Effect of management strategies on reducing heat stress of feedlot cattle: Feed and water intake[1]

T. L. Mader*[2] and M. S. Davis†

*University of Nebraska, Northeast Research and Extension Center, Concord 68728; and
†Koers-Turgeon Consulting Services, Inc., Salina, KS 67401

ABSTRACT: Three experiments were conducted to evaluate management strategies designed to decrease heat stress of cattle finished during the summer. In Exp. 1, 144 Angus crossbred yearling steers were assigned to three treatments: 1) ad libitum access to feed at 0800 (ADLIB); 2) fed at 1600 with feed amount adjusted so that no feed was available at 0800 (BKMGT); and 3) fed at 1600 at 85% of predicted ad libitum levels (LIMFD). Treatments were imposed for 23 d of an 82-d study, after which all steers were fed ad libitum at 0800. Treatment did not affect ($P > 0.10$) overall DMI, although ADLIB cattle tended to consume less feed. Overall water intake was decreased ($P < 0.05$) by 6.8 L·animal^{-1}·d^{-1} for LIMFD vs. ADLIB steers. In Exp. 2, 96 Angus crossbred yearling steers were assigned to three treatments: 1) control, no water application; 2) water applied to the pen surfaces between 1000 and 1200 (AM); and 3) water applied to pen surfaces between 1400 and 1600 (PM). Water intake and DMI did not differ among treatments; however, feed efficiency of AM steers was superior ($P = 0.06$) to that of PM steers. Conversely, marbling scores of PM steers were higher ($P = 0.06$) than those of AM steers. In Exp. 3, 192 crossbred steers were used to determine the effects of feeding time (0800 [AMF] vs. 1400 [PMF]), with (WET) and without (DRY) sprinkling (20 min every 1.5 h between 1000 and 1750). Feed DMI did not differ among treatments; however, water intake and marbling scores were highest ($P < 0.05$) for AMF/DRY steers. During these experiments, bunk scores (0 = <10% of feed delivered remaining; 1 = 10 to 50% of feed remaining; 2 = >50% of feed remaining) were assigned to each pen at various times during the day. In Exp. 1, bunk scores of BKMGT pens remained similar ($P > 0.20$) under varying environmental conditions, whereas LIMFD steers had lower scores ($P < 0.05$) as days on feed increased, even under hot environmental conditions. In Exp. 3, bunk scores of PMF/WET steers tended to be lower ($P < 0.10$) at 1700 and 2000 compared with PMF/DRY pens under mild heat stress but not under severe heat stress. Alternative feeding regimens and sprinkling can alter the feed intake pattern of steers. Heat stress management strategies imposed in these experiments had minimal effects on cattle performance. Such strategies would be most useful for decreasing the susceptibility of cattle to hyperthermia and reducing related feedlot cattle deaths without adversely affecting performance.

Key Words: Feed Intake, Feedlot, Heat Stress, Management, Sprinkling

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Introduction

Episodes of high environmental temperatures coupled with high relative humidity, solar radiation, and low wind speeds can decrease performance by feedlot animals (Hahn, 1994, 1995; Hubbard et al., 1999; Mader et al., 1999a). In extreme instances, these conditions may manifest simultaneously and result in large numbers of cattle that die as a result of hyperthermia (Busby and Loy, 1996; Hahn and Mader, 1997; Mader, 2003).

Management strategies to decrease or alleviate heat stress-related production losses are warranted. Provision of sprinklers to heat-stressed feedlot cattle has resulted in improved performance in the hot, dry climates of Arizona (Morrison et al., 1973; Morrison et al., 1981). These methods have also been shown to decrease body temperature (Igono et al., 1985; Armstrong, 1994) and respiration rates (Lin et al., 1998; Chen et al.,

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[2]Correspondence: Haskell Agricultural Laboratory, 57905 866 Road (phone: 402-584-2812; fax: 402-584-2859; e-mail: tmader@unlnotes.unl.edu.

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1993). Altering feeding time and/or amount have been shown to be beneficial in reducing heat stress (Brosh et al., 1998). Feeding cattle later in the day prevents the coincidal occurrence of peak metabolic and environmental heat load (Reinhardt and Brandt, 1994; Brosh et al., 1998). Limiting energy intake can effectively decrease basal metabolic heat production (Carstens et al., 1989) and therefore decrease total metabolic heat load of animals subjected to high environmental temperatures. Furthermore, energy restriction programs have resulted in improved efficiency of cattle maintained under thermoneutral environments (Murphy and Loerch, 1994).

Davis et al. (2003) reported that altering feeding regimen and/or sprinkling cattle significantly decreased feedlot cattle heat stress, as determined from tympanic temperature. The objectives of these studies were to evaluate the strategic use of altered feeding times and amounts both apart from and in addition to provision of sprinklers on feedlot steers finished in the summer months.

Materials and Methods

All experiments reported herein were conducted at the University of Nebraska Haskell Agricultural Laboratory with the approval of the University of Nebraska-Lincoln Institutional Animal Care and Use Committee. Facility design and layout has been reported by Mader et al. (1997, 1999a). Facilities are located at lat 42°23′ N and long 96°57′ W, with a mean elevation of 445 m above sea level. Details of the vaccination, parasite control, and implant regimens utilized for these experiments are reported by Davis et al. (2003). Experimental design, sprinkling procedures, and climate data were also reported by Davis et al. (2003). Procedures used to obtain carcass data are described by Mader and Lechtenberg (2000). In all experiments, individual initial weight was the average of two nonshrunk weights taken on consecutive days (d –1 and 0).

Experiment 1

On June 23, 144 Angus × Charolais crossbred steers were randomly assigned to one of 24 pens (six steers per pen). Treatments assigned to pens (eight pens per treatment) were as follows: 1) providing ad libitum access to feed at 0800 (**ADLIB**); 2) providing feed at 1600 with amount adjusted so that none was available at 0800 (**BKMGT**); and 3) providing feed at 1600 at 85% of predicted ad libitum levels (**LIMFD**). All steers were adjusted to the diet being fed, over a 21-d period, before initiation of this experiment. The DMI by steers in the LIMFD treatment group was determined before initiation of 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. Ingredient and nutrient composition of the diet in this and subsequent experiments are shown in Table 1. Treatments were imposed for a 23-d managed feeding phase, after which all steers were fed ad libitum at 0800 h. A 23-d managed feeding phase was used to correspond with the period of time cattle were adapting to summer heat, typically late June and the first few weeks of July, and the more stressful portion of the summer (Mader et al., 1999a). A short managed feeding period was used because minimal use of alternative feeding systems is preferred to the norm in most feeding operations.

