Indicators of Heat Stress in Shaded and Non-Shaded Feedlot Cattle

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Abstract. *Heat stress in feedlot cattle can cause decreases in feed intake and growth, and in extreme cases may result in death. Providing shade during hot weather has shown inconsistent results, reducing direct and indirect losses in some areas of the United States, but not in others. The objectives of this study were to evaluate the dynamic responses of feedlot cattle to environmental conditions with and without access to shade, and to determine the most appropriate physiological measurement for monitoring feedlot cattle during hot weather as a guide for improved management. Eight crossbred steers (initially weighing 294.7±10.8 kg) were randomly assigned to one of eight individual pens, where one of two treatments were applied: shade access (SA), or no shade access*

(NS). Respiration rate (RR), daily feed intake (DFI), and core body temperature (t_{core}) were collected, using automated systems during eight periods, for a total of 37 days. The data were analyzed using four categories of daily maximum Temperature Humidity Index (THI) values (Normal: THI_{max} <74; Alert: 74< THI_{max} >78; Danger: 79<THI_{max} >83; Emergency: THI_{max} >84). Shade was found to impact the physiological responses in all THI categories, with the largest impacts in the Danger and Emergency categories. Shade lowered RR and t_{core} during the peak temperature hours of the day. It was concluded that RR is the most appropriate indicator of thermal stress to monitor because it was consistently affected in all THI categories, it is easy to monitor without the need for costly equipment, and there is little or no lag associated with it.

Keywords. Shade, Respiration rate, Body temperature, Feed intake, THI (Temperature Humidity Index)

Introduction

Hot weather affects animal bioenergetics, and has negative impacts on animal performance and well-being. Reductions in feed intake, growth, and efficiency are commonly reported in heat-stressed cattle (Hahn, 1999). The impacts of heat load on these production parameters are quite varied, ranging from little to no effect in a brief exposure, to death of vulnerable animals during an extreme heat event (Hahn and Mader, 1997). An extreme event in July, 1995, caused the loss of approximately 3,750 head of cattle in western Iowa; direct losses were estimated at $2.8 million, and production losses at $28 million (Busby and Loy, 1996). *Bos taurus* feedlot cattle are particularly vulnerable to heat stress as a result of the high-energy diet they are fed, and their inability to move into a more suitable environment (Blackshaw and Blackshaw, 1994). With the increased concern for global warming and animal welfare, along with the high number of cattle in feedlots, researchers and producers have increased their interest in methods to reduce thermal stress.

Because absorbed solar radiation may exceed metabolic heat production by several times (Riemerschmid, 1943), the use of shade during hot weather has been of interest for many years. A simple shade can reduce the animals' radiant heat load by 30% or more (Bond et al., 1967). Results from performance trials with shaded and unshaded feedlot cattle have shown inconsistent results. Garrett (1963) summarized results from several shade studies and concluded that feedlot cattle in areas with more than 750 hrs per year of temperatures above 29.5ºC generally show a performance improvement, while gains of cattle in areas that receive 500 -750 hrs per year of temperatures above 29.5ºC are less conclusive. This lack of performance improvement from shade can be explained by the ability of cattle to acclimate and compensate for a short-term suppression in feed intake and growth resulting from a heat stress event (Hahn, 1982; Mader et al., 1999).

While shades have not consistently shown a performance improvement, cattle with access to shade have consistently shown a reduction in core body temperature (t_{core}) and respiration rate (RR) (Mitloehner et al., 2001; Valtorta et al., 1997; Paul et al., 1999). During times of high solar radiation, high temperature, and high humidity, a reduction of solar radiation may be a method of reducing heat stress (Blackshaw and Blackshaw, 1994), improving animal well-being, and preventing death in extreme cases.

Objectives

The objectives of this study were to evaluate the dynamic responses of feedlot cattle RR, daily feed intake (DFI), feeding behavior, and t_{core} to different environmental conditions with and without access to shade, and to determine which physiological measurement is the most appropriate to monitor feedlot cattle under heat stress conditions.

Materials and Methods

Eight crossbred steers (1/4 Angus, 1/4 Hereford, 1/4 Pinzgauer, 1/4 Red Poll) initially weighing 294.7±10.8 kg were randomly assigned to one of eight individual concrete-surfaced pens where one of two treatments was applied (shade access [SA] or no-shade access [NS]). The pens were located at the U.S. Meat Animal Research Center near Clay Center, Nebraska; they had a north/south orientation and were connected to the south side of a 122 m long building. Animal access to the building was prevented. The pens were 3.6 m x 12 m, with a 3.6 m space between pens. Shade pens were equipped with free-standing shade structures made of 5.5 oz

polyvinyl 100% shade cloth, and were 3.6 m x 6 m x 3 m high at the peak, 2.4 m high on the east side, and 1.8 m high on the west side. These shade structures were designed such that steers had access to shade from mid-morning (1000 h Central Daylight [CDT]]) to early evening (1900 h CDT). The shade structures covered approximately 50% of the pen area. Data were collected during eight periods during the summer of 2001. The steers were moved to a new pen and changed treatments at the end of each period.

