitum at 0800) and PMF (fed at 1400 with bunks clean by 0800). Time of day effect ($P < 0.001$). Feeding time × time of day interaction ($P < 0.001$). [a,b]Means within a time with unlike superscripts differ ($P < 0.05$).

to Mader et al. (2002), who reported cattle receiving restricted feeding regimens had 0.3°C lower TT than ad libitum fed cattle during environmental HS conditions.

Reductions in body temperature of restricted fed cattle may be the result of acute effects, such as reductions in substrates available for metabolism or may have longer-term effects as a result of alterations in organ size in response to lower levels of intake (Koong et al., 1985; Burrin et al., 1990; Lapierre et al., 2000). The alterations in organ size could contribute to the carryover effect of limit-feeding regimen observed in Exp. 1 after steers were fed ad libitum. There is general agreement that heat production is reduced for some time following realimentation of restricted animals (Graham and Searle, 1972; Thorbeck and Henckel, 1976; Ledger and Sayers, 1977); however, the extent and duration of the reduction vary considerably (NRC, 1996).

Freetly et al. (1995) examined O_2 consumption of the liver and portal-drained-viscera during feed restriction and subsequent realimentation of sheep to determine the length of time for steady-state O_2 consumption to occur in each scenario. Portal-drained viscera O_2 consumption decreased as a result of feed restriction and reached a steady-state after 29 d of restriction, whereas hepatic O_2 reached steady-state conditions at 21 d. Although animals in the Freetly et al. (1995) study remained on the restricted feeding regimen longer than steers in the current experiment (80 vs 23 d), steady-state hepatic and portal-drained-viscera O_2 consumption did not occur in Freetly et al. (1995) until d 38 and 40, respectively. Due to this lag time of steady-state conditions and the relationship between portal-drained-viscera O_2 consumption and metabolic heat production, reduced TT of steers previously on the restricted feeding regimen in Exp. 1 may be the result of a reduction basal metabolic heat production.

Differences in TT of steers in Exp. 1 as a result of coat color supports findings of Finch et al. (1984) and Arp et al. (1983a,b). Finch et al. (1984) reported that rectal temperature average 0.3°C higher in dark-red vs white *Bos taurus* cattle. This difference was attributed to the greater heat flux present at the skin of the darker-haired animals (159 vs 115 W/m^2). In addition, Arp et al. (1983b) observed that black-haired steers in commercial feedlots had body surface temperatures as much as 5.6°C greater than red-haired contemporaries and as much as 11.7°C greater than white-haired contemporaries. The fact that coat color influenced TT virtually every time it was assessed lends support to commercial feedlot surveys reporting increased susceptibility of black-haired animals during times of HS (Busby and Loy, 1996; Mader et al., 2001). The higher TT of black-haired steers suggests their upper critical temperature may be lower, especially during periods of high radiant heat load since the differences in TT were more pronounced during daylight hours. The data collected during ad libitum feeding (d 35 to 37) clearly show the impact of coat color on cattle being full-fed on hot days in the summer.

Altering feeding time in Exp. 1 had limited effect on TT during the managed feeding period, although the response was found to be more beneficial the longer the cattle were on the program. However, carryover effects were found, which would suggest that effects of diet management strategies may not be realized immediately. Once animal effects occur, such as changes in metabolic rate, it may take a comparable length of time for the animal to adjust back. These data suggest that the effects of bunk management and limit-feeding programs on TT were observed under HS and SHS but not under MHS conditions and effects of LIMFD on TT and possibly metabolism can be carried over to subsequent full-feeding periods.

Altering feeding time for the entire feeding period in Exp. 3 did alter TT of these cattle early in the feeding period as effectively as sprinkling. However, later in the feeding period these same cattle had higher TT irrespective of sprinkling. Afternoon and evening feeding of cattle prevents the simultaneous occurrence of peak metabolic and environmental heat loads (Reinhardt and Brandt, 1994). This suggests that cattle consuming diets during the late evening hours may be better able to cope with heat load and utilize metabolizable energy more efficiently than those fed in the morning (Gaughan et al., 1996). Differences in response to feeding time early vs late in the feeding period in the present study may be related to changes in feeding pattern (De Dios and Hahn, 1993) as well as temperature.

