

DETERMINING BEST PREDICTORS OF ANIMAL PERFORMANCE IN FEEDLOT  
STEERS

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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled

DETERMINING BEST PREDICTORS OF ANIMAL PERFORMANCE IN FEEDLOT STEERS

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A candidate for the degree of MASTER OF SCIENCE and

Hereby certify that in their opinion it is worthy of acceptance

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# DETERMINING BEST PREDICTORS OF ANIMAL PERFORMANCE IN FEEDLOT STEERS

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## ABSTRACT

Two studies were performed in a feedlot environment to determine the long-term effects of heat events on animal performance and well-being. Experiments in this thesis were designed to pinpoint ambient variables that most strongly elicit animal thermoregulatory responses. These animal responses included core temperature ( $T_{\text{core}}$ ) alone in the first study, and both  $T_{\text{core}}$  and animal respiration rate (RR) in the second. Both experiments went a step further by using both ambient conditions and animal responses to predict feed intake (FI) response to heat stress. The ability to predict FI based on measurable independent variables could be very helpful to beef producers who are otherwise subject to environmental stressors and loss in animal production. The first study followed 26 crossbred Angus steers during 42 days of a central Missouri summer in 2011 (July 12 through August 22), and was strictly aimed at predicting  $T_{\text{core}}$  and FI using ambient information. Animals were housed at the University of Missouri Beef Research and Teaching Farm (BRTF) in Columbia, Missouri and had *ad libitum* access to feed and water, with ~50% shade coverage over the pens. All variables were automatically measured and recorded throughout the entire study period. Linear and polynomial regression analyses of variance (ANOVA, JMP statistical software; SAS Institute; Cary, NC) were used. Both ambient and mean herd  $T_{\text{core}}$  readings were averaged by hour to analyze the relationship between environment and  $T_{\text{core}}$  during daytime (0700 to 1700

CST). Hourly lags of between zero and five hours were then considered in order to determine existence of delayed response. Further, whole herd FI values were averaged by day. When considering the ambient effect on FI, we averaged daytime conditions by day and considered lags of between zero and seven days to determine the existence of a delayed response. Our group deemed quadratic regressions to be the best in terms of predictive value for both  $T_{\text{core}}$  and FI. Mean daytime black globe (BG) temperature in the shade (BGShade) and ambient temperature ( $T_a$ ) were the best predictors of  $T_{\text{core}}$ , (quadratic  $R^2 = 0.68$  and  $0.67$ , respectively;  $p < 0.0001$ ) with one hour of delay in  $T_{\text{core}}$ . Mean daytime BG temperature in the sun (BGSun), in combination with the sunlit BGTHI (BGTHISun) to be the best predictor of FI five days in the future (quadratic  $R^2 = 0.30$ ,  $p = 0.0044$ ). The second study took place in the same location over 100 days during the summer of 2013 (June 4 through September 11). The crossbred Angus steers that were born and raised on pasture at the University of Missouri BRTF. Animals were selected to ensure black hides and predominately (>95%) black coats. One goal of the 2013 study was to repeat the 2011 study over a longer period of time, with the addition of RR as a predictor. A second goal was to determine if the absence of a heavy hair coat early in the summer affected animal thermal status and FI. Half of the steers were randomly selected as treatment animals (TRT), and their winter hair coat was removed from their topline and heart girths. Again, ambient and mean herd  $T_{\text{core}}$  readings were averaged by hour to analyze the relationship between environment and  $T_{\text{core}}$ . This time, respiration rates were also incorporated, and were averaged by hour and by treatment group. Hourly lags of between 0- and 7-h were then considered in order to determine existence of delayed response during daytime. Feed intake values were averaged by day

and whole herd. When considering the ambient effect on FI, we again averaged daytime conditions by day and considered lags of between zero and five days to determine the existence of a delayed response. Our group deemed quadratic regressions to be the best in terms of predictive value for both  $T_{\text{core}}$  and FI. During the entire study, and including all hours of all days, the TRT animals had significantly lower  $T_{\text{core}}$  ( $p < 0.0001$ ), with no effect on respiration rate ( $p > 0.10$ ). Surprisingly, TRT animals had significantly lower ( $p < 0.0001$ ) feed consumption over the entire course compared to controls (CONT). Possibly the animals had a higher skin temperature than CONT animals as a result of increased radiant heat exposure. Further, the 2013 study sought to determine of the relationships between ambient variables and RR,  $T_{\text{core}}$ , and FI. The assumption was that the inclusion of mean hourly RR would improve prediction of  $T_{\text{core}}$  and that consideration of daily averaged RR might improve prediction of FI. The best predictor for whole-herd (not separated by treatment)  $T_{\text{core}}$  was  $T_a$  with two to three hours of lag in  $T_{\text{core}}$  (quadratic  $R^2 = 0.52$ ,  $p < 0.0001$ ). Further, whole-herd RR was strongly related (quadratic  $R^2 = 0.47$ ,  $p < 0.0001$ ) to whole-herd  $T_{\text{core}}$  with no lag. Also, variation in whole-herd RR was best explained by  $T_a$  (quadratic  $R^2 = 0.63$ ,  $p < 0.0001$ ) with no time lag. Finally, the best predictor of whole-herd FI was mean daytime THI calculated using sunlit BG temperature, with two days of lag against FI (quadratic  $R^2 = 0.25$ ,  $p < 0.0001$ ). When separated by treatment, variation in the CONT group appeared to better explained by a model using  $T_a$  (quadratic  $R^2 = 0.63$ ,  $p < 0.0001$ ) than did variation in the TRT group ( $R^2 = 0.60$ ,  $p < 0.0001$ ). However, this difference in variation explained by the model is minute, and our group concludes it is likely insignificant in a production environment. The best predictor of FI in the CONT group was maximum daily  $T_a$  with a 1-day lag

(quadratic  $R^2 = 0.23$ ,  $p < 0.0001$ ). Similarly, the best predictors of FI in the TRT group were mean  $T_a$  with a 2-day lag (quadratic  $R^2 = 0.31$ ,  $p < 0.0001$ ). Perhaps the most valuable finding to producers is that of significantly ( $p < 0.0001$ ) lower mean daily  $T_{core}$  ( $0.23^\circ\text{C}$  lower) among TRT steers compared to CONT. Similarly, maximum daily  $T_{core}$  was significantly ( $p < 0.0001$ ) lower in TRT versus CONT animals ( $0.30^\circ\text{C}$ ). The finding that a torch protocol can decrease  $T_{core}$  appears to be novel, and may reveal an economical method by which producers can increase animal welfare during heat events.

# CHAPTER 1

## LITERATURE REVIEW

### **Introduction**

One of the biggest challenges for livestock producers around the world is heat stress. Heat stress in cattle is of particular concern for outdoor production systems where the animal has limited ability to utilize avenues of cooling, such as evaporation, to effectively and efficiently dissipate heat. High producing bovines also generate significant metabolic heat as a byproduct of rumination and lactation (West, 2003) to compound the need for effective cooling. Environmental factors such as visible and infrared radiation, relative humidity (RH), and  $T_a$  can all impact animals in the field, directly and indirectly. Indirect effects that compound the problem include increased pathogen loads and illness from animals lying in urine and feces to supplement evaporative cooling. Reduced feed conversion, intake, virility, and average daily gain (ADG) are all well documented consequences of heat stress and subsequent strain (Cartwright, 1955; Ingram and Mount, 1975; Kibler and Brody, 1951). Of particular importance to beef producers is the tendency of animals to reduce daily FI, which has the effect of decreasing metabolic heat production. Significant levels of heat stress from the environment and, more importantly, strain on the animal negatively affect FI, well-being, reproduction, and growth performance (Hahn, 1997).

The duration of heat load exposure is an additional complicating factor that can modulate the heat stress effect on growth performance, with sustained heat events producing more performance suppression than brief ones (Hahn, 1997). Summer heat

waves, combined with elevated RH, are annual occurrences in many areas. Although there is no universal definition for a heat wave (Meehl and Tebaldi, 2004), the most applicable one for animal producers defines a heat wave as the maximum number of consecutive days where the daily summer maximum air temperature (DSMT) exceeds the long-term 95<sup>th</sup> percentile of DSMT within a June to August season (Della-Marta et al., 2007). This potentially harmful climatic pairing shows no sign of relenting, and may worsen if theories regarding global climate change and warming prove accurate (Karl, 2009). Research in this area will continue to be an important area of study for animal scientists, as long as beef producers are subject to financial and animal losses from heat stress.

### **1.1 Economic losses**

One of the biggest sources of concern for producers is the potential for heat stress to reduce profits. Decreased yields resulting from thermal strain on animals can be considerable. In fact, estimates of annual losses more than a decade ago are 897 million, 229 million, and 128 million dollars for dairy, beef, and poultry industries, respectively (St-Pierre et al., 2003). These estimates are low since they did not account for inflation or the impact of heat stress on animal health and reproductive performance. Beef animals in feedlot settings are particularly susceptible to environmental stress due to their high plane of production, frequent lack of adequate shade, and tendency for feedlots to be located in warmer parts of the United States. Increased knowledge among producers of the benefits of heat abatement methods like shades, fans, misters, and waterers, has helped to reduce total economic losses from 2.4 billion to 1.7 billion dollars (St-Pierre et

al., 2003). However, strong beef prices mean any production declines are financially significant. For example, during the decade preceding the year 2003, economic losses from environmental stress, such as decreased dry matter intake (DMI) and diminished weight gain (Mader et al., 1999), resulted in a loss of 10 to 20 million dollars annually in the US feedlot industry (St-Pierre et al., 2003). For each animal that dies, the effect on feedlot operations nears 1,200 dollars, with the current value of feeder cattle averaging over 2.00 dollars per pound as of March 2015. Nationwide, gain losses from heat stress can range from 1.4 to 17 kg per head during finishing (St.-Pierre et al., 2003). Feedlot operators end up having to keep animals on feed for an average of seven additional days as a result of heat stress (St-Pierre et al., 2003).

## **1.2 The problem and challenge**

Since typical feedlots subject cattle to all manner of ambient stress, producers must work to alleviate environmental stressors. Excessive heat load, in particular, can result in significant production losses and animal welfare considerations (Meat and Livestock Australia, 2006). Hyperthermia can develop in feedlot cattle when a combination of local environmental conditions and animal factors exceed their ability to dissipate excess body heat. The challenge for producers is to find ways to limit environmental stress to animals maintained outdoors.

## **1.3 The solution**

Feedlot operators can influence the severity of the heat load burden placed on cattle during hot conditions by implementing a range of management strategies (Meat and

Livestock Australia, 2006). If implemented individually, these strategies may only have a limited effect, but when applied in combination they can reduce the significance of excessive heat load on feedlot cattle. Shades, fans, and sprinklers are all components that can be incorporated into feedlot infrastructure to possibly remedy cattle heat load. Water quality and adequacy is also an important consideration when implementing heat stress solutions (Meat and Livestock Australia, 2006). Additionally, an animal's diet will directly influence its body heat load and contribute to its ability to withstand excessive heat challenge. Different feed ingredients produce different amounts of body heat. Fats have the lowest heat increment (HI), followed by carbohydrates and then protein (Meat and Livestock Australia, 2006). By modifying environment and diet, and managing animals appropriately, producers can limit the negative effects of heat stress on their cattle. However, a concise model for when and how these practices should be implemented is needed.

## **2. Thermal balance**

Body heat balance refers to the steady-state relation in which total heat gain in the body equals its heat loss to the environment. It can be illustrated by a mathematical equation that describes the net rate at which a subject generates and exchanges heat with its environment under the rule of the First Law of Thermodynamics (IUPS Thermal Commission, 2001). If the heat loss is equal to the heat gain, thermal balance can be maintained (see Equation 1).

## 2.1 Homeothermy

All living organisms exchange heat with their external environment. Cattle are able to regulate their internal body temperature within a certain range, and independent of  $T_a$ . For this reason, cattle are referred to as homeotherms (IUPS Thermal Commission, 2001).

Homeothermy is the ability of animals to physiologically regulate central body temperature and provide a stable thermal environment (Zavos, 1972). Homeotherms are colloquially known as hot-blooded organisms. Birds and mammals, such as cattle, are unique in the animal kingdom in that they have evolved this ability, and therefore are classified as homeotherms (Spiers, 2000). As opposed to poikilotherms, like fish and reptiles, homeotherms exhibit much greater (7 to 10 times) metabolic heat production (Robertshaw, 1985). In other words, they can generate heat from physiological processes, and more effectively regulate internal temperature relative to ambient conditions. This ability is important, as most homeotherms need a relatively constant internal temperature to maintain physiological functions (Reece, 2004). Highly mobile and energized animals such as birds (Dawson et al., 1972) generally maintain a relatively elevated rectal temperature (RT; 40°C to 45°C) compared to mammals, including humans (DuBois, 1948) generally maintain RT close to 36°C to 38°C. Above a critical internal body temperature (i.e., hyperthermia), crucial proteins can denature and animals must quickly dissipate heat in order to avoid permanent damage. In homeotherms, a lethal temperature for most organs is between 43°C and 45°C (Reece, 2004).

### **2.1.2 Comparison with poikilothermy**

Poikilothermy, as exhibited by animals like reptiles, fish, and invertebrates, refers to thermal states in which  $T_{\text{core}}$  remains comparatively close to  $T_a$  (IUPS Thermal Commission, 2001). In fact, many poikilotherms are able to alter their internal temperatures entirely via behavioral changes relative to environmental conditions (Kerkut and Taylor, 1958). An interesting example of this ability is the movement of pregnant live young-bearing lizards (*Sceloporus jarrovi*) within a gradient to regulate a lower body temperature ( $32^{\circ}\text{C}$ ) than that of their male or post-parturient female counterparts ( $34.5^{\circ}\text{C}$ ). This is an apparent attempt to achieve the lower optimum temperature for development of their embryos. Poikilotherms are colloquially known as cold-blooded animals. Many are characterized by being cold tolerant, as they are able to survive low and even sub-freezing body temperatures (IUPS Thermal Commission, 2001). This ability represents a fundamental difference when comparing homeotherms to poikilotherms.

### **2.1.3 Advantages and disadvantages of homeothermy**

It is common knowledge that cattle are homeotherms. However, there are noted disadvantages associated with the maintenance of a constant body temperature. One is an increased susceptibility to changes in animal size or mass. For homeotherms, metabolic rate generally increases with decreasing body size in order for heat production (normalized to body weight) to match heat loss (Schmidt-Nielsen, 1975). Homeothermy is perhaps less attractive for smaller animals than it is for larger ones, particularly in cold environments. Small mammals cool faster than do large ones, and have a greater

metabolic cost when compared to larger species when all other environmental factors are equal. For example, when living at 21°C, house mice (26 to 44 grams) consume approximately 25-fold more food than poikilothermic lava lizards (*Microlophus*) of similar mass (Farmer, 2003). The difference becomes even greater in the cold. When exposed to cold (8°C), the same mice consume 38-fold more food than the lizards. Larger species are less affected by a transient shift in metabolic heat production due to a smaller surface area: body mass ratio (Sarrus and Rameaux, 1839). In fact, large homeotherms can be viewed as essentially trapped in their *thermal milieu*, meaning that their thermal inertia impedes the lowering of  $T_{\text{core}}$  in response to environmental change (Gordon et al., 2008).

Another disadvantage of homeothermy is the comparatively large metabolic cost of maintaining a narrow  $T_{\text{core}}$  range versus poikilothermy. Some homeotherms will even abandon homeothermy, with its associated energy cost, and reap large benefits due to the physical effects of low body temperature on metabolic rate. That is, by allowing body temperature to fall, these animals can conserve stored energy via hibernation or torpor. Examples include squirrels (Bartholomew and Hudson, 1960), cactus mice (MacMillen, 1965), and gerbils (Buffenstein, 1985). Several species also depress their metabolic rate independently of body temperature. An example of this is illustrated by the Golden Spiny Mouse (*Acomys russatus*). When subjected to lengthy periods of limited food availability, these mice were able to reduce their metabolic rates by nearly half, while not significantly altering their core body temperature (Merkt and Taylor, 1994). Since the metabolic rate of an animal is a measure of its cost of living (Else et al., 2004), homeotherms have relatively high costs. These costs impact virtually every aspect of

mammalian and avian biology, including their ecology, physiology, and biochemistry being linked to factors such as food requirements, growth rate, capacity for aerobic exercise, and thermoregulatory ability (Hulbert and Else, 2000).

Homeothermy does have its advantages, however. It provides a steady state for physiological and biochemical functions (e.g. locomotion, enzymatic activity, membrane and action potentials, digestion, growth, excretion) and offers profound ecological consequences by allowing these animals to be active for longer periods and over a wider range of habitats (Wooden and Walsburg, 2002).

## **2.2 Thermoregulatory control system**

The thermoregulating homeothermic animal strives to maintain internal body temperature (Hardy and Bard, 1974). This thermal set-point is the value which a healthy organism tends to stabilize by processes of thermoregulation (IUPS Thermal Commission, 2001). The thermoregulatory responses are under hypothalamic control. With increased heat load, these responses include cutaneous vasodilation and opening of arteriovenous anastomoses by reduced sympathetic vasoconstrictor discharge. The result is a redistribution of blood flow from other organs to increase cutaneous flow and favor heat loss. Local cooling of the hypothalamus or skin has the opposite effect (Reece, 2004).

### **2.2.1 Controller**

A classical control system is often used to describe the homeothermic ability of birds and mammals such as cattle, with the principle function of the hypothalamus being

the controller of body temperature. In addition, the hypothalamus itself is thermosensitive. That is, heating or cooling the hypothalamus alone will initiate thermolytic and thermogenic activities, respectively (Hammel et al., 1960). Input generally begins with thermoreceptors, both internally and cutaneously, that relay information to the central nervous system and hypothalamus (Curtis, 1983). The rostral and preoptic hypothalamic (POAH) areas contain an interconnection of neurons that protect the body against hyper- and hypo-thermic conditions, and control output to thermogenic and thermolytic processes. More specifically, body surface temperature is detected by cutaneous thermal sensors, while relative internal body temperature is determined via thermosensitive structures in the POAH, brain stem, spinal cord, and other places throughout the internal regions of the body (Curtis, 1983). Then, the POAH elicits the thermoregulatory responses that are the most appropriate for both internal and environmental thermal conditions (Boulant, 2000). For example, hypothalamic cooling results in vasoconstriction, while direct warming of this region produces an opposite effect (vasodilation) (Hammel et al., 1960). The importance of the hypothalamus, and the physical partitioning of its tasks in thermal homeostasis has been demonstrated by numerous experiments. It has been shown that if the preoptic region is destroyed, the animal is unable to regulate internal body temperature in a hot environment, but still regulates during cold exposure (Clark et al., 1939). Furthermore, electrical stimulation of the anterior hypothalamus itself results in vasodilatation of peripheral capillaries and panting, even in a thermoneutral environment (Andersson and Wyrwicka, 1957). Although the hypothalamus is clearly important to thermoregulation, it is not the only region affected by changes in body temperature. One example is the spinal cord.

Though its control seems to be less fine-tuned than that of the hypothalamus, heating and cooling the spinal cord elicits a similar response as heating or cooling the hypothalamus. However, this response can be controlled and potentially altered by the hypothalamus. In fact, heating or cooling the spinal cord while doing the opposite to the hypothalamus results in a dampened response (Ingram and Mount 1975). Likewise, it appears as though the abdomen of animals also contains a significant concentration of thermosensitive cells. Heating and cooling the abdomen, specifically the rumen, has been shown to activate thermoregulatory mechanisms in the ewe. Shivering can be suppressed in cold environments via intra-abdominal heating. Conversely, panting can be suppressed in hot environments via intra-abdominal cooling (Rawson and Quick, 1972). The practical importance of hypothalamic control has been shown during times of high heat. Heat stress causes the rostral cooling center of the hypothalamus to stimulate the medial satiety center which inhibits the lateral appetite center, resulting in reduced FI and milk production (Albright and Alliston, 1971).

### **2.2.2 Effectors and affectors**

Virtually all neurons are affected by temperature. Typically, cooling a neuron decreases its excitability and reduces its frequency of spontaneous discharge. The opposite effect occurs when a neuron is warmed (Reece, 2004). Sensory thermoreceptors respond to a broad range of nonnoxious temperatures. In fact, cutaneous thermoreceptors are highly sensitive to very small changes ( $< 0.1^{\circ}\text{C}$ ) in temperature (Reece, 2004). Hot and cold receptors are found throughout the body, including the brain, spinal cord, and

skin (Blumberg, 2002). It is the integration of temperature information acquired via these sensors that ultimately elicits a behavioral and/or physiological response.

### **2.2.3 Modifications**

In biological systems, the apparent set-points of many regulated variables may change with time, either periodically or temporarily (e.g., nychthermerally, annually, with the ovulatory cycle, or in connection with other physiological events). In temperature regulation, the set-point may change temporarily, due to interference with the regulations of nonthermal variables (e.g., dehydration, starvation, etc.), or due to pathological, nonthermal influences (e.g., fever, anapyrexia). Also, the processes of acclimatization and adaptation may change the set-point of temperature regulation. Hibernation is a special condition in which the set-point differs distinctly from that existing in the same animal under thermoneutral conditions (IUPS Thermal Commission, 2001). The change of set-point in these processes is thought to be due to changes in the thermal controller characteristics, particularly changes of thresholds (e.g., thermoeffector threshold temperature) and/or changes of thermoeffector gain, which obviously have neuronal correlates as well (IUPS Thermal Commission, 2001).

### **2.3 Heat Exchange in general**

Cattle produce heat primarily as the byproduct of metabolic conversion of the chemical energy stored in consumed food. The rate of this production is variable and depends on temperature, growth rate, lactation status, and other variables (Finch, 1985; McLean, 1963). Metabolic heat ranges from approximately 70 to 250 W m<sup>-2</sup> depending

on  $T_a$ , growth rate, and milk production, and must be dissipated at a rate equal to production in order to maintain thermal equilibrium (Maia et al., 2005). The excess heat in the body must be dissipated to the environment by two routes: nonevaporative (i.e., sensible or dry heat loss) and latent (i.e., non-sensible heat loss) heat transfer (Maia et al., 2005).

Although cattle can lose some body heat by expelling urine and feces (Meat and Livestock Australia, 2006), this does not cool the animal. The relevant paths for cattle to actually dissipate body heat are evaporative and non-evaporative means. Evaporative heat loss is the only exchange avenue that does not rely on a temperature gradient. Thus, evaporative heat loss (e.g., sweating in cattle) is an efficient way to lose heat even at an environmental temperature that is above skin temperature (Hardy and Bard, 1974). Nonevaporative heat loss relies on a temperature gradient between two materials (i.e., gases, solids, or fluids). Conduction, convection, and radiation fall under this category (Hansen 2004).

In order to maintain thermal equilibrium, homeotherms must exchange heat produced or gained from the environment with their surroundings, and the net exchange must equal zero if they are to maintain a stable thermal state. This phenomenon is illustrated by the equation

$$\text{Equation 1: } S = M - W - [E - (R + C + D)] \text{ (Hardy and Bard, 1974)}$$

where,

$S$  = rate of body heat storage (considered positive if body temperature rises)

$M$  = total metabolic rate

$W = \text{useful physical work rate}$

$E = \text{evaporative heat loss rate}$

$R + C + D = \text{rates of heat loss (or gain) by radiation (R), convection (C), and conduction (D)}$

In general, the magnitude of sensible heat loss via conduction and convection relies on the magnitude of the thermal gradients between the skin and surrounding air, and between the body core and the skin. Heat exchange by radiation, on the other hand, depends upon animal surface area, temperature, and the reflective properties of the hair coat. Lighter colored and shiny hair coats reflect a greater proportion of solar energy than darker, more matte hair coats (Stewart, 1953; Finch and Western, 1977; Hutchinson and Brown, 1969; Finch, 1986; Hansen, 1990).

### **2.3.1 Conduction**

Conduction can occur between two objects in contact with one another or even within a single object or body. Conductive heat transfer refers to the net rate of transfer in a solid material or a non-moving gas or fluid, down a thermal gradient within an organism, or between an organism and its environment. The latter is usually expressed in terms of unit area of the total body surface or area associated with heat exchange. A common unit to express the amount of heat exchanged is watts. This exchange is dependent on the thermal conductance of materials in question, surface area, temperature gradient between the materials, distance between the two, and thermal conductivity that exists at the time. The temperature gradient is important since heat flows from higher

(e.g., body core) to lower levels (e.g., skin surface) in solids and liquids. The amount of heat transferred is proportional to the magnitude of the gradient (Robertshaw, 1985).

Conductive heat exchange is summarized in the following equation:

$$\text{Equation 2: } Q_k = (A_k) (k) [(T_1 - T_2) / (s)] \quad (\text{Curtis, 1983})$$

where,

$Q_k$  = conductive heat flux ( $\text{cal sec}^{-1}$ )

$A_k$  = animal's effective conductive surface area ( $\text{cm}^2$ )

$k$  = thermal conductivity of environmental substance ( $\text{cal cm}^{-1} \text{sec}^{-1} \text{C}^{-1} \text{cm}$ )

$T_1$  = temperature of environmental substance at a point some distance from the animal

$T_2$  = environmental surface temperature at point of contact with animal ( $^{\circ}\text{C}$ )

$s$  = distance between points where  $T_1$  and  $T_2$  were measured (cm)

During periods of heat stress, blood flow to the peripheral tissues (ears, dewlap, etc.) increases to capitalize on the radiative effect of these capillary beds. As a result, heat loss from these areas via conduction (and convection) is increased (Choshniak et al., 1982). When considering thermal conductivity of external insulation in cattle, it is worth noting the presence of air trapped against the skin in the coat. Air has a low coefficient of thermal conductivity, and, as a result, acts as an effective insulator against heat transfer with the environment. When animals are stationary, and air movement is minimal, this trapped air barrier remains intact. Thus, in this scenario, conductive heat transfer plays a small role in total heat exchange with the environment. Any air trapped against the skin

in the hair coat reduces conductive heat exchange and acts as an effective insulator (Robertshaw, 1985).

### **2.3.1.1 Hair coat and heat stress**

Cattle achieve some thermal insulation from their hair coats (Bennett, 1964). In hot and humid conditions, water from sweat gets trapped in spaces between the hair follicles causing the animal to expend more energy for thermoregulation by increasing evaporative heat loss through increased RR and sweating (Finch, 1985). Thus, cattle with thick or wooly coats, that are characteristic of a winter coat, are at a distinct disadvantage in hot, humid climates and are at increased risk of heat stress and dehydration (Gray et al., 2011).

#### **2.3.1.1.1 Hair coat quantity**

Cattle, and *Bos taurus* cattle in particular, grow thicker coats in colder months and shed this excess hair in the summer. Not surprisingly, cattle with slick hair coats have been observed to maintain lower RT than those with normal hair. Animals exhibiting slick hair coats give the same appearance and tactual sensation when stroked about the poll, neck, and lower tail as an animal recently clipped (Olson et al., 2003). One study, involving predominantly Holstein cows, indicated that cattle exhibiting slick hair coats had between 0.18°C and 0.4°C lower RT than their normal-haired counterparts (Olson et al., 2003). Cattle are routinely clipped to reduce hair coat length and improve appearance in show environments. Subsequently, these animals, depending on the

surface area clipped, may experience increased heat dissipation and a lower RT from a possible reduction in thermal insulation (McClanahan et al., 2008).

#### **2.3.1.1.2 Hair quality**

Hair coat quality can also affect its thermal properties. Coat color, for example, can affect thermal balance in beef cattle during exposure to sunlight. There is evidence that hair color can influence bovine susceptibility to heat stress via absorption of solar radiation. One study showed that mean tympanic temperature was 0.2°C to 0.6°C higher for dark-haired versus light-haired cattle (Mader et al., 2002). Another study using beef cattle indicated that the inward flow of heat at the skin of black-haired steers was 16% greater than for brown-haired steers, and 58% greater than for white-haired steers (Finch, 1986). Perhaps more important to producers was the decreased weight gains observed among these darker haired subjects (Finch, 1986).

In dark-colored cattle, absorptivity of solar radiation is between 0.8 and 0.9 at perpendicular or normal incidence, but it drops slowly as the angle of incidence increased to approximately 75 degrees (Curtis, 1983). Ultimately, white hair coats reflect more incident solar radiation than do darker ones. However, a greater proportion of the radiant energy that is not reflected is transmitted through white coats (Curtis, 1983).