Respiration rate, t_{core}, and feeder weights were continuously recorded during each of the eight treatment periods. Respiration rate was obtained using RR monitors; the output signal from the RR sensor was recorded for one minute every 15 minutes at 10 Hz (Eigenberg et al., 2000). These data were then post-processed using software developed in-house (Eigenberg et al., 2000).

Core body temperature was measured using a telemetry system manufactured by HQ, Inc (West Palmetto, FL , U.S.A.), consisting of an implantable transmitter and a CorTemp™ data logger. Twenty-eight days prior to the initiation of the experiment, a licensed veterinarian implanted a transmitter in the abdominal cavity of each steer (Brown-Brandl et al., 2003). Data were logged at a frequency of one reading/minute.

Feed and water were available on an ad-libitum basis, with fresh feed provided before 0900 CDT. In the SA treatment, both the feed and the water were placed under the shade structure. Water was provided using an automatic waterer. Feed intake and feeding behavior were monitored using a load cell (Model 1250, Tedea-Huntleigh International Ltd., Israel) placed under the feedbox. Signal processing was provided by a Daytonic signal conditioning system (Model 9170; Daytronic Corporation, Dayton, Ohio U.S.A.). The output voltage was then recorded on a Pace Pocket Logger (Model XR 440-M; Pace Scientific Inc., Mooresville, NC U.S.A.) every one minute.

Four video cameras recorded animal location in the shade treatments. Videotapes were analyzed after the completion of the experiment; animal position (under the shade structure or in the open) was recorded every 15 minutes between 1000 h and 1900 h.

Weather data were collected from an automated weather data center located 2.5 km north of the pens (South Central Station of the Automated Weather Data Network [AWDN], operated by the High Plains Regional Climate Center Central Weather Station). This data included drybulb temperature (t_{db},°C), relative humidity (RH, %), wind speed (WS, m/s), and solar radiation (RAD, W/m^2). Weather conditions at the AWDN were recorded on a 15-minute basis. On-site weather data were collected for the last four of eight data collection periods and data were collected every 15 minutes by a Davis Instruments weather station (Model Vantage PRO; Hayward, CA U.S.A.). On-site data were used for analyses when available.

For the analyses, dynamic data were reduced to 15 minute averages and then categorized into four groups (Normal: THI_{max} <74; Alert: 74< THI_{max} >78; Danger: 79<THI_{max} >83; Emergency: THI_{max} >84) using daily maximum Temperature Humidity Index (THI-Thom, 1959; LCI, 1970). Animal data for each category (CAT) were analyzed using the general linear model procedure in SAS (SAS, 1999) for effects of animal (A), treatment (TRT), period (P), hour of the day (h), and the interaction of TRT and h (TRT*h). Least-square means was used to discern differences between TRT at each hour.

Daily data were analyzed using the general linear model procedure in SAS (SAS, 1999) for the effects of A, TRT, CAT and the interaction of TRT and CAT (TRT*CAT). Daily data included average RR, average t_{core}, DFI, and feed behavior data. Feed behavior data was derived from feeder weights recorded every one minute, and included daily feed intake, total eating duration, number of meals, average meal size, average meal duration, and rate of eating. Significant

differences were determined when the P-values were less than 0.05, except in the case of feeding behavior values, then P-values of less than 0.1 were used.

The time an animal spent in the shade between the hours of 1000 h and 1900 h was converted to a percent on a daily basis. The percentages were analyzed using the general linear model procedure in SAS (SAS, 1999) for the effects of A and CAT.

Results and Discussion

A total of 37 days of data were used in the analyses. Of those, four were categorized in Normal, six in Alert, 13 in Danger, and 14 in Emergency range. Categories of individual experimental days are shown in Figure 1. Average hourly weather data for the four categories are shown in Figure 2. The ambient dry-bulb temperature (t_{db}), and the dew-point temperature (t_{dp}) and THI for the four categories had good separation (Figure 2 and Table 1). Although wind speed was significantly different between all categories except Normal and Alert, the average numeric differences were only slight (Normal=2.9 m/s; Alert= 2.9 m/s; Danger=3.5 m/s; Emergency= 2.6 m/s). The average solar radiation was slightly less in the Normal category (Normal= 249.3 W/m^2) than Alert (not significant), Danger, or Emergency categories (Alert= 281.8 W/m^2; Danger=303.1 W/m^2; Emergency= 301.5 W/m^2).