Benefits of shifting to an afternoon vs morning feeding regimen were not evident in Exp. 3 and in fact would support an opposite conclusion in that feeding more feed in the afternoon may be detrimental. Difference between Exp. 1 and 3 in the managed feeding programs and subsequent response would suggest that shifting to a 1600 feeding time is superior in managing HS than shifting to a 1400 feeding time, particularly if bunks can be kept empty several hours prior to the afternoon feeding. The lower TT of steers fed in the afternoon in Exp. 1 can occur despite higher humidity and ambient temperatures during time of TT measurement. However, difficulty arises in managing afternoon or early evening feeding programs, when feedmill and/or feeding equipment fail, and maintenance crews are no longer on duty. From a management perspective, feeding cattle earlier vs later in the afternoon would be preferred.

Providing access to sprinklers altered body temperature. Application of water to cattle is beneficial in alleviating HS because of the latent heat of vaporization associated with the change of water from a liquid to gaseous state. The transfer of heat by evaporation occurs despite an equal or reversed thermal gradient between the animal and its surrounding environment (Arkin et al., 1991). Therefore, under extreme environmental conditions, evaporative transfer is the only means by which an animal may dissipate heat. It is assumed that thermal conductivity of a wet coat is similar to a dry one; however, the amount of wetness in the coat increases linearly with the amount of heat dissipated (Arkin et al., 1991). The ability of evaporating water to cool an animal, in addition to being dependent on the wetness of the coat, also depends on the degree of water saturation of the of the air (relative humidity). Cattle, as a whole, are a sparsely sweating species, leading Kibler and Brody (1952) to conclude that the main limitation of evaporative skin cooling is the rate of moisture secretion of the body surface. However, evaporative heat loss is the only means an animal can dissipate heat when the environmental temperature surrounding the animal is higher than the temperature of the animal.

Allowing cattle access to sprinklers in an effort to increase evaporative cooling has been evaluated extensively in dairy research. The hypothesis behind these studies is that sprinkling maximizes the amount of heat removed from the animal via evaporation. In addition, as water is evaporated from the air surrounding the animal, the ambient air temperature is lowered, thus, increasing the heat gradient and allowing for greater heat flow away from the animal. Within the dairy environment, economic benefits of sprinkling to promote increased evaporative cooling are easily realized (Wiersma et al., 1973). Dairy cattle allowed access to sprinklers (with and without forced ventilation) have increased milk production (Igono et al., 1985; Wolfenson et al., 1988; Lin et al., 1998), improved reproduction (Ealy et al., 1994), and improved conversion of feed to milk (Chan et al., 1997). Comparable economic benefits of cooling feedlot cattle are less evident, likely due to the ability of heat-stressed cattle to exhibit rapid compensatory growth following HS (Baccarri et al., 1983).

The objective in both of the current studies was not only to directly cool cattle by sprinkling but also to cool the pen surface and provide an area conducive to conductive heat exchange between the animal and feedlot surface. It is known that cooling surfaces provides a mechanism for more efficient heat transfer between the animal and the surface. Kelly et al. (1950), reported that shade decreased feedlot surface temperatures over 25°C during the day. In addition, Kelly et al. (1964) reported heat transfer up to 221 W/m^2 for pigs housed on cooled slabs and maintained at 21°C. In dry soils, thermal conductivity is very low and has been reported to average only 0.25 W/m^2 (Campbell et al., 1994). Because of this low value the ability of the animal to dissipate heat to the soil is poor. Thermal conductivity of soil is not constant and may be improved by the addition of water (Sepaskhah and Boersma, 1979; Campbell et al., 1994). Measurements of a clay-type soil similar to that typically found in feedlots indicates that thermal conductivity may be enhanced fivefold with increasing water content. Therefore, application of water to the ground can greatly enhance heat transfer of the animal.

Improving thermal conductivity of soils has not been quantitatively evaluated, but it is an inviting area for future feedlot studies. Water application certainly would cool ground surface temperature under most summer conditions. When ground temperature is greater than body temperature, the animal is absorbing heat from the feedlot surface due the reversal of the thermal gradient between skin and ground surface temperature. Application of water would not only cool the ground and increase the thermal gradient but would also provide for increased thermal conductivity and better heat flow down the gradient.

Implications

Altering feeding time and amount can alter body temperature response of feedlot cattle under both thermoneutral and heat stress environmental conditions. However, switching from a morning to afternoon feeding regimen will most likely be beneficial in reducing body temperature when cattle are fed fairly late in the afternoon (past 1500), and bunks have been empty for several hours prior to feeding. Reductions in body temperature, as a result of restricted feeding regimens, were found in steers under heat stress with the reduction in body temperature sustained for a brief period following realimentation. Sprinkling cattle and/or feedlot surfaces effectively lowers body temperature allowing for improved heat flow between the animal and surroundings. Improved management strategies can be employed to improve animal well-being during adverse climatic conditions.