#### **2.3.1.2 Body tissue**

An animal's thermal insulation consists of two components in series: the tissue insulation below the skin surface and the external insulation superficial to the skin (Mount, 1979). Tissue insulation resists heat flow between core and skin surface (Curtis,

1983) and depends largely on subcutaneous fat (Mount, 1979). Most heat flows from the visceral organs to the skin of the trunk and extremities via blood, the magnitude of an animal's tissue insulation is determined largely by the status of its peripheral blood vessels perforating subcutaneous fat (Curtis, 1983). Determining the total amount of tissue insulation in an animal is the subject of debate. A review of the literature revealed at least five difference regression equations for determining the total body tissue of a bovine (Berman, 2004; Webster, 1970; Webster et al., 1970; Webster et al., 1974; Bruce and Clark, 1979) and all are based on body weight. Some, such as the National Research Council (NRC) also consider chronological age (NRC, 2000). Surface area (Berman, 2004), and body condition score (NRC, 2000) have also been used. Differences among equations have been attributed to regional disparities (Webster, 1970) and acclimation (Webster et al., 1970) among cattle.

#### **2.3.1.2.1 Fat**

Aquatic mammals provide a good example of fat insulation. Seals, whales, and walrus rely on the 10 cm thick layer of blubber fat that surrounds their internal organs to prevent loss of body heat in arctic waters (Hardy and Bard, 1974). Likewise, cattle may also gain some thermal insulation from fat deposits. Bovine back fat (subcutaneous fat) thickness has been considered a potential insulator for animals in cold-stress studies. For example, a study of mature cows indicated that fatter cattle required fewer calories to maintain body condition than moderate cattle (Wagner et al., 1988). This difference was attributed to different thicknesses of subcutaneous fat. Another example is an Australian study in which *Bos indicus* cattle demonstrated an ability to lower resistance to internal

heat transfer to a far greater extent than *Bos taurus* breeds and maintained this low resistance at high levels of heat stress (Finch, 1985). The reason for this difference is not known, but a more substantial layer of subcutaneous fat in *Bos taurus* cattle has been offered as a possible cause (Finch, 1985; Ledger, 1959).

#### **2.3.1.2.2 Muscle**

Thermal conductivity of muscle is greater than that of fat, but the magnitude of this increase is the subject of some debate. One study indicated a thermal conductivity (heat flow x thickness/temperature difference) of  $0.00205 \text{ kJ cm}^{-1} \text{ sec}^{-1} \text{ }^{\circ}\text{C}^{-1}$  for beef fat (Hatfield and Pugh, 1951). Another study found thermal conductivity of 0.00527 and  $0.00230 \text{ kJ cm}^{-1} \text{ sec}^{-1} \text{ }^{\circ}\text{C}^{-1}$  for bovine muscle and fat, respectively (Poppendiek et al., 1966). Similarly, calf muscle has also been shown to be more thermally conductive than fat. Poppendiek et al. (1966) found the conductance of calf muscle to be 0.00544. Since muscle tissue insulation can be affected by muscle fat content (e.g., marbling in cattle) and other differences in composition, it appears to be quite variable. Maximal insulation of an organism, thus, is a complex function of adipose tissue thickness, tissue perfusion, and muscle mass, with muscle providing an important component of total body insulation (Anderson, 1999).

#### **2.3.2 Convection**

Convective heat transfer refers to the net rate of heat exchange in a moving gas or fluid, within an organism, or between an organism and its external environment. Unlike conduction, convection is not dependent on the distance between the materials in

question since the material is in motion. However, like conduction, the rate of convective heat exchange is affected by surface area, coefficient of convective heat transfer, and temperature gradient. Convective heat exchange may be amplified by the thermal gradient, and by outside thermal catalysts such as forced or natural airflow. Fans and ventilation systems are often categorized as examples of forced convection (IUPS Thermal Commission, 2001). The alternative type of convection is known as free or natural convection. This occurs inherently between two fluids in contact with one another. Heat from the hot surface, or fluid, changes the density of the fluid with which it comes in contact. This change in local fluid density causes fluid to move away from the heat source and be replaced by cooler fluid. Thus, cool fluid (air, water, etc.) flows through the medium and consistently replaces the warm fluid as long as a gradient exists (Scharf et al., 2008). If a large enough gradient and coefficient of transfer exists, and enough skin (surface area) is exposed, hypothermia can occur. The equation summarizing convective heat transfer is described as follows:

*Equation 3:  $Qh = (h) (Ah) (T_a - T_s)$  (Curtis, 1983)*

*where,*

*$Qh = \text{convective heat flux (kcal min}^{-1}\text{)}$*

*$Ah = \text{animal surface area effective in convection (m}^2\text{)}$*

*$h = \text{convection coefficient (kcal min}^{-1} \text{m}^{-2} \text{C}^{-1}\text{)}$*

*$T_a = \text{air temperature (}^\circ\text{C)}$*

*$T_s = \text{surface temperature (}^\circ\text{C)}$*

The equation illustrates the direct relationship between convective heat transfer and the coefficient of transfer, surface area, and temperature gradient. At the onset of heat stress, cattle may take advantage of convective heat loss to a cooler fluid, and will seek sources of heat abatement, including those that utilize convection.

### **2.3.2.1 Blood flow**

Blood serves as an avenue for heat transfer from the core to the periphery. Heat transfer to surroundings occurs at the skin's surface, and hot blood from the viscera can exchange heat through capillary beds beneath the skin. Some heat flows from the visceral organs to the skin of the trunk and extremities via conduction, but most is carried by the blood (Curtis, 1983). Heat is absorbed from sites of high metabolic rate as the blood passes through the core. It is carried to the cooler periphery, where some of it is dissipated to the environment. Hence, altering the rate of blood flow through different parts of the body, and thus the circulatory convection of heat to the periphery, greatly influences an animal's heat loss. If more heat is produced internally than can be dissipated, cattle may become too hot and become hyperthermic. Thus, a balance exists between the amount of heat created and the amount of heat dissipated. In these two ways, cattle regulate their body temperatures and maintain homeothermy (McDowell, 1972). Physically, the magnitude of an animal's tissue insulation is determined largely by the status of its peripheral blood vessels. The importance of blood flow to tissue insulation is illustrated particularly well in the case of fat. The thermal conductivity of vasoconstricted animal fat is about one third that of normal animal fat: 10 versus 35 kcal m<sup>-2</sup> h<sup>-1</sup> °C<sup>-1</sup> cm (Curtis, 1983). In a thermoneutral or warm environment, when the rate of

blood flow to the surface is unrestricted or even increased, tissue insulation is affected little by subcutaneous fat.

### **2.3.2.2 Skin to air**

Convection allows for heat flow between the skin surface and the surrounding air, but the outer edge of the surface is often resisted by cover insulation like hair or plumage (Curtis, 1983), as is the case for cattle. Thus, convection is particularly important in animals that pant as the enhanced air flow over the nasal passage surface and respiratory tract can carry away a large amount of body heat. For panting animals in hot situations, the majority of metabolic heat load is lost via the respiratory tract (Meat and Livestock Australia, 2006).

#### **2.3.2.2.1 Forced convection**

Forced convection results from air movement due to wind, fans, or other mechanical means (Meat and Livestock Australia, 2006), and plays an important role in the removal of heat from an animal, as long as the air temperature is lower than the surface temperature of the animal. Convective heat transfer should be independent of water vapor in the air. The movement of cool air can achieve significant body cooling for cattle, but the movement of hot air provides little relief in hot situations (Meat and Livestock Australia, 2006). Forced convection via tunnel ventilation systems, for example, is characterized by a bank of fans on one end of the building with inlets on the opposite end. Such a system is designed to achieve a specific air speed to optimize convective heat loss (Gooch and Stowell 2003; Bray et al., 2003).

#### **2.3.2.2.2 Natural convection**

Natural convection is a passive process in which hot air rises and is replaced by cooler air from below (Meat and Livestock Australia, 2006). In a feedlot setting during calm, still-air situations passive convection plays a small but important role in heat transfer from cattle to the environment. Warm air eddies develop at the skin, particularly in animals with short, sleek coats. Eddies also develop from the heated surface of the feedlot pad and may aid in cooling cattle by drawing in cooler air to replace the rising warmer air (Meat and Livestock Australia, 2006).

#### **2.3.3 Radiation**

Radiation is a unique form of energy transfer in that it does not require a medium to transfer heat. As a result, radiant heat can travel through a complete vacuum, does not require any surface contact, and is the method by which the sun's energy reaches Earth. Radiant energy travels in the form of electromagnetic waves, with ultraviolet, visible, infrared, and microwave radiation being components of the spectrum (IUPS Thermal Commission, 2001). When considering energy transfer with a body, the term radiant heat exchange (R) refers to the net rate of heat exchange by radiation between an organism and its environment, usually expressed in terms of unit area of the total body surface (IUPS Thermal Commission, 2001) Heat flux is more than just R. The avenue for radiant heat exchange is summarized by the following equation:

$$\text{Equation 4: } Q_r = A_r \sigma [(aT_e^{-4}) - (eT_s^{-4})] \text{ (Curtis, 1983)}$$

where,

$Q_r$  = thermal-radiant flux ( $\text{kcal h}^{-1}$ )

$A_r$  = effective radiant-surface area of animal ( $\text{m}^2$ )

$a$  = absorptivity of animal surface for thermal radiation

$\sigma$  = Stefan-Boltzmann constant

$T_e$  = average absolute temperature of animal's radiant environment ( $^{\circ}\text{K}$ )

$e$  = average emissivity of environmental surfaces for thermal radiation

$T_s$  = average absolute temperature ( $^{\circ}\text{K}$ )

The heat exchanged via the range of visible light is influenced by color and reflectivity of surfaces. Other ranges, such as those denoted by the terms ultraviolet, infrared, and microwaves, are not influenced by surface color. Cattle will seek out and use shade during periods of high solar radiation (Meat and Livestock Australia, 2006). In times of heat stress, cattle may also change posture relative to the sun to combat radiant heat absorption. This can include crowding together to create shade, moving to seek reprieve from solar radiation, and changing orientation relative to the heat source (i.e., sun) to limit its effect (Stewart and Brody, 1954).

### **2.3.3.1 Electromagnetic spectrum**

Heat exchange by radiation involves transfer of heat via electromagnetic waves and consists of heat transfer within the electromagnetic spectrum; mainly, visible and infrared ranges. The electromagnetic spectrum of significance in thermal physiology is divided into the ultraviolet, visible, infrared, and microwave bands (IUPS Thermal Commission, 2001), but in field studies it is likely limited to only visible and infrared.

#### **2.3.3.1.1 Visible**

The visible part of the electromagnetic spectrum covers the range from 0.38 to 0.78  $\mu\text{m}$  wavelengths (IUPS Thermal Commission, 2001). Within the visible spectrum, the amount of heat transfer is determined by the color and absorbance of the surface. A totally matte black surface has an absorbance of 1, with lighter and glossier surfaces having lower absorbance values (Curtis, 1983). Thus, darker objects absorb more heat than lighter materials when exposed to sunlight. The heat gain within the visible light is derived entirely from the sun and is referred to as solar radiation.

#### **2.3.3.1.2 Infrared**

The infrared part of the electromagnetic spectrum covers the range from 0.78 to 100.00  $\mu\text{m}$  wavelengths (IUPS Thermal Commission, 2001). Heat exchange in the infrared spectrum is, unlike the visible range, independent of color and is referred to as thermal radiation (Gonzalez, 1983). Radiant heat transfer between bodies takes place in both directions. However, net transfer of heat is always from the warmer to the cooler body (Esmay, 1969). Objects that emit radiant heat and are known as radiators. Radiators transmit energy away from themselves and towards other objects within visual range. Any two objects that “see” each other (and are at temperatures exceeding absolute zero) radiate toward each other with the net direction of heat flow depending on the surface-temperature gradient (Curtis, 1983). This net heat transfer involves the loss or gain of heat by the animal through absorption or emission of infrared radiation. In general, heat is gained and lost by the animal with its surrounding environment by this avenue.

### **2.3.3.2 Radiant Exchange in the Environment**

All materials above absolute zero are absorbers and emitters of thermal radiation. The Second Law of Thermodynamics requires that, for a given wavelength, each substance's emissivity and absorptance are the same. This holds true when emissivity is defined as the ratio, for a given wavelength interval, of the energy emitted per unit area divided by the energy emitted by a black-body of the same area (Gonzalez, 1983). Objects in the environment emit and absorb infrared radiation that can impact cattle. Metal roofs, for example, are a source of some concern as they emit infrared heat to cattle standing beneath them (West, 2003). However, any material that intercepts direct solar radiation will heat up (Meat and Livestock Australia, 2006). If the lower side of a roof or shade becomes hot it will then radiate heat to the air and the animals below. An advantage can be gained by having shade structures that are reflective on the top surface, absorptive on the bottom surface, and allow free airflow (Meat and Livestock Australia, 2006). Access to open sky is beneficial to animals as well. At night, a clear sky has practically no incoming radiation and is an important heat sink for animals. Night cooling occurs largely from exposure to a clear night sky (Meat and Livestock Australia, 2006).

### **2.3.3.3 Animal and radiant exchange**

Animals, like inanimate objects, continually emit and receive radiant energy from the sun and other objects in their environment. If the temperature of the animal's body is greater than the temperature of the surroundings, a greater quantity of heat will be radiated from the body than is radiated to the body. However, in situations of direct sun

exposure or when the animal is surrounded by hot surfaces, which can occur in a feedlot, radiation may actually increase the temperature of the animal rather than reduce it (Meat and Livestock Australia, 2006).

#### **2.3.4 Evaporation**

Evaporative, or insensible, heat loss does not require a temperature gradient for heat flow, like previously described for sensible heat loss avenues. Evaporative heat loss refers to the passive movement of heat from a body to the ambient, with the change in water from a liquid to gaseous state at the surfaces of the skin (i.e., sweat) and the respiratory tract (i.e., mucous) during perspiration and/or panting, respectively (IUPS Thermal Commission, 2001). Thermoregulatory components of evaporative heat loss are controlled by the autonomic nervous system. These components or thermoeffectors include sweating and panting, as well as behavioral means of thermoregulation such as saliva spreading (e.g., rodents) and wallowing in mud or water (e.g., swine) in an attempt to accomplish surface wetting and subsequent evaporation. Unique to evaporative heat loss is its relative independence of temperature gradients. Rather, evaporation efficacy is reliant upon vapor-pressure gradients. In most physiological applications, the vapor-pressure gradient can be considered the driving force for the evaporative process since the temperature difference between the evaporating surface and the ambient air is small in relation to the average temperature of the surface-water vapor medium (IUPS Thermal Commission, 2001). Thus, heat loss can occur when a liquid's molecules move with sufficient energy to overcome surface tension and escape from the medium into the environment. The rate of evaporative heat transfer (E) is defined as the rate at which heat

energy is transferred by evaporation from or condensation onto the skin and the surfaces of the respiratory tract. This is usually expressed in terms of the unit area of total body surface. Evaporative heat loss is summarized by the equation:

*Equation 5:*  $Q_e = (L_e)(A_e)(d)(E_a - E_s)$  (Curtis, 1983)

where,

$Q_e$  = evaporative heat flux density ( $\text{kcal dm}^{-2} \text{day}^{-1}$ )

$L_e$  = water's latent heat of evaporation at surface temperature ( $\text{cal gm}^{-1}$ )

$A_e$  = wet area of animal surface ( $\text{m}^2$ )

$d$  = evaporative diffusion coefficient ( $\text{mg min}^{-1} \text{m}^2 \text{mb}^{-1}$ )

$E_a$  = vapor pressure of air (mb)

$E_s$  = vapor pressure at evaporation surface – assumed to be saturation vapor pressure at surface temperature (mb)

Evaporative cooling is heavily influenced by airflow over the surface. Higher air speed over the surface can increase vapor removal from the immediate area and contribute to a favorable vapor pressure gradient for further evaporation. Relative humidity is also an important factor, as higher ambient humidity can create a less favorable vapor pressure gradient between the surface and the ambient. This can result in slowing or cessation of evaporation. Heat stress can also lead to the activation of sweat glands as animals attempt to dissipate heat via evaporation. During hot weather cattle utilize evaporative cooling to lose body heat to their environments. Feedlot cattle depend

on their ability to vaporize moisture as a means of generating heat loss, particularly as the  $T_a$  rises (Meat and Livestock Australia, 2006).

#### **2.3.4.1 Sweating**

Under excessive heat loads, about 15% of heat in cattle is lost directly from the body core via the respiratory tract (Finch, 1986). The remainder must be transferred to the skin where it is then dissipated using either non-evaporative (i.e., convection, conduction, and radiation) or evaporative mechanisms (i.e., sweating). It has been shown that cutaneous evaporative heat loss accounts for up to 84% of total evaporative heat loss at a  $T_a$  of 40°C (McLean, 1963). While sweat rate appears to be a less sensitive indicator of heat load than respiration rate, sweat rates have been shown to measurably increase at  $T_a$  above 25°C (Scharf et al., 2008). Heat-adapted cattle are able to increase sweating rapidly as soon as body temperature, either skin or core, begins to rise (Finch et al., 1982). Cattle breeds differ markedly in their rate and capacity to sweat. For instance, *Bos indicus* cattle increase sweat rates exponentially in response a rise in body temperature. This is in contrast to sweat rates of *Bos taurus* that tend to plateau after an initial increase (Finch et al., 1982). In general, sweating conforms largely to the concepts of negative feedback control, with shifts in body temperature increasing evaporative heat losses that restabilize body temperature (Finch, 1986).

#### **2.3.4.1.1 Sweat glands**

Cattle respond to heat stress by actively secreting sweat onto the skin surface. Apocrine sweat glands in cattle occur as part of hair-follicle units, which consist of a follicle, arrector pili muscle, sebaceous gland, and sweat gland (Curtis, 1983). These glands, in food mammals, have secretory epithelial cells next to the gland lumen and a layer of myoepithelial cells on the outside. These myoepithelial cells are presumably stimulated to contract, thus expelling the gland's luminal contents onto the skin surface. Cattle sweat glands vary in size and distribution over the body. They vary in density depending on location, and can be as sparse as 1000 glands per sq. cm. in the lower limbs and as dense as 2500 glands in the axilla and neck regions of Ayrshire cows (Findlay and Yang, 1950). Sweat gland population density and individual sweat gland volume tend to be inversely related (Curtis, 1983).

In cattle, an important aspect of internal heat transfer via the blood is capillary density. It has been established that sweat production in *Bos taurus* cattle is at least partially dependent on a blood supply to the skin (Ingram et al., 1963). Increasing blood flow to the sweat gland in the skin facilitates both thermal heat transfer through all avenues (Finch, 1986), with very little energy expenditure.

#### **2.3.4.2 Respiratory cooling**

Respiratory frequency is affected by a number of factors including environmental temperature (Reece, 2004). Ungulates, like cattle, lose heat via evaporation in the upper portions of the respiratory tract. The output of the thermoregulatory center also affects the function of respiratory centers in the pons and medulla oblongata, which in turn

control breathing. By this mechanism, panting and the consequent increase in respiratory evaporation rate are activated in response to heat stress. Panting starts abruptly when skin and/or hypothalamic sites are warmed to a certain threshold even without a change in body  $T_{\text{core}}$  (Curtis, 1983). Interestingly, the critical skin temperature in European-type cattle for the onset of panting seems to be up to four degrees higher than the onset of sweating (32°C versus 36°C; Curtis, 1983). This could indicate an evolutionary predisposition toward sweating instead of increased respiration as a means of heat dissipation. One reason for such an apparent preference could be the incidence of metabolic alkalosis, as discussed in the following section.

#### **2.3.4.2.1 Panting and heat stress**

Under hot environmental conditions, cattle (like many other mammals) use evaporative exchange to increase heat loss to help maintain homeothermy (Taylor et al., 1969). In the case of cattle, sweating is the primary method of evaporative heat loss. About 70 to 85% of maximal heat loss via evaporation is due to sweating, with the remainder due to respiration (Hansen, 2004).

Sweating alone may not be enough during extraordinarily hot days, however. During these times, the other method of evaporative heat loss is panting (Kibler and Brody, 1952; Taylor, 1969; Hahn, 1997) which may initiate at skin temperatures starting around 36°C (Curtis, 1983). Panting has long been used as an indicator of heat stress in cattle (Gaughan et al., 2004; Gaughan et al., 2000) and can be defined as any increase in respiratory ventilation (Mader et. al., 2002). McDowell (1972) stated that increased respiration rate is the first outward indication of cattle responding to increased thermal

load. Panting draws outside air over moist lung, trachea, and oral tissues and, as evaporation occurs over these areas, heat can be lost. Some evidence suggests a biphasic aspect to panting in cattle. Cattle may initiate panting as rapid, shallow breathing (i.e. first phase) called thermal polypnea (Bianca and Findlay, 1962). But if heat stress continues cattle may transition to open-mouth (i.e. second-phase) breathing (Mader et al., 2002) called thermal hyperpnea.

#### **2.3.4.2 Respiratory cooling**

The first respiratory response (phase) to hot surroundings is a progressive increase in breathing frequency and a decrease in breathing depth. Thermal polypnea is effective at increasing the amount of air passing through the upper respiratory passages, but does not greatly increase above the basal level the rate of ventilation of the respiratory-exchange surface in the lungs' alveoli. If body temperature still continues to increase after peak polypnea is reached, cattle shift to a second phase in which breathing frequency drops and breathing depth increases (Curtis, 1983). This panting, termed thermal hyperpnea, is slower and deeper than peak thermal polypnea, and minute volume increases markedly (Bianca and Findlay, 1962). This change is due to increased alveolar ventilation as well as increased upper-respiratory ventilation. Field trials have shown the biphasic nature of panting in cattle. One study involving Holstein cows indicated a decrease in tidal volume from 6.5 to 2.9 L/breath as RR increased from 20 to 80 breaths per minute (BPM; Maia et al., 2005). A similar reduction has been reported in Zebu cattle, where a decrease in tidal volume from 1.8 to 1.0L/breath occurred as RR increased from 10 to 55 BPM (Taylor et al., 1969). Maia et al. (2005) and Taylor et al. (1969)

measured the animal response during what can be considered the first phase, or thermal polypnea. Further, Bianca and Findlay (1962) showed the result of thermal hyperpnea that can occur as respiratory cooling fails to lower body temperature. During this trial, as RT increased from 38°C to 42°C, animal respiration rate increased, as anticipated, but then decreased as RT increased beyond 40.5°C. Similar evidence of phase shift occurred as individual breath volume decreased, but then rebounded at a RT of 40.5°C. Rapid breathing can result in a phase shift and a change in respiratory dynamics. The higher-alveolar ventilation rate associated with thermal hyperpnea can have the adverse secondary effect of respiratory alkalosis (Curtis, 1983). Respiratory alkalosis can occur when excessive amounts of carbon dioxide are lost through the lungs, and is marked by elevated blood pH and decreased carbon dioxide capacity (Dale et al., 1954). This condition has been demonstrated in Zebu (Taylor et al., 1969) and Holstein cattle (Schneider et al., 1986), and is a classic example of disruption of acid-base homeostasis. In order to compensate for the high blood pH, animals are forced to increase renal excretion of bicarbonate to adjust the acidity toward normal levels (Sanchez et al., 1994). Finally, RR and panting are indicators of thermal load, and thus internal body temperature (Gaughan et al., 2010b). Increased RR indicates that cattle have been unable to radiate sufficient body heat to their environments (Gaughan et al., 2010b). Open-mouthed labored breathing is an indication that the animal's system is failing to cope with hot conditions (Meat and Livestock Australia, 2006). Likewise, excessive salivation (i.e., drooling) that results from intense panting is another indicator of an animal's failure to cope. Panting and drooling are examples of mechanisms animals use later in the sequence of behavioral changes due to heat stress (Meat and Livestock Australia, 2006).

That is, they tend to make various other attempts at heat dissipation before resorting to respiratory cooling.

## **2.4 Thermoregulatory behavior**

Cattle are homeotherms, as noted previously, and as a result they usually act to maintain a stable body temperature or thermal balance. When  $T_a$  rises or falls from the optimum range, cattle react with different physiological and behavioral approaches to prevent body temperature from diverging more than a small amount from the optimal setpoint (Frazzi et al., 2000). Sweating and panting are perhaps the clearest signs of physiological responses to heat, but more subtle behavioral changes are equally relevant. In fact, behavioral changes can be just as important to note when diagnosing the impact acute and chronic heat events (Meat and Livestock Australia, 2006).

### **2.4.1 Heat stress response**

Cattle react to heat stress with a number of behavioral attempts to reduce the heat load. These changes begin with apparent attempts at maintaining comfort levels, but may become more survival oriented if animals fail to cope with the load (Meat and Livestock Australia, 2006). Behavioral changes can range from relatively benign body alignment with the sun, to much more serious and potentially fatal staggering, collapse, and inability to move. One of the most immediate responses to sun exposure and heat stress among bovines is shade seeking. Depending on their level of adaptation, most *Bos taurus* cattle will begin seeking shade when  $T_a$  exceeds 20°C to 28°C (Meat and Livestock Australia, 2006). For example, dairy cattle in freestall barns have been observed to stay inside

during the hottest hours of the day in an apparent attempt to avoid the most intense solar radiation. Then, at night, they go outside (Arave and Albright, 1981). Cattle may or may not lie down in response to heat stress. Evidence suggests that if animals have access to cool floors like those found in some feedlots, they will lie down to cool themselves in hot weather (Curtis, 1983). However, this may only be the case when the animals are in windless environments, and when the floor is cooler than the air and not covered by an insulator, such as straw. Ansell (1981) has suggested that cattle may actually avoid lying down during heat stress in what appears to be an attempt to increase surface area exposure to air flow. The merit of this behavior was demonstrated in sheep when the skin temperature of the animal on its windward side was significantly lower than that on the leeward side (Curtis, 1983). Aside from postural changes, cattle appear to actively seek sources of heat abatement. These may include shade, water sprinklers, and fans, depending on availability (Igono et al., 1987). One example is the tendency of animals to seek standing water during heat stress. Lakes or streams serve as opportunities for animals to partially submerge and take advantage of water's high specific heat. The deeper animals can get, the greater the surface area in contact with the water, and the greater the potential for conductive heat loss. Standing water access also allows animals to take advantage of evaporative heat loss by sprinkling themselves to augment natural sweating (Ragsdale et al., 1951). Since natural bodies of water in feedlots may be limited or nonexistent, one problem for producers may be the tendency for animals to crowd waterers during heat events. Crowding in this way is potentially harmful, as dominant animals tend to block weaker counterparts from drinking. Crowding does appear to have at least one benefit, though. When cattle bunch together, they obtain shade and even

some defense from flies (Meat and Livestock Australia, 2006). The importance of adequate water provision is illustrated by Ragsdale et al. (1951) who noted that cattle with access to water during heat stress frequently sprinkle it over their bodies in what appears to be an attempt to increase evaporative cooling. For producers, one of the biggest concerns is the feeding behavior of animals, and the most important environmental factor that affects feeding behavior is  $T_a$  (Reece, 2004). Reduced feed or energy intake during heat stress benefits the animal by decreasing metabolic heat production and heat load, albeit at the cost of reducing overall productivity. During heat events, grazing during the warm daylight hours is reduced, while nighttime grazing appears to increase in order for animals to avoid as much sun and heat exposure as possible. Grazing events in hot environments are longer and more frequent during the evening than during the day. During the early to mid-afternoon, animals nearly completely cease grazing activity until cooler evening air temperatures returned. In one trial, an average of 67% of *Bos taurus* grazing behavior occurred at night in hot environments (Ragsdale et al., 1951). Cattle in feedlots exhibit similar behavioral coping mechanisms to those in pastoral settings. Instead of spending time eating or ruminating, cattle without access to shade spent more time at waterers than their shaded counterparts (Castañeda et al., 2004). This does not necessarily indicate increased water consumption. Rather, animals appeared to be taking advantage of the marginally cooler temperatures directly above and surrounding the standing water. In both feedlot and pastoral settings, cattle experiencing heat stress will spend more time searching for and resting in shade, and less time feeding (Scharf et al., 2008). Moreover, feed that had previously been

consumed may cease to be utilized as rumination slows or even halts when animals suffer heat stress (Meat and Livestock Australia, 2006).

## **2.5 Metabolism**

An animal's metabolic rate refers to the rate of transformation of chemical energy into heat and mechanical work by aerobic and anaerobic metabolic activities within an organism, and is usually expressed in terms of heat (e.g., calories, watts, joules) per unit area of the total body surface area (when referring to heat flow across a surface) or as a unit of body mass (when referring to heat production by the tissues in that body). (IUPS Thermal Commission, 2001). The oxidation of energy within the body is not 100% efficient. For example, glucose oxidation is only about 50% efficient (Reece, 2004). A useful byproduct of this inefficiency is metabolic heat. Although acute heat stress affects systemic metabolism in cattle, it is difficult to differentiate between the direct versus indirect (mediated by reduced FI) effects of a thermal load (Rhoads et al., 2009). Additionally, physiological adaptations to acute and/or chronic thermal stress alter metabolism of absorbed energy substrates and nutrients (Beede and Collier, 1986).