Shade use

Due to equipment failure, the second, sixth, seventh, and eighth periods were not videotaped. To help balance data, all days that were inadvertently videotaped were added to the analyses (Day 191-Alert; Day 192-Normal; Day 220-Danger; Day 221-Normal). A total of 23 days were analyzed: Normal - 3, Alert - 3, Danger - 8, Emergency – 9. There was no significant difference in percentage of time cattle spent under shade in the lowest three categories (Normal 80.8±5.6%; Alert 83.5±5.2%; Danger 83.6±3.3%) (Table 2). However, cattle exposed to the Emergency category spent significantly more time in the shade than in any other category (Emergency 96.4±3.3%).

Respiration rate

The mean daily RR was significantly affected by A, TRT, CAT (P<0.05), and tended to have a significant interaction effect (P=0.11). Cattle in the SA treatment had slower increase in mean daily RR through the categories than cattle in the NS treatment (Table 2). Differences between the treatments were significant at the Danger and Emergency levels, with the SA treatment having a lower mean daily RR.

Upon analyses of the dynamic data patterns, treatment differences began to emerge. It appeared that under normal conditions SA had only a slight impact on RR (significant effects of A, P, h, and TRT*h [P<0.05]), while in all other categories the SA had a larger impact (significant effects of A, P, TRT, h, TRT*h [P<0.05]).

Figure 3 illustrates the difference in RR patterns between SA and NS treatments in all categories. In the Normal category, animals in SA had lower RR between 1200 – 1800 h (average SA=69.8 bpm; average NS=79.5 bpm); the maximum difference (SA$_{max}$-NS$_{max}$=MAX$_{dif}$) was 11.9 bpm. In the Alert category, SA animals had lower RR between 1000 – 1800 h (SA=80 bpm; NS=94 bpm; MAX$_{dif}$ = 19.9 bpm), but had higher RR at night (0400 and 0500), and again in midmorning (0900 h) (SA=64.8;NS=57.7). Under Danger conditions, shade was beneficial for animals between 1000 – 1900 h (SA=85.0;NS=100.6; MAX$_{dif}$ =20.7 bpm), but had no effect the remainder of the day. The response in the Emergency category was similar to the Danger

category, with beneficial effects observed for the hours of 1000-1800, 2000 h (SA=91.0;NS=114.6; MAX_{dif} =31.0 bpm).

Overall, it appears that SA reduced RR during portions of the day in all weather categories. Regardless of weather category, the SA cattle's RR followed NS cattle's RR until approximately 1100 h, at which time SA flattened out, while NS cattle's RR continued to rise. This large impact of shade on RR has been previously documented (Blackshaw and Blackshaw, 1994; Brown-Brandl et al., 2001a; Mitloehner et al., 2001; and Mitloehner et al., 2002). Respiration rate of NS cattle appeared to peak at or before t_{db} peaked, which indicated RR had little or no lag effect associated with t_{db}, and also indicated RR was impacted by RAD. Hahn et al. (1997) reported similar lags in RR ranging from 0 to 3 h for feeder cattle exposed to hot cyclic conditions in an environmental chamber. Gaughan et al. (2000) reported RR lagged t_{db} by about two hours. These slight discrepancies in lags are most likely a result of experimental conditions (cattle in the current study were housed outside, while cattle in Hahn's and Gaughan's studies were in environmental chambers with no solar load and no wind).

Body temperature

Mean daily t_{core} revealed differences between categories in both treatments. The SA treatment showed a slow increase in mean daily t_{core} (Table 2). The NS treatment showed a distinct difference between Normal and Alert, and Danger and Emergency categories. Mean daily t_{core} did not reveal differences between treatments.

In the analyses of the dynamic data, clear differences were found between the two treaments. The t_{core} of cattle exposed to any of the four weather categories were significantly affected by all parameters (A, P, TRT, h, TRT*h).

The effect of shade on t_{core} in the four weather categories is shown in Figure 4. Under Normal conditions, SA cattle had lower t_{core} between 0500 – 1900 h and 1600 – 1700; average t_{core} for SA was 37.7 and NS was 38.0, In the Alert category, SA cattle had a lower t_{core} only 2 h during the day (1500, 1600 h); the average difference was 0.3 ºC (SA=38.3 ºC;SH=38.6 ºC). Also in the Alert category, cattle in the SA treatment had a higher t_{core} for 5 h of 24 h , 1900 – 2200 h and 0400 h (SA=38.6 ºC; NS=38.2 ºC). Shade became a more important factor in the Danger category: between 1000 – 1900 h, in addition to 2300 and 0600, SA cattle had a lower t_{core} (38.4 ºC) than NS cattle (38.7 ºC), with maximum difference being 0.5 ºC. When cattle were exposed to weather conditions in the Emergency category, SA cattle had a lower t_{core} for a total of 7 h (1200 – 1800h); SA treatment had average t_{core} of 38.5 ºC and NS treatment had 38.9 ºC. The maximum difference between two treatments in the Emergency category was 0.6 ºC. Between the 2200 – 0600 and also 0900, the NS treatment had a lower t_{core} than SA treatment (SA=38.3 ºC;NS=38.3 ºC); maximum difference was -0.2 ºC.