Table 1. Ingredient and nutrient composition of diets fed during Exp. 1, 2, and 3

Item	Exp. 1 and 2	Exp. 3
	%, DM basis	
Ingredients		
Dry-rolled corn	84.00	81.00
Alfalfa hay	7.50	5.00
Corn silage	—	5.00
Soybean meal	2.00	2.50
Liquid supplement[a]	4.50	4.50
Dry supplement[b]	2.00	2.00
Composition[c]		
CP, %	13.0	13.0
NE_m, Mcal/kg	2.10	2.10
ME, Mcal/kg	3.08	3.08
NE_g, Mcal/kg	1.43	1.43
Ca, %	0.70	0.70
P, %	0.34	0.33
K, %	0.75	0.76

[a]Contained on a DM basis: 61.54% CP; 12.30% Ca; 5.39% salt; 3.85% K; 0.71% P; 0.43% Mg; 0.148% Zn; 0.037% Fe; 0.050% Mn; 0.021% Cu; 0.002% I; 0.001% Co; 7×10^4 IU/kg vitamin A; 1×10^4 IU/kg vitamin D; and 44 IU/kg vitamin E.

[b]Contained on a DM basis: 50.01% soybean meal; 48.57% ground corn; 0.85% Rumensin 80 (176.4 g of monensin/kg; Elanco Animal Health, Indianapolis, IN); 0.51% Tylan 40 (89 g of tylosin/kg; Elanco Animal Health); and 0.06% thiamine mononitrate.

[c]Calculated composition (NRC, 1996).

Daily feed was recorded. Water meters (model C700, ABB Water Meters, Inc., Ocala, FL) were used to record daily water intake when bunks were read before feeding. Body weights were obtained on d 23 and 82 (experiment termination). On d 83, steers were slaughtered at a commercial slaughter facility where hot carcass weight, 12th-rib fat thickness, marbling score, and yield grade were obtained. Each pen shares a waterer and mound with an adjoining pen; therefore, for this and subsequent experiments, treatments were randomly assigned to sets of two pens, which shared a waterer and a mound.

Experiment 2

On June 23, 96 Angus × Charolais crossbred steers were randomly assigned to one of 12 pens (eight steers per pen). Treatments assigned to pens (four pens per treatment) were as follows: 1) no water sprinkling (**CON**); 2) sprinkling of pen surface from 1000 to 1200 (**AM**); and 3) sprinkling of pen surface from 1400 to 1600

(**PM**) when predicted maximum temperature-humidity index (**THI**) was ≥77. The decision for water application was made at 1000 based on local weather reports and current climatic conditions. The THI was calculated as THI = (0.8 × ambient temperature) + [(% relative humidity/100) × (ambient temperature − 14.4)] + 46.4 (Thom, 1959; NOAA, 1976). Water was applied to the mound areas of the pens using impact sprinklers (Rainbird, Nelson, Peoria, IL) placed at ground level. 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/steer of wetted surface. Water was applied for a total of 23 d of the 82-d study. Water was strategically applied only on those days when heat stress had a high probability of occurring to minimize mud accumulation and undesirable effects of acclimating cattle to cool conditions in the event water was applied on nonheat-stress days.

Daily feed and water intake were recorded throughout the experiment. Body weights were obtained on d 34 and 82 (experiment termination). On d 83, steers were slaughtered at a commercial slaughter facility where hot carcass weight, 12th-rib fat thickness, marbling score, and yield grade were obtained.

Experiment 3

One hundred ninety-two British crossbred steers were assigned randomly to 24 pens (eight steers per pen) and used in a 2 × 2 completely randomized design. The two factors were feeding time (0800 [**AMF**] vs. 1400 [**PMF**]) and sprinkling (no water application [**DRY**] vs. sprinkling [**WET**]). From d 0 (June 8) to 21, all steers had ad libitum access to feed beginning at 0800, with no application of water to the treatment pens (covariate period). Treatments were initiated on d 21. Method of water application was similar to Exp. 2 except that sprinklers were positioned approximately 2 m above the pen surface. Water was applied to pens when THI at 0900 was ≥ 68 using sprinklers electronically linked to the on-site weather stations. If the THI threshold was obtained, an electronic solenoid opened to allow for water flow. Electronic timers (Nelson, Peoria, IL) controlled water flow and the time water was to be applied, as described by Davis et al. (2003). Based on data obtained in Exp. 2, the THI threshold value of 68 was determined using regression equations with THI at 0700, 0800, and 0900 as the independent variable, and daily maximal THI as the dependent variable. The database for the equation comprised 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. Experiment 3 was initiated at an earlier date than Exp. 1 and 2 to mimic conditions for cattle that are already on feed before the start of the summer season and typically would not require management for heat stress at that time. In addition, in Exp. 2 and 3, the sprinklers were set up to apply water only on days with a high probability of being stressful for the cattle. In Exp. 2 and 3, sprinklers were set to deliver approximately 38 L of water per head during the total sprinkling period of 2 h. The area sprinkled in Exp. 3 was the same as that sprinkled in Exp. 2. Since the sprinkling regimen was imposed throughout the 22 to 83-d experimental period in Exp. 3, the alternative feeding system used in that experiment was imposed during the same period vs. using a shorter managed feeding phase described in Exp. 1.

Daily feed and water intakes were recorded throughout the experiment. Monensin and Tylan (Elanco Animal Health, Indianapolis, Indiana) were provided in the diet at 30 and 9 mg/kg, respectively (DM basis). Body weights were obtained on d 21, 56, and 83 (experiment termination). On d 84, steers were slaughtered at a commercial slaughter facility where hot carcass weight, 12th-rib fat thickness, marbling score, and yield grade were obtained.

Throughout these experiments, bunk scores were obtained for each pen based on the following scale: 0 = <10% of feed delivered remaining in bunk; 1 = 10 to 50% feed remaining; and 2 = >50% of feed remaining. In Exp. 1 and 2, bunk scores were obtained at 0900, 1300, 1700, and 2100. In Exp. 3, bunk scores were obtained at 0800, 1100, 1400, 1700, and 2000 h. Depending on environmental conditions associated with these experiments, scores were obtained during one or more of the following environmental periods: thermoneutral (**TNL**) when average THI was <70; mild heat stress (**MHS**), when THI was between 70 and 74; heat stress (**HS**) when THI was between 74.1 and 77; and severe heat stress (**SHS**) when THI was >77. With the exception of the TNL period in Exp. 1, data were collected for a minimum of two consecutive days within an environmental period and experiment.