### **2.5.1 Basal and resting metabolisms**

Basal metabolic rate (BMR) is calculated from measurements of heat production or oxygen consumption in an organism that is rested, awake, and sufficiently fasted while in a post absorptive state. Additionally, the animal must be in its thermoneutral zone (TMZ; IUPS Thermal Commission, 2001). Alternatively, the resting metabolic rate of an animal is measured when an animal is resting in a thermoneutral environment, but not in

a postabsorptive state. During heat stress, decreased feed consumption can result in decreased rumen fermentation, feed digestion, nutrient absorption, thermogenic hormone activity, and lowered BMR, that in turn reduces the internal heat load (Lu, 1989; Silanikove, 1992). If animals are at a productive stage (e.g., growth or lactation), the reduction in FI and internal heat production is reflected in a reduction in productivity (Silanikove, 1992).

### **2.5.2 Heat stress response**

Bovines can achieve metabolic heat gain through biological processes associated with maintenance, exercise, growth, lactation, gestation, and feeding (Fuquay, 1981). High rates of these activities can increase heat gain from metabolism. One way that cattle automatically reduce their internal heat production during heat stress is to limit their daily FI. This occurs when  $T_a$  exceeds the upper limit of the thermoneutral zone (TNZ). The TNZ is a range of  $T_a$  throughout which temperature regulation is achieved only via sensible heat loss. Within the confines of the TNZ, no regulatory changes in metabolic heat production or evaporative heat loss need occur (IUPS Thermal Commission, 2001). This is relevant to producers because the best-recognized effect of raised body temperature is an adaptive depression of the metabolic rate associated with reduced appetite (Silanikove, 2000). Although this tactic can reduce some metabolic heat, it comes at the obvious expense of growth and lactation (West, 2003).

### **2.5.3 Endocrine response to heat stress**

Adrenaline and noradrenaline both affect sweat gland activity and sweating rates (Findlay and Robertshaw, 1965). It seems likely that the increase in cutaneous moisture loss that occurs after adrenaline and noradrenaline administration is due to increased sweat gland activity. It appears that this increased adrenomedullary activity is increased even during prolonged heat stress and even in nonsweating species (Curtis, 1983). Likewise, cortisol concentrations in heat stressed dairy cattle are elevated (Wise et al., 1988). This rise appears to be early and non-specific (Curtis, 1983) and is followed by the longer-termed reaction to heat stress of reduced glucocorticoid secretion rate and plasma concentration. Cortisol has a general effect on metabolism of the lactating animal, and is required to maintain the secretory activity of the epithelial cells. However, cortisol has no identified role in milk synthesis (Sjaastad et al., 2003). Higher concentrations of cortisol may have been produced in heat-stressed cows in an attempt to maintain milk production via secretory stimulation. Heat stress also appears to have an effect on reproductive hormones. Acutely heat stressed dairy cows, for example, have lower frequencies of luteinizing hormone pulses at five days post estrus (Wise et al., 1988). This may actually be a result of increased cortisol levels, as cortisol has been implicated as an inhibitor of anterior pituitary release of luteinizing hormone in bovines (Li and Wagner, 1983). Thyroxine ( $T_3$ ) and triiodothyronine ( $T_4$ ) are important determinants of basal metabolic rate and are positively correlated with weight gain and tissue production (Magdub et al., 1982). During heat stress, the response of  $T_3$  and  $T_4$  is not immediate. In fact, it appears to take several days for concentrations to fall and settle at a new steady state (Silanikove, 2000). Growth hormone (GH) is implicated in

increased calorogenesis during anabolism as well as stimulation of thyroid activity (Yousef and Johnson, 1966). Not surprisingly, GH reductions have also been reported in heat-stressed cows (McGuire et al., 1989) and levels remain suppressed during prolonged heat stress (Curtis, 1983).

## **2.6 Thermoregulatory profile**

The thermoregulatory profile of an animal revolves around the concept of a TNZ. The TNZ is subject to change, however, when insulation, posture, or BMR vary. Moreover, the TNZ is affected by species, age, breed, gender, degree of thermal acclimation, and time of day. They can all affect the limits of the TNZ (Yousef, 1985). For example, the TNZ is narrower for young and wider for older animals of the same species (Scharf et al., 2008). The TNZ is not applicable to ectotherms, like insects or amphibians. Ectotherms are notable for their body temperature being heavily dependent on behaviorally modified exchange of heat with the environment. Rather, the TNZ applies to endotherms like cattle. Unlike ectotherms, endotherm body temperature depends on a high, controlled rate of internal heat production (IUPS Thermal Commission, 2001).

The TNZ is bound, top and bottom, by the upper and lower critical temperatures (UCT and LCT, respectively; Gordon, 2012). The LCT is defined as the  $T_a$  below which the rate of metabolic heat production of a resting, thermoregulating, tachymetabolic (that is, having a metabolic rate similar to birds and mammals as opposed to lizards or insects) animal must be increased by shivering and/or nonshivering thermogenesis (NST) in order to maintain thermal balance (IUPS Thermal Commission, 2001). It is worth noting that

NST refers to heat production due to metabolic energy transformation via processes that do not involve contractions of skeletal muscles. Conversely, shivering thermogenesis increases the rate of heat production during cold exposure via increased contractile activity of skeletal muscles, and not involving voluntary movements and external work. The UCT indicates the  $T_a$  above which the rate of evaporative heat loss (i.e. sweating or panting) of a resting thermoregulating animal must be increased in order to maintain thermal balance (IUPS Thermal Commission, 2001). The UTC is also used to define the point, above which, the capacities of the mechanisms of heat transfer to the environment of a resting animal are exceeded, such that  $T_{core}$  is forced to rise and, as a consequence, internal heat load is increased (IUPS Thermal Commission, 2001).

### **2.6.1 Definition of upper and lower critical temperatures**

The UCT and LCT represent the inner, and generally more useful, thermal borders of the thermoregulatory profile (Spiers, 2000). The terms have been used for decades, and serve to conceptualize the boundaries of thermoregulation for a given animal (Stitt and Hardy, 1971; Adams et al., 1970).

### **2.6.2 Profile shifts**

The thermoregulatory profile of an animal is subject to change. For example, a reduction in thermal insulation with hair loss during summer months (shedding) may shift both UCT and LCT upward (Bligh, 1985). Other sources of variation in normal body temperature include the level of physical activity an animal undergoes, dietary changes, age, body size, gender, seasonal and circadian rhythms, and climatological shifts

(Blatteis, 2011). Shifts in the TNZ can be useful in assessing the impact of an environmental stressor on animal performance, if other potential influences are controlled or identified as a part of the evaluation (Spiers, 2000).

### **2.6.2.1 Thermal adaptation**

Adaptation defines the innate characteristics that allow an animal to survive in adverse environments (Reece, 2004). Adaptation can result in a thermoregulatory profile shift, and shifts in the TNZ can be useful in assessing the impact of an environmental stressor on animal performance if other potential influences are controlled or identified as a part of the evaluation (Spiers, 2000). Most cattle can adapt to prevailing environmental conditions provided the temperature range is not too wide (Meat and Livestock Australia, 2006).

### **3. Differences between *Bos taurus* and *indicus* breeds**

It is commonly stated that *Bos indicus* cattle (i.e., Zebu breeds) are better adapted to thrive in warm climates than are *Bos taurus* cattle (Berman, 2011). The *Bos indicus* subspecies of cattle is presumed to be better adapted to heat owing to its evolution in hot climates and the resultant decrease in productivity. Conversely, the sensitivity to heat stress that plagues many *Bos taurus* breeds is attributed to their evolution under more temperate weather conditions (Roy and Collier, 2012).

### 3.1 Physical differences

*Bos indicus* cattle have greater heat tolerance than *Bos taurus* cattle, because they produce less heat, have increased capacity to lose heat to their environment, or a combination of both (Hansen, 2004). More specifically, sweat gland diameter has been shown to be greater for *Bos indicus* than for *Bos taurus* cattle in Brazil (Carvalho et al., 1995). Furthermore, crossbred (*Bos taurus* x *Bos indicus*) cattle have more sweat glands per unit area of the skin than pure *Bos taurus* cattle (Nay and Hayman, 1956). Sweat gland density appears to vary greatly between European and *Bos indicus* cattle. In *Bos indicus*, sweat gland population density is around 1,600 cm<sup>-2</sup> and in European cattle it is around 800 cm<sup>-2</sup> (Curtis, 1983). Physiological heat tolerance is directly related to sweat gland population density and sweating rate in cattle. However, this relationship does not appear to be particularly strong. Indeed, although Zebu cattle have larger and more sweat glands, they have only slightly higher sweating rates than European-type cattle under comparable conditions of heat stress (Curtis, 1983). *Bos indicus* cattle also typically have fur that is light colored and covers a large surface area for heat exchange, with extension of the skin in folds in the dewlap region and prepuce; and subcutaneous fat stored in one subcutaneous area, the hump, rather than being universally distributed underneath their skin (Reece, 2004).

### 3.2 Physiological differences

Physical differences between *Bos taurus* and *indicus* cattle can contribute to physiological differences between the sub species as well. For example, Finch (1985) found that the tissue resistance to heat flow from core to skin was lower for Brahman

than for Shorthorn cattle. One explanation for this difference is that *Bos indicus* cattle may have a higher density of arteriovenous anastomoses than *Bos taurus* cattle (Hansen, 2004). Since these structures have lower resistance to blood flow than vascular passages involving capillary networks, they facilitate increased blood flow to the skin during heat stress (Hales et al., 1978). With more cutaneous blood flow, *Bos indicus* animals may be able to more effectively lose core heat to their environments via non-evaporative avenues. Additionally, *Bos indicus* animals tend to have longer appendages than *Bos taurus* cattle (Roy and Collier, 2012). This contributes to a greater surface area to body mass ratio than *Bos taurus* cattle. This greater surface area, coupled with increased sweat gland density per unit area (Curtis, 1983), could contribute to greater heat loss via evaporation. As a result, *Bos indicus* cattle have been shown to maintain as much as 1.3°C lower ( $p < 0.05$ ) RT than *Bos taurus* animals when subject to 10 h of  $>90$  THI (Gaughan et al., 1999). Another physiological difference that has been noted between *Bos taurus* and *Bos indicus* cattle is that of semen quality. It has been shown (Johnston et al., 1963; Skinner and Louw, 1966) that heat stress has a less severe impact on *Bos indicus* semen quality than on that of *Bos taurus*. A physical explanation of this finding is provided by Brito et al. (2004) who found that the ratio of testicular artery length to testicular volume was greater for *Bos indicus* than for *Bos taurus* bulls. Likewise, testicular artery walls were thinner in *Bos indicus* than *Bos taurus*, and as a result of these differences, as well as the lower  $T_{\text{core}}$  apparently experienced by *Bos indicus* during heat, intra-arterial temperatures were lower.

### **3.3 Growth and metabolism**

The ability to limit heat production that is illustrated in *Bos indicus* cattle is, at least partially, the result of lower metabolic rates than *Bos taurus* animals. When generally compared to *Bos taurus* cattle, *Bos indicus* cattle have reduced growth rates and milk yields. In fact, even the BMR of *Bos indicus* cattle has been shown to be lower than for *Bos taurus* cattle (Finch, 1985). It appears that *Bos indicus* have lower body temperatures than *Bos taurus* cattle under thermoneutral conditions, as well. For example, one study of Afrikaner (*Bos indicus*) and Friesland (*Bos taurus*) cattle indicated that, prior to heat exposure of 40°C, the Afrikaners had a mean RT of 0.20°C lower than their Friesland counterparts (Skinner and Louw, 1966). The observed differences between *Bos indicus* and *Bos taurus* temperatures might be explained as a lower body heat content that results from the lower BMR.

## **4. Short-term response to heat stress**

### **4.1 Heat stress and metabolism**

Cattle, as ruminants, produce a great deal of heat as a by-product of anaerobic metabolism. This heat of fermentation accounts for around five percent of a ruminant animal's total heat production (Curtis, 1983). Further, different feedstuffs have different HI in spite of having similar energy values (Meat and Livestock Australia, 2006). That is, certain feedstuffs, such as carbohydrates, have a high HI and release more heat as a byproduct of digestion than those with lower HIs, like fats and proteins. Thus, animals fed highly digestible feedstuffs with low HI may better cope with heat events than those

that are subject to more metabolic heat production from carbohydrate rich and fibrous diets. For example, the heat of fermentation of bovine ruminal contents shortly after feeding is about  $0.8 \text{ kcal h}^{-1}$  per kg of concentrate, versus about  $0.4 \text{ kcal h}^{-1}$  per kg of roughage. But it is not just digestion that contributes to an internal heat load. Rather, heat is a by-product of many biochemical reactions. Maintenance and production demands like growth, lactation, and pregnancy all rely upon biochemical reactions that indirectly release heat (Meat and Livestock Australia, 2006). As such, high producing animals are more vulnerable than those that are less productive. An important concept to understand when considering the relationship between metabolic rate and body temperature is the  $Q_{10}$  effect. That is, when environmental temperature increases beyond the TNZ, metabolic rate also increases as a result of increased body temperature and the  $Q_{10}$  effect. The  $Q_{10}$  effect is a temperature coefficient that represents the factor by which the rate of a reaction increases for every  $10^{\circ}\text{C}$  rise in tissue temperature (Mount, 1979). The  $Q_{10}$  is commonly about two for many chemical reactions, and values close to this have been observed for the rate of heat production by the whole animal (Mount, 1968). This heat, of course, is very beneficial during cold conditions; nearly a third of a cow's heat load is generated from metabolism alone. However, when subjected to hot environments, cattle must dissipate this heat to stay within the confines of a relatively narrow body temperature range (Finch, 1986). This can be accomplished through physiological changes within the animal. However, since limiting heat inherent to biological processes is not feasible, a decrease in production must result from the metabolic side. This can be achieved by a decrease in metabolic hormone synthesis and secretion, as described previously, or via a reduction in FI. Changes in meal size vary as

intake drive is related to energy metabolism within the animal. The size of the meal may be dictated by a physiological attempt to reduce waste products (i.e. heat) that result from digestion and metabolism during times of heat stress. Thus, the setpoint time for ending a meal is determined by a control operating on a much longer time scale than that of the meal itself (Gill and Romney, 1994).

#### **4.2 Feed intake**

Limiting inherent heat from biological processes is not an option, as previously mentioned. Therefore, a decrease in FI will produce a reduction in heat production. The short-term response of FI to heat stress is well documented. However, a review of the literature indicates that bovine trials tend to measure FI on a daily basis, and higher resolutions of feed intake appear to be lacking for evaluation. During one of the few high-resolution trials, Hahn et al. (1990) used telemetric dataloggers to measure feeding events with high frequency. In this study, Hahn et al. (1990) found that, though feeding event frequency did not necessarily decrease as a result of increased tympanic temperature, feed consumed during those events decreased immediately. Likewise, Bhattacharya and Warner (1968) found that Holstein heifers treated with a cold water ruminal infusion ate more during the hours after feeding than did the animals subject to a warm water infusion. The effect of heating or cooling the rumen was evident within an hour. An apparently larger number of trials have shown that FI reduction indeed occurs, but with comparisons drawn from daily, as opposed to hourly, differences. For example, Rhoads et al. (2009), Mader et al. (1999), and Hahn (1997) all found daily FI to diminish within one day of increasing mean daily body temperature. Thus, it appears that FI depression

in response to increases in temperature can be nearly immediate. One reason behind short-term FI depression could be decreased gut motility and increased digesta retention rate in response to dehydration. It has been suggested that the increased feed digestibility that previous trials have noted during water restriction (Balch et al., 1953) and dehydration (Brosh et al., 1986) is due to reduced passage rate of ruminal contents (Silanikove, 1992). This phenomenon has been confirmed in sheep (Westra and Christopherson, 1976) as mean retention times significantly decreased as temperatures dropped from 21.2°C to 2.3°C. Increased retention times could decrease appetite by increasing the activity of stretch receptors in the reticulum, as shown in sheep by Grovum (1979). Similarly, Campling (1970) briefly discussed the probability that the amount eaten at a meal is limited by rumen capacity. However, results of other studies revealed that a hot environment did not depress passage rate or rumen activity (Attenbery and Johnson, 1969; Silanikove, 1987; Warren et al., 1974). Even if increased gut fill is not the primary driver for reduced FI, the importance of water provision is again illustrated as DMI and water intake have been shown to be linearly related (Macfarlane and Howard, 1972). Perhaps a more broadly accepted rationale for short-term feed reduction is that animals simply eat less in an attempt to reduce internal heat load, and rumen transit time is symptomatic rather than causal. Strominger and Brobeck (1953) noted that any increase in the total amount of heat in the body would initiate impulses inhibiting the mechanisms responsible for feeding, and an increase in environmental temperature would do the same. That is, at a high temperature where loss of heat is difficult, FI should be low, lest by eating and assimilating food the body acquire more heat than it can dispose of (Brobeck, 1948). Bodily regions of thermal sensitivity that modulate short-term FI

appear to be varied. Heating of the rumen (Gengler et al., 1970), hypothalamus (Andersson et al., 1962), and spinal cord (Engelhardt and Hales, 1977) have all been shown to decrease feeding behavior in ruminants. Thermal stimulus of these effectors elicit similar reductions in feeding response, and this collective result has been termed the thermostatic mechanism of controlling FI (Bhattacharya and Warner, 1968). The extent of FI reduction during short-term response can vary. Cattle being fed high-energy grain concentrates may reduce DMI by more than 25% and take longer to return to normal levels of consumption than those fed low quality roughage. Animals fed less digestible roughage may decrease consumption by around 10% and return to their original rate of ingestion faster than those on higher energy grain-based diets (Meat and Livestock Australia, 2006). This would suggest that cattle in feedlot settings are particularly susceptible to intake depression. Since any feedstuff will exhibit a HI, any feeding event can contribute to an increase in body temperature (Shibata and Mukai, 1979). High FI, like that found in feedlot settings, increases metabolic rate and water intake that gives rise to a need for greater heat loss.

## **5. Long-term responses to heat stress**

### **5.1 Adaptation**

Long-term adaptations to heat stress are highly variable and difficult to measure. They include physical characteristics such as long and short coats in cold-adapted and heat-adapted species, respectively. They can also include physiological changes like less anabolic hormone production and different nutrient partitioning. For the purposes of this

literature review, adaptive changes will be considered that can occur to an individual animal, as well as evolutionary changes that may occur over time in response to environmental conditions that transcend generations. Changes that result in what has been termed “within life-time phenotypic adaptation” (Horowitz, 2001) may include shedding or lightening of the coat over many days of hot weather. Conversely, evolutionary adaptation is evident when comparing, for example, the greater surface area of *Bos indicus* to that of *Bos taurus* cattle.

### **5.1.1 Physical**

Physical changes in response to heat stress include a variety of adaptations. Loss of body condition (e.g., loss of subcutaneous fat) is one physical adaptation that occurs in response to heat stress. Fatter cattle appear to be more sensitive to heat (Brown-Brandl et al., 2006). Since subcutaneous fat acts like an insulator and can slow heat dissipation, decreased fat thickness that has been reported during heat stress conditions (Mitloehner et al., 2001) may actually benefit the animal in terms of heat acclimation. Hair coat scores are also influenced by seasonal environmental factors (Turner and Schleger, 1960). Thinning of the hair coat (e.g., shedding) occurs in cattle in response to warmer  $T_a$  (Mount, 1979). Long-term physical adaptations tend to occur over the course of generations. Thus, animals of the *Bos indicus* variety are better adapted to high temperatures and have a shorter, glossier and less dense coat than *Bos taurus*. Hayman and Nay (1961) evaluated the winter and summer coats, as well as relative shedding rates, of *Bos taurus* and *Bos indicus* cattle. They observed that all cattle had short, light

summer coats and long, heavy winter coats but the coats of *Bos indicus* were always shorter and lighter.

#### **5.1.1.1 Feed intake**

Cattle exposed to moderate heat stress have reduced FI as noted earlier. If initial attempts at limiting heat stress (i.e., increasing evaporative cooling, drinking more water, etc.) are not enough or hot conditions persist (usually more than one to two days), cattle must reduce heat production to control their body temperature (Meat and Livestock Australia, 2006). They may accomplish this by lowering FI. In a study of Friesian heifers, DMI was measured after three periods. Measurements were taken during thermoneutral conditions, following three days in a hot environment (THI of 84), and after 24 days of exposure. The mean DMI was significantly ( $p < 0.01$ ) higher during the thermoneutral period when compared to the periods of heat stress. However, the mean DMI was not significantly different between the 3-day and 24-day exposures (Bernabucci et al., 1999). This may indicate some adaptation over that time to heat stress. Another example of adaptation to heat stress, as it relates to FI, is that of cattle preference for different feedstuffs. When forages and concentrates are fed separately, heat-stressed cows have been shown to reduce fiber intake and adjust the forage to concentrate ratio in their own diets, in an apparent attempt at limiting metabolic heat production (Coppock and West, 1986). This behavior is considered an adaptive response to reduce heat production that results from fibrous fermentation (Beede and Shearer, 1991).

### **5.1.1.2 Growth**

Since FI decreases during heat stress, growth rate is surely reduced under long-term heat stress as well. However, the reduction in growth may be masked to some degree by the increased retention of water, so that the reduction in body weight increase is not as marked as would otherwise be the case (Mount, 1979). It is evident, however, that heat stress has a negative impact on GH secretion (McGuire et al., 1991). Decreased growth and thyroid hormone production and secretion may be a mechanism by which animals attempt to limit metabolic heat production (Yousef, 1987).

### **5.1.2 Physiological**

Exposure of cattle to long-term heat stress may reduce some of the physiological responses seen during acute heat exposure. However, research in physiological adaptability is relatively difficult, even when limited to a single environmental variable (Curtis, 1983). It has been established that animals display an ability to adjust their physiological mechanisms to overcome long-term shifts in  $T_a$ . Persistent heat stress induces a variety of changes at all levels of body organization, ultimately leading if successful to decreased strain and increased thermal endurance and/or an improvement in tolerance to a  $T_{core}$  that is greater than normal (Horowitz, 2001). Physiological acclimation, a type of adaptation, is a process by which animals adapt to environmental conditions and engage behavioral, hormonal, and metabolic changes that are characteristics of either acclimatory homeostasis or homeorhetic mechanisms used by the animals to survive repeated heat exposure. For example, alterations in the hormonal

profile are mainly characterized by a decline and increase in anabolic and catabolic hormones, respectively (Bernabucci et al., 2010).

#### **5.1.2.1 Core body temperature**

A review of present literature reveals that a comparatively small body of work specifically considers adaptation as it related to body temperature. However, trials have shown that some adaptation may indeed occur. One study (Bianca, 1968) indicated that prolonged heat stress produces a smaller effect on RT than it does prior to exposure. When three calves were exposed to 45°C for five hours for each of 21 successive days, adaptation became evident during the first 10 days, with initial RT falling progressively. Similarly, Bernabucci et al. (2009) found that ovine RT (measured daily at 0900 h) decreased over the course of a 45-day exposure to a THI of 82. Adaptation appeared to occur as temperatures declined from an average peak of 39.9°C near the beginning of the heat challenge, to an average low of 39.4°C near the end. This change is likely due to the decrease DMI that was also noted during the course of the heat challenge. Finally, it may be that body temperature adaptation is not only a matter of diminishing temperature readings, but rather an increasing range of the thermoneutral zone (Horowitz, 2001). An expansion of this thermoregulatory range, as described in rats by Maloyan et al. (1999), would lower the temperature at which heat dissipation responses begin, and increase the temperature at which thermal injury begins. Thus, instead of acclimated animals decreasing body temperatures absolutely, it may be that the process of adaptation over time is represented by a modification of their internal temperature setpoints.

### 5.1.2.2 Metabolism

In general, when cattle are subjected to heat stress conditions, FI is reduced within a short amount of time; usually within a day (Rhoads et al., 2009). However, metabolic rate may or may not be changed, as it depends on plane of nutrition and whether or not the animal exceeds the upper critical temperature of its TNZ (IUPS Thermal Commission, 2001). If heat stress persists, metabolic adaptations may occur in feed consumption and energy metabolism, protein metabolism, and endocrine status (Collier et al., 1982). One apparent adaptation that may be of particular concern to producers of high-producing cattle occurs as animals decrease production of volatile fatty acids (VFA) during heat stress (Gengler et al., 1970). These VFAs, such as acetate and propionate, provide a major source of metabolizable energy, and have been shown to decline during chronic heat stress (McDowell, 1972). It has been suggested that decreased VFA production is not exclusively a result of reduced FI as high environmental temperatures were shown to affect VFA concentrations independent of FI (Kelley et al., 1967). This may suggest a metabolic adaptation that aims to limit heat load via decreased VFA production regardless of feeding behavior. Dale and Brody (1953) suggested that heat stressed cattle may eventually experience metabolic ketosis as energy input would not satisfy demands, and accelerate body fat catabolism. Increased lipid catabolism could serve as a useful metabolic adaptation, as subcutaneous fat has been shown to act as an insulator in animals, as previously discussed. The obvious risk associated with increased catabolism, however, is the development of potentially harmful ketosis or ketonuria (Dale and Brody, 1953). Protein metabolism also appears to undergo some adaptation due to chronic heat stress. Since dietary protein intake is subject to depression during heat

stress, it has been suggested that animals would respond by elevating glucocorticoid and catecholamine concentrations in an attempt to catabolize lean tissue (Kamal and Johnson, 1970). However, trials have shown that chronic heat stress actually reduces plasma glucocorticoid concentrations (Alvarez and Johnson, 1973; Niles et al., 1980). This finding could represent an attempt at self-preservation on the part of chronically heat stressed animals, as degradation of lean tissue would be a less physiologically attractive method of stored energy metabolism than that the aforementioned fat mobilization. Metabolic rate may actually increase in an attempt to fuel efforts to alleviate excess heat load, and may increase in combination with the  $Q_{10}$  effect. This potential metabolic increase, paired with reduced energy and nutritional intake, can lower animal production (Collier et al., 1982) as the energy required to fuel these metabolic changes may come from mobilized adipose tissue (Dale and Brody, 1953). The metabolic change during adaptation is variable, as adaptation itself appears variable. For example, Berman (1968) reported reduction in metabolic rate among Holstein cows from of about 20% from winter to summer. This finding suggests that under normal production conditions, metabolic adaptations to warm climates and their seasonal changes may be sufficient to maintain normal productivity in warm climates. However, if hot conditions are sudden and prolonged, as is often the case in parts of the United States, cows are less likely to acclimatize (Kadzere et al., 2002).

### **5.1.2.3 Blood flow**

Heat adaptation increases the cardiovascular reserve of animals to improve the capacity for heat transfer and dissipation. For example, augmented thermoregulatory

skin blood flow for removal of heat from internal organs is complemented by several coordinated events, among which are a lowered temperature threshold for skin vasodilation (Roberts et al., 1977), and the occurrence of skin vasodilation coincidentally with splanchnic vasoconstriction (Horowitz, 1998). A lowered threshold for vasodilation allows for greater blood flow and heat loss at the skin earlier in the course of a heat event. Heat acclimation also increases the efficiency of cardiac output. Acclimation in human studies have shown lowered heart rates accompanied by larger stroke volumes, together leading to an increase in cardiac work efficiency within four days of heat exposure (Senay et al., 1976). This result is supported by Haddad and Horowitz (1994) who found that 30 days of heat acclimation in rats enhanced force generation in the aortic artery in response to alpha adrenergic signaling. Finally, heat adaptation appears to have an effect on the rapidity of splanchnic vasoconstriction and cutaneous vasodilation. Studies considering heat-acclimated rats subjected to heat stress showed that a major feature of their acclimation was a greater proportion of cardiac output distributed to the splanchnic area at heat stress onset. This is accompanied by delayed thermoregulatory splanchnic vasoconstriction when compared to non-acclimated rats (Shochina et al., 1996). Thus, in acclimated animals, greater heat-induced splanchnic vasoconstriction allows greater thermoregulatory blood flow through cutaneous vascular beds, coincidentally with the maintenance of adequate splanchnic blood and heat flow from internal organs (Horowitz, 2001). This is in contrast to non-acclimated animals that appear unable to maintain the same blood flow to organs as they did before heat stress.

#### **5.1.2.4 Sweat rate**

The capacity of the evaporative cooling system increases in all species following prolonged exposure to moderate heat (Horowitz, 2001). When cattle are exposed to heat there are periodic increases in evaporative loss instead of a continuous increase, with the stepped increases taking place at the same time on different parts of the skin surface (Mount, 1979). Among mammalian species, extensive studies on acclimation of this system have been carried out only in humans, primates, and rodents (Horowitz, 2001). In these studies, cooling power is enhanced by a lowering of the temperature threshold for sweat secretion, allowing a faster and potentially more effective evaporative response to heat stress, via greater rate and volume of secretion (Horowitz, 2001). Concomitantly, the energy cost of secretion is significantly lower than in the preacclimation state due to increased efficiency of the secretory mechanisms.