In all weather categories, shade reduced cattle's t_{core} during daytime hours. However, in all weather categories except the Danger category, animals SA treatment had higher t_{core} during night-time hours. This response has been documented (Blackshaw and Blackshaw, 1994; Brown-Brandl et al., 2001a), and it has been hypothesized that this is due to radiation losses to the night sky. Although these animals were not confined to the shaded portion of the pen, and behavior data were not collected at night, it is possible the animals remained under shade during nighttime hours. Unlike RR, the benefit of shade on t_{core} is not consistent during the diurnal period between categories..

Feeding behavior and feed intake

Three days were eliminated from the dataset (JD 166, 215, and 262) due to missing data. A summary of feeding behavior data is shown in Table 2. Daily feed intake was significantly affected by A and CAT, and tended to have an interaction effect (TRT*CAT). Animals in SA treatment had an increase in DFI between Normal, Alert, and Danger categories, and then a significant decrease in the Emergency category. The NH treatment had a constant DFI over the lower three categories and then a significant decrease in the Emergency category. Animals in the SA treatment had a higher intake in the Emergency category (SA=12.5 kg; NS=11.3 kg); however, the reverse was true in the Normal category (SA=11.3 kg; NS=13.6 kg). This indicates that animals in the NS treatment were compensated for the decrease in feed intake at higher temperatures. Total eating duration followed a similar pattern and also indicated some compensation in the Normal category. Although there were no significant differences between treatments in other meal parameters, there were differences between categories. The differences indicate cattle compensate for higher temperatures by eating more smaller meals. It appears that this compensation is in place through the lower three categories to maintain DFI. However, it appears that conditions in the Emergency category cannot be compensated; in this category DFI, number of meals, total duration, and meal size all decrease.

Twenty-four hour accumulative feed intake of cattle exposed to the weather conditions in Normal, Alert, and Danger categories was significantly affected by A, P, and h, while in the Emergency category accumulative feed intake was significantly affected by all parameters (A,P, h, TRT, TRT*h).

There were no significant differences in accumulative feed intake in the Normal, Alert or Danger categories. However, in the Emergency category SA cattle had significantly more accumulative feed intake starting at 1400 h through the remainder of the day. Although no significant differences were found, it appeared the NS animals exposed to Emergency conditions shifted their feed intake to the no-peak hours of the day; NS animals had a higher hourly intake at the hours of 0200 – 0600 and 1900 h.

Conclusions

Shade was found to impact the physiological responses in all weather categories, with the largest response observed in the Danger and Emergency categories. As expected, the largest impact of shade was at the higher temperature categories. It appeared that the physiological parameters (RR and t_{core}) were impacted at lower temperature categories than the production related parameters (DFI, or feeding behavior). Respiration rate showed the most consistent diurnal response pattern between SA and NS of any measured parameter. The beneficial effects of shade on t_{core} were largest in the Danger and Emergency categories. While shade did not influence AFI in the Danger category, it had a 1.2 kg advantage in the Emergency category, which should be favorable for maintaining growth in such conditions.

When managing animals during hot weather, it is critical to have an early indicator of stress. Based on these data, RR is an appropriate indicator of stress for several reasons: 1) little or no lag is associated with it, 2) it was consistently affected in all categories (shade had lower RR at the similar time of day in all categories), 3) it is easy to monitor without need of costly equipment (manually counting of flank movements using only a stop watch).

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Table 1. Daily average weather conditions and standard errors reported for each of the four weather categories.

Parameter	Category			
	Normal	Alert	Danger	Emergency
Number of Days	4	6	13	14
N	384	576	1248	1344
Ambient dry-bulb temp (ºC)	19.7±0.22[a]	23.6±0.18[b]	26.0±0.12[c]	27.7±0.12[d]
Dew-point (ºC)	15.8±0.17[a]	18.9±0.14[b]	19.1±0.09[b]	20.4±0.09[c]
Relative Humidity, %	81.5±0.84 [a]	77.5±0.69[b]	68.1±0.47[c]	68.8±0.45[c]
Wind Speed (m/s)	2.9±0.08[a]	2.9±0.07[a]	3.5±0.05[b]	2.6±0.02[c]
Solar Radiation (W/m^2)	249.3±16.7[a]	281.8±13.6[ab]	303.1±9.2[b]	301.5±8.9[b]
Temperature Humidity Index	63.7±0.3[a]	68.0±0.3[b]	71.5±0.2[c]	73.9±0.2[d]