Literature Cited

Arkin, H., E. Kimmel, A. Berman, and D. Broday. 1991. Heat transfer properties of dry and wet furs of dairy cows. Trans. Am. Soc. Agric. Eng. 34(6)2550–2558.

Arp, S. C., F. N. Owens, S. L. Armbruster, and Y. Kojima. 1983a. Effect of lot type and coat color on respiration rate, surface temperature and feeding behavior of feedlot steers. Oklahoma Anim. Sci. Res. Rep. 79–81.

Arp, S. C., F. N. Owens, S. L. Armbruster, and S. Laudert. 1983b. Relationship of coat color, body surface temperature and respiration rate in feedlot steers. Oklahoma Anim. Sci. Res. Rep. 82–86.

Baccari, F., Jr., H. D. Johnson, and G. L. Hahn. 1983. Environmental heat effects on growth, plasma T_3, and postheat compensatory effects on Holstein calves. Proc. Soc. Exp. Biol. Med. 173:312–318.

Brosh, A., Y. Aharoni, A. A. Degen, D. Wright, and B. 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.

Buffington, D. E., A. Collazo-Arocho, G. H. Canton, D. Pitt, W. W. Thatcher, and R. J. Collier. 1981. Black globe-humidity index (BGHI) as comfort equation for dairy cows. Trans. ASAE (Am. Soc. Agric. Eng.) 771–714.

Burrin, D. G., C. L. Ferrel, R. A. Britton, and M. Bauer. 1990. Level of nutrition and visceral organ size and metabolic activity in sheep. Br. J. Nutr. 64:439–448.

Busby, D., and D. Loy. 1996. Heat stress in feedlot cattle: Producer survey results. Pages 108–110 in Iowa State Univ. Beef Res. Rep. AS-632, Ames.

Campbell, G. S., J. D. Jungbauer, Jr., W. R. Bidlake, and R. D. Hungerford. 1994. Predicting the effect of temperature on soil thermal conductivity. Soil Sci. 158(5):307–313.

Carstens, G. E., D. E. Johnson, M. A. Elenberger, and J. D. Tatum. 1991. Physical and chemical components of the empty body during compensatory growth in beef steers. J. Anim. Sci. 69:3251–3264.

Chan, S. C., J. T. Huber, K. H. Chen, J. M. Simas, and Z. Wu. 1997. Effects of ruminally inert fat and evaporative cooling on dairy cows in hot environmental temperatures. J. Dairy Sci. 80:1172–1178.

DeDios, O. O., and G. L. Hahn. 1993. Thermoregulation of growing bovines during fall and spring transitional periods. Pages 289–297 in Proc. 4th Intl. Lvstk. Environ. Symp. Amer. Soc. Agric. Eng., St. Joseph, MO.

Ealy, A. D., C. F. Arechiga, D. R. Bray, C. A. Risco, and P. J. Hansen. 1994. Effectiveness of short-term cooling and vitamin E for alleviation of infertility induced by heat stress in dairy cows. J. Dairy Sci. 77:3601–3607.

Finch, V. A., I. L. Bennett, and C. R. Holmes. 1984. Coat colour in cattle: effect on thermal balance, behavior and growth, relationship with coat type. J. Agric. Sci. (Camb.) 102:141–146.

Freetly, H. C., C. L. Ferrell, T. G. Jenkins, and A. L. Groetsch. 1995. Visceral oxygen consumption during chronic feed restriction and realimentation in sheep. J. Anim. Sci. 73:843–852.

Gaughan, J. B., T. L. Mader, D. Savage, and B. A. Young. 1996. Effect of feeding regimen on feed intake of cattle exposed to heat. Proc. Aust. Soc. Anim. Prod. 21:223–226.

Graham, N. M., and T. W. Searle. 1972. Balance of energy and matter in growing sheep at several ages, body weights and planes of nutrition. Aust. J. Agric. Res. 23:97–108.

Hahn, G. L., and T. L. Mader. 1997. Heat waves and their relation to thermoregulation, feeding behavior and mortality of feedlot cattle. Pages 563–567. in Proc. 5th Int. Livestock Environ. Symp., Minneapolis. ASAE, St. Joseph, MO.

Holt, S. M., T. L. Mader, J. B. Gaughan, A. Lisle, and T. L. Scott. 1999. Limit feeding feedlot cattle during the summer. Asian-Aus. J. Anim. Sci. 13 (Suppl. C):329–332.