### **5.2 Heat tolerance**

#### **5.2.1 Thermoregulatory differences in heat adaptation within *Bos taurus* breeds**

Within the *Bos taurus* species, there are large differences in thermoregulatory ability. For example, Hammond et al. (1996) showed in a study of Romosinuano (tropical origin), Senepol (tropical origin), and Angus (temperate origin) breeds that differences appeared as heat stress increased. Rectal temperature on the hottest day of the summer study (August 19, 1992) was 0.9°C greater ( $p < 0.001$ ) in the Angus heifers compared to the Romosinuano cattle. This indicates that, even though all cattle were *Bos taurus*, those that developed in the tropics respond less to heat stress than those from

temperate climates. Similarly, Angus steers have been found to have higher RT, RR, and sweat rate than Romosinuano counterparts at thermoneutral (21°C) and heat stress (26°C to 36°C) conditions (Scharf et al., 2010). Additionally, through crossbreeding of *Bos taurus* and *indicus* animals, producers can maintain productivity coupled with heat tolerance. An example is the Santa Gertrudis, which is a Shorthorn-Brahman cross (*Bos indicus* x *taurus*). The use of crossbreds is of considerable importance because cattle taken from temperate zones to a tropical environment fall off markedly in productivity so that direct transfer of cattle is self-defeating (Mount, 1979).

## **6. Predictive models of adaptation**

Long-term factors that regulate DMI of ruminants are complex and not understood fully (NRC, 2000). However, the concept of predicting FI based on ambient variables has been previously explored. Spiers et al. (2004) found that increases in  $T_a$  correlated directly with increases in RT among dairy cows. In turn, changes in RT produced inverse changes in FI. That is, mean daily RT related negatively to DMI. Spiers et al. (2004) clearly demonstrated a chain of predictors that move from ambient stress to thermal strain to animal performance. Previous trials have also considered respiration rate (Bernabucci et al., 2009), sweat rate (Ingram et al., 1963), and skin temperature (Montanholi et al., 2008) as predictors of heat load in cattle.

## **6.1 Long-term effects of heat stress**

Although prediction of FI for shorter periods is highly desirable, no database exists from which to develop such prediction equations for the wide variety of production situations and feeds available to beef cattle producers (NRC, 2000).

### **6.1.1 Thermoregulatory effector responses**

Shifts in  $T_a$  likely affect body temperature first and then invoke thermoregulatory responses to maintain thermostability (Spiers et al., 2004). Cattle, as homeotherms, need to tightly regulate body temperature (around 39°C) and even small increases can decrease production (Berman et al., 1985; Silanikove, 2000). For this reason, cattle undertake thermoregulatory effector responses in an attempt to limit swings in body temperature. These responses may occur simultaneously, but some appear to occur more rapidly in response to heat than others, as discussed in the following sections.

#### **6.1.1.1 Respiration rate**

As noted earlier, body heat content is a net balance between heat production and heat loss. The heat loss processes (e.g., respiratory evaporation) respond initially to a shift in environmental thermal stress, with a change in body heat content only after heat loss avenues reach their maximum capacity. One of the first responses to heat exposure is a shift in respiration rate, and respiration rate appears to be one of the most accessible methods for evaluating heat stress on farm animals (Silanikove, 2000). This rate can be used as an indicator of heat strain in cattle, provided animal condition, prior exposure, ambient conditions (increasing or decreasing  $T_a$ ) and previous cooling strategies are

considered (Gaughan et al., 2000). A system of scoring panting rates also exists, with values ranging from 0 (i.e., respiration rate less than 40 breaths per minute), to 4.5 (respiration rate over 160 breaths per minute) (Meat and Livestock Australia, 2006). The rapidity of respiratory response has been illustrated in studies such as Gaughan et al. (2000) and Hahn (1997), who both found that respiratory response in cattle lagged behind  $T_a$  by approximately two hours in thermal chambers. Further, RR has been shown to effectively parallel RT in ruminants, with no lag reported (Bernabucci et al., 2009). Respiration rates may not, however, be particularly good predictors of FI. This is because the  $T_a$  threshold for increased respiration values is significantly lower (21.3°C, Hahn, 1997) than that of decreased FI (24°C to 25°C; Hahn et al., 1992). Although respiration rate appears to be a poor predictor of FI, it may be a good predictor of near-term heat load in cattle, and help producers to make management decisions in the interest of limiting further strain.

#### **6.1.1.2 Sweat rate**

Sweat rate is another avenue for heat loss that rapidly responds to heat stress prior to a change in body heat content. However, it is not as easily measured as RR since the animal must be restrained and handled. Long-term sweat rate response to heat stress is negatively related to metabolic rate suggesting the difficulty in combining desirable traits of heat adaptation (e.g., increased heat loss) and metabolic potential in cattle (Finch et al., 1982). In addition, when body temperature increases, sweating rates are greater and increase more quickly in indigenous tropically adapted cattle than in temperate zone *Bos taurus* animals in which sweating rates tend to reach a plateau after the first increase

(Finch, 1985). If the impractical aspect of sweat rate measurement can be overcome, and the aforementioned differences between adapted and non adapted animals are accounted for, producers may be able to use sweat rate as an additional predictor of heat load and, at least indirectly, of FI. This is because the  $T_a$  threshold for an increase in sweating rate (25.6°C, McLean, 1963) appears to be roughly the same as the threshold for FI decline (Hahn et al., 1992). In theory, producers may be able to determine FI response based on the rate of change in sweat rate. However, due to the ease of application of other variables as predictors, the value of sweat rate as an additional predictor may be relatively lacking.

#### **6.1.1.3 Skin temperature**

In theory, skin temperature should be one of the first physical parameters to change when a bovine is subjected to ambient variables. Skin temperature is largely dependent on blood flow (Hsieh et al., 1990), so it should also theoretically act as a real-time indicator of body temperature. However, accurate measurement appears difficult, as values are subject to regional variability (Spiers et al., 2004). Further, measured values may be subject to errors caused by increased vasodilation in response to heat stress, coat coverage, sweat response, or even the relationship between animal color and radiant heat load. For example, in *Bos indicus* cattle, the inward flow of heat at the skin of black steers is 16% greater than for brown steers, and 58% greater than for white steers (Finch, 1986). Depending on the measurement method, even brief gusts of wind may contribute to false skin temperature readings (Houdas and Guieu, 1975). Nonetheless, skin temperature may have some value in determining animal thermal status in a relatively

stable environment. Montanholi et al. (2008) observed moderate to high correlation coefficients ( $r = 0.58$  to  $0.88$ ) between skin surface temperature and heat production in Holsteins. Similarly, Berry et al. (2003) found a positive correlation between udder skin temperature and RT in dairy cows. However, these trials used relatively sophisticated and expensive infrared imagery. This methodology is likely cost-prohibitive for most producers, so the practical value of skin temperature as a predictor is likely lower than that of RR.

### **6.1.2 Core body temperature**

Body temperature is generally considered a better indicator of animal performance than environmental factors (Hansen, 2004). Core body temperature is tightly regulated and even small increases above  $39^{\circ}\text{C}$  are negatively correlated with milk production in cows (Berman et al., 1985; Silanikove, 2000). Similarly, mean daily core (i.e. rectal) temperatures have been shown to be related ( $r = 0.83$ ) to a decrease in DMI (Spiers et al., 2004). The application of a single day of lag did not improve this coefficient of determination. Some  $T_{\text{core}}$  adaptation appears to occur when comparing heat adapted and heat sensitive animals. One Brazilian study involving imported Simmental (*Bos taurus*) and native Simmental indicated some  $T_{\text{core}}$  adaptation among the native cattle. Rectal temperatures were obtained from sedentary cattle at  $37^{\circ}\text{C}$   $T_a$  and 60% RH. Rectal temperatures were greater ( $p < 0.001$ ) in imported Simmental ( $40.52 \pm 0.04^{\circ}\text{C}$ ) than in native Simmental ( $38.92 \pm 0.04^{\circ}\text{C}$ ) (Carvalho et al., 1995). However, if adaptive changes are taken into account,  $T_{\text{core}}$  appears to be a promising predictor of animal production, at least in the near-term. In addition, the availability and relative

affordability of telemetric transmitters could make  $T_{\text{core}}$  data acquisition easier for producers.

### 6.1.3 Feed intake

Accurate estimates of FI are vital to predicting rate of gain and to the application of equations for predicting nutrient requirements of beef cattle (NRC, 2000). Long-term estimates of FI in feedlot cattle under thermoneutral conditions have been summarized by equations that have been extensively used in commercial settings. These models rely on initial calf body weight to predict FI behavior. One such equation, a modified version of a 1984 NRC equation, also takes into account the energy content of a feedlot diet:

$$\text{Equation 6: } DMI = SBW^{0.75} * (0.2435 * NE_m - 0.0466 * NE_m^2 - 0.01128) \text{ (NRC, 2000)}$$

Where,

*DMI* = dry matter intake expressed in kg/day

*SBW* = shrunk body weight in expressed in kg

*NE<sub>m</sub>* = expressed as Mcal/kg dietary dry matter

Data for the preceding equation were obtained from experiments conducted with growing and finishing beef cattle, and published in the Journal of Animal Science from 1980 to 1992 (NRC, 2000). Each of 185 data points extracted from the literature represents a treatment mean for average DMI throughout a feeding period. The regression accounts for 69.87% of the variation in  $NE_m$  intake per unit  $SBW^{0.75}$ . These

same data points were used to formulate a second regression equation that relies on initial body weight to estimate DMI over a period.

*Equation 7:  $DMI=1.85 + .01937 *iBW$  (NRC, 2000)*

*Where,*

*DMI= dry matter intake in kg/day*

*iBW= initial body weight in kg*

The preceding equation, which relies on initial weight with adjustments for animal size/sex/class, accounts for 59.78% of the variation in DMI (NRC, 2000).

#### **6.1.4 Growth**

A reduction in GH secretion rate (GHSR) has been seen in heat stressed cattle (Mitra et al., 1972) compared to those at thermoneutrality over the course of two, successive 5-week studies. In spite of animals being subjected to hotter temperatures over the course of 10-weeks, their GHSR continued to decline and no adaptation was noted. However, understanding of the biological functions of GH may be insufficient to determine whether it is involved in homeostatic adaptations (Beede and Collier, 1986). Although management strategies can be implemented to buffer the animal against adverse environmental conditions, the primary factors limiting the precision of predicting growth and performance is our ability to predict DMI (Hicks et al., 1990). Although large variation exists among cattle relative to the effect of  $T_a$  on DMI, the general relationships can be determined (Mader, 2003). Since DMI can be a predictor for growth

if forage composition is taken into account (Shem et al., 1995), the intake response of animals to heat stress may act as a predictor for growth. Cattle on high-energy grain diets (i.e., consistent with a higher heat of digestion) can reduce DMI by more than 25% and may never return to previous levels of intake despite lower  $T_a$  (Meat & Livestock Australia, 2006). Cattle on low quality roughage (low energy) diets experience variable intake reductions, often around 10%, and are more likely to return to full feed when conditions return to normal (Meat & Livestock Australia, 2006). Long-term studies are lacking, but do not indicate heat stress adaptation in terms of FI (and subsequent growth) as animals that showed decline in intake during prolonged heat stress do not even rebound to pre-heat stress intakes readily after heat loads were removed (Beatty et al., 2006).

## **7. Summary**

Although the short-term effects of heat stress on beef cattle are more easily studied than long-term effects, there are few short- or long-term models predicting performance that are based on ambient conditions. For producers to know that heat stress negatively impacts cattle performance may not be enough to combat global warming trends and determine the genetic improvements that are needed to increase productivity. A need still exists for a reliable model that can accurately predict animal FI based on easily measurable ambient or animal conditions. If this can be done, producers may be better prepared to combat negative impacts on their animals from heat events. Producers could make changes to housing, handling, or diet to help their animals cope with heat events and continue producing at a high level. If this can be accomplished, not only will

the producers benefit in terms of financial bottom lines, but the animals may be raised more humanely as well.

## CHAPTER 2

### DETERMINANTS OF BODY TEMPERATURE AND FEED INTAKE IN BEEF CATTLE DURING EXPOSURE TO SUMMER HEAT STRESS

#### **Abstract**

Heat stress in feedlot cattle is known to reduce their well-being and decrease performance. The challenge comes in determining reliable predictors of heat stress in the form of measurable, independent variables that indicate current and near-future changes in performance. A 42-day study, using crossbred Angus (*Bos taurus*) steers (n=26; ABW=347±29 kg) was conducted from July through August 2011 to identify best environmental determinants of core body temperature ( $T_{core}$ ) and feed intake (FI). Further, our group sought to clarify the relationship between  $T_{core}$  and FI, as well as predict animal response to environmental stress. Animals were stratified by weight and housed in five different pens, with *ad libitum* access to the approximate 50% shade coverage in each pen. Steers were provided one of five feedlot diets and water *ad libitum*. Intraruminal telemetric boluses (SmartStock, Pawnee, OK) recorded  $T_{core}$  several times each hour throughout the study. Electronic ID tags (Allflex US Inc., Dallas-Fort Worth, TX) connected to a feed monitoring system (GrowSafe Systems Ltd., Airdrie, AB, Canada) provided FI data. Data loggers (Hobo H8 Pro; Onset Computer, Bourne MA; accuracy: ±0.2°C and ±3% relative humidity (RH)) recorded ambient conditions in sun and shade, along with black globe (BG) temperature. Temperature-Humidity Index (THI) was calculated for all combinations. Analysis used average daily herd FI as well as ambient conditions measured during daylight hours (0700 to 1700 h

CST) to determine best FI predictors. In addition,  $T_{\text{core}}$  analysis used hourly daylight ambient values averaged by hour. Linear and polynomial regressions and analyses of variance (ANOVA, JMP statistical software; SAS Institute; Cary, NC) were used for same-day to 7-day delay evaluations. Ambient temperature ( $T_a$ ) during this period ranged from 17.3°C to 40.7°C with a mean of 27.2°C. Analysis of  $T_{\text{core}}$  used herd averages for each hour during daylight. Regression analyses identified daylight BG in shade (BGShade) with one hour of delay as the best indicator of  $T_{\text{core}}$  (quadratic  $R^2 = 0.68$ ,  $p < 0.0001$ ). This was very closely followed by  $T_a$  with one hour of delay (quadratic  $R^2 = 0.67$ ,  $p < 0.0001$ ). Best FI predictor, based on highest  $R^2$  and including ambient data gathered during daylight and averaged by day, was maximum BG temperature in the sun, in combination with THI (BGTHISun) with a 5-day delay (quadratic  $R^2 = 0.30$ ,  $p = 0.0044$ ). There was no DMI difference ( $p > 0.46$ ) due to diet (Russell et al., 2013). These results indicate that although air temperature alone may be the best predictor of  $T_{\text{core}}$  in the heat for this region of the US, radiant heat load may be a better determinant of FI over time.

## **Introduction**

Daily temperature humidity indexes have been shown to negatively impact FI and milk production, and have been shown to elicit responses in respiration rate, heart rate, and RT in cattle (Bouraoui et al., 2002). In addition, it has been shown that environmental stressors may not have an immediate effect on production variables, like milk yield and DMI. Rather, stressful heat events can affect cattle production days in the future (Spiers et al., 2004; West et al., 2003). Accurate estimates of FI are vital to

predicting rate of gain and to the application of equations for predicting nutrient requirements of beef cattle (National Research Council, 1987). Equations exist that predict DMI over time based on independent variables such as initial body weight and energy content of feed (NRC, 2000). However, long term models based on dynamic environmental variables are lacking. Rectal temperature has been shown to be the best, single predictor of production in cattle in chambers (Spiers et al., 2004). In a production setting, however, RT may be nearly impossible to measure with any useful resolution. But with advances in telemetric technology, it is now possible to wirelessly collect internal body temperature with high resolution in production settings. Telemetry is also useful because it does not rely on cattle capture or restraint to measure  $T_{\text{core}}$ . As a result, the  $T_{\text{core}}$  increase that has been associated with cattle handling (Hahn et al., 1990) does not mask genuine temperature values. One potential source of error that may accompany this method is the influence rumen fermentation may have on the bolus. Compared to RT, rumen temperature is thought to be 1°C to 2°C higher (Dale et al., 1954). The heat associated with fermentation could result in artificially high  $T_{\text{core}}$  values. However, since the relationship between rectal and rumen temperatures appears to be constant (Beatty et al., 2008), and the ability to measure relative  $T_{\text{core}}$  changes is as important as the ability to measure absolute changes, rumen boluses were deemed an acceptable means of data collection in the present study.

By using telemetric tools in a production setting, this experiment sought to answer several questions: What are the best ambient predictors of core body temperature? Is core body temperature the best predictor of FI? How much delay, if any, exists between ambient and physical responses to heat stress and production responses?

## **Materials and Methods**

All cattle used in this study were subject to approval from the University of Missouri Animal Care and Use Committee. They were maintained in feedlots at the University of Missouri Beef Research and Teaching Farm in Columbia, Missouri (38.9516°N, 92.3286°W).

### *Animals*

Cattle for the study were acquired from local salebarns and were assumed to be acclimated to the environment when the study began. Only 26 steers (347 +/- 29 kg BW) were used out of a collection of 40 steers and 50 heifers. All steers were crossbred Black Angus (*Bos taurus*).

### *Animal Management*

Upon acquisition, all calves received an electronic ID tag (Allflex US Inc, Dallas-Fort Worth Airport, TX) in the left ear. These tags served to visually and electronically identify individual animals. In addition, tags facilitated FI measurement via a feed monitoring system (GrowSafe Systems Ltd, Airdrie, AB, Canada). Initial animal treatment included a topically applied liquid anthelmintic (Cydectin, Boehringer Ingelheim Vetmedica Inc., St. Joseph, MO) to eliminate internal and external parasites. All steers were subcutaneously implanted with a trenbolone acetate and estradiol pellet (Revalor IS, Intervet Inc., Millsboro, DE) on day zero. Steers and heifers were separated throughout the study.

### *Boluses*

Twenty-six steers received a telemetric bolus (Smartstock, Pawnee, OK) inserted on day zero of the study. A large balling gun (Bovikal© Bolus Gun, Boehringer Ingelheim GmbH, Ingelheim, Germany) was used to carefully pass through the esophagus and release the boluses to lodge inside the reticulum. Intraruminal boluses provided real-time internal body temperatures ( $T_{\text{core}}$ ) in 15-minute intervals. Telemetric readings were only recorded during the initial 42 days of the study. These data were then sorted by highest temperature per animal per hour in order to avoid cool artifacts resulting from water consumption. Prior to statistical analysis, a Tukey outlier box plot (JMP statistical software; SAS Institute; Cary, NC) was used to determine potential outlying  $T_{\text{core}}$  values. In the interest of maintaining data integrity, not all potential outliers were removed. Only the extraordinarily high or low values that were likely associated with fever or long drinking events, respectively. This was only done to 87  $T_{\text{core}}$  values out of a total of over 24 thousand collected. Following the outlier test, analysis of variance (ANOVA) began.

### *Housing*

Animals were kept in pens built upon inclined concrete that measured 7.32 by 16.46 meters. Wood shavings were used to line pens and were periodically removed and replaced to ensure cleanliness throughout the study. The pens were 50% covered by a corrugated metal roof that provided shelter from sun and rain. The roof sloped and height ranged from 2.62 to 5.69 meters above the pen floors. Calves could move freely within each pen to eat, drink, or seek shade. Animals were not restricted to shade or sun

conditions to allow for measurements in a “normal” feedlot environment. Light intensity ranged from ~2EV (10 Lux) in the shade under the roof on a cloudy day to ~13.5EV (28,900 Lux) in the sun on a clear day. Light values were obtained using a Minolta Auto Meter light meter (Konica Minolta, Tokyo, Japan). Pens contained automatic waterers (Richie Industries, Conrad, IA) in the uncovered areas of the pens and each waterer was shared by two pens. Each pen contained two Growsafe bunks for feed provision and intake measurement. Bunks were located under the feedlot roof, and only one animal could eat from a bunk at a time.

### *Diets*

Water was provided *ad libitum* via automatic waterers. All calves were initially fed a corn based receiving diet (Table 1) for one week before shifting to a treatment diet. Calves were ultimately fed one of five diets with increasing soybean hull (SH) to whole shelled corn (WSC) ratios (Table 2). There was no DMI difference ( $p > 0.46$ ) due to diet (Russell et al., 2013). Treatments including 20 (SH20), 60 (SH60), 80 (SH80), 90 (SH90), and 100 % (SH100) SH were fed to beef cattle to determine the effect of increasing fiber inclusion on digestibility of DM (DMd), NDF (NDFd), and ADF (ADFd) as well as DMI, ADG and G:F. Diets were blocked by gender, stratified by BW, and distributed across subject animals. Preliminary body weight was determined by averaging weights measured on two consecutive days. Steers were stratified by weight to pens with one pen per diet and eight steers per pen. Subsequent body weights were obtained on day 35. To ensure accurate FI data, only one animal could eat from each bunk at a time. Feed was blended daily in a truck-mounted mixer (Reel Auggie 3120, Kuhn North America

Inc., Broadhead, WI) and was provided each morning at approximately 0800 h. Diets were mixed in a random order every day. The diets were fed for 70 days with titanium dioxide included in the diet for the final 14 days. Diets were formulated to meet RDP and RDN requirements (Russell et al., 1992) and amino acid requirements were met by incorporating Amino Plus (Ag Processing Inc., Omaha, NE) and Alimet (88% Methionine; Novus International, St. Charles, MO). Minerals were provided to meet NRC recommended rates for inclusion in feedlot cattle (NRC, 2000). Monensin was provided at the rate of 30 mg per kg of dry matter on an as fed basis (Rumensin 90; 200 g per kg Monensin; Elanco Animal Health, Indianapolis, IN). Choice white grease was included in the pelleted supplement at a rate of 20g per kg to improve pellet quality and consistency. With the exception of the WSC, hay, and SH, all ingredients were pelleted. All ingredients were combined on-site in the truck-mounted mixer.

### *Readings*

Environmental data were collected using Data Loggers (Hobo H8 Pro; Onset Computer, Bourne MA; Accuracy: +/-0.2°C T<sub>a</sub> and +/-3% RH). Hourly T<sub>a</sub> and RH readings were obtained from a local weather station. Measured ambient values included T<sub>a</sub>, RH, BG temperatures (BGSun, BGShade), and THI. The THI was calculated as described by Thom (1959).

### *Equation 8*

$$[(\%RH)/100] * (T_a - 14.4) + (.8)(T_a) + 46.6 \text{ (Thom, 1959)}$$

*Where,*

*%RH = Percent relative humidity*

*T<sub>a</sub> = Current air temperature in °C*

Black globe (BG) data were obtained from BG thermometers (hollow copper sphere; 15.24 cm diameter, matte black exterior; Scharf et al. 2011) placed in the sun and shade at approximately 2.44 meters from ground level. In addition, THI was calculated using sunlit BG temperature data instead of T<sub>a</sub> to provide BGTHISun and using shaded BG values (BGTHIShade).

### *Analysis*

Data were collected from 26 crossbred Black Angus steers for consecutive days from July 12, 2011 to August 22, 2011. However, due to poor data resolution on the first day, it was excluded during analysis. Day 16 and day 42 also yielded very poor ambient readings, and these days were excluded from analysis. The end result was collection from 39 total days during the study. Analyses of best ambient predictor of T<sub>core</sub> occurred using real-time and hourly lagged data and included daytime hours from 0700 to 1700 h CST to better isolate daytime heat events. Lags of between zero and five hours were considered in order to determine if a delayed animal reaction existed after ambient exposure. Herd T<sub>core</sub> data were averaged by hour of day. Additionally, a lag ranging from zero to five hours was incorporated to determine if a delayed effect could be demonstrated between the onset of ambient stress and T<sub>core</sub> response. Analyses of best ambient or T<sub>core</sub> predictor of daily herd FI was done in a similar way, except in this case, daytime values were averaged by day. Lags of between zero and seven days were

applied to daily herd  $T_{\text{core}}$  and ambient averages in an attempt to determine the existence of a delayed FI response. Linear, 2<sup>nd</sup>, and 3<sup>rd</sup> order polynomial regressions were performed to determine coefficients of determination among variables. Quadratic regressions were deemed the best in terms of high proportion of variation explained and low complexity (Figure 1). Resulting equations utilized polynomial centering as described by Bradley and Srivastava (1979). This is a default function of JMP analysis and improved the model when regression variables are related to each other.

## **Results and Discussion**

### *Ambient Conditions*

Ambient measurements included hourly  $T_a$ , RH, BGShade, BGSun, THI, BGTHISun, and BGTHI Shade. These data were collected 24 h per day for all days. Data are summarized in Table 3 and shown in Figures 3, 4, and 5. Hourly-averaged  $T_{\text{core}}$  ranged from 39.58°C at 0800 h to 40.30°C at 2200 h over the entire period of study, excluding days 1, 16, and 42 due to poor resolution, with the results showing the 24 h daily pattern in Figure 3. Hourly-averaged  $T_a$  ranged from 22.82°C at 0600 h to 32.04°C at 1600 h. The lowest overall level for  $T_a$  was 0500 to 0700 h (23.06°C;  $p > 0.05$ ) followed by an increase from 0700 to 1400 h (28°C;  $p \leq 0.05$ ) a decrease from 1700 to 2300 (28.50°C;  $p \leq 0.05$ ) and then a plateau at 0000 to 0600 h (23.72°C;  $p > 0.05$ ). Both the high and low  $T_{\text{core}}$  values occurred while  $T_a$  was in transition, with the low  $T_{\text{core}}$  during the initial rise in  $T_a$  and the high  $T_{\text{core}}$  during the initial decrease in  $T_a$ . Because THI incorporates  $T_a$  and RH into its calculation, it was expected to have a similar pattern, with a low point of 72.48 at 0600 h and a high point of 81.64 at 1600 h. Therefore, even

the average daily shift in THI moves from little thermal stress at 0600 h to a significant stress of 81.64 at 1600 h. The THI nadir was between 0500 and 0600 h (72.62;  $p > 0.05$ ) with an increase to 76.91 at 0900 h ( $p \leq 0.05$ ) and a plateau of 81.35 ( $p > 0.05$ ) at 1400 to 1800 h. The THI then decreased ( $p \leq 0.05$ ) to 75.95 at 2300 h. Relative to  $T_a$  and THI, a shift to the left occurred with BGSun and BGTHISun. That is, we found minimum and maximum BG values preceded minimum and maximum  $T_a$  and THI values by one to two hours. Black globe in the sun reached a low hourly-averaged temperature of 25.88°C at 0500 h and a peak of 46.89°C at 1400 h. Black globe THI in the sun ranged from 77.60 at 0500 to 102.55 at 1300 h. This is likely the result of the sun's influence on the BG thermometer. The sun likely heated the globe faster than the rest of the surrounding air, and this phenomenon is captured when BG is compared to other ambient values. The nadir for BG temperature was 26.27°C at 0300 to 0600 h ( $p > 0.05$ ) with an increase to 40.22°C at 0900 h ( $p \leq 0.05$ ) before a plateau of 46.54°C at 1200 to 1600 h ( $p > 0.05$ ). Following the plateau, there was a decrease to 41.63°C at 1800 h ( $p \leq 0.05$ ). As seen for THI, the pattern for BGTHI was similar to BG temperature with a nadir of 77.99 from 0300 to 0500 h ( $p > 0.05$ ). This was followed by a rapid increase to 87.56 at 0700 h ( $p \leq 0.05$ ), and a plateau of 102.26 from 1100 to 1400 h ( $p > 0.05$ ). By 1800 h, BGTHI had decreased to 95.76 ( $p \leq 0.05$ ). Since the high and low  $T_{core}$  values occur while  $T_a$  was in transition, it appears that some lag is associated with the comparison of ambient and animal variables. Further, since BG values were found to precede  $T_a$  and THI values, it may be that BG values are better at predicting  $T_{core}$  changes. This is likely only the case in environments where sunlight can actually reach the animals.