[a,b,c,d] Columns with differing superscripts are significantly different, P<0.01

Table 2. Daily average responses and standard errors reported for each of the four weather categories

	Category			
	Normal	Alert	Danger	Emergency
Feed Intake (kg)[*]				
Shade	11.3 ± 0.9^{a1}	14.2 ± 0.6^{b}	13.8 ± 0.4^{b}	12.5 ± 0.4^{a1}
No-Shade	13.6 ± 0.9^{a2}	13.6 ± 0.6^{a}	13.6 ± 0.4^{a}	11.3 ± 0.4^{b2}
Total Duration (min)[*]				
Shade	177 ± 15^{ab}	192 ± 11^{a}	202 ± 7^{a}	167 ± 7^{b1}
No-Shade	192 ± 15^{a}	195 ± 10^{a}	208 ± 7^{a}	150 ± 7^{b2}
Number of Meals[*]				
Shade	12.7 ± 1.1^{a}	14.7 ± 0.8^{ab}	15.0 ± 0.6^{b}	13.7 ± 0.5^{ab}
No-Shade	13.5 ± 1.1^{ab}	14.6 ± 0.8^{a}	15.2 ± 0.6^{a}	12.8 ± 0.5^{b}
Average Meal Size (g)[*]				
Shade	898 ± 67	1009 ± 49	946 ± 34	930 ± 32
No-Shade	1034 ± 67^{a}	970 ± 48^{ab}	947 ± 34^{ab}	910 ± 32^{b}
Average Duration (min)[*]				
Shade	13.8 ± 0.8^{ab}	13.5 ± 0.5^{ab}	13.8 ± 0.4^{a}	12.6 ± 0.4^{b}
No-Shade	14.1 ± 0.8^{a}	13.6 ± 0.5^{a}	14.2 ± 0.4^{a}	12.2 ± 0.4^{b}
Rate of Eating (g/min)[*]				
Shade	65.2 ± 3.3^{ac}	74.1 ± 2.4^{b}	66.1 ± 1.7^{c}	72.4 ± 1.6^{b}
No-Shade	73.6 ± 3.3^{a}	69.0 ± 2.4^{a}	63.4 ± 1.7^{b}	71.2 ± 1.6^{a}
Average Respiration Rate (bpm)[†]				
Shade	66.9 ± 3.7^{ab}	69.6 ± 3.0^{a}	74.2 ± 2.0^{b1}	82.3 ± 1.8^{c1}
No-Shade	65.2 ± 3.4^{a}	73.7 ± 2.9^{b}	79.4 ± 1.8^{c2}	93.4 ± 1.9^{d2}
Average Core Body Temperature (ºC)[†]				
Shade	38.0 ± 0.16^{a}	38.2 ± 0.14^{ac}	38.4 ± 0.08^{b}	38.3 ± 0.8^{bc}
No-Shade	38.3 ± 0.15^{a}	38.3 ± 0.12^{a}	38.6 ± 0.08^{b}	38.42 ± 0.8^{ab}
Percent of time spent in shade (%)[†]				
Shade	80.7 ± 5.5^{a}	83.5 ± 5.2^{a}	83.6 ± 3.3^{a}	96.4 ± 3.3^{b}
No-Shade	N/A			

[a,b,c,d] Columns with differing superscripts are significantly different.

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[1,2] Rows with differing superscripts are significantly different.

[*] Significant differences at the P<0.1 level
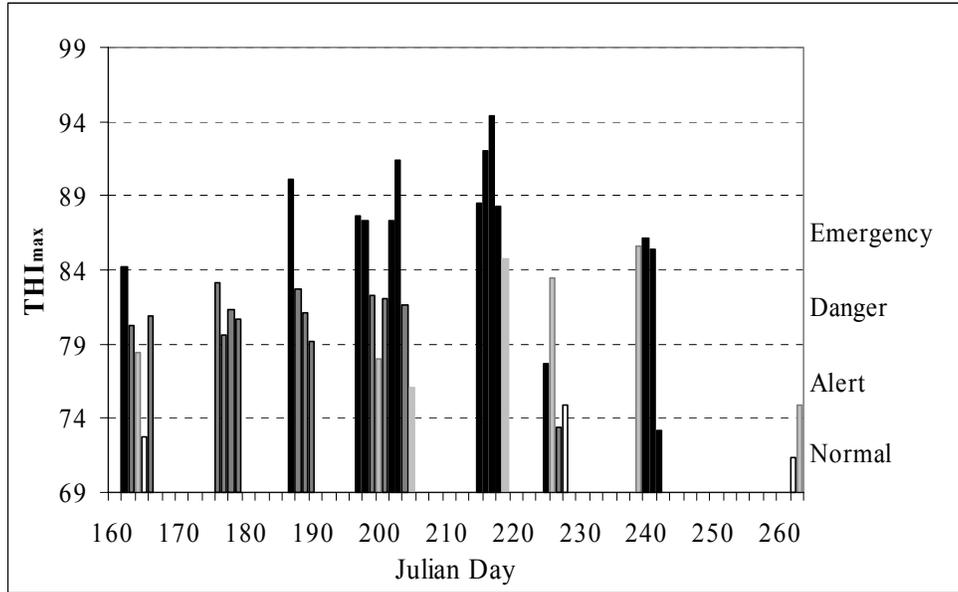
[†] Significant differences at the P<0.05 level