Hubbard, K. G., D. E. Stooksbury, G. L. Hahn, and T. L. Mader. 1999. A climatological perspective on feedlot cattle performance and mortality related to the temperature-humidity index. J. Prod. Agric. 12(4):650–653.

Igono, M. B., B. J. Steevens, M. D. Shanklin, and H. D. Johnson. 1985. Spray cooling effects on milk production, milk, and rectal temperature of cows during a moderate temperature summer season. J. Dairy Sci. 68:979–985.

Kelly, C. F., T. E. Bond, and W. Garrett. 1964. Heat transfer from swine to a cold slab. Trans. ASAE. 7:34–37.

Kelly, C. F., T. E. Bond, and N. R. Ittner. 1950. Thermal design of livestock shades. Agr. Eng. 31:601–606.

Kibler, H. H., and S. Brody. 1952. Relative efficiency of surface evaporative, respiratory evaporative, non-evaporative cooling in relation to heat production in Jersey, Holstein, Brown Swiss and Brahman cattle, 5° to 105°F. Mo. Agr. Exp. Sta. Res. Bull. 497.

Koong, L. J., C. L. Ferrell, and J. A. Nienaber. 1985. Assessment of interrelationships among levels of intake and production, organ size and fasting heat production in growing animals. J. Nutr. 115:1383–1390.

Lapierre, H., J. F. Bernier, P. Dubreuil, C. K. Reynolds, C. Farmer, D. R. Ouellet, and G. E. Lobley. 2000. The effect of feed intake on splanchnic metabolism in growing beef steers. J. Anim. Sci. 78:1084–1099.

Ledger, H. P., and A. R. Sayers. 1977. The utilization of dietary energy by steers during periods of restricted feed intake and subsequent realimentation. 1. The effect of time on the maintenance requirements of steers held at constant weight. J. Agric. Sci. Camb. 88:11–26.

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

Lin, J. C., B. R. Moss, J. L. Koon, C. A. Flood, S. Rowe, J. R. Martin, B. Brady, F. Degraves, and R. C. Smith. 1998. Effect of sprinkling over the feed area and misting free stalls on milk production. Prof. Anim. Sci. 14:102–107.

Loerch, S. C., and F. L. Fluharty. 1998. Effects of programmed intake on performance and carcass characteristics of feedlot cattle. J. Anim. Sci. 76:371–377.

Mader, T. L., S. M. Holt, G. L. Hahn, M. S. Davis, and D. E. Spiers. 2002. Feeding strategies for managing heat load in feedlot cattle. J. Anim. Sci. 80:2373–2382.

Mader T. L., L. L. Hungerford, J. A. Nienaber, M. J. Buhman, M. S. Davis, G. L. Hahn, W. M. Cerkoney, and S. M. Holt. 2001. Heat stress mortality in Midwest feedlots. J. Anim. Sci. 79(Suppl. 2):33.

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

Mader, T. L., J. M. Dahlquist, and J. B. Gaughan. 1997. Wind protection effects and airflow patterns in outside feedlots. J. Anim. Sci. 75:26–36.

Monty, D. E., and J. L. Garbareno. 1978. Behavioral and physiological responses of Holstein-Friesian cows to high environmental temperatures and artificial cooling in Arizona. Am. J. Vet. Res. 39:877–882.

NOAA. 1976. Livestock hot weather stress. Operations Manual Letter C-31-76. NOAA, Kansas City, MO.

NRC. 1996. Nutrient Requirements of Beef Cattle. 7th Ed. Nat. Acad. Press, Washington, DC.

Reinhardt, C. D., and R. T. Brandt. 1994. Effect of morning vs evening feeding of limit-fed Holsteins during summer months. Cattlemen's Day, Kansas State Agricultural Experiment Station, Manhattan.

Sainz, R. D., F. De la Torre, and J. W. Oltjen. 1995. Compensatory growth and carcass quality in growth-restricted and refed beef steers. J. Anim. Sci. 73:2971–2979.

Sepaskhah, A. R., and L. Boersma. 1979. Thermal conductivity of soils as a function of temperature and water content. Soil Sci. Soc. Amer. J. 43:439–444.

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

Thorbek, G., and S. Henckel. 1976. Studies on energy requirements for maintenance in farm animals. Energy Metab. Proc. Symp. 19:117–120.

Wiersma, F., D. Ray, and C. Roubicek. 1973. Modified environment for beef in hot climates. Trans. Am. Soc. Agric. Eng. 16:348–353.

Wolfenson, D., I. Flamenbaum, and A. Berman. 1988. Dry period heat stress relief effects on prepartum progesterone, calf birth weight, and milk production. J. Dairy Sci. 71:809–818.