Minimum, maximum and mean ambient values were determined for each day of the trial in order to eventually compare daily ambient conditions to daily FI. Daily maximum THI values consistently reached and exceeded 77, which is the upper end of a range that Gaughan et al., (1999) defined as moderate heat stress conditions. Likewise, daily maximum THI values consistently exceeded the point at which stress-limiting measures should be considered (THI of 75, Hahn, 1997). Daily minimum, maximum and mean  $T_a$  were similar to those measured in previous summer feedlot trials (Mitloehner et al., 2001; Mitloehner et al., 2002), and  $T_a$  values frequently exceeded 21°C and 25°C, which are the points at which animals have been shown to increase respiration rates and decrease FI, respectively (Hahn, 1997). Other ambient variables, including BG and BGTHI values were similar to previously published field studies during summer (Scharf et al., 2011; Gaughan et al., 1999; Schneider et al., 1986). Ultimately, only daytime (0700 to 1700 h CST) hours were used for analyses in a way similar to that used by Scharf et al. (2011) in an attempt to better capture only the daytime heat events when heat stress is increasing and the relationships between variables are forced to a greater level.

### *Core Temperature*

The first goal of the study was to determine the best ambient predictor(s) for  $T_{core}$ , since this indicator of whole body thermal status has previously been found to be the best predictor of animal production (Spiers, 2004). Therefore, the present study sought to make a connection between relatively easy-to-measure ambient conditions, thermal status, and FI. Following a Tukey outlier boxplot test and outlier removal, results are

summarized in Table 4, Figure 3, and Figure 8. Summarized values include whole-herd averages for the entire study period of daily (24 h) min, mean, max, and range of  $T_{\text{core}}$ . Measured  $T_{\text{core}}$  values are comparable to findings in other summertime studies (Gaughan et al., 2010a; Scharf et al., 2011). The mean herd  $T_{\text{core}}$  for the entire period of study (Figure 8) increased from its lowest levels at 0700 to 0900 h ( $39.60^{\circ}\text{C}$ ;  $p > 0.05$ ) to 1000 h ( $39.74^{\circ}\text{C}$ ;  $p \leq 0.05$ ) and again from 1100 to 1200 h ( $39.96^{\circ}\text{C}$ ;  $p > 0.05$ ), before briefly falling between 1900 and 2000 h ( $40.08^{\circ}\text{C}$ ;  $p > 0.05$ ) and plateauing at 2200 to 0500 h ( $40.19^{\circ}\text{C}$ ;  $p > 0.05$ ). The relationship between  $T_{\text{core}}$  and  $T_{\text{a}}$  is illustrated in Figure 3. When separated by mean hourly temperature ( $> 25^{\circ}\text{C}$  and  $< 25^{\circ}\text{C}$ ), both the lag and strength of relationship can be seen between  $T_{\text{core}}$  and  $T_{\text{a}}$ . This is most apparent when  $T_{\text{core}}$  values are considered at temperatures greater than  $25^{\circ}\text{C}$ . Below this temperature,  $T_{\text{core}}$  variability is increased as an apparent result of inconsistent heat loss during cooler daytime hours. Interestingly,  $T_{\text{core}}$  values were found to rise late in the day in spite of falling air temperature. This could be the result of animals eating during the cooler evening hours, as previously described by Ragsdale et al. (1951). It may be that after eating in the evening,  $T_{\text{core}}$  values increase as feed is digested and metabolized. Future research could confirm this theory if feeding times for individual animals could be recorded.

Core temperature analysis used linear, and both 2<sup>nd</sup> and 3<sup>rd</sup> order polynomial regressions to define the best ambient predictors for  $T_{\text{core}}$ . Quadratic  $R^2$  values that consider 0700 to 1700 h are summarized in Figure 2 and Table 10. Following regressions, the best predictor of  $T_{\text{core}}$  was mean hourly BGShade with one hour of lag (quadratic  $R^2 = 0.68$ ;  $p < 0.0001$ ). However, the strong relationship between BGShade

and  $T_{core}$  was closely followed by hourly  $T_a$  with one hour of lag (quadratic  $R^2 = 0.67$ ;  $p < 0.0001$ ). Since  $T_a$  is an easy ambient variable for producers to measure, and BGShade is essentially measuring  $T_a$  anyway, we suggest  $T_a$  alone to be the best single predictor of  $T_{core}$ . Our group initially thought that BGSun would be useful in predicting  $T_{core}$  response in cattle, as this variable incorporates the effect of radiant heat from the sun. However, it appears that BGSun values were generally less valuable in terms of their coefficients of determination with  $T_{core}$ . One reason for this is the fact that BGSun was likely influenced by cloud cover during the summer, and the resulting variability may have had a negative impact on predictive value. Further, when BGSun was reading high values on hot, sunny days, the animals tended to crowd under the shade. Thus, the BGSun values were likely exaggerated when compared to what the animals were actually experiencing.

Ultimately, our equation relies on  $T_a$  to best predict  $T_{core}$ :

*Equation 9*

$$LagT_{core}1 = 38.0539 + 0.0669(T_a) + 0.0006[(T_a - 29.0527)^2]$$

*Where,*

*LagT<sub>core</sub>1 = Average herd core temperature in °C one hour in the future*

*T<sub>a</sub> = Current ambient temperature in °C*

In addition, this conclusion agrees with previous studies such as Lefcourt and Adams (1996), Al-Haidary et al. (2001) and Scharf et al. (2011) wherein variation in core body temperature was best explained a model that included  $T_a$ . Lefcourt and Adams (1996) found that maximum daily body temperatures increased with increasing maximum

daily  $T_a$  above a threshold of  $25.6^\circ\text{C}$ , after which point, maximum daily  $T_{\text{core}}$  increased  $0.57^\circ\text{C}$  for every  $5^\circ\text{C}$  of ambient increase ( $p < 0.01$ , linear  $R^2 = 0.24$ ) in a comparable feedlot study. Similarly, Scharf et al. (2011) showed that a model utilizing a quadratic function of  $T_a$  explained the most variation in  $T_{\text{core}}$  ( $R^2 = 0.56$ ) in a field environment. In terms of the lag effect, previous studies (Hahn, 1997; Brown-Brandl et al., 2005) have shown an improvement in model explanation of variation with the addition of lag. Hahn (1997) indicated that entrainment of  $T_{\text{core}}$  by  $T_a$  was apparent with a 3-h to 4-h time lag. Brown-Brandl et al. (2005) also indicated that  $T_{\text{core}}$  lagged  $T_a$  by one to five hours, and is dependent on ambient conditions. However, unlike the current study, Scharf et al. (2011) showed that a delay in response from one to three hours did not significantly improve  $R^2$  for the relationship between  $T_a$  and  $T_{\text{core}}$ . The worst ambient predictor of  $T_{\text{core}}$  was consistently BGTHISun across all hours of lag (Figure 2, Table 10). In addition, BGSun was generally the second-worse predictor of hourly  $T_{\text{core}}$  across all hours of lag. As BG values took into account radiant heat load while THI and  $T_a$  did not, the previous reason for its poor value as a predictor could be that the steers were spending much of their time in the shade and when in the sun there would be huge transient shifts in BGSun in and out of cloud conditions while  $T_{\text{core}}$  remained unchanged due to the excessive thermal inertia. When  $T_{\text{core}}$  by ambient coefficients of determination were lagged, a trend arose. Predictor  $R^2$  values generally rose from zero hours delay for the first two to three of lag, and then fell as more lag was considered. The value in  $T_a$  as a predictor of  $T_{\text{core}}$  lies not just in its high  $R^2$  values across periods, but also from the ease with which it can be measured by producers. Practical value of  $T_a$  is likely higher than that of BG or THI readings, as no special equipment or calculations are required to determine readings. The reason for this

observed lag is largely related to thermal inertia. That is, large homeothermic species are figuratively trapped in a *thermal milieu* and  $T_{\text{core}}$  values are slow to respond to changes (Gordon et al., 2008). Thus, changes in ambient variables may not elicit an immediate response in corresponding  $T_{\text{core}}$  changes. Rather, it is apparent from the present study, as well as others like it, that some lag ranging from zero to four hours is associated with animal response.

### *Feed Intake*

Another goal of this study was to determine if it is possible to identify a reliable ambient predictor for FI. Feed intakes were measured on a daily basis for each animal as noted earlier. Data are summarized in Table 4 and Figure 6. Mean daily whole-herd animal intakes ranged from 3.06 to 14.30 kg per day. Mean daily whole-herd FI for the entire period was 8.70 kg, with 2.81 kg SD. These values were comparable to previous trials using cattle in environmental chambers (Hahn, 1997). This FI level was also similar to values measured in previous feedlot trials (Brown-Brandl et al., 2005; Mader, 2003) involving *Bos taurus* animals. An ANOVA was performed to compare the effects of daily (0700 to 1700) ambient conditions and herd  $T_{\text{core}}$  versus daily herd FI. All animals within the herd were averaged for each day and used in the analysis. This time, a range of between zero and seven days of lag was considered. Previous trials have shown that FI can decrease two to four days in response to the onset of heat stress (Spiers et al., 2004; West, 2003). Our group wanted to consider these previously established lags, as well as determine if any improvement in variation explanation could be realized with additional lag. Ambient predictors again included mean, maximum, range, and minimum

daytime (0700 to 1700 h CST)  $T_a$ , RH, BGSun, BGShade, THI, BGTHIShade, and BGTHISun in addition to daytime mean, maximum, minimum, and range of daily herd  $T_{core}$  values. Hourly  $T_a$  and RH values were measured as previous studies have indicated an inverse relationship between dry- and wet-bulb  $T_a$  and FI (Beatty et al., 2008). Further, BG values were considered in an attempt to capture the effects of radiant heat load on predominantly black animal subjects. Since BG temperature combines the effects of total incoming radiation from the sun, horizon, and other objects (Bond and Kelly, 1955), our group thought BG values would be valuable in determining predictors in a field environment. Hourly THI values were measured as previous studies have indicated that FI decreased in response to elevated THI levels (Bernabucci et al., 1999). Finally, minimum ambient values were considered based on evidence suggesting that nighttime cooling in feedlot animals was important in limiting heat load from day to day (Meat and Livestock Australia, 2006). Herd  $T_{core}$  values were considered as RT has been shown to be the best, single predictor of production in cattle (Spiers et al., 2004). The resulting analysis considered between 31 to 39 observations, depending on the number of days of lag. Following regression, most predictors were found to be insignificant at  $p < 0.05$ . However, among those that were significant, BG values in sun accounted for the majority. This appears to demonstrate the value of considering the impact of radiant heat on FI. The best predictor for mean daily herd FI was maximum daily BGTHISun with a 5-day lag (quadratic order  $R^2 = 0.30$ ,  $p = 0.0044$ ). No same-day ambient predictors of FI were statistically significant at  $p < 0.01$ . The predictive equation is:

*Equation 10*

$$\text{LagFI5} = 17.5474 - 0.0801(\text{MaxBGTHISun}) - 0.0037[(\text{MaxBGTHISun} - 106.46)^2]$$

*Where,*

*LagFI5 = Average daily herd feed intake in kg at five days in the future*

*MaxBGTHISun = Maximum daily BGTHI value in the sun*

This delayed response is in agreement with other studies such as Spiers et al. (2004) and West et al. (2003) who showed that FI did not necessarily decrease immediately in response to heat stress, but could take days to decrease and reach a nadir. The gradual (as opposed to immediate) decrease in FI may be partly due to the significant thermal inertia associated with large homeotherms (Gordon et al., 2008). As previously discussed in greater depth in the literature review, diminished FI could be the result of slower gut motility during heat challenge (Westra and Christopherson, 1976). This decreased motility may yield greater gut fill, which would potentially decrease appetite (Grovum, 1979). Whether gut motility is the main driver for decreased FI is not entirely clear, as other studies (Attenbery and Johnson, 1969; Silanikove, 1987; Warren et al., 1974) did not reveal decreased passage rates in hot environments. Animals may simply be eating less feed so as to reduce internal heat load (Silanikove, 2000), and gut motility may be symptomatic rather than causal. In the present study, the lag required for greatest explanation of variation was longer (five days) than previous studies. Other predictors did show significance ( $p < 0.05$ ) with less lag (e.g. Mean BGTHISun with three days of lag), but the coefficients of determination were not as great ( $R^2 = 0.21$ ,  $p = 0.0211$ ). A review of literature did not reveal trials in which five days of lag offered the best

coefficients of determination between ambient predictors and FI. Rather, it appears that previous studies have shown less lag to be associated with FI prediction. One reason for this discrepancy could be that Spiers et al. (2004) and West et al. (2003) considered dairy cows, instead of the beef steers considered in the current study. The greater metabolic rate that has been shown in dairy compared to beef animals (Brody, 1945) as well as different animal body weights between studies could account for the observed difference between our beef steers and the Holstein cows used in previous trials. In addition, Spiers et al. (2004) studied animals in controlled environmental chambers. It may be that the additional environmental variability to which our animals were subjected resulted in more lag needed to achieve a stronger coefficient of determination. Spiers et al. (2004) also showed that RT was superior at predicting change in FI ( $r = 0.83$ ). This result was not replicated in the present study. In fact, daily  $T_{\text{core}}$  values offered no significant ( $p < 0.01$ ) predictive value. Minimum, mean, maximum, and range of daily herd  $T_{\text{core}}$  values were considered, but none of these variables, even when combined with daily lags, were significant. This result was unexpected, but one explanation is that the animals could be more susceptible to radiant heat than in the study conducted by Spiers et al. (2004) in environmental chambers. It may be that FI decreased in the present study as animals felt hotter from the incoming solar energy than they would have in environmental chambers. That is, the sunlight made the animals respond as if they were hotter than they actually were. This could explain the superior coefficients of determination realized when BG variables were analyzed against FI. Likewise, it could explain why  $T_a$  and BGShade, which is essentially the same as  $T_a$ , were superior at predicting  $T_{\text{core}}$  values. That is, animals may respond to radiant heat and high humidity as if their  $T_{\text{core}}$  is high, but  $T_{\text{core}}$

actually appears to be more responsive to changes in variables that do not include radiant heat load.

## **Conclusions**

We investigated the feasibility of predicting FI and  $T_{\text{core}}$  based on ambient and animal variables. The ability to gather and analyze data at varying resolutions (hourly for  $T_{\text{core}}$  and daily for FI) was afforded by telemetry. As expected and previously described in the literature, variation in  $T_{\text{core}}$  was positively and quickly (within one hour) explained by changes in  $T_{\text{a}}$ . Due to the ease with which producers can apply  $T_{\text{a}}$  to their own animals, it appears as though BG and THI readings may not have as much value in predicting  $T_{\text{core}}$  at least in this region of the US where humidity is not as severe a problem. However, the present study also succeeded in establishing predictors for FI, in the form of BGTHISun with a 5-day lag. This finding illustrates the importance of both BG and the THI in predicting FI in typical feedlot settings. Further, it illustrates the impact that total heat load has on animals in the field. The amount of lag required to achieve the best predictor is longer than in previous studies such as Spiers et al. (2004) in which FI suppression occurred over the course of only three days. Ultimately, more research is needed to determine whether FI prediction can be improved or predicted with less delay.

## CHAPTER 3

### EFFECT OF REDUCED HAIR COAT ON PERFORMANCE OF FEEDLOT STEERS DURING SUMMER HEAT STRESS

#### **Abstract**

Heat stress in feedlot cattle is known to reduce their well-being and performance. The challenge is to develop effective procedures for heat stress mediation under feedlot conditions and over the entire summer period. This necessitates the identification and development of reliable predictors of heat strain in the animal that can be created with ambient conditions. Likewise, there is little understanding of the impact of hair coat on thermoregulatory ability in the summer. Therefore, a 94-day study, using crossbred Angus steers ( $n = 36$ ;  $ABW = 284 \pm 29$  kg) was conducted in Missouri from June through August 2013. At the beginning of the summer, animals still had much of their winter hair coat. Animals were stratified by weight, housed in groups of nine among four different pens with ~50% shade coverage, and hair scored (1 to 4 scale; with higher values indicating a shorter coat). Hair coat was carefully removed from the trunk of half of the steers (Treatment; TRT) at the beginning of the study, with the remaining animals (Normal; NORM) being unaltered (average initial hair score = 1.9) for the remainder of the study. Ambient temperature ( $T_a$ ) and relative humidity (RH) were recorded using Hobo H8 Pro data loggers (Onset Computer, Bourne, MA) in sun and shade. Range of  $T_a$  was 12.2°C to 36.6°C, and calculated temperature humidity index (THI) was 54.4 to 85.3. Steers were provided a corn-based feedlot diet and water *ad libitum*, and core temperature ( $T_{core}$ ) measured hourly using intraruminal telemetric boluses (Smartstock, Pawnee, OK).

Electronic ID tags (Allflex US Inc., Dallas-Fort Worth, TX) connected to a feed monitoring system (GrowSafe Systems Ltd., Airdrie, AB, Canada) provided feed intake (FI) data. Respiration rate (RR), expressed in breaths per minute (BPM), was measured at 0800 to 0900 and 1700 to 1800 h on select days throughout the study, with measurement frequency increasing with heat events. Data analysis was conducted using linear and polynomial regression analyses (ANOVA, JMP Statistical Software; SAS Institute; Cary, NC) to determine the temporal change throughout the study on FI, feed efficiency (FI/ADG), RR, and  $T_{\text{core}}$ , and the effect of a reduced hair coat. Another goal was to determine the magnitude of relative change in animal response from beginning to end of the summer, and among treatments. Analysis revealed an effect of hair level on daily FI ( $p < 0.001$ ), but no difference in feed efficiency (FI/ADG) in NORM versus TRT ( $p > 0.10$ ) during the entire study. In addition, hair level appeared to have no significant effect on average RR ( $p > 0.10$ ). However, analysis of mean daily  $T_{\text{core}}$  over the entire period by animal and hour of day showed a  $0.23^{\circ}\text{C}$  lower  $T_{\text{core}}$  value for TRT versus NORM animals ( $p < 0.001$ ). Likewise, maximum daily  $T_{\text{core}}$  was  $0.30^{\circ}\text{C}$  lower in TRT versus NORM animals ( $p < 0.0001$ ), with a smaller difference of  $0.13^{\circ}\text{C}$  in daily minimum  $T_{\text{core}}$  ( $p < 0.0001$ ). Since overall FI over the course of the study was slightly reduced as an apparent result of this procedure ( $p < 0.0001$ ), additional studies are needed to determine the reason for this intake reduction. However, the torch protocol has shown promise as an economical method of reducing  $T_{\text{core}}$  in feedlot cattle.

## Introduction

Internal body temperature has long been considered a reliable indicator of heat load and has been measured at different locations in cattle in different trials. Tympanic (Mader et al., 2010), abdominal (Gaughan et al., 2010a), rumen (Ipema et al., 2008; Rose-Dye et al., 2011), and rectal (Gaughan et al., 1999) measurements have all been considered as indicators of  $T_{\text{core}}$ . Recording  $T_{\text{core}}$  via telemetry allows for passive  $T_{\text{core}}$  measurements that do not rely on cattle capture or restraint. This is important, as restraining animals may induce a stress response that masks the desired  $T_{\text{core}}$  measurement (Hahn et al., 1990). In addition, telemetric boluses have increased longevity and survivability in the animal when compared with other measuring devices. One potential source of error, however, is the heat of fermentation that might influence bolus readings and create artificially high  $T_{\text{core}}$  values. Compared to RT, rumen temperature is thought to be 1°C to 2°C higher (Dale et al., 1954). However, since the relationship between rectal and rumen temperatures appears to be constant (Beatty et al., 2008), and the ability to measure relative  $T_{\text{core}}$  changes is as important as the ability to measure absolute values, rumen boluses have been determined to be an acceptable means of data collection in the present study.

It has been well established that light-colored hair coats, and hair coats that are sleek and shiny reflect a greater proportion of incident solar radiation than hair coats that are dark in color, more dense, or are wooly (Stewart, 1953; Hutchinson and Brown, 1969; Finch, 1986; Hansen, 1990). Thick and dense hair coats, such as are typical of many *Bos taurus*, reduce heat flow via conduction and convection, and exacerbate the effects of heat stress (Berry and Shanklin, 1961; Finch et al., 1984). Likewise, it has been shown

that clipping the hair coat of Shorthorn cattle reduces the magnitude of hyperthermia in response to heat exposure (O'Bannon et al., 1955). Since hyperthermia decreases FI in cattle (Spiers et al., 2004), hair removal may reduce the production effects of high heat load in cattle.

The current study sought to answer several questions: What are the ambient and animal variables, measured reliably in a feedlot environment, that can be used to predict the impact of heat stress on the thermal status of cattle and ultimately their FI throughout an entire summer period? Will hair removal at the beginning of summer decrease hyperthermia and improve FI in cattle?

## **Materials and Methods**

The study took place from June 4, 2013 to September 11, 2013 at the University of Missouri Beef Research and Teaching Farm in Columbia, Missouri (38.9516°N, 92.3286°W), using an animal care protocol (#7769: “Monitoring of Beef Cattle in Feedlots under Summer Conditions”) that was approved by the Animal Care and Use Committee at the University of Missouri.

### *Animals*

The study used crossbred Black Angus (*Bos taurus*) steers (n = 36; ABW = 284 +/- 29 kg at study onset) that were born and raised on pasture at the University of Missouri Beef Research and Teaching Farm. Animals were selected to ensure black hides and predominately (>95%) black coats. Since subjects were locally sourced, they

were assumed to be acclimated to the environment when the study began. Figure 9 shows the  $T_a$  experienced by the study calves for the month prior to the start of measurement.

### *Coat Treatment*

The day before data collection began, animals were hair scored (1 to 4 scale; higher numbers indicating less fur). Animals were then stratified by weight and hair score, and randomly selected for treatment. Half of the animals retained a normal hair coat (NORM), while hair on the remaining animals was carefully singed to remove excess amounts along the topline, flank, and heart girth where the largest amount is located (TRT). Torching has been used as a quick and safe method of hair removal on dairy cow udders (Harrington et al., 2005) and our protocol aimed at replicating this method on the trunks of beef cattle. Average hair scores for TRT and NORM animals before treatment were 1.95 and 1.89, respectively. Subsequent hair scores were not measured as the torched animals had resultant slick coats. Average, non-fasted starting weights for TRT and NORM animals before treatment were 283.37 and 284.03 kg, respectively. Hair removal was accomplished by restraining animals in a hydraulic squeeze chute (Moly Manufacturing Inc., Lorraine, KS) and applying a propane-fueled flame 20 to 40 centimeters away from the target coat. The resulting singed follicles were easily brushed away with a livestock comb. Approximately 11 percent (average of .38 m<sup>2</sup>) of each coat was subject to treatment. Treatment area was calculated using an equation developed by Elting (1926), which estimates surface area from animal body weight in *Bos taurus*:

### *Equation 11*

$$SA = 1470(W^{.56}) \text{ (Elting, 1926)}$$

*Where,*

*SA = Animal surface area in cm<sup>2</sup>*

*W = Animal weight in kg*

Safety was the top priority as the chute area was assessed for flame resistance and ventilation, animals were constantly monitored, and torching was accomplished by animal professionals under strict supervision. There were no signs of any injury as a result of this procedure.

### *Animal Management*

Initial treatment of subjects also included half-duplex electronic ID tags (Allflex US Inc, Dallas-Fort Worth Airport, TX) in the left ear. These tags served to visually and electronically identify individual animals. Tags also facilitated FI measurement via a feed monitoring system (GrowSafe Systems Ltd. Airdrie, AB, Canada). Steers were treated with a topically applied liquid anthelmintic (Cydectin, Boehringer Ingelheim Vetmedica Inc., St. Joseph, MO) to eliminate internal and external parasites. All steers were subcutaneously implanted with an 80 mg trenbalone acetate and 16 mg estradiol pellet (Component TE-IS with Tylan, Ivy Animal Health Inc., Overland Park, KS, lot# 01217T, Exp 01/15/14). Intraruminal, telemetric bolus insertion occurred at study onset (Smartstock, Pawnee, OK) as described below. Body weights were obtained at the study

onset and roughly every two weeks thereafter to monitor ADG. For better accuracy, 2-day weights were obtained and averaged.

### *Boluses*

Boluses were calibrated in a warm water bath for 5.5 h at 37°C through 41°C, and tested for resolution before being administered to the steers. Animals were provided intraruminal boluses at the start of the trial. This was accomplished at the same time as the hair removal and vaccination protocols to avoid unnecessary handling of subjects. Boluses were cylindrical in shape and measured 31.5 mm by 82.3 mm. They weighed 120 grams each. A large balling gun (Bovikal© Bolus Gun, Boehringer Ingelheim GmbH, Ingelheim, Germany) was used to carefully pass through the esophagus and place boluses inside the reticulum of the animals. Intraruminal boluses served to provide real-time internal body temperatures ( $T_{\text{core}}$ ) in 15-minute intervals throughout the study. Telemetric data were filtered by highest temperature per hour in order to avoid artifacts resulting from water consumption. Prior to analysis, an examination of  $T_{\text{core}}$  data was performed. A Tukey outlier box plot was used in JMP to determine potential outliers. These outlying values included high fevers or instances of recording failure. The high resolution (every hour and every animal) afforded by the telemetric boluses allowed a few values to be assumed based on the preceding and following hourly temperatures. This was done to only 87  $T_{\text{core}}$  hourly values out of over 68 thousand used in analyses. Total failure in  $T_{\text{core}}$  recording occurred on June 17, 18, 19, and 20 and these days were excluded from analyses.

### *Respiration Rates*

Respiration rates were measured at 0800 and 1700 h CST on selected days, and respiration measurements ended on September 6<sup>th</sup>, 2013. The objective was to measure RR early and late on particularly hot days during the study. While using a stopwatch (Traceable® ISO Calibrated Water/Shock-Resistant Stopwatch, Fisher Scientific, Pittsburgh PA) breaths were counted for each animal at each time and represented in BPM. If animal movement prevented a full minute of recording, breaths were measured for 30 s and that number was then doubled to achieve BPM.

### *Housing*

Steers were stratified by weight to pens, with nine steers in each pen. Stratification by weight occurred before animals were randomly selected for treatment, so NORM and TRT animals were housed among all pens. Each pen contained either four or five NORM and TRT animals. Pens were inclined concrete and measured 7.32 by 16.46 m. Shavings were used to line pens and were periodically removed and replaced to ensure cleanliness throughout the study. The pens were 50% covered by a corrugated metal roof that provided shelter from sun and rain. Light intensity ranged from ~2EV (10 Lux) in the shade under the roof on a cloudy day to ~13.5EV (28,900 Lux) in the sun on a clear day. Light values were obtained using a Minolta Auto Meter light meter (Konica Minolta, Tokyo, Japan). The area of the roof under which the animals had access measured 7.62 by 35.97 m. The slope of the roof resulted in a height of between 2.62 to 5.69 m above the pen floors. Steers could freely move within each pen to eat, drink, or seek shade. They were not restricted to shade or sun conditions to allow for

measurements in a “normal” feedlot environment. Automatic waterers (Richie Industries, Conrad, IA) were located in the uncovered areas of the pens and two pens shared each waterer. Each pen contained two Growsafe bunks for feed provision and intake measurement. Bunks were located under the feedlot roof, and only one animal could eat from a bunk at a time.

### *Diet*

Water and feed was provided *ad libitum* and feed was blended daily in a truck-mounted mixer (Reel Auggie 3120, Kuhn North America Inc., Broadhead, WI) and was provided each morning at ~0800 h. All calves were initially fed a corn based receiving diet (Table 5) for 16 days before shifting to the treatment diet. The corn and soy based treatment diet was mixed with a mineral concentrate to provide additional calcium, salt, vitamin A, E and vitamin D (Table 6). Prior to analyses, an examination of FI data was performed. A Tukey outlier box plot was used in JMP to determine potential outliers. As an apparent result of dietary transition, FI values during the first eight days were deemed outliers and excluded from FI analyses. Likewise, FI values on June 16 were inexplicably low, and were also excluded. Finally, total failure in FI recording occurred on June 17, 18, 19, and 20, and in one animal after July 22, and these individual values were excluded from FI analyses.

### *Readings*

Ambient conditions were recorded for every hour and every day throughout the study. Measured ambient parameters included  $T_a$ , RH, and sunlit BG temperature

(BGSun). In addition, temperature humidity index (THI) was again calculated as described by Thom (1959; Equation 8). Black globe data were obtained from BG thermometers (hollow copper sphere; 15.24 cm diameter, matte black exterior; Scharf et al., 2011) placed in the sun and shade at 2.74 and 2.44 m above ground, respectively. The BGShade values were deemed analogous to  $T_a$  and were not used in analysis. Environmental data were collected using Data Loggers (Hobo H8 Pro; Onset Computer, Bourne MA; Accuracy:  $\pm 0.2^\circ\text{C}$   $T_a$  and  $\pm 3\%$  RH). A white shade data logger was placed under the shelter, between feed bunks, at a height of 1.22 m above ground. In addition, THI was calculated using BG temperature data instead of  $T_a$  to provide a black globe-based temperature humidity index (BGTHI). Finally, additional  $T_a$  and RH readings were obtained from the Missouri Historical Agricultural Weather Database (<http://agebb.missouri.edu/weather/history/>) when on-site ambient data failed to record consistently. A comparison of values from this database with those onsite showed similarity.