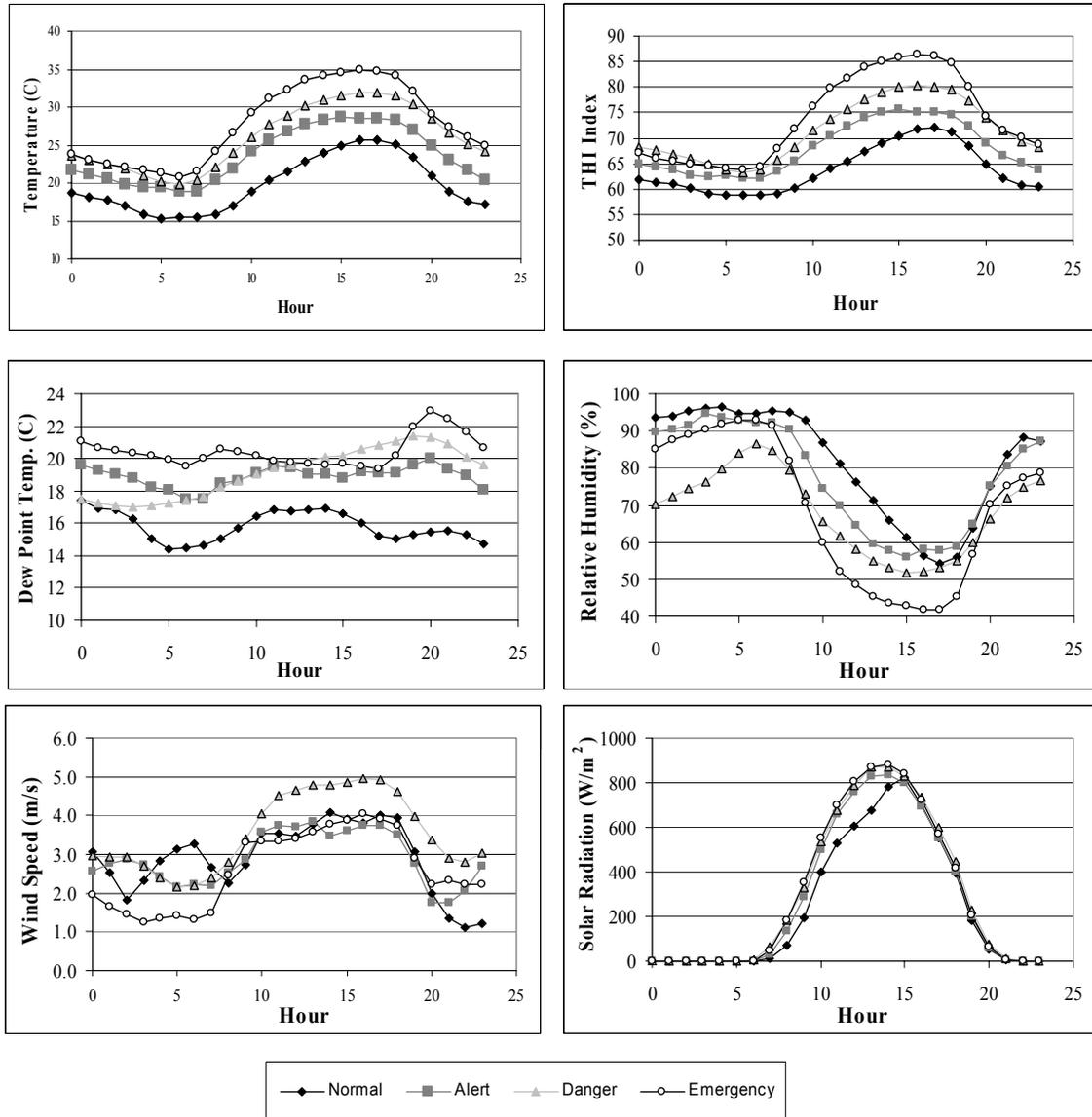Figure 1. Category assigned to each experimental day, Normal-- THI_{max} <74; Alert--74< THI_{max} >78; Danger--79<THI_{max} >83; Emergency--THI_{max} >84