Statistical Analyses. Quantitative data from each experiment were analyzed using GLM procedures of SAS (SAS Inst., Inc., Cary, NC). Data for Exp. 1 were analyzed for the effects of treatment with the model including treatment and replication. Treatment differences were determined using LSD procedures. Statistical models for Exp. 2 included treatment and replication. Orthogonal contrasts were used to determine treatment differences for CON vs. AM and PM, and AM vs. PM treatment groups. Experiment 3 was analyzed for main effects (feeding time and water application) and their interaction. Gain from d 0 to 21 was used as a covariate. Bunk score data were analyzed using PROC FREQ of SAS. During the 23-d managed feeding period of Exp. 1, bunk scores were analyzed within treatment with comparisons made among environmental periods within time of observation. In Exp. 2, treatment comparisons of bunk scores were made within time under hot conditions. In Exp. 3, differences in bunk scores between AMF and PMF feeding times were expected due to treatment design; thus, bunk scores were ana-

Table 2. Effect of managed feeding regimen on feed and water intake of yearling steers in Exp. 1

	Treatments[a]			
Item	ADLIB	BKMGT	LIMFD	SEM
Weight, kg				
Initial (d 0)	433	434	432	0.9
Interim (d 23)	480[b]	482[b]	469[c]	2.6
d 82	582	583	585	3.6
DMI, kg/d				
d 0 to 23	9.60[b]	9.59[b]	8.44[c]	0.13
d 24 to 82	10.61[b]	10.98[bc]	11.41[c]	0.22
d 0 to 82	9.78	9.97	10.01	0.16
G:F				
d 0 to 23	0.213	0.217	0.191	0.009
d 24 to 82	0.164[bc]	0.157[b]	0.171[c]	0.004
d 0 to 82	0.187	0.183	0.185	0.003
Water intake, L/d				
d 0 to 23	33.15	33.46	27.52	1.69
d 24 to 82	41.06[e]	43.49[e]	35.03[d]	0.63
d 0 to 82	39.35[de]	41.18[e]	32.58[d]	0.87
Water intake, L/Mcal of ME intake				
d 0 to 23	1.13	1.15	1.03	0.05
d 24 to 82	1.22[de]	1.31[e]	1.02[d]	0.03
d 0 to 82	1.28[e]	1.36[e]	1.08[d]	0.02

[a]ADLIB = cattle were allowed access to feed at all times; BKMGT = cattle were fed at 1600 with bunks slick at 0800 the following day; LIMFD = cattle were delivered 85% of their predicted DMI at 1600. The BKMGT and LIMFD regimens were utilized for the first 23 d of experiment.

[b,c]Means within a row that do not have common superscripts differ ($P < 0.05$).

[d,e]Means within a row that do not have common superscripts tended to differ ($0.05 < P < 0.10$).

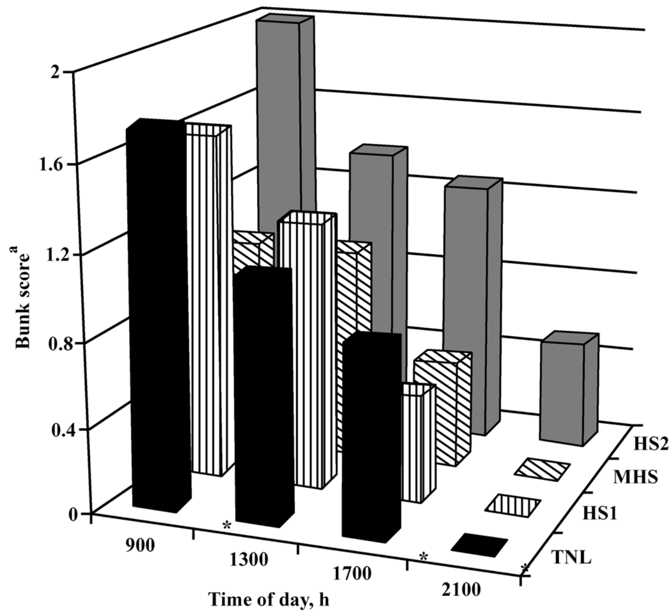

Figure 1. Mean bunk scores of cattle fed ad libitum at 0800 on d 9 and 13 (thermoneutral = TNL), 11 and 12 (first heat stress period = HS1), 14 and 15 (moderate heat stress = MHS), and 21 and 22 (second heat stress period = HS2) of Exp. 1. [a]Bunk scores were assigned based on a 0 to 2 scale: 0 = <10% of feed delivered remaining; 1 = 10 to 50% of feed delivered remaining; 2 = >50% of feed delivered remaining. Environmental conditions were based on the temperature-humidity index (THI) and classified as follows: TNL = mean THI < 70; moderate heat stress (MHS) = mean THI between 70 to 74; heat stress = mean THI between 74.1 and 77. *Bunk scores within an observation time differ (χ^2 $P < 0.05$).

lyzed for the effect of sprinkling within each main effect of feeding regimen.

Results

Environmental conditions associated with the various periods of heat stress during these experiments are provided by Davis et al. (2003). Experiments 1 and 2 were conducted simultaneously over an 82-d time period. Mean daily (± SD) temperature and THI for Exp. 1 and 2 were 22.1 ± 3.5°C and 69.5 ± 5.5°C, respectively. In Exp. 3, mean daily (± SD) temperature and THI were 22.8 ± 3.20°C and 70.5 ± 4.7°C, respectively, during the 22- to 83-d period treatments were imposed.

Experiment 1

Body weight, feed intake, gain efficiency, and water intake for the different feeding regimens are shown in Table 2. During the managed feeding period, LIMFD steers had a lower ($P < 0.05$) BW gain and DMI. This decrease in DMI was consistent with the treatment design. Following the initiation of ad libitum feeding (d 24 to 82), LIMFD steers exhibited a 7.0% ($P < 0.05$) compensatory increase in DMI when compared with the DMI of the ADLIB treatment group. However, the BKMGT treatment group exhibited only a 3.5% numerical compensatory intake response when compared with the ADLIB group. These increases in DMI found during the ad libitum feeding period for the LIMFD treatment groups were achieved with a relatively short (23 d) managed feeding period. As a result of the LIMFD group compensating for the weight gain not realized during the 23-d managed feeding phase, weight gain and efficiency of feed conversion were increased ($P < 0.05$) during the 24- to 82-d feeding period for the LIMFD group, particularly when compared with the BKMGT group. Water intake was similar during the ad libitum period between ADLIB and BKMGT steers, but numerically (although not significantly, $P > 0.10$) lower in LIMFD steers. This decrease resulted in overall water intake of LIMFD steers tending to be 16 and 22% ($P < 0.10$) lower than ADLIB and BKMGT steers, respectively. When expressing water intake as L/Mcal of ME intake, LIMFD steers tended to have lower water intake ($P < 0.10$) than ADLIB and BKMGT steers over the entire experiment.