### *Analysis*

Data were collected for consecutive days from June 4, 2013 to September 11, 2013. However, very poor or nonexistent FI and  $T_{\text{core}}$  data resolution on June 17, 18, 19, and 20 resulted in these days being excluded from analysis. The end result was a 96-day collection period. As previously mentioned, FI values during the first eight days and on June 16 were deemed outliers and excluded from FI analyses. The initial collection period was further separated into four (4) particularly hot periods and one (1) particularly cool period (Period 4) in order to better isolate events of heat stress and to quantify

adaptation. Analyses of best ambient predictor of  $T_{\text{core}}$  occurred using real-time and hourly lagged data and included hours from 0700 to 1700 h CST. This time period was chosen because it roughly coincided with the hours of RR collection and also captured the hours of the day during which an approximately linear increase in both  $T_{\text{core}}$  and  $T_{\text{a}}$  occurred (Figure 12). Lags of between zero and five hours were considered in order to determine if a delayed animal reaction existed during heat exposure. Analyses of best ambient or  $T_{\text{core}}$  predictor of daily herd FI was performed in a similar way, except in this case, values were averaged by day. Lags of between zero and seven days were applied to daily herd  $T_{\text{core}}$  and ambient averages in an attempt to determine the existence of a delayed FI response. Linear and 2<sup>nd</sup> order polynomial regressions were performed to determine best fit among variables. Quadratic values were deemed the best in terms of variation explained by the model as well as limited complexity (Figure 7).

One relatively cool and four hot periods were chosen for further analysis (Table 11, Figure 10). The four hot periods were initially chosen for their similarity in terms of  $T_{\text{a}}$  slopes (Figure 11), with the cool period chosen because of a combination of reduced slope and y-intercept. Each contains  $T_{\text{a}}$  values that increase over the course of the period. Hot periods were chosen in order to isolate brief heat events and to analyze their acute effects on animal variables. A cooler period was also chosen in order to compare the ambient predictors deemed successful in hot periods with those in a cooler period. Including short periods in our analysis allowed the comparison of long- and short-term predictors of FI and  $T_{\text{core}}$ . Finally, selecting periods throughout the study allowed us to determine any changes that may be associated with herd adaptation or hair coat shedding in the NORM group.

## Results and Discussion

### *Ambient Conditions*

Ambient values during the study are summarized in Table 7 and Figures 8, 9, 10, 11, and 12. Hourly-averaged  $T_a$  ranged from 19.59°C at 0600 h to 28.94°C at 1600 h (Figure 8). The lowest overall level for  $T_a$  was 0000 to 0700 h (20.53°C;  $p > 0.05$ ) followed by an increase to 0900 h (23.68°C;  $p > 0.05$ ) and then a plateau at 1200 to 1900 h (28.14°C;  $p > 0.05$ ) before decreasing ( $p \leq 0.05$ ) to 23.95°C at 2100 h. As expected, THI because it incorporates  $T_a$  and RH had a similar pattern with a low point of 66.85 at 0600 h and a high point of 77.42 at 1600 h. The THI nadir was between 000 and 0700 h (68.23;  $p > 0.05$ ) with an increase to 72.66 at 0900 h ( $p \leq 0.05$ ) and a plateau of 76.60 ( $p > 0.05$ ) at 1100 to 1900 h. The THI then decreased ( $p \leq 0.05$ ) to 72.83 at 2100 h. A shift to the left occurred with BG and BGTHI which reached a low hourly-averaged temperature of 22.56°C at 0500 hours and a peak of 44.30°C at 1300 h for BG, and 70.25 and 92.10 for the BGTHI lows and highs that occurred at the same hours. The nadir for BG temperature was 23.82°C at 2300 to 0500 h ( $p > 0.05$ ) with an increase to 29.21°C at 0700 h ( $p \leq 0.05$ ) before a plateau of 43.19°C at 1100 to 1600 h ( $p > 0.05$ ). Following the plateau, there was a decrease to 37.08°C at 1800 h ( $p \leq 0.05$ ). As seen for THI, the pattern for BGTHI was similar to BG temperatures with a nadir of 71.66 from 2300 to 0600 h ( $p > 0.05$ ). This was followed by a rapid increase to 77.13 at 0700 h ( $p \leq 0.05$ ), and a plateau of 91.03 from 1100 to 1600 h ( $p > 0.05$ ). By 1800 h, BGTHI had decreased to 84.74 ( $p \leq 0.05$ ).

Significant ( $p < 0.05$ ) differences among the five periods were minimal, with the exception of period 4, which was selected as a cool period. All hours of the day were

used in the determination of minimum, maximum, mean, and range of ambient values. These values were then averaged by day and by period. Average daily maximum THI values consistently reached and exceeded 77, which is the upper end of a range that Gaughan et al., (1999) defined as moderate heat stress conditions for beef cattle. Likewise, average daily maximum THI values consistently exceeded the point at which stress-limiting measures should be utilized (THI of 75; Hahn, 1997). Average daily maximum and mean  $T_a$  were similar to those measured in previous summer feedlot trials (Mitloehner et al., 2001; Mitloehner et al., 2002), and  $T_a$  values frequently exceeded 21 and 25°C, which are the points at which animals have been shown to increase respiration rate and decrease FI, respectively (Hahn, 1997). Other ambient variables, including BGSun and BGTHI were similar to previously published field studies during summer (Scharf et al., 2011; Gaughan et al., 1999; Schneider et al., 1986).

### *Core Temperature*

Core temperature response is summarized in Table 8 Figure 8, and Figure 12. Hourly-averaged  $T_{core}$  ranged from 39.72°C at 0800 h to 40.42°C at 2300 h over the entire period of study, with the results showing the 24 h daily pattern in Figure 8. The  $T_{core}$  increased from its lowest level at 0800 to 1200 h (39.77°C;  $p > 0.05$ ) to 1300 h (39.96°C;  $p \leq 0.05$ ) and again to 1600 h (40.02°C;  $p \leq 0.05$ ), before plateauing at 2100 to 0500 h (40.34°C;  $p > 0.05$ ). Measured  $T_{core}$  values were comparable to findings in other summer studies (Gaughan et al., 2010b; Scharf et al., 2011). Gaughan et al. (2010b) found that mean daily maximum  $T_{core}$  values among feedlot steers with access to shade (like those in the present study) ranged from approximately 39.5°C to 40.7°C over the 45-

day collection period. Scharf et al. (2011) also considered animals in a feedlot setting, albeit unshaded. In this trial, average daily  $T_{core}$  ranged from approximately 37.7°C to 40.4°C. As anticipated,  $T_{core}$  closely followed  $T_a$  in a way similar to previous field (Scharf et al., 2011) and chamber (Al-Haidary et al., 2001) studies. Summarized values include whole-herd averages of daily (24 h) minimum, mean, maximum, and range of  $T_{core}$ . Both NORM and TRT groups are included to show the differences across periods for the entire herd.

Core temperature analysis involved linear and second order polynomial regressions between ambient predictors (with aforementioned zero to five hours of lag) and hourly herd  $T_{core}$  values (Table 9). The best single predictor of hourly herd  $T_{core}$  was  $T_a$  with 2 and 3 h of lag (quadratic  $R^2 = 0.52$ ,  $p < 0.0001$ ). That is, the proportion of variation explained by the model did not change between two and three hours of lag. This finding is summarized by the following equation:

*Equation 12*

$$Mean(Lag T_{core}2) = 38.5763 + 0.0511(Mean T_a) + 0.0027[(Mean T_a - 26.0814)^2]$$

*Where,*

*Mean(Lag  $T_{core}2$ ) = Mean herd core temperature in °C 2 h in the future*

*$T_a$  = Current ambient temperature in °C*

The THI was an equally good predictor in terms of explained variation. However, THI required more hours of lag to achieve the same fit as  $T_a$ . The worst predictors were consistently BGSun ( $R^2 = 0.23$  to 0.45) and BGTHI ( $R^2 = 0.24$  to 0.50) (Figure 13 and

14). We assumed that BG values would be the better predictors of  $T_{\text{core}}$  since they took into account radiant heat load while THI and  $T_a$  did not. However, this was not the case to suggest that the steers were spending much of their time in the shade. When  $T_{\text{core}}$  by ambient coefficients of determination were plotted by amount of lag, a trend arose (Figures 6 and 7; Table 9). Predictor  $R^2$  values generally rose from zero hours of delay (e.g.  $T_a R^2 = 0.36$ ) for the first two to three hours of lag (e.g.  $T_a R^2$  rose from 0.36 to 0.52), and then fell as more lag was considered (e.g.  $T_a R^2$  fell from 0.52 to 0.47). All ambient predictor  $R^2$  values fell during period 4 as an apparent response to a diminished level of heat stress. The value of  $T_a$  as a predictor of  $T_{\text{core}}$  lies not just in its high  $R^2$  values across periods, but also from the ease with which it can be measured by producers. Practical value of  $T_a$  is likely higher than that of BG or THI readings, as no special equipment or calculations are required to determine readings.

This result was generally agrees with previous studies such as Lefcourt and Adams (1996) wherein variation in  $T_{\text{core}}$  among dairy cows was best explained by  $T_a$ . Lefcourt and Adams (1996) found the that maximum daily body temperatures increased with increasing maximum daily  $T_a$  above a threshold of 25.6°C, after which point, maximum daily  $T_{\text{core}}$  increased 0.57°C for every 5°C of ambient increase ( $p < 0.01$ , linear  $R^2 = 0.24$ ). Lefcourt and Adams (1996) did not consider the impact of hourly lag on the data, however. Similar to the present study in terms of hourly lag, Hahn (1997) indicated that entrainment of  $T_{\text{core}}$  by  $T_a$  was apparent with a three to four hour time delay. Brown-Brandl et al. (2005) also indicated that  $T_{\text{core}}$  lagged  $T_a$  by one to five hours in beef steers. Finally, Scharf et al. (2011) showed that a model utilizing a quadratic function of  $T_a$  also explained the most variation in  $T_{\text{core}}$  ( $R^2 = 0.56$ ) among beef steers. However, Scharf et

al. (2011) showed that a delay in response from one to three hours did not significantly improve  $R^2$  for the relationship between  $T_a$  and  $T_{core}$ . In contrast, the present study showed that delay did increase the proportion of variation explained by the model between  $T_{core}$  ambient conditions.

Hair removal prior to heat stress in the present study appeared to have an effect on  $T_{core}$ . Analysis of mean daily  $T_{core}$  over the entire period by animal and hour of day showed a  $0.23^\circ\text{C}$  lower  $T_{core}$  value for TRT versus NORM animals ( $p < 0.001$ ).

Likewise, maximum daily  $T_{core}$  was  $0.30^\circ\text{C}$  lower in TRT versus NORM animals ( $p < 0.0001$ ), with a smaller difference of  $0.13^\circ\text{C}$  in daily minimum  $T_{core}$  ( $p < 0.0001$ ). This is likely due to increased evaporative heat loss from the skin as reported by Zimbelman et al. (2010) via increased skin-level airflow. In theory, convective and radiative exchange from the skin could also be increased by hair coat removal. However, the animals used by Zimbelman et al. (2010) were shaded, so the effect of radiation was likely limited. Further, a literature review did not reveal studies in which differences in convective transfer were analyzed between shaved and normal hair coats.

Separate period analyses revealed a general decrease in quadratic  $R^2$  values when considering ambient predictors of  $T_{core}$  over the course of the study (Figures 13 and 14). As expected, coefficients of determination fell during the cooler period (period 4) as heat stress diminished relative to previous periods and  $T_{core}$  response decreased. Interestingly, both TRT and NORM responsiveness (based on quadratic  $R^2$  values of ambient predictors) also appeared to decrease during period 5 relative to the earliest three periods. This occurred despite period 5 being statistically similar (Table 7) to previous warm

periods. This may be an indication of adaptation over time, as lower  $R^2$  values could represent less responsiveness to heat events.

### *Respiration Rates*

Mean herd respiration rates, when averaged by time of measurement, ranged from 34 to 120 BPM. These values covered a greater range than means measured in lactating dairy cows subject to heat stress in chambers (Spiers et al., 2004; ~51 to 105 BPM), but were similar to that of Brahman steers subject to heat challenge in thermal chambers (Gaughan et al., 1999; 33 to 125 BPM). The range of mean respiration rates in the present study also appears to be similar to that seen in unshaded heifers in a Texas summer feedlot setting by Mitloehner et al. (2002; ~48 to 128 BPM). However, the range of mean respiratory values in the present study was actually smaller than that measured in Angus heifers in a Nebraska feedlot during summer by Brown-Brandle et al. (2006; 40 to 160 BPM). The discrepancies among ranges may be because of differences in animal numbers and animal acclimation. Our group found variation in average hourly herd RR to be best explained with both average hourly herd  $T_{core}$  (quadratic  $R^2 = 0.46$ ,  $p < 0.0001$ ) and average hourly  $T_a$  across the entire period of study (quadratic  $R^2 = 0.63$ ,  $p < 0.0001$ ). Thus, it appears that producers can predict  $T_{core}$  to an extent, based on RR. This finding is summarized in the following equation:

### *Equation 13*

$$\text{Mean(BPM)} = -1325.8370 + 35.0660(\text{MeanMax } T_{core}) - 7.0032[(\text{MeanMax } T_{core} - 40.2138)^2]$$

Where,

*Mean(BPM) = Current average respiration rate in breaths per minute*

*MeanMaxT<sub>core</sub> = Current average core temperature in °C*

Although hourly lags were incorporated and considered, lagging the data did not improve the coefficients of determination. This is consistent with previous studies, such as Valtorta et al. (1997) and Brown-Brandl et al. (2005) in which RR closely followed ambient conditions, but differs from Gaughan et al. (2000) and Hahn (1997) who both found that RR lagged behind T<sub>a</sub> and dry-bulb T<sub>a</sub> by two, and zero to three hours, respectively. Brown-Brandl et al. (2005) found that average RR actually preceded dry bulb T<sub>a</sub> by just under one hour, evidently because it was influenced by other environmental factors such as solar radiation (Brown-Brandl et al., 2005). Discrepancies in lag are likely due to animal housing and levels of solar exposure. For example, Gaughan et al. (2000) considered animals in environmental chambers, while Brown-Brandl et al. (2005) housed animals outside. Respiratory differences among periods are summarized in Table 8. Mean herd BPM generally increased as time went on, and roughly coincided with the response behavior in T<sub>core</sub>.

Treatment did not appear to have an effect on RR over the course of the study ( $p > 0.10$ ). However, when herd RR was averaged by hour of measurement, separated by treatment and plotted against unlagged T<sub>a</sub> during the whole study, the RR of TRT animals did appear slightly less responsive to T<sub>a</sub>. That is, less variation of TRT herd RR was explained by T<sub>a</sub> (quadratic  $R^2 = 0.60$ ,  $p < 0.0001$ ) than was the RR of NORM animals

(quadratic  $R^2 = 0.63$ ,  $p < 0.0001$ ). This finding was consistent when data were separated into the aforementioned hot periods (Figure 15). When separated by treatment and analyzed by period, the linear slopes of TRT animals were generally less steep than those of the NORM animals. The notable exception was the cooler period 4, which seemed to show less responsiveness among NORM animals. However, treatment appeared to have no effect ( $p > 0.10$ ) on RR means within periods. This was unexpected, as the lower  $T_{\text{core}}$  values that were an apparent result of the treatment would be expected to lower RR, as  $T_{\text{core}}$  and RR have been previously shown to be strongly related ( $r = 0.81$  to  $0.82$ ; Spiers et al., 2004). Nonetheless, the finding that variation in RR in real time is best explained by  $T_a$  is in agreement with other studies such as Elvinger et al., (1992) who showed a significant ( $p < 0.01$ ) heat stress effect on respiration rates in cattle. In terms of RR, no adaptation can be confirmed. There was a significant ( $p < 0.05$ ) increase in mean whole-herd RR from the first to last period. When further separated by treatment, RR also increased significantly for NORM ( $p < 0.05$ ) and TRT ( $p < 0.05$ ) groups from the first to last period. Initially, these results are contrary to what our group would expect to see in adapted animals. However, Horowitz (2001) argued that acclimation might lower the set point for thermoregulatory mechanisms to begin. That is, the onset of response in heat-adapted animals may begin at lower temperatures as they attempt to limit the impact of  $T_a$  on  $T_{\text{core}}$ . If so, this could account for the increased RR later in the trial, as the steers may have been shifting their set points for panting to lower temperatures in an adaptive coping mechanism.

### *Feed Intake*

A primary goal of this project was to determine predictors of FI in a feedlot environment during summer months. Animal #2550 was excluded from analysis after July 22 due to reading failure after this point. Prior to July 22, animal #2550 logged FI values consistently, and was included in the analysis. As an apparent result of the transition from receiving (Table 5) to treatment (Table 6) diets, early FI values were extraordinarily low. Thus, FI values for June 4 through June 11 and June 16, 2013 were determined to be outliers (Tukey Test) and were not subject to analysis. Raw mean daily herd FI, separated by treatment, is shown in Figure 16, and is also separated by period in Table 8. Figure 16 includes June 4 through 11 and 16, but these days were not statistically analyzed- only plotted. Mean daily whole-herd values ranged from 6.36 kg to 16.71 kg, over the entire trial, and the mean intake was 13.56 kg. As expected, mean herd FI, when averaged by period, tended to increase over time as the steers grew. Herd FI was significantly ( $p < 0.05$ ) higher in the later periods (Table 8) than in the first period, and was highest during period 4, likely because of the cooler  $T_a$  values during that period (Table 7). Whole-trial FI values tended to be higher than those measured in cattle used in environmental chamber studies (Hahn, 1997), but were similar to those measured in previous feedlot trials (Brown-Brandl et al., 2005; Mader, 2003) involving animals of comparable initial weight. The FI differences among trials are likely due to a combination of different animal weights, treatment diets, and environmental conditions, as FI regulators are complex and not understood fully (NRC, 2000).

Ambient predictors again included mean, maximum, range, and minimum daytime (0700 to 1700 h CST)  $T_a$ , RH, BGSun, THI, and BGTHI in addition to daytime

mean, maximum, minimum, and range of daily herd  $T_{\text{core}}$  values. Hourly  $T_a$  and RH values were measured as previous studies have indicated an inverse relationship between  $T_a$  and FI (Beatty et al., 2008). Further, BG values were considered in an attempt to capture the effects of radiant heat load on predominantly black animal subjects. Since BG temperature combines the effects of total incoming radiation (Bond and Kelly, 1955), it was thought to be a predictor in a field environment. Hourly THI value was also used since previous studies have indicated that FI decreases in response to elevated THI levels (Bernabucci et al., 1999). Finally, minimum ambient values were considered based on evidence suggesting that nighttime cooling in feedlot animals was important in limiting heat load (Meat and Livestock Australia, 2006). Regressions were performed using these potential predictors versus daily herd average FI. In addition, a lag was built into the analysis to determine FI response zero to seven days after ambient and/or  $T_{\text{core}}$  events. During the whole study, the best predictor of whole-herd herd FI was mean daytime BGTHI with a 2-day lag (quadratic  $R^2 = 0.25$ ,  $p < 0.0001$ ). This finding is summarized in the following equation:

*Equation 14*

$$\text{Lag2} = 27.9270 - 0.1596(\text{MeanBGTHI}) + .0009[(\text{MeanBGTHI} - 88.1911)^2]$$

*Where,*

*Lag2 = Mean herd feed intake in kilograms two days in the future*

*MeanBGTHI = Mean daily BGTHI value in the sun*

When separated by treatment, the best predictors of FI in the NORM group were maximum daily  $T_a$  with a 1-day lag (quadratic  $R^2 = 0.23$ ,  $p < 0.0001$ ) and mean daily  $T_a$  with a 1-day lag (quadratic  $R^2 = 0.21$ ,  $p < 0.0001$ ). Similarly, the best predictors of FI in the TRT group were mean  $T_a$  with a 2-day lag (quadratic  $R^2 = 0.31$ ,  $p < 0.0001$ ) followed by maximum  $T_a$  with a 2-day lag (quadratic  $R^2 = 0.30$ ,  $p < 0.0001$ ). This delayed response is in agreement with other studies such as Spiers et al. (2004) and West et al. (2003) who showed that FI did not necessarily decrease immediately in response to heat stress, but falls, up to three days after the onset of heat stress. As discussed in detail in the preceding literature review, the reason for the gradual (as opposed to immediate) decrease in FI during heat stress is controversial. One potential reason for the decrease in FI is the “thermostatic theory” proposed by Brobeck (1948). That is, at a high temperature where loss of heat is difficult, FI should be low, lest by eating and assimilating food the body acquire more heat than it can dispose of. Gut distention has been implicated in satiety and decreased feeding (Della-Fera and Baile, 1980) and some studies have indicated increased gut fill during heat challenge (Westra and Christopherson, 1976; Grovum, 1979). Thus, the increased gut fill noted during heat may be at least partially responsible for decreased FI. As previously noted, other studies (Attenbery and Johnson, 1969; Silanikove, 1987; Warren et al., 1974) did not reveal that a hot environment depresses passage rate. Thus, increased retention time and gut fill may just be a symptom rather than a driver of FI reduction. Ultimately, the reduction of FI is likely the manifestation of the animals’ attempts at maintaining homeothermy in a coping response to new thermal stress (Silanikove, 2000). Since any feedstuff will exhibit a HI,

any feeding event can contribute to an increase in body temperature (Shibata and Mukai, 1979). Thus, FI is reduced in response to greater heat load.

Hair coat reduction appeared to significantly ( $p < 0.0001$ ) decrease daily FI over the course of the study. Average FI for the NORM group over the study was 14 kg per day, while that of the TRT group was only 13.5 kg per day. One explanation for this reduction is the possibility for more solar radiation to be reaching the skin of the animals, making them “feel” hotter and decrease FI, in spite of actually being measurably cooler internally. This theory is supported by findings by Hutchinson and Brown (1969) that indicated dense hair coats limited penetrance of radiant energy better than thin hair coats.

### *Conclusions*

We investigated the feasibility of predicting FI based on ambient and animal variables, as well as the impact hair removal has on animal heat response and performance. The ability to gather and analyze data at varying resolutions (hourly for  $T_{\text{core}}$  and daily for FI) was afforded by telemetry. As expected and previously described in the literature, variation in  $T_{\text{core}}$  was quickly (within three hours) explained by a model fit using  $T_a$ , and hair coat reduction appears to have significantly lowered  $T_{\text{core}}$  values during the study. It is possible that treatment made animals more susceptible to radiant heat and seek shade more readily. If so, it is this behavioral modification alone may explain the generally lower  $T_{\text{core}}$  values in the torched group. More research is needed to determine the impact of treatment on behavior. Due to the weaker coefficients of determination between  $T_{\text{core}}$  and BG values than between  $T_{\text{core}}$  and  $T_a$  or THI, we can conclude that BG readings may not have as much value in predicting  $T_{\text{core}}$  when animals

have free access to shade. It appears that  $T_{\text{core}}$  responsiveness to ambient conditions was decreased by means of hair reduction. Additionally, and as previously described in the literature, variation in RR was immediately (no hourly lag) explained by a model fit using  $T_a$ . The reduction of hair coat slightly affected responsiveness to ambient conditions, but did not affect overall RR levels during the study. The present study also succeeded in establishing predictors for FI, in the form of  $T_a$  and BGTHI with 2-day lags. This finding illustrates the importance of the temperature humidity index in feedlot settings. It also illustrates the tendency for FI to decrease over the course of days in response to acute heat stress, as opposed to an immediate drop. However, it is worth noting that, since  $T_a$  is easier to measure and practically just as effective at predicting FI changes as BGTHI, it may be that  $T_a$  is superior in a production setting. Unexpectedly, hair coat reduction appeared to negatively and significantly impact FI. Further study is needed to determine the reasons for lowered FI, but it is our hypothesis that the reduction in hair coverage led to a weaker barrier between the skin and radiant heat. This may have caused the animals to “feel” hotter despite generally lower  $T_{\text{core}}$  values, and subsequently depress FI. Overall, the low cost of the treatment and significant lowering of  $T_{\text{core}}$  achieved make coat singeing an attractive option to producers interested in improving animal welfare.

## CHAPTER 4

### SUMMARY AND COMPARISON OF FINDINGS DURING FEEDLOT STUDIES

#### **Introduction**

The objective of the present studies was to determine if ambient conditions could be used to predict current and near-term animal performance in a field environment (e.g. herd  $T_{\text{core}}$  and FI). It is well known that cattle exposed to heat challenge decrease production (e.g. FI and milk yield). However, what is less well known is the rate by which changes in ambient conditions result in changes in animal performance. One major goal of the 2011 study was to determine the best ambient variable(s) for predicting animal response ( $T_{\text{core}}$ ) and performance (FI) as well as the time required for these changes to occur in the animals. Further, since it has been shown that animal variables such as RR and  $T_{\text{core}}$  respond relatively quickly to changes in ambient conditions, studies in this thesis also aimed at finding the relationship between animal responses to ambient conditions, and animal performance. Specifically, during the 2013 trial, our group sought to determine the value of RR in predicting  $T_{\text{core}}$  as well as the value of RR and  $T_{\text{core}}$  as predictors of FI. Further, we wanted to determine whether or not winter hair coat removal had practical value as a therapy for hyperthermia.

Studies presented in this thesis were designed to replicate summer conditions that could be experienced nearly ubiquitously in feedlots in other Midwestern locales. However, a thorough review of literature revealed that many of the conditions measured in these studies are similar to those recorded in previous studies in different parts of the world. Thus, it may be that the results of the present trials translate effectively to feedlot

environments in many other production settings. That is, results presented in this thesis are likely applicable to other animals of similar age, metabolic status, and biological type regardless of location, as long as the ambient conditions and housing is similar.

In order to achieve a realistic feedlot setting, animals were housed outdoors at the BRTF. Animals were fed a mixed ration and provided water ad libitum, as is typical in feedlot settings. Further, animals had access to shade, but pens were only ~50% covered by a metal roof. Since the cattle were housed outside, as opposed to environmental chambers, it was imperative that  $T_{\text{core}}$  values be recorded via telemetry. Previous studies that recorded  $T_{\text{core}}$  relied on physical measurement of RT. This could likely not be achieved in a typical feedlot setting with any useful resolution. Similarly, FI data were gathered for each animal using unique RFID tags and corresponding scaled feedbunks. These telemetric aids allowed our group to gather  $T_{\text{core}}$  and FI data with high resolution in a feedlot setting.

**Summary of Chapter Two:** *Determinants of body temperature and feed intake in beef cattle during exposure to summer heat stress*

The purpose of this summer 2011 experiment was to scrutinize the relationship between ambient variables and animal response to heat stress over a single, extended period of time. Previous research has shown that  $T_{\text{core}}$  and FI respond to climatic changes within hours and days, respectively. Our group sought to build on these previously established findings in order to develop predictive equations that may be applied by producers in realistic production settings. We hypothesized that equations could be developed that would allow feedlot operators to accurately predict animal responses

based on easily measureable ambient conditions. Further, we considered the relationship between  $T_{\text{core}}$  and FI in an attempt to capture the best predictor of near term FI. Our group initially thought that herd  $T_{\text{core}}$  would show a stronger relationship with FI than would ambient predictors. A heat-induced change in FI must depend on a shift in the thermal status of the animal at some location in the body. Ruminal  $T_{\text{core}}$  serves as one of many integrators of animal conditions and thermal status within the animal, and so was expected to be a primary determinant of FI.

Since climatic conditions were not controlled, study animals were subject to typical summer conditions. This fact likely decreased the strength of relationships we measured, due to greater variance among ambient conditions. However, by conducting the experiment in a field environment, our results may be of more value to producers than previous trials that tested animals over a short period of time in thermal chambers under strictly controlled conditions. Additionally, our group considered a larger number of animals than did previous chamber studies, which inserted greater variability into the analysis by default. The goal was to make the trial as similar to a “real-world” setting as possible.

Results from this experiment reinforced the value of using BG thermometers in field environments. Analysis performed by our group also corroborated previous trials that showed a short lag associated with  $T_{\text{core}}$  response to ambient conditions. Findings showed that BG temperature in shade was the best indicator of herd  $T_{\text{core}}$  within the next hour, and this predictor was nearly matched by  $T_a$  in terms on the strength of the measured relationship. The BG values may have been better predictors of  $T_{\text{core}}$  as they account for the radiant heat experienced by the animals. As the cattle tended to stand in

the shade during hot, sunny parts of the day, it seems that BG temperature accounted for the effect of this shade provision.