Figure 2. Average hourly weather data for each of the four weather categories:
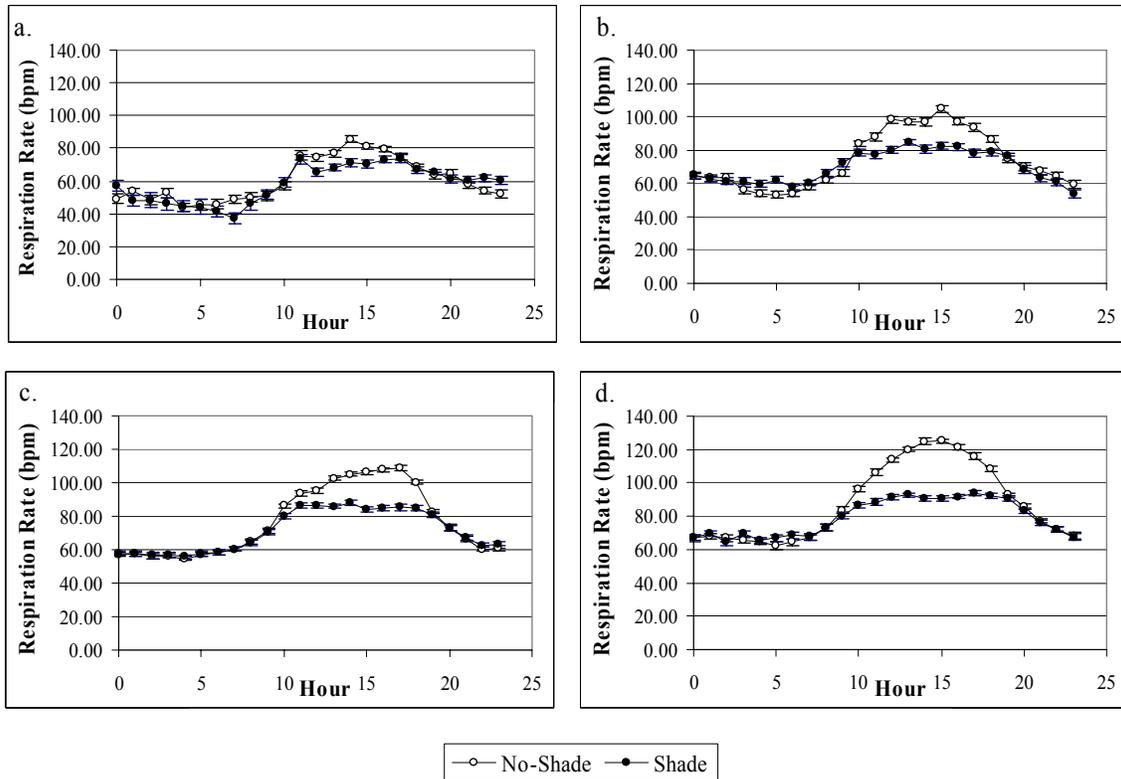Normal--THI$_{max}$ <74; Alert--74< THI$_{max}$ >78; Danger--79<THI$_{max}$ >83; Emergency--THI$_{max}$ >84