Bunk scores for ADLIB steers during the managed feeding phase in Exp. 1 across TNL (d 9 and 13), the first HS period (**HS1**: d 11 and 12), MHS (d 14 and 15), and the second HS period (**HS2**: d 21 and 22) are presented in Figure 1. Compared within an observation

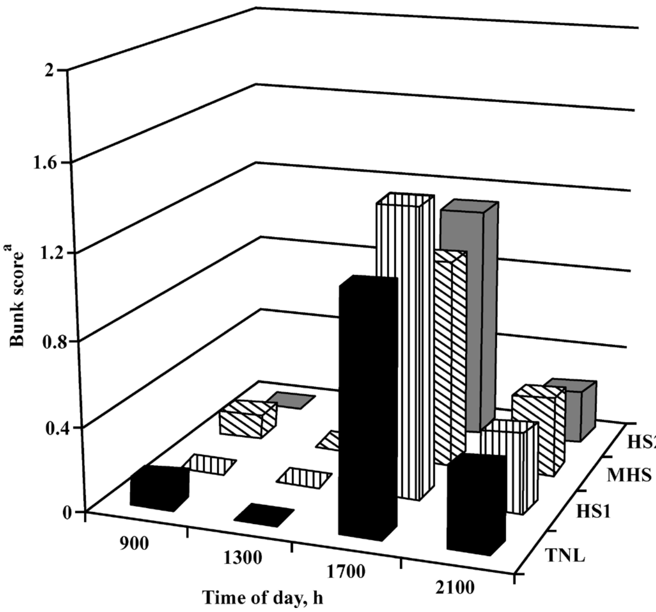

Figure 2. Mean bunk scores of cattle fed at 1600 with bunks slick by 0800 the following day on d 9 and 13 (thermoneutral = TNL), 11 and 12 (first heat stress period = HS1), 14 and 15 (moderate heat stress = MHS), and 21 and 22 (second heat stress period = HS2) of Exp. 1. [a]Bunk scores were assigned based on a 0 to 2 scale: 0 = <10% of feed delivered remaining; 1 = 10 to 50% of feed delivered remaining; 2 = >50% of feed delivered remaining. Environmental conditions were based on the temperature-humidity index (THI) and classified as follows: TNL = mean THI < 70; MHS = mean THI 70 to 74; heat stress = mean THI between 74.1 and 77.

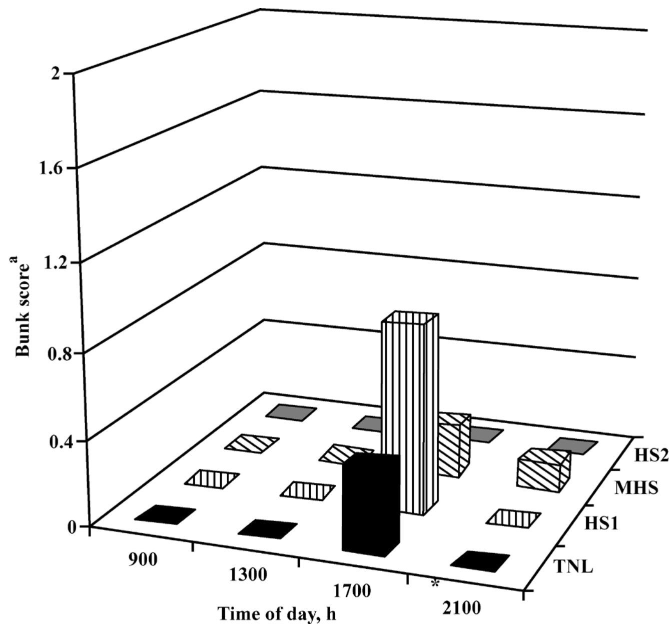

Figure 3. Mean bunk scores of cattle fed 85% of predicted ad libitum intake at 1600 on d 9 and 13 (thermoneutral = TNL), 11 and 12 (first heat stress period = HS1), 14 and 15 (moderate heat stress = MHS), and 21 and 22 (second heat stress period = HS2) of Exp. 1. [a]Bunk scores were assigned based on a 0 to 2 scale: 0 = <10% of feed delivered remaining; 1 = 10 to 50% of feed delivered remaining; 2 = >50% of feed delivered remaining. Environmental conditions were based on the temperature-humidity index (THI) and classified as follows: TNL = mean THI < 70; MHS = mean THI between 70 and 74; heat stress = mean THI between 74.1 and 77. *Bunk scores within an observation time differ (χ^2 $P < 0.05$).

time across days, differences ($P < 0.05$) were observed at 0900, 1700, and 2100. Among environmental periods, bunk scores at 0900 were lower during MHS (d 14 and 15). At 1300, bunk score for all days were similar, but those at 1700 and 2100 were highest during HS2 (d 21 and 22).

Bunk scores for BKMGT steers during the managed feeding phase are presented in Figure 2 and did not differ within time of observation across TNL (d 9 and 13), HS1 (d 11 and 12), MHS (d 14 and 15), or HS2 (d 21 and 22), suggesting that under this system, cattle handled the heat load reasonably well and/or eating pattern was not affected by climatic heat load. Figure 3 shows bunk scores of LIMFD steers. There were differences ($P < 0.001$) in bunk scores of these steers at 1700. During HS1 (d 21 and 22), 50% of the pens had a bunk score of 1, whereas bunks were nearly clean during HS2 by 1700, suggesting that over time LIMFD is an aid to cattle coping with excessive heat. Bunk scores of steers following ad libitum feeding were not affected by previous feeding regimen.

Experiment 2

Body weight, DMI, and efficiency of feed conversion did not differ among treatments, although sprinkled cattle had a 2.5% numerically greater DMI compared with the control cattle (Table 3). However, over the entire feeding period, AM-sprinkled cattle tended to have greater ($P = 0.06$) G:F than PM-sprinkled cattle. Water intake tended to be lower ($P = 0.08$) in CON compared with AM- and PM-sprinkled steers from d 0 to 34. An 8% decrease ($P < 0.05$) in water intake was observed in PM steers compared with AM steers from d 0 to 34. When water intakes were corrected for ME intake, AM steers tended ($P = 0.10$) to consume more water per unit of ME intake than PM steers, but only in the early (d 0 to 34) portion of the experiment.