It appears that cattle may actually respond to heat stress by eating less in a way that is more dependent on ambient conditions than on their  $T_{\text{core}}$  level. That is, when our group plotted daytime ambient values in addition to daytime  $T_{\text{core}}$  values against daily herd FI,  $T_{\text{core}}$  served as a very poor predictor. The  $T_{\text{core}}$  regressions against FI yielded poor coefficients of determination across all days of lag, and even when considering average range, minimum, mean, and maximum herd  $T_{\text{core}}$ . In addition, attempts at using  $T_{\text{core}}$  as a predictor consistently yielded less significant ( $p > .02$ ) analyses of variance than did ambient predictors. One contributing factor may be the disconnect that exists between ambient and  $T_{\text{core}}$  values, as evidenced by the hourly lag discussed previously. As an example, animal  $T_{\text{core}}$  values tended to rise in the evenings, in spite of falling  $T_a$  readings. While it was not studied during this trial, our group supposes that this  $T_{\text{core}}$  increase may be the result of animals increasing FI late in the day, as  $T_a$  decreased. Future studies of similar types could benefit from recording the exact time of day each animal consumes feed. This information could account for otherwise inexplicable  $T_{\text{core}}$  increases during times of ambient cooling. In the end,  $T_{\text{core}}$  did not represent an effective means of anticipating future FI. Rather, BG ambient values proved to be the best predictors, not only of  $T_{\text{core}}$ , but also of future FI response. Future research is needed to determine the repeatability of our findings, or whether FI can be predicted with confidence within a shorter timeframe.

The present trial demonstrated the benefits of quantifying radiant heat load in feedlot cattle. The BG temperature in the sun, in combination with THI, proved the best

combination when anticipating near-term (5-day) FI changes. Likewise, BG temperature in the shade was the best ambient predictor of  $T_{\text{core}}$ . It may be worth noting that raw  $T_a$  data was nearly as effective as BG temperature in the shade at forecasting herd  $T_{\text{core}}$  within the hour. Thus, we can conclude that in a production setting, where BG thermometers may not be convenient or available,  $T_a$  provides a satisfactory means of determining within-hour herd thermal status. Previous trials that attempted to predict FI did not require the 5-day delay that our study indicated. One reason for this difference could be the lack of radiant heat experienced by animals in previous chamber studies. However, this particular area of research appears lacking, and future research is needed to determine the repeatability of our findings, or whether FI can be predicted with confidence within a shorter timeframe.

**Summary of Chapter Three:** *Effect of reduced hair coat on, and ambient and animal predictors of performance of feedlot steers during summer heat stress*

The purpose of this experiment was similar to that conducted in 2011. Our group wanted to determine the repeatability of the findings from the 2011 study, and confirm the ability to predict animal response to heat stress in a feedlot setting. However, our group made two critical changes to the previous experimental design. The first was to record animal RR twice per day (morning and afternoon) during hot periods of the summer. Previous studies have shown the value of RR as an indicator of animal thermal status. We hypothesized that RR could be analyzed in the same way as other ambient variables in another attempt at developing effective predictive equations. That is, our group wanted to see if RR was as good or better at predicting  $T_{\text{core}}$  as BG temperature and

$T_a$  had been during the 2011 trial. The second change was the addition of a treatment group. Half of the animals were subject to treatment consisting of winter hair removal from the flank and topline. Previous studies have shown that excess hair removal can help lower  $T_{core}$  in cattle, and our group sought to investigate this and subsequent effects on performance.

The housing of the 2013 cattle was the same as that in 2011, although more animals were used. Treatment involved hair removal via propane torch, and aimed to mimic the ultimate result of natural shedding. This protocol was carefully adapted from its original design as an aid to dairy udder hygiene. There were no repeated hair removals since hair growth was minimal once heat stress began. In fact, the NORM group lost hair as well and was expected to approach the TRT group towards the end of the summer. Again, care was taken to maintain as realistic a design as possible, so as to make findings applicable to production settings.

Treatment, as expected, achieved the goal of decreasing herd  $T_{core}$  significantly, and this effect was consistent from beginning to end of the trial. That is, the magnitude of  $T_{core}$  reduction was similar from early periods to later periods. Thus, even over the course of the trial, it does not appear that NORM animals shed their hair coats to the extent that TRT animals had theirs removed. Decreased  $T_{core}$  is likely the result of increased airflow at the level of the skin. Animals with less hair to insulate capillary beds may lose more core heat to their environment than those in the NORM group.

Surprisingly, treatment did not appear to have an effect on RR during the summer. Our group had hypothesized that winter hair removal would make animals less hyperthermic and pant less as a result. As this was not the case, it may be that decreased

hair coverage allows more radiant energy to reach the skin, and animals panted faster in response to this radiant heat instead of elevated  $T_{\text{core}}$ . If so animals with less hair might feel hotter than they actually are, and RR may not decrease with treatment, as animals mistakenly exhibit a coping mechanism associated with increased  $T_{\text{core}}$ . Similarly, analysis did not show a significant effect of hair removal on FI during the course of the trial. Again, it may be that TRT animals felt hotter as a result of increased radiant heat absorption. Animals that feel hot may not be willing to feed, and any  $T_{\text{core}}$  advantage enjoyed by treatment animals would not be manifest in FI recordings. Further research is needed to determine whether a hair removal protocol can offer benefits beyond that of increased animal welfare.

In terms of predictive equations, the 2013 study again found value in  $T_a$ , perhaps the most simple to measure of all ambient variables. Even RR didn't surpass  $T_a$  as the best single predictor of herd  $T_{\text{core}}$ , as evident in the equation our group developed. Unlike the 2011 study, BG values were not superior to  $T_a$  in predicting  $T_{\text{core}}$ . As in 2011, however, animal  $T_{\text{core}}$  response to  $T_a$  was found to be rapid, although this time no lag was required to achieve a strong coefficient of determination. This was consistent with previous trials, and reinforces the theory that  $T_{\text{core}}$  is strongly and nearly immediately dependent on  $T_a$  in a field environment. Also similar to previous trials, was the finding that herd FI decreased in response to daily  $T_a$ —within two days. Predictor discrepancies between the 2011 and 2013 studies are likely due to different numbers of animals and study days. The amount of lag required for strongest coefficient of determination was less than previously determined in 2011, but since it is similar to previous studies, our group suspects that the 2-day lag may ultimately be deemed the standard in industry

predictive calculus. Further study is needed in order to confirm this and previous studies' finding of a 2-day lag.

## **Conclusions**

The economic impact of heat stress is large and is may be poised to increase as beef prices remain strong. In addition, climate change may contribute to less predictable environmental conditions in general, and higher summer temperatures specifically. If these trends continue, the ability of producers to apply predictive equations that determine the thermal status and future performance of herds will be increasingly important from both an animal welfare and economic standpoint. The studies presented in this thesis showed that these equations can be developed in a realistic feedlot setting. In spite of variance inherent to field studies, our group succeeded in using relatively easy-to measure ambient variables to anticipate otherwise difficult to measure animal responses. What's more, our group did not rely on multiple linear regressions to find the best combination of predictors. Rather, in the interest of making data as applicable to producers as possible, our analyses found the best, single variables at forecasting  $T_{\text{core}}$  and FI.

While further research may be needed to repeat and refine the findings presented, it is clear that the impact on heat on feedlot animals can be accounted for using these techniques. The equations presented in this thesis represent ways by which producers can quantify the near-term thermal status of their animals, and "see into the future" when it comes to animal performance. Further, our group showed that RR is no better than  $T_a$  at quantifying herd heat load. This was a surprising finding, as RR is an example of an

animal's attempt to cope with higher temperature. We also showed that a torching protocol can be safely applied in a production setting to remove excess winter hair coat. This specific application is novel, but also appears relatively cheap and effective. More important, hair removal at the onset of summer significantly lowered animal herd  $T_{\text{core}}$  during the trial. This finding may prove valuable to producers interested in economical means of improving animal welfare during hot periods.

TABLES

**Table 1. Ingredient composition of receiving diet before 2011 study**

<b>Ingredient</b>	<b>% As fed</b>
Whole corn	55.00
Ground corn	10.89
Hay	10.00
Soybean meal	7.50
DDGS <sup>a</sup>	7.50
Blood meal	4.50
Limestone	1.23
Dyna-K <sup>b</sup>	1.10
Choice white grease	0.80
Salt	0.50
Cocci Curb 10x <sup>c</sup>	0.50
Pellet binder	0.30
Ruminate Trace Mineral	0.08
Aureo 50 <sup>d</sup>	0.05
Vitamin A, D, & E	0.05

Table 1. Ingredient composition on an as fed basis of receiving diet provided to calves prior to the start of the 2011 study

<sup>a</sup> DDGS: Distiller's Dried Grains with Solubles

<sup>b</sup> Dyna-K: Feed-grade Potassium Chloride

<sup>c</sup> Cocci Curb 10x: .05% Decoquate Coccidiostat

<sup>d</sup> Aureo 50: Chlortetracycline calcium complex equivalent to 50 g chlortetracycline hydrochloride per pound

**Table 2. Ingredient composition of treatment diets during 2011 study**

<b>Ingredient</b>	<b>Diets (% of DM)</b>				
	<b>SH20</b>	<b>SH60</b>	<b>SH80</b>	<b>SH90</b>	<b>SH100</b>
Whole corn	59	31.40	16.10	8.20	0
Soyhull pellets	14.90	47.10	64.70	73.80	82.30
Hay	10	10	10	10	10
Dry supplement <sup>a</sup>	0.27	0.27	0.27	0.27	0.27
Amino plus <sup>b</sup>	14.10	9.90	7.80	6.70	6.50
Alimet <sup>c</sup>	0.06	0.08	0.09	0.10	0.10
Salt	0.18	0.15	0.15	0.15	0.14
Limestone	1.14	0.67	0.38	0.23	0.10
Dicalcium phosphate	0	0.16	0.31	0.39	0.45
Choice White Grease	0.32	0.23	0.18	0.16	0.15

Table 2. Ingredient composition on a dry matter basis of the five different treatment diets provided to animals during the 2011 study

<sup>a</sup> Dry Supplement: Composition: 40.7% Beef Vitamin Premix (3,006,302 IU/kg Vitamin A; 751,575 IU/kg Vitamin D; 75,157 IU/kg Vitamin E), 27.1% Beef Trace Mineral Premix (10,000 ppm Copper; 25,000 ppm Iron; 20,000 ppm Manganese; 30,000 Zinc; 100 ppm Coalt; 100 ppm Selenium; 500 ppm Iodine), 26.7% Titanium dioxide (digestibility marker included during final 14 days) and 5.4% Rumensin 90 (200g/kg Monensin; Elanco Animal Health, Indianapolis, IN)

<sup>b</sup> Amino Plus: Ag Processing Inc., Omaha, NE

<sup>c</sup> Alimet: 88% Methionine; Novus International, St. Charles, MO

**Table 3. Average ambient conditions during 2011 study**

<b>Ambient</b>	<b>Daytime<sup>a</sup> Mean</b>	<b>Daytime<sup>a</sup> Range</b>	<b>Total<sup>b</sup> Mean</b>	<b>Total<sup>b</sup> Range</b>
T <sub>a</sub> (°C)	29.05	23.23- 32.49	27.26	22.61- 32.51
RH (%)	67.94	53.34- 91.79	75.17	53.27- 93.66
BGShade (°C)	29.89	23.69- 33.39	27.58	22.70- 33.39
BGSun (°C)	43.03	31.26- 49.60	35.71	25.49- 49.60
THI	79.03	73.10- 82.07	77.40	72.11- 82.09
BGTHI Shade	80.29	73.88- 83.35	77.86	72.22- 83.35
BGTHI Sun	99.31	86.73- 106.46	89.85	76.88- 106.46

Table 3. Minimum, maximum and range values were obtained for each day (excluding days 1, 16, and 42) and then averaged over the entire 2011 study

<sup>a</sup> Daytime: 0700 to 1700 h

<sup>b</sup> Total: 24 h

**Table 4. Average core temperature and feed intake during 2011 study**

	<b>Daytime<sup>a</sup> Mean</b>	<b>Daytime<sup>a</sup> Range</b>	<b>Total<sup>b</sup> Mean</b>	<b>Total<sup>b</sup> Range</b>
T <sub>core</sub> (°C)	39.96	38.38- 41.50	40.06	38.35- 41.70
FI (kg)	-	-	8.70	3.06-14.31

Table 4. Average herd minimum, maximum, and range values were obtained for each day (excluding days 1, 16, and 42) and then averaged over the entire 2011 study

<sup>a</sup> Daytime: 0700 to 1700 h

<sup>b</sup> Total: 24 h

**Table 5. Ingredient composition of receiving diet before 2013 study**

<b>Ingredient</b>	<b>% As Fed</b>
Whole corn	55.00
Ground corn	10.88
Hay	10.00
Soybean meal	7.50
DDGS <sup>a</sup>	7.50
Blood meal	4.50
Limestone	1.23
Dyna-K <sup>b</sup>	1.10
Choice white grease	0.80
Salt	0.50
Cocci Curb 10x <sup>c</sup>	0.50
Pellet binder	0.30
Ruminant Trace Mineral	0.08
Aureo 50 <sup>d</sup>	0.06
Vitamin A, D, & E	0.05

Table 5. Receiving diet composition on an as fed basis provided to calves prior to the start of the 2013 study

<sup>a</sup> DDGS: Distiller's Dried Grains with Solubles

<sup>b</sup> Dyna-K: Feed-grade Potassium Chloride

<sup>c</sup> Cocci Curb 10x: .05% Decoquate Coccidiostat

<sup>d</sup> Aureo 50: Chlortetracycline calcium complex equivalent to 50 g chlortetracycline hydrochloride per pound

**Table 6. Ingredient composition of treatment diet during 2013 study**

<b>Ingredient</b>	<b>% As Fed</b>
Whole corn	47.40
DDGS <sup>a</sup>	22.90
Corn Silage	19.80
Ground Corn	5.00
Soy Plus	1.76
Blood Meal	1.52
Limestone	1.14
Salt	0.24
Ruminate Trace Mineral	0.12
Vitamin A, D, & E	0.05
Magnesium Oxide	0.04
Vitamin E	0.03

Table 6. Treatment diet composition on an as fed basis provided to calves during the 2013 study

<sup>a</sup> DDGS: Distiller's Dried Grains with Solubles

**Table 7. Average total ambient conditions during 5 periods of the 2013 study**

	Periods				
	1	2	3	4	5
Mean T <sub>a</sub>	23.84 <sup>ab</sup>	24.26 <sup>ab</sup>	26.74 <sup>a</sup>	22.61 <sup>b</sup>	24.68 <sup>ab</sup>
Range T <sub>a</sub>	9.11 <sup>bc</sup>	10.53 <sup>ab</sup>	9.78 <sup>abc</sup>	7.88 <sup>c</sup>	11.12 <sup>a</sup>
Min T <sub>a</sub>	19.49 <sup>a</sup>	19.06 <sup>a</sup>	22.18 <sup>a</sup>	18.94 <sup>a</sup>	19.25 <sup>a</sup>
Max T <sub>a</sub>	28.59 <sup>ab</sup>	29.58 <sup>ab</sup>	31.96 <sup>a</sup>	26.82 <sup>b</sup>	30.37 <sup>ab</sup>
Mean BGSun	31.87 <sup>ab</sup>	32.98 <sup>ab</sup>	35.17 <sup>a</sup>	29.91 <sup>b</sup>	33.40 <sup>ab</sup>
Range BGSun	22.49 <sup>ab</sup>	24.58 <sup>ab</sup>	23.47 <sup>ab</sup>	21.49 <sup>b</sup>	25.89 <sup>a</sup>
Min BGSun	22.24 <sup>a</sup>	21.84 <sup>a</sup>	25.31 <sup>a</sup>	21.88 <sup>a</sup>	22.05 <sup>a</sup>
Max BGSun	44.73 <sup>ab</sup>	46.42 <sup>ab</sup>	48.78 <sup>a</sup>	43.37 <sup>b</sup>	47.93 <sup>a</sup>
Mean THI	72.17 <sup>a</sup>	71.92 <sup>a</sup>	76.45 <sup>a</sup>	71.38 <sup>a</sup>	72.95 <sup>a</sup>
Range THI	11.18 <sup>a</sup>	11.66 <sup>a</sup>	9.75 <sup>a</sup>	10.50 <sup>a</sup>	11.77 <sup>a</sup>
Min THI	66.52 <sup>a</sup>	65.51 <sup>a</sup>	71.35 <sup>a</sup>	66.01 <sup>a</sup>	66.49 <sup>a</sup>
Max THI	77.70 <sup>a</sup>	77.18 <sup>a</sup>	81.10 <sup>a</sup>	76.51 <sup>a</sup>	78.25 <sup>a</sup>
Mean BGTHI	79.74 <sup>ab</sup>	80.20 <sup>ab</sup>	83.87 <sup>a</sup>	78.04 <sup>b</sup>	81.11 <sup>ab</sup>
Range BGTHI	23.04 <sup>a</sup>	24.52 <sup>a</sup>	23.42 <sup>a</sup>	22.12 <sup>a</sup>	25.66 <sup>a</sup>
Min BGTHI	69.76 <sup>a</sup>	68.96 <sup>a</sup>	73.95 <sup>a</sup>	69.57 <sup>a</sup>	69.79 <sup>a</sup>
Max BGTHI	92.80 <sup>a</sup>	92.48 <sup>a</sup>	97.37 <sup>a</sup>	91.69 <sup>a</sup>	95.44 <sup>a</sup>

Table 7. 2013 Ambient conditions were averaged by day and analyzed across periods. Values within rows that are not connected by the same letter are significantly different ( $p < 0.05$ ).

**Table 8. Average core temperature, feed intake, and respiration rates during 5 periods of the 2013 study**

	Periods				
	1	2	3	4	5
Mean T <sub>core</sub> (°C)	39.89 <sup>c</sup>	40.05 <sup>bc</sup>	40.34 <sup>a</sup>	40.13 <sup>ab</sup>	40.27 <sup>a</sup>
Range T <sub>core</sub>	4.63 <sup>a</sup>	5.04 <sup>a</sup>	4.69 <sup>a</sup>	5.07 <sup>a</sup>	5.32 <sup>a</sup>
Min T <sub>core</sub>	37.42 <sup>b</sup>	37.56 <sup>ab</sup>	38.07 <sup>a</sup>	37.37 <sup>b</sup>	37.61 <sup>ab</sup>
Max T <sub>core</sub>	42.05 <sup>b</sup>	42.59 <sup>ab</sup>	42.76 <sup>a</sup>	42.44 <sup>ab</sup>	42.94 <sup>a</sup>
Mean FI (kg)	11.33 <sup>c</sup>	13.58 <sup>b</sup>	13.87 <sup>ab</sup>	15.23 <sup>a</sup>	13.21 <sup>b</sup>
Range FI	17.88 <sup>a</sup>	17.37 <sup>a</sup>	15.24 <sup>a</sup>	16.22 <sup>a</sup>	14.74 <sup>a</sup>
Min FI	1.12 <sup>c</sup>	3.09 <sup>bc</sup>	7.74 <sup>a</sup>	7.36 <sup>a</sup>	5.08 <sup>ab</sup>
Max FI	19.01 <sup>c</sup>	20.46 <sup>bc</sup>	22.97 <sup>ab</sup>	23.58 <sup>a</sup>	19.82 <sup>c</sup>
Mean RR (BPM)	65.86 <sup>b</sup>	77.80 <sup>ab</sup>	88.59 <sup>a</sup>	83.20 <sup>ab</sup>	85.90 <sup>a</sup>
Range RR	21.92 <sup>a</sup>	11.94 <sup>a</sup>	25.76 <sup>a</sup>	15.26 <sup>a</sup>	16.15 <sup>a</sup>
Min RR	55.01 <sup>b</sup>	71.84 <sup>ab</sup>	75.10 <sup>ab</sup>	71.91 <sup>ab</sup>	77.84 <sup>a</sup>
Max RR	76.92 <sup>a</sup>	83.78 <sup>a</sup>	93.99 <sup>a</sup>	87.17 <sup>a</sup>	93.99 <sup>a</sup>

Table 8. 2013 Mean, range, minimum, and maximum core temperature, feed intake, and respiration values by period. Values were averaged by day and period and then analyzed across periods. Intake values from June 5 through 12, and 16 are excluded. Intake values from animal #2550 are excluded after July 28. Core temperature values include all hours of the day and readings from June 17 through 20 are excluded. Values within rows that are not connected by the same letter are significantly different ( $p < 0.05$ ).

**Table 9. Quadratic R<sup>2</sup> values for core temperature prediction during the 2013 study**

N	Lag	T <sub>a</sub>	BGSun	THI	BGTHI
1044	0	0.36	0.23	0.31	0.24
949	1	0.48	0.38	0.44	0.40
854	2	0.52	0.44	0.49	0.48
759	3	0.52	0.45	0.52	0.50
664	4	0.50	0.42	0.52	0.49
569	5	0.47	0.36	0.49	0.43

Table 9. 2013 Coefficients of determination were calculated by plotting ambient conditions against lagged and real-time core temperature averaged by entire herd. All values are significant ( $p < 0.01$ ).

**Table 10. Quadratic R<sup>2</sup> values for core temperature prediction during the 2011 study**

N	Lag	TA	BGShade	BGSun	THI	BGTHIShade	BGTHISun
507	0	0.64	0.62	0.52	0.59	0.55	0.25
468	1	0.67	0.68	0.62	0.64	0.63	0.40
429	2	0.60	0.63	0.60	0.61	0.62	0.45
390	3	0.52	0.54	0.53	0.54	0.57	0.46
351	4	0.43	0.45	0.43	0.46	0.49	0.41
312	5	0.35	0.37	0.34	0.39	0.41	0.36

Table 10. 2011 Coefficients of determination calculated by plotting ambient conditions against lagged and real-time core temperature averaged by entire herd. All values are significant ( $p < 0.01$ ).

**Table 11. Periods and corresponding dates and days during the 2013 study**

<b>Period</b>	<b>Day of Study</b>	<b>Dates</b>
1	2 - 25	6/5 - 6/28
2	27 - 37	6/30 - 7/10
3	41 - 48	7/14 - 7/21
4	55 - 66	7/28 - 8/08
5	71 - 91	8/13 - 9/2

Table 11. Days and dates of the 2013 study that correspond with individual periods

## FIGURES

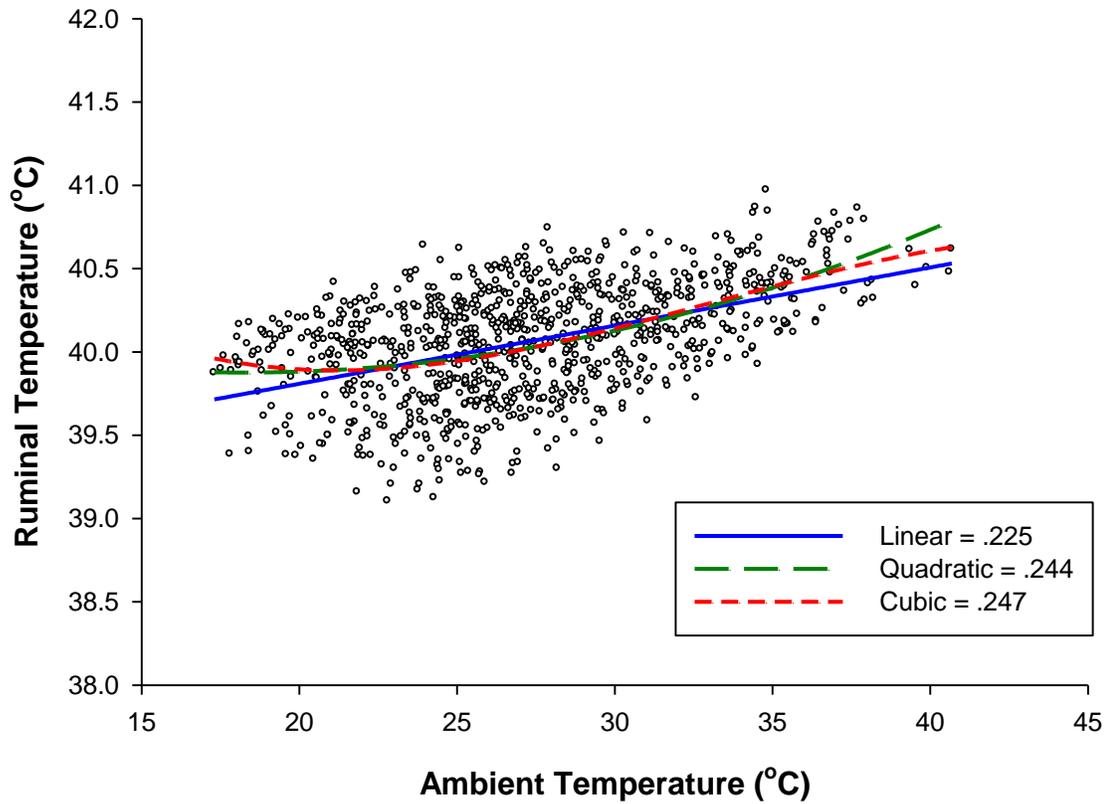


Figure 1. Example of typical regressions used when considering ambient and animal predictors. Ambient and ruminal temperatures were averaged by hour. Every hour of every day during the study is included, excluding days 1, 16, and 42. Quadratic coefficients of determination were consistently better than linear, and cubic coefficients were generally only marginally better than quadratic.

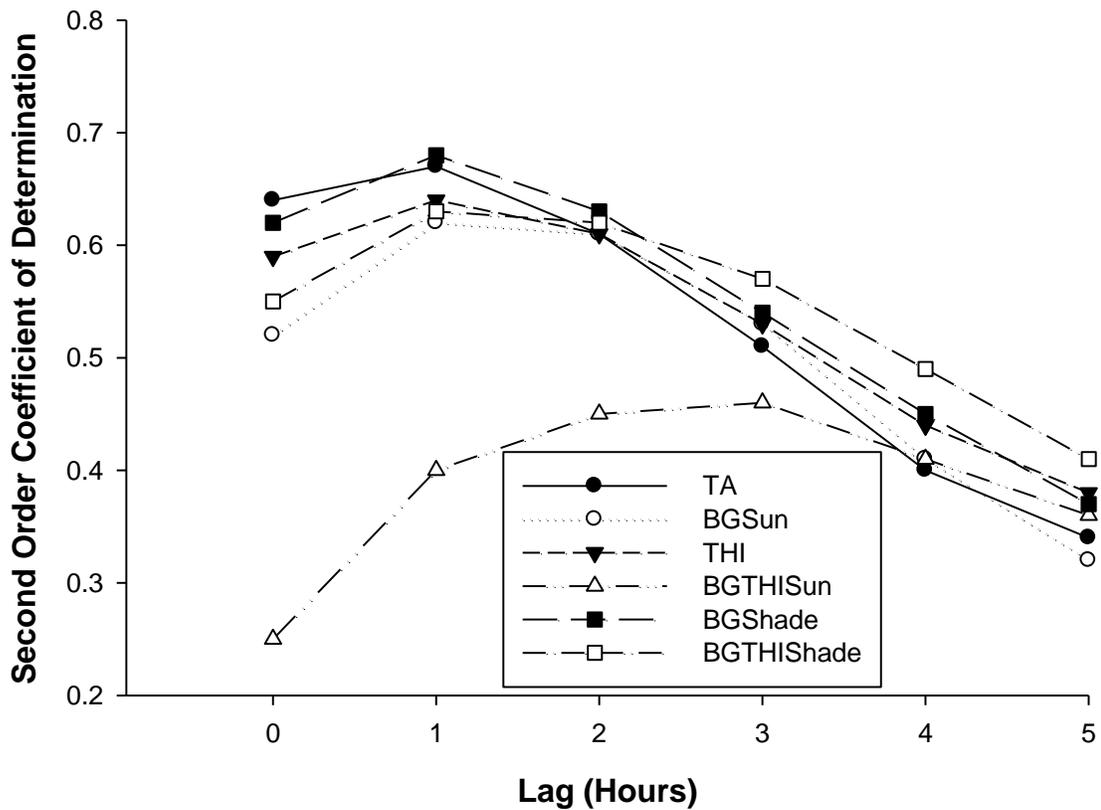


Figure 2. Coefficients of determination for the 2011 study between ambient variables and  $T_{\text{core}}$  with different time lags. Each point represents a quadratic  $R^2$  value. Coefficients were calculated by averaging herd ruminal temperature and ambient values by hour. Ambient values were then lagged and plotted against ruminal temperature to determine the coefficients. Only 0700 to 1700 h CST were considered during all days of the study, excluding days 1, 16, and 42.