Figure 3. Average hourly respiration rate for shaded and non-shaded feedlot cattle exposed to weather conditions in the a) Normal, b) Alert, c) Danger, or d) Emergency categories. Error bars represent standard error associated with each point
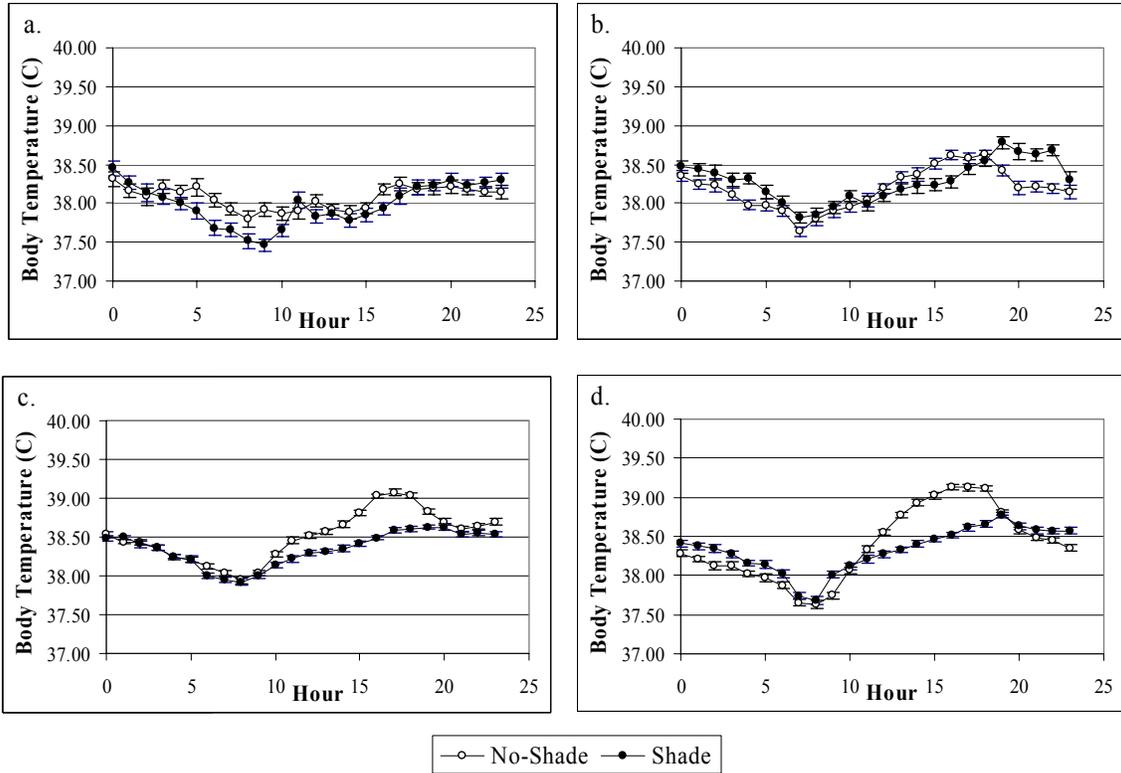
Figure 4. Average hourly body temperature for shaded and non-shaded feedlot cattle exposed to weather conditions in the a) Normal, b) Alert, c) Danger, or d) Emergency categories. Error bars represent standard error associated with each point
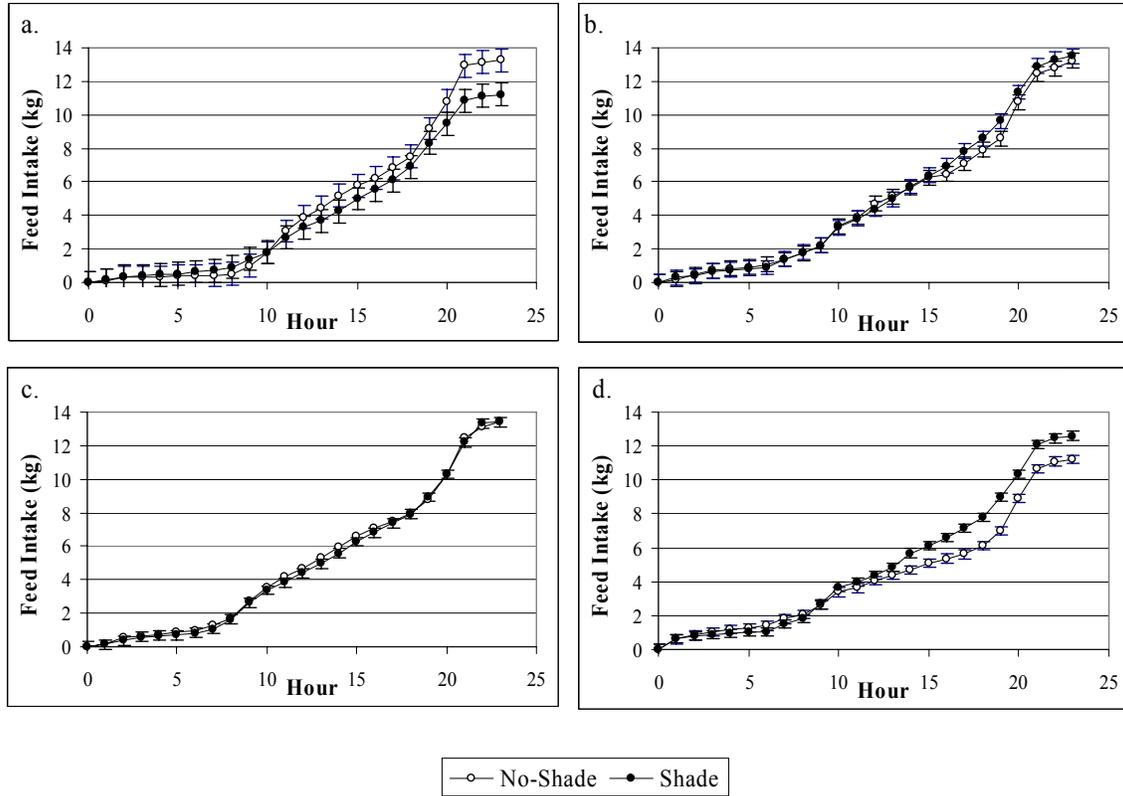
Figure 5. Hourly accumulative feed intake for shaded and non-shaded feedlot cattle exposed to weather conditions in the a) Normal, b) Alert, c) Danger, or d) Emergency categories. Error bars represent standard error associated with each point