Bunk scores in Exp. 2 were obtained during an HS (THI between 74 and 77) period (Table 4). Differences in bunk scores were found only at 2100. At this time, 100% of PM pens and 87.5% of AM pens were assigned a bunk score of 0, whereas only 50% of CON pens were assigned a 0 ($P < 0.05$) indicating that sprinkling during HS days likely enhanced DMI during the day.

Experiment 3

Body weights, efficiency of feed conversion, and DMI for all periods did not differ among treatments (Table

Table 3. Effect of morning and evening wetting of feedlot pen surfaces on feed and water intake of yearling steers in Exp. 2

	Treatments[a]				Contrast *P*-values[b]	
Item	CON	AM	PM	SEM	CON vs. AM & PM	AM vs. PM
BW, kg						
Initial (d 0)	477	476	477	1.1	0.26	0.42
Interim (d 34)	532	533	530	3.1	1.00	0.53
Final (d 82)	632	639	628	4.9	0.75	0.16
DMI, kg/d						
d 0 to 34	9.85	10.13	10.02	0.16	0.30	0.65
d 35 to 82	11.23	11.52	11.54	0.20	0.26	0.97
d 0 to 82	10.79	11.08	11.04	0.17	0.25	0.89
G:F						
d 0 to 34	0.162	0.167	0.157	0.008	1.0	0.42
d 35 to 82	0.188	0.190	0.178	0.004	0.47	0.07
d 0 to 82	0.175	0.180	0.168	0.004	0.80	0.06
Water intake, L/d						
d 0 to 34	37.63	38.29	35.29	0.21	0.08	0.01
d 35 to 82	38.01	37.70	40.11	1.89	0.72	0.43
d 0 to 82	38.32	38.42	38.59	1.12	0.90	0.92
Water intake, L/Mcal of ME intake						
d 0 to 34	1.22	1.21	1.13	0.02	0.16	0.10
d 35 to 82	1.09	1.05	1.11	0.07	0.94	0.54
d 0 to 82	1.14	1.11	1.12	0.05	0.71	0.89

[a]CON = no water application; AM = water applied to pen surface between 1000 and 1200; PM = water applied to pen surface between 1400 and 1600.
[b]Single-df orthogonal contrasts.

5); however, from d 22 to 83 (0.1715 vs. 0.1800) and d 57 to 83 (0.1480 vs. 0.1695), sprinkling numerically (P = 0.09) enhanced efficiency of feed conversion. Also, there was a feeding time × sprinkling interaction for water intake from d 22 to 56, with AMF/DRY steers having greater ($P < 0.05$) water intake than the other treatments. Also, PMF/WET steers consumed 5% less ($P < 0.05$) water than AMF/WET steers, with PMF/DRY steers being intermediate. Water intakes during the final phase of the trial (d 57 to 83) continued to display a feeding time × sprinkling interaction ($P < 0.05$), with AMF/DRY steers averaging approximately 13% greater water intake than the other treatments. During the entire experimental period, AMF/DRY steers had greater ($P < 0.05$) water intake than all other treatments. When water intake was adjusted for ME intake, differences between treatments were only detected during d 57 to 83. Water intake per unit of ME intake was 11% greater ($P < 0.05$) for AMF/DRY steers than all others. Because drinking water will provide cooling to the animal, greater water intakes would be expected for the AMF/DRY group.

Bunk scores of steers in Exp. 3 for TNL, MHS, and SHS environmental conditions are shown in Table 6. For equal comparison, bunk scores were compared for the effect of sprinkling on the different feeding strategies independently. Bunk scores of AMF and PMF steers were designed to differ at least for part of the day.

Under TNL, sprinklers did not operate. There was no difference in bunk scores of AMF steers with respect to sprinkling at any observation ($P > 0.20$); however, steers fed in the afternoon without access to sprinklers (PMF/DRY) had a larger percentage ($P < 0.001$) of bunks receiving a score of 0 and 1 at 1700 than did PMF/WET steers, although no differences in bunk scores were observed at 2000.

Bunk scores during MHS differed at 1400 for steers fed in the morning and at 2000 for steers fed in the afternoon, with sprinkled AMF cattle having fewer scores of 2 at 1400, and no scores of 1 or 2 at 2000 for PMF-treated cattle, indicating that sprinkling was effective in stimulating DMI under those conditions. For all treatment groups, the majority, if not all, of the feed was consumed by 2000. Under SHS, sprinkling steers did not alter bunk scores. When compared with TNL and MHS conditions, a greater quantity of feed remained at 2000 for all treatments. The AMF/WET and PMF/WET cattle had numerically (8.33%) more bunk scores at 0, but under these conditions, all cattle were apparently too uncomfortable to eat.

Carcass Traits. Carcass characteristics are presented in Table 7. In Exp. 1, feeding regimen had no effect on carcass weight, dressing percent, or 12th-rib fat. Steers on the BKMGT treatment had numerically (P = 0.17) greater marbling scores than the other treatment groups. In Exp. 2, marbling scores of PM steers tended (P = 0.06) to be higher than AM. All other carcass characteristics were similar. In Exp. 3, steers did not differ ($P > 0.10$) in hot carcass weight or dressing percent (348.0 ± 2.0 kg and 61.7 ± 0.4%, respectively). Fat thickness likewise was not affected by treatment ($P > 0.10$). A feeding time × sprinkling interaction ($P < 0.05$) was

Table 4. Effect of morning (AM) vs. afternoon (PM) mound wetting on bunk scores of steers throughout the day during heat stress conditions (mean daily temperature-humidity index between 74 and 77) on d 14 and 15 of Exp. 2

	Treatments[a]			
Item[b]	CON	AM	PM	*P*-value
0900				
Bunk score				1.0
0	0.00	0.00	0.00	
1	0.00	0.00	0.00	
2	100.00	100.00	100.00	
1300				
Bunk score				0.59
0	0.00	0.00	0.00	
1	62.50	50.00	75.00	
2	37.50	50.00	25.00	
1700				
Bunk score				0.14
0	25.00	0.00	0.00	
1	62.50	100.00	100.00	
2	12.50	0.00	0.00	
2100				
Bunk score				0.04
0	50.00	87.50	100.00	
1	50.00	12.50	0.00	
2	0.00	0.00	0.00	

[a]CON = no water application; AM = water applied to pen surface between 1000 and 1200; PM = water applied to pen surface between 1400 and 1600. Values in the table represent the average percentage of pens within each treatment that had respective bunk scores.