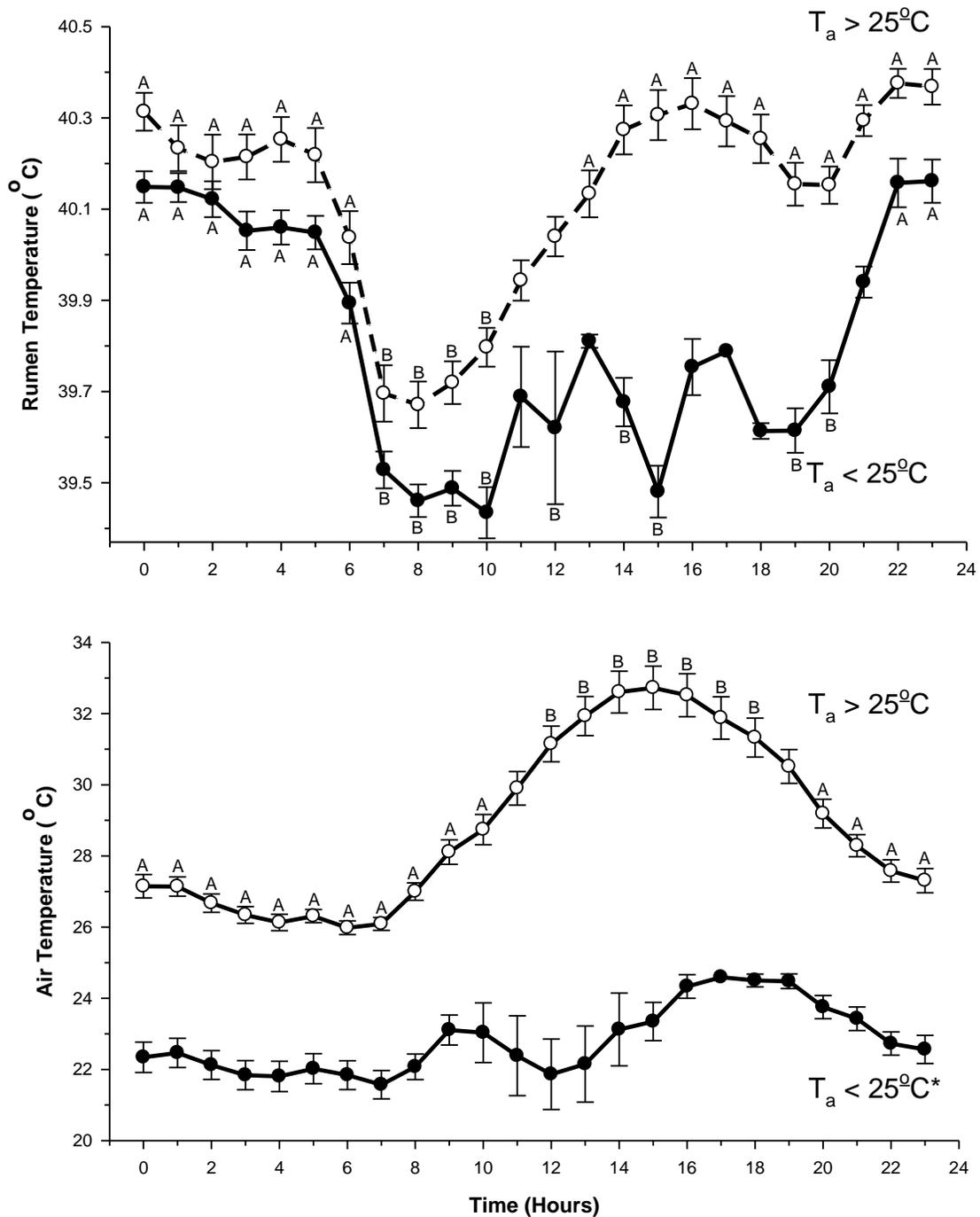


Figure 3. Average hourly core and air temperature by hour for the 2011 study, and separated by values greater than or less than ambient temperature of  $25^\circ\text{C}$ . Standard error bars are included. Hourly values that are not connected by the same letter (i.e. “A” or “B”) are significantly ( $p < 0.05$ ) different. \*No hourly air temperatures of less than  $25^\circ\text{C}$  were significantly different.

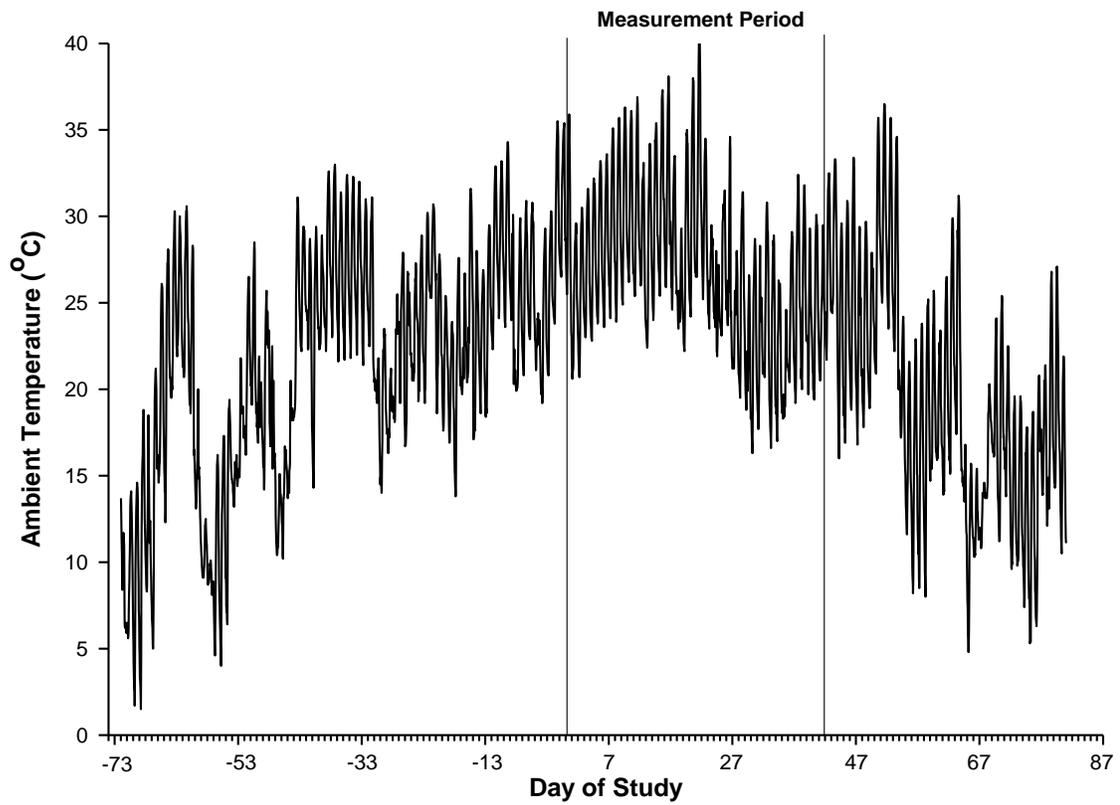


Figure 4. Air temperature was averaged by hour and every hour of every day was measured during the 2011 study, including periods preceding and succeeding the trial.

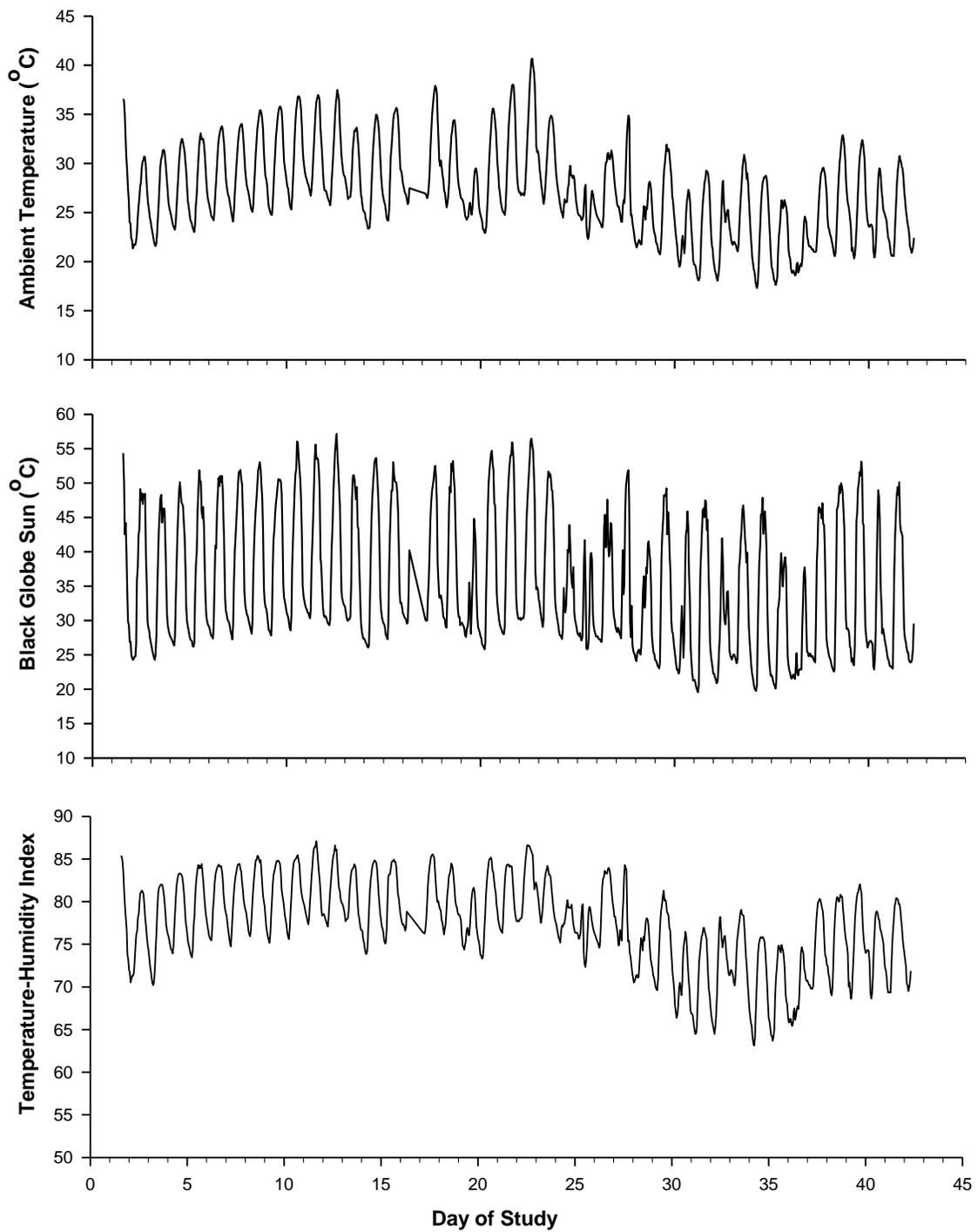


Figure 5. Ambient conditions for the 2011 study were obtained for every hour of every day and plotted by day and hour of study.

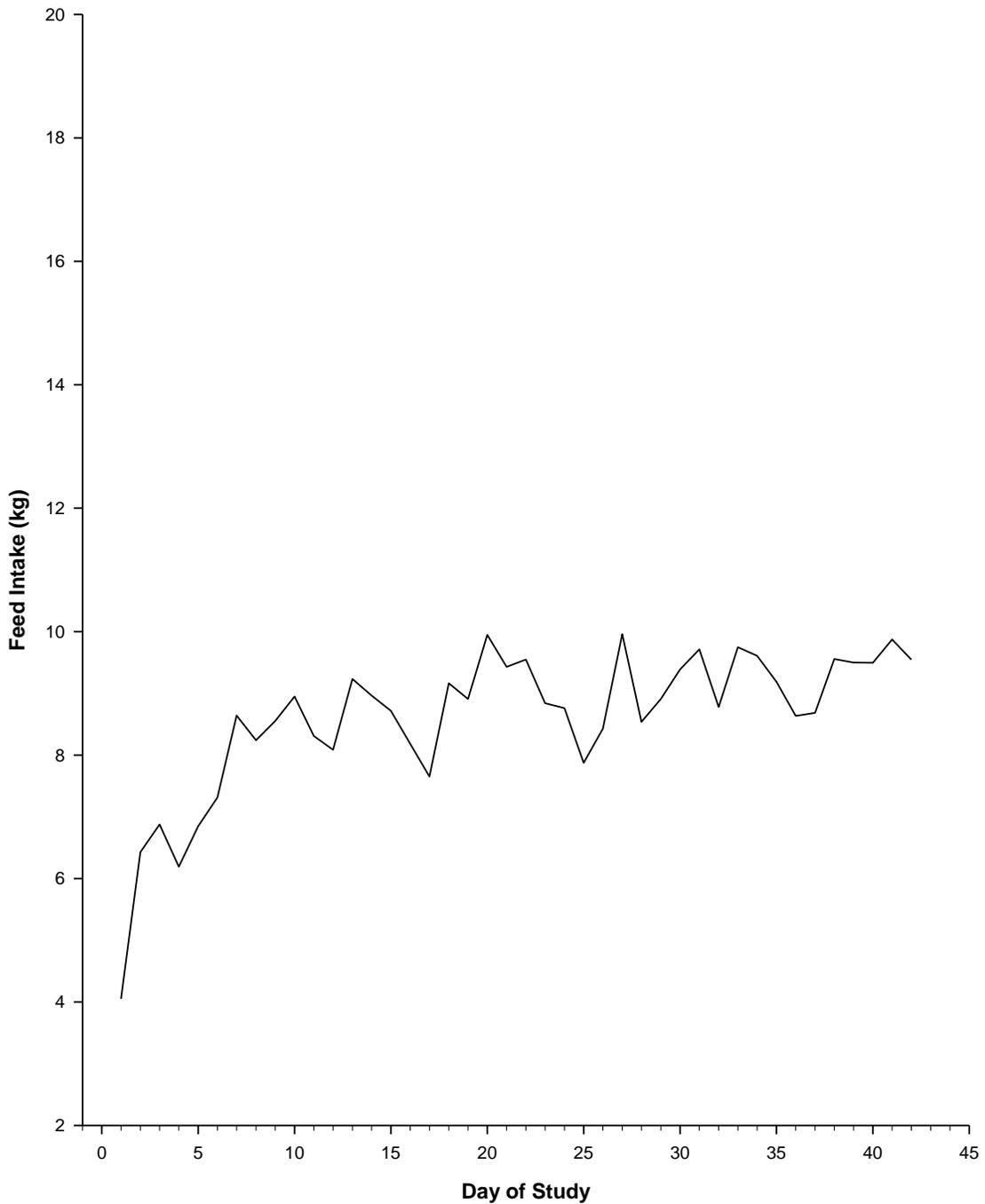


Figure 6. Average daily herd feed intake for the 2011 study plotted by day of study. Values were obtained from all animals for each day, and then averaged by day.

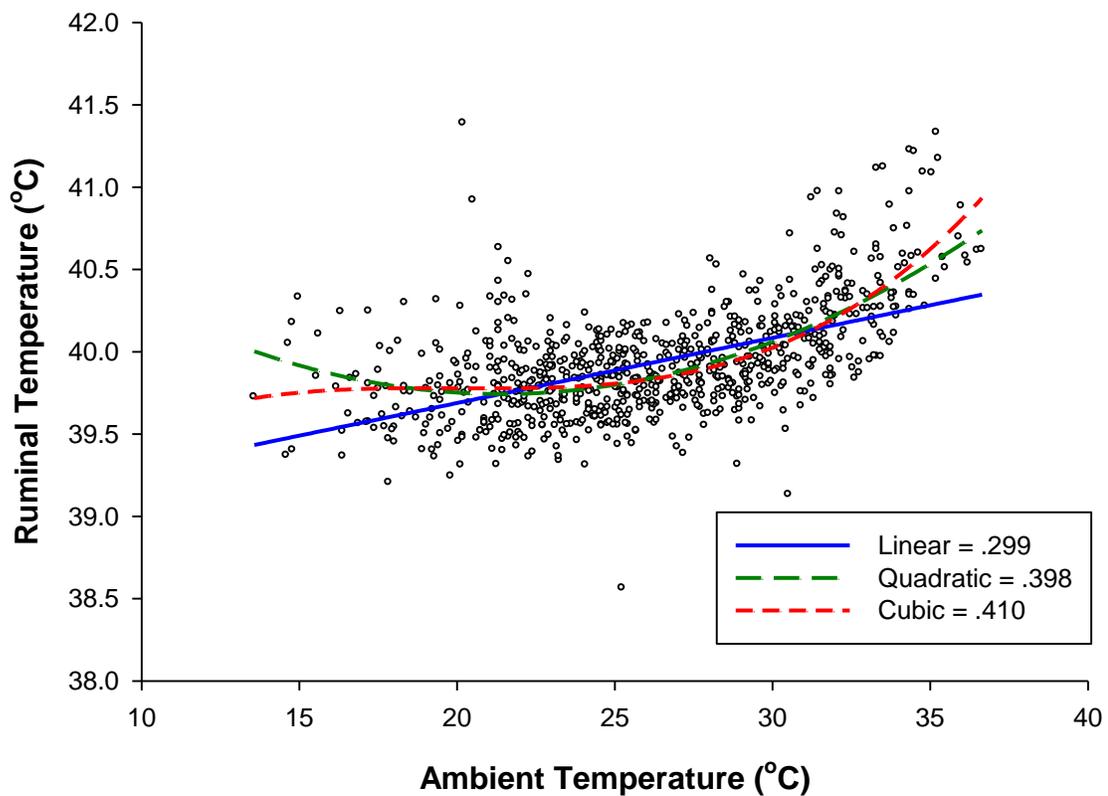


Figure 7. 2013 Example of typical regressions used when considering ambient and animal variables. Ambient and ruminal temperatures were averaged by hour. Every hour from 0700 to 1700 h CST of every day during the study is included, excepting those days deemed outliers. Quadratic coefficients of determination were consistently better than linear, and cubic coefficients were generally only marginally better than quadratic.

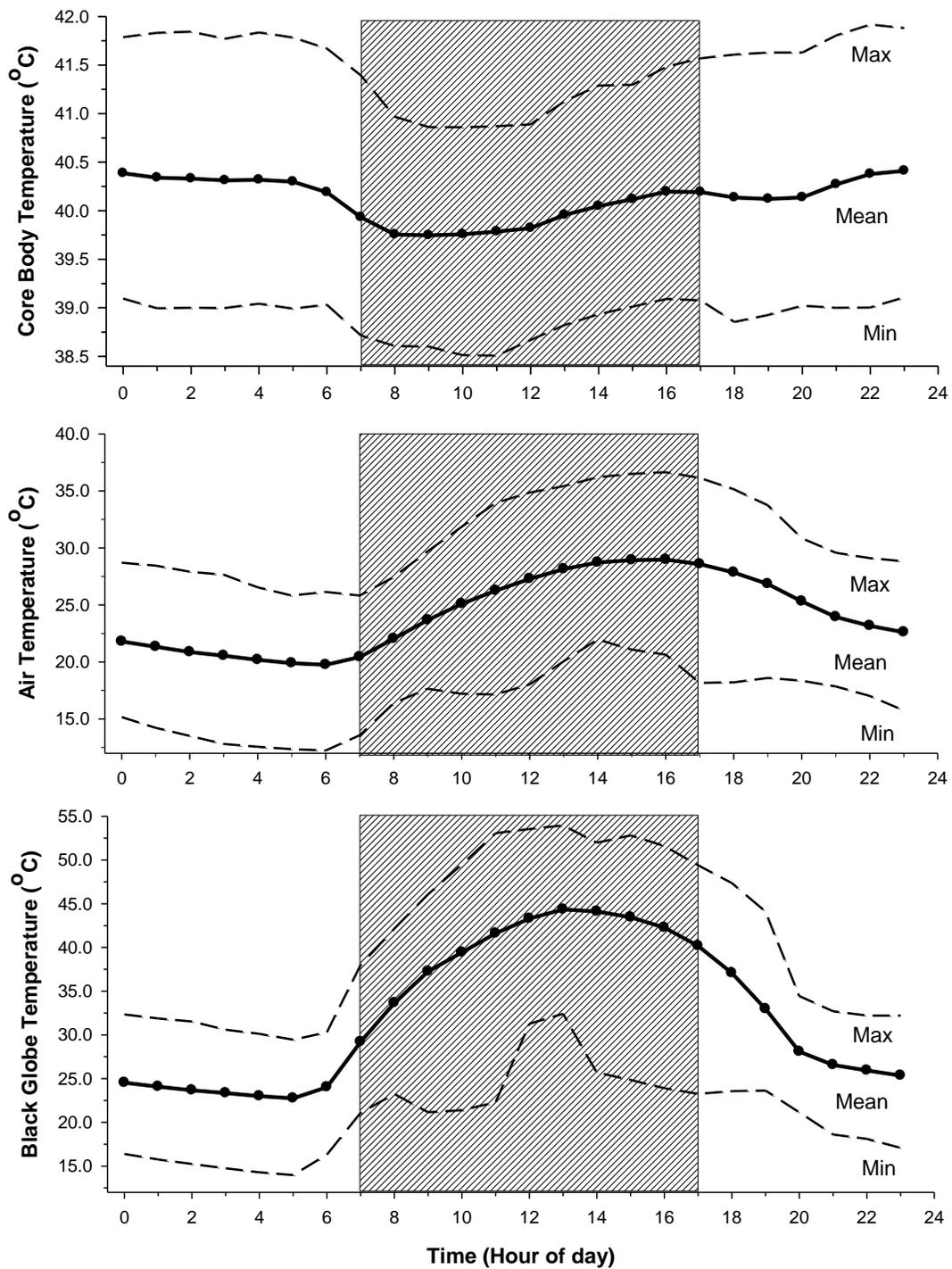


Figure 8. Average hourly minimum, mean, and maximum core, ambient, and black globe temperatures plotted by hour during the course of the 2013 study. Shaded areas denote hours used in analyses.

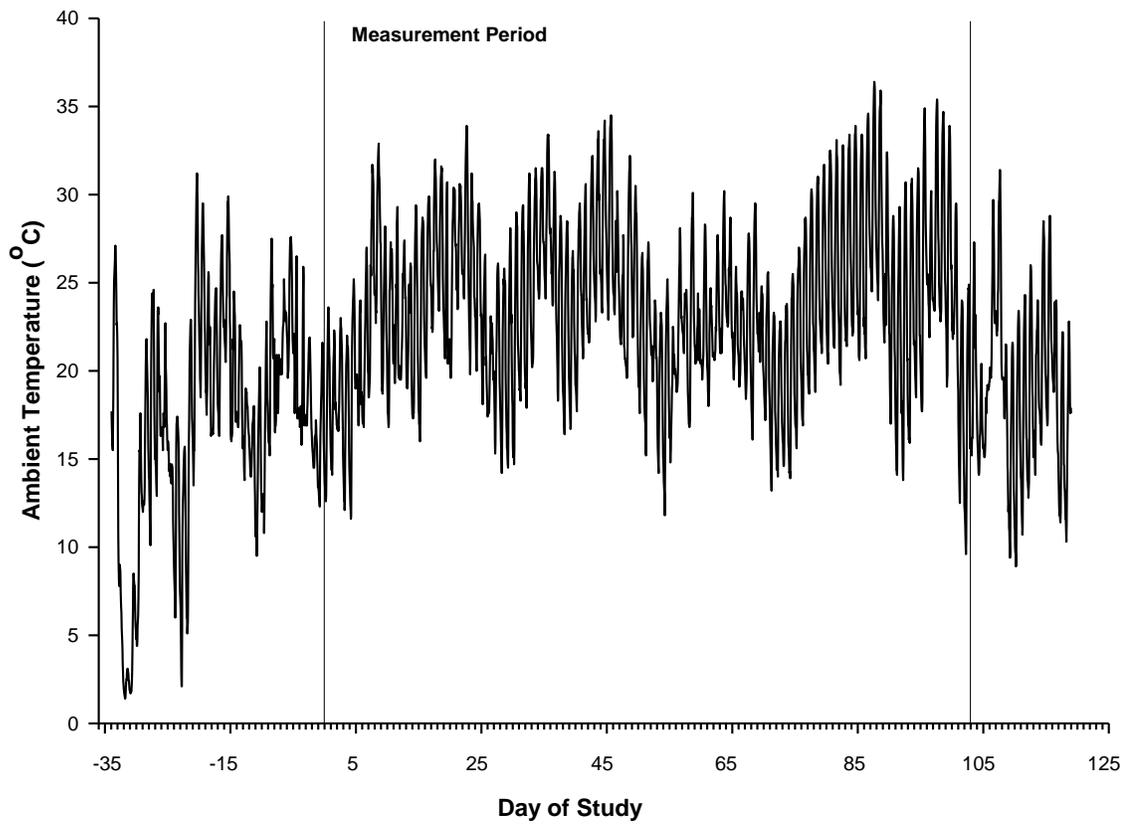


Figure 9. Air temperature was averaged by hour and every hour of every day was measured during the 2013 study, including periods preceding and succeeding the trial.

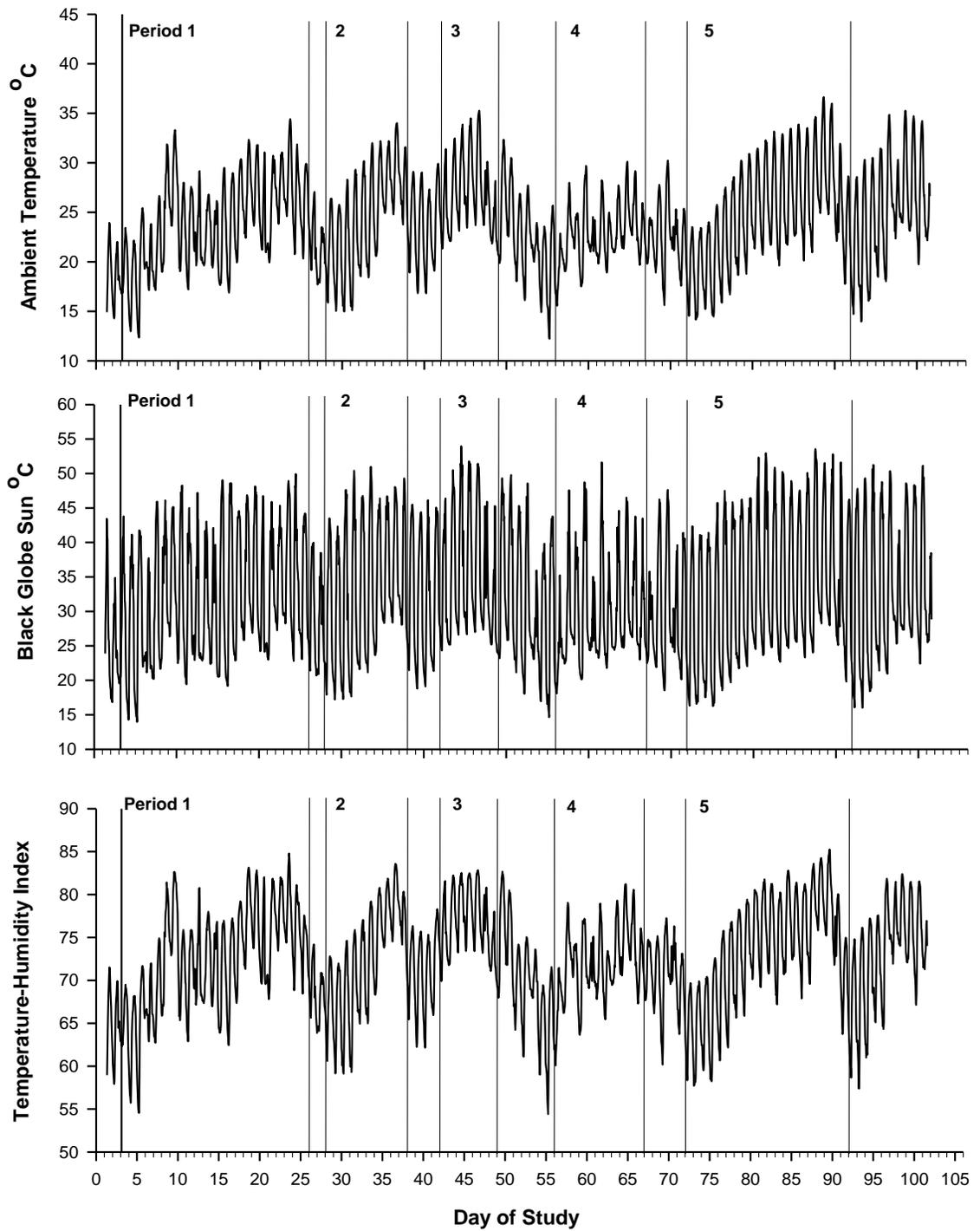


Figure 10. Ambient conditions for the 2013 study were averaged by hour and every hour of every day of the study was measured. Period partitions are shown.