[b]Bunk scores of the pens were determined based on visual observation at 0900, 1300, 1700, and 2100 using the following criteria: 0 = <10% of the delivered feed remaining; 1 = between 10 and 50% of the delivered feed remaining; 2 = >50% of the delivered feed remaining.

found for marbling score with AMF/DRY steers having greater marbling scores than the other treatments.

Discussion

In Exp. 2, 23 out of 82 d sprinklers were turned on when maximal THI was predicted to equal or exceed 77. Based on outcomes of Exp. 2, an automated sprinkling regimen was implemented in Exp. 3. During Exp. 3, sprinklers operated on 31 of 61 d during the 22 to 83 d treatment period. In addition, during Exp. 3, 90% of the days (28 of 31) that sprinklers were operational, maximal THI was greater than or equal to 77. However, THI exceeded 77 on 7 of the 30 nonsprinkling days of the treatment period. These data suggest that a THI of 68 or greater at 0900 will predict a daily maximal THI of 77 or greater 90% of the time; however, about 25% of the time, when THI at 0900 is less than 68, a maximal THI of 77 is reached. The latter condition may not be as great a concern as those conditions in which THI at 0900 is greater than 68. A lower THI (<68) at 0900 would mean cattle had greater opportunities to cool down at night as opposed to conditions in which a nighttime and/or morning THI was greater than 68. The greater extent to which nighttime cooling occurs, the less daytime heat load relief would be required (Fuquay, 1981).

Altering the feeding regimen in Exp. 1 and 3 did not affect overall DMI or hot carcass weight. Soto-Navarro et al. (2000) observed no improvement in ADG, DMI, or feed conversion for cattle fed in the afternoon compared with cattle fed in the morning. Prawl et al. (1997) examined feed availability times of 3, 6, 9, and 24 h on performance of steers. Gain and efficiency were maximized when feed exposure was limited to 9 h/d. Steers in Exp. 1 and 3 were managed to have no feed available to them for 8 and 6 h, respectively. Altering the feeding regimen did tend to enhance overall DMI in Exp. 1, but not in Exp. 3.

Absence of a large improvement in animal performance in response to the various treatments designed to decrease heat stress was not surprising given the ability of heat-stressed animals to compensate following the return of TNL environmental conditions (Baccari et al., 1983). Decreasing energy intake by either increased dietary roughage levels (Brosh et al., 1998; Mader et al., 1999b) or decreased feed availability (Mader et al., 2002) during times of heat stress have been shown to be beneficial in reducing the susceptibility of feedlot cattle to heat stress. Other studies conducted under TNL conditions have shown that feed efficiency is maximized at less than maximal intake (Sainz et al., 1995; Murphy and Loerch, 1994; Carstens et al., 1991).

Reinhardt and Brandt (1994) evaluated performance of morning (0800) vs. evening (2000) limit-fed Holstein steers fed during the summer. Steers fed at 2000 gained 18% faster and were 17% more efficient than those fed in the morning. The authors attributed the increase in performance to a change in the fermentation peak from the hottest part of the day to the period between sundown and sunrise. Steers in the present experiment with access to feed at 1600 also would have most likely benefited from altering time of fermentation peak.

An important aspect of heat stress reduction strategies is to improve animal well being during times of potentially high environmental temperatures, as well as to decrease body temperature to protect against hyperthermia (Davis et al., 2003). Long-term production benefits to such strategies are elusive due to the ability of the animal to exhibit compensatory growth following exposure to heat stress conditions (Baccari et al., 1983). In addition to the well-being aspects, heat stress reduction strategies should aid in maintaining stable DMI and water intake. Excessive heat load is known to reduce DMI and increase water requirements (NRC, 1996).

Research examining the benefits of sprinkling cattle with water has been numerous (Morrison et al., 1973, 1981; Garner et al., 1989). Sprinkling cattle to alleviate heat stress is beneficial because of the latent heat of vaporization associated with the change of water from a liquid to a gaseous state. This mode of heat transfer is especially important to cattle exposed to high envi-

Table 5. Effect of altered feeding time and sprinkling on feedlot performance of yearling steers in Exp. 3

	Treatments[a]				
Item	AMF/DRY	AMF/WET	PMF/DRY	PMF/WET	SEM
BW, kg					
Initial (d 0)	425	424	423	425	1.0
d 21	460	458	458	459	1.0
d 56	524	521	519	522	2.8
Final (d 83)	562	567	561	566	4.0
DMI, kg/d					
d 0 to 21	9.17	9.09	9.02	9.52	0.18
d 22 to 56	9.61	9.42	9.37	9.61	0.23
d 57 to 83	9.80	9.61	9.67	9.74	0.20
d 22 to 83	9.70	9.50	9.50	9.67	0.21
G:F					
d 0 to 21	0.179	0.182	0.182	0.175	0.004
d 22 to 56	0.183	0.184	0.181	0.180	0.004
d 57 to 83[b]	0.144	0.172	0.152	0.167	0.012
d 22 to 83[b]	0.170	0.183	0.173	0.177	0.005
Water intake, L/d					
d 0 to 21	26.95	26.99	25.52	25.11	2.8
d 22 to 56[c]	38.79[f]	36.17[e]	35.31[de]	34.47[d]	0.40
d 57 to 83[c]	36.85[e]	32.26[d]	32.16[d]	33.73[d]	0.90
d 22 to 83[c]	37.93[e]	34.39[d]	33.91[d]	34.14[d]	0.40
Water intake, L/Mcal of ME intake					
d 0 to 21	0.96	0.94	0.92	0.87	0.12
d 22 to 56	1.33	1.26	1.24	1.18	0.05
d 57 to 83[c]	1.22[e]	1.08[d]	1.10[d]	1.12[d]	0.03
d 22 to 83	1.28	1.18	1.17	1.15	0.04

[a]Treatments were imposed from d 22 to the end of the study and consisted of altered feeding time (0800 [AMF] vs. 1400 [PMF]) with (WET) and without (DRY) sprinkling. Sprinkling was accomplished via overhead sprinklers that operated 20 min/1.5 h from 1000 to 1750 on days when temperature-humidity index at 1900 was ≥68. Cattle were not sprinkled during the thermoneutral period.
[b]Sprinkling (WET) tended to differ from no sprinkling (DRY) treatments (0.05 < P < 0.10).
[c]Feeding time × sprinkling interaction (P < 0.05).
[d,e,f]Means within a row that do not have common superscripts differ (P < 0.05).

ronmental temperatures because evaporative heat transfer does not depend on the thermal gradient between the animal and its environment (Arkin et al., 1991).

Morrison et al. (1973) conducted two trials comparing the performance of cattle that were sprinkled with those raised in climate-controlled confinement and a third control treatment. The sprinkling system operated for 1 min every 30 min when ambient temperature was above 27°C. Sprinkling increased DMI 17% over control and increased ADG between 20 and 28%. Morrison et al. (1981) also conducted three experiments comparing sprinkler activation times of 22 and 32°C. Lower activation temperature significantly increased DMI by 5% and increased gains in one of the experiments by 7%. These results support our findings of improved performance of Exp. 2 steers receiving the morning sprinkling regimen relative to those sprinkled in the afternoon, and suggests sprinkling must be initiated before periods of the day when ambient temperatures are near maximum. Additionally, it is apparent from the results of Exp. 3, in which cattle were sprinkled for 20 min every 1.5 h, that intermittent sprinkling throughout the day is needed to improve animal performance (efficiency tended to be improved (P = 0.09) by sprinkling). The primary benefit of cooling cattle would be to decrease panting and the expenditure of energy (up to 18% increase) associated with panting (NRC, 1996). In addition, less variation in daily DMI would be expected when cattle are kept cool on hot days. Garner et al. (1989) compared gains of steers and heifers subjected to control or sprinkling treatments and observed that sprinkled heifers gained 20% faster than their unsprinkled counterparts, whereas sprinkled and unsprinkled steers performed similarly. The authors and others attributed this difference to the fact that the heifers were fatter than the steers and therefore more susceptible to heat stress (Mader et al., 2001; Busby and Loy, 1996).

Altering the microclimate of the sprinkled area is a major benefit to improving the well being of feedlot cattle under extreme environmental conditions by reducing body temperature (Davis et al., 2003). Ground temperatures have been shown to be decreased over 15°C when sprinkled feedlot surfaces were compared with unsprinkled surfaces (Wiersma et al., 1973). When ground temperature exceeds skin temperature, heat will flow from the ground to the animal, increasing the heat load to be dissipated. By cooling the ground with sprinkled water, this gradient of heat flow is reversed, allowing for better heat balance.

Table 6. Effect of altered feeding time and sprinkling on bunk scores of steers fed under thermoneutral (TNL), mild heat stress (MHS), and severe heat stress (SHS) conditions of Exp. 3[a]

	AMF			PMF		
Item[b]	DRY	WET	*P*-value	DRY	WET	*P*-value
		TNL (mean THI < 70)				
1400						
Bunk score			0.67			1.0
0	0.00	0.00		100.00	100.00	
1	41.67	33.33		0.00	0.00	
2	53.33	66.67		0.00	0.00	
1700						
Bunk score			0.46			0.01
0	16.67	16.67		16.67	0.00	
1	66.67	75.00		58.33	33.33	
2	16.67	8.33		25.00	66.67	
2000						
Bunk score			0.22			0.23
0	66.67	41.67		50.00	33.33	
1	33.33	58.33		41.67	58.33	
2	0.00	0.00		8.33	8.33	
		MHS (70 < mean THI < 74)				
1400						
Bunk score			0.03			1.0
0	25.00	16.67		100.00	100.00	
1	50.00	75.00		0.00	0.00	
2	25.00	8.33		0.00	0.00	
1700						
Bunk score			0.70			0.10
0	50.00	41.67		16.67	16.67	
1	41.67	50.00		0.00	25.00	
2	8.33	8.33		83.33	58.33	
2000						
Bunk score			1.0			0.01
0	100.00	100.00		41.67	100.00	
1	0.00	0.00		58.33	0.00	
2	0.00	0.00		0.00	0.00	
		SHS (mean THI > 77)				
1400						
Bunk score			0.55			1.0
0	0.00	0.00		100.00	100.00	
1	16.67	25.00		0.00	0.00	
2	83.33	75.00		0.00	0.00	
1700						
Bunk score			0.21			0.12
0	0.00	0.00		0.00	0.00	
1	25.00	50.00		16.67	8.33	
2	75.00	50.00		83.33	91.67	
2000						
Bunk score			0.46			0.69
0	0.00	8.33		8.33	16.67	
1	91.67	75.00		75.00	58.33	
2	8.33	16.67		16.67	25.00	

[a]Treatments were imposed from d 22 to the end of the study and consisted of altered feeding time (0800 [AMF] vs. 1400 [PMF]) with (WET) and without (DRY) sprinkling. Sprinkling was accomplished via overhead sprinklers that operated 20 min/1.5 h from 1000 to 1750 on days when temperature-humidity index at 0900 ≥ 68. Cattle were not sprinkled during TNL period.

[b]Bunk scores of the pens were determined based on visual observation at selected times using the following criteria: 0 = <10% of the delivered feed remaining; 1 = between 10 and 50% of the delivered feed remaining; 2 = >50% of the delivered feed remaining. Values in the table represent the average percentage of pens within each treatment that had respective bunk scores.

Table 7. Effect of managed feeding and/or sprinkling on feedlot cattle carcass characteristics

	Carcass characteristics			
Treatment[a]	HCW, kg[b]	Dress, %	12th-rib fat, cm	Marbling score[c]
Feeding regimen, Exp. 1				
ADLIB	362.4	64.9	1.06	507.7
BKMGT	361.0	64.5	1.02	524.1
LIMFD	361.3	64.3	1.00	501.0
SEM	2.6	0.3	0.05	10.0
Morning or evening pen surface wetting, Exp. 2				
CON	395	65.2	1.39	558.4
AM	396	64.6	1.21	538.8[d]
PM	388	64.5	1.24	571.5[d]
SEM	3.9	0.3	0.08	10.6
Altered feeding time and sprinkling, Exp. 3				
AMF/DRY	349.8	62.1	1.01	550.6[f]
AMF/WET	348.7	61.6	1.19	519.3[e]
PMF/DRY	347.8	61.9	1.09	505.5[e]
PMF/WET	345.6	61.3	1.13	519.6[e]
SEM	2.0	0.4	0.09	10.5

[a]ADLIB = cattle were allowed access to feed at all times; BKMGT = cattle were fed at 1600 with bunks slick at 0800 the following day; LIMFD = cattle were delivered 85% of their predicted DMI at 1600; CON = control; AM = water applied to pen surface between 1000 and 1200; PM = water applied to pen surface between 1400 and 1600; AMF = ad libitum amount of feed delivered at 0800 h; PMF = ad libitum amount of feed delivered at 1400 with bunks empty at 0800 h; DRY = no water sprinkling; WET = water applied to pen surface when temperature humidity-index was ≥68 at 0900.

[b]Hot carcass weight.

[c]Small 0 = 500; modest 0 = 600.

[d]AM vs. PM tended to differ ($P < 0.06$).

[e,f]Feeding time × sprinkling interaction ($P < 0.05$). Means in a column within an experiment that do not have common superscripts differ ($P < 0.05$).

Kelly et al. (1964) examined the benefit of cooled slab floors on growing pig performance. In the second year of the 2-yr study, pigs with access to the cooled slab floor gained 17.5% faster and 9% more efficiently than did control pigs. Creating a cool surface for feedlot cattle via a sprinkled pen surface is a plausible option. Additionally, conductivity of the soil is improved by wetting. In dry soils, thermal conductivity is about 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. Wetting the soil can improve its conductivity fivefold (Sepaskhah and Boersma, 1979; Campbell et al., 1994). Therefore, application of water to the ground can greatly enhance heat transfer from the animal.

Another aspect of managed feeding and sprinkling programs were the noted reductions in water requirements and demands by the animal when compared with traditional feeding programs. Although the reductions ranged from nonsignificant in Exp. 2 to significant in Exp. 1 and 3, any management strategies which reduce demand for water would be useful, particularly at times when water demands are large and in regions where water is limited and/or becoming more costly. In general, water intakes were approximately 20 to 30% lower than those reported in NRC (1996) for cattle finished under comparable ambient temperatures. A large variation in water intake by animals is noteworthy. In the experiments reported herein, as in many experiments, water usage was measured rather than actual water intake. For control cattle used in these experiments, water intake per unit of DMI ranged from 0.96 to 1.33 L/kg.

Alterations in eating pattern, as represented by bunk scores, were found in Exp. 1 during the 23-d managed feeding period as a result of limit feeding and restricted access to feed. Representation of bunk scores within a treatment across environmental periods is useful in evaluating adaptive adjustments made by the steers as an effect of both treatment and environmental conditions. Comparisons across treatments results in limited interpretation due to differences in bunk scores as a result of the imposed treatment.

One behavioral adaptive change cattle undergo during heat stress is an alteration in eating behavior such that a larger portion of their intake is consumed during the late afternoon and early evening period (Cowan, 1975; Monty and Garbareno, 1978). The lower scores of the ADLIB treatment group for the MHS period in Exp. 1 suggest acclimatization was occurring by the cattle; however, the greater scores in HS2 indicate that under more severe heat, lowering DMI was used as a coping mechanism. For ADLIB steers (Figure 1), 50% of the pens were assigned a bunk score of 1 (10 to 50% of feed delivered remaining) during HS2 (d 21 to 22) compared with none during the other three periods at 2100. Although mean (76 vs. 77) and maximal (82 vs. 83) THI were slightly lower during HS2 than HS1, minimal THI was slightly higher (69 vs. 67) for HS2. Hahn and Mader (1997) concluded that adequate nighttime recovery (THI $\leq$ 74) was needed to reduce death in vulnerable feedlot animals. Whereas THI during the night in Exp. 1 was well below this threshold, these data support the concept that nighttime environmental conditions play a key role in the management of heat stress.

Steers in BKMGT treatment group showed no difference in bunk scores over the varying environmental periods, suggesting their intake patterns remained very consistent despite the changing environmental conditions. A consistent feed intake pattern improves animal production (Soto-Navarro et al., 2000) by allowing for more efficient nutrient use (Zinn, 1994; Soto-Navarro et al., 2000). Steers on LIMFD during Exp. 1 altered their feeding pattern; however, results suggest that this alteration seemed to be more of an effect of days on feed than environmental conditions. As days on the LIMFD regimen increased, steers became aggressive meal eaters regardless of environmental conditions. One hour after feed delivery, during HS2, LIMFD steers had consumed the majority of their feed. Soto-Navarro et al. (2000) reported steers fed 90% of ad libitum intake twice daily consumed all feed offered within 1 to 2 h. The fact that LIMFD steers in the current study remained aggressive in their eating pattern in spite of warmer environmental conditions may have been due to their lower body temperature (Davis et al., 2003).

Sprinkling did not have a large effect on bunk scores of steers when it was the only heat stress relief method employed (Exp. 2 and 3). Under mild heat stress, differences between sprinkling treatments were noted; however, under severe heat stress, sprinkling did not alter feeding pattern. This is likely due to the cattle staying close to the sprinkled areas and not going to bunks to feed.

Treatment differences were noted in marbling scores in two of the three experiments. These differences may be related to alterations in hormonal profiles caused by varying degrees of heat stress experienced by each of the treatment groups. In the experiments, cattle exposed to greater heat stress tended to have greater marbling score.

Kouba et al. (2001) examined the effect of prolonged exposure to environments of 31 or 20°C on fat deposition of pigs. Internal fat deposits were increased 2-fold in pigs reared in 31 vs. 20°C environments, whereas backfat deposition was similar. The difference in the location of fat deposition in response to heat stress is important because excessive external fat deposition can be detrimental to heat exchange capabilities. Mader et al. (1997) reported cattle fed during the winter in open facilities north of a windbreak that were subjected to mild cold stress, tended to have increased marbling and backfat values. However, steers finished in the same facility in the summer, when the prevailing southerly wind flow would be restricted, also had higher marbling compared with cattle finished in facilities where airflow was not restricted. Adequate airflow in the summer months is needed for optimal animal performance (Mader et al., 1997), presumably to reduce heat stress. It would seem that slight heat stress might cause increased im. fat deposition.

Implications

Altering feeding time, feed amount, and water sprinkling are options to decrease steers' susceptibility to heat stress. Although enhanced productivity may be realized by using sprinklers in intensive beef cattle production systems, production responses to altered feeding regimens are not always obtained. However, preventing peaks in metabolic heat load from occurring during peaks in climatic heat load can be accomplished by altering feeding regimen, thereby minimizing animal discomfort during summertime heat episodes. Alterations in feeding regimen increase animal well being without adversely affecting performance. An altered feeding regimen enhances the animal's ability to cope with metabolic and climatic heat load during the summer, whereas sprinkling cattle and/or feedlot surfaces serves to decrease overall heat load.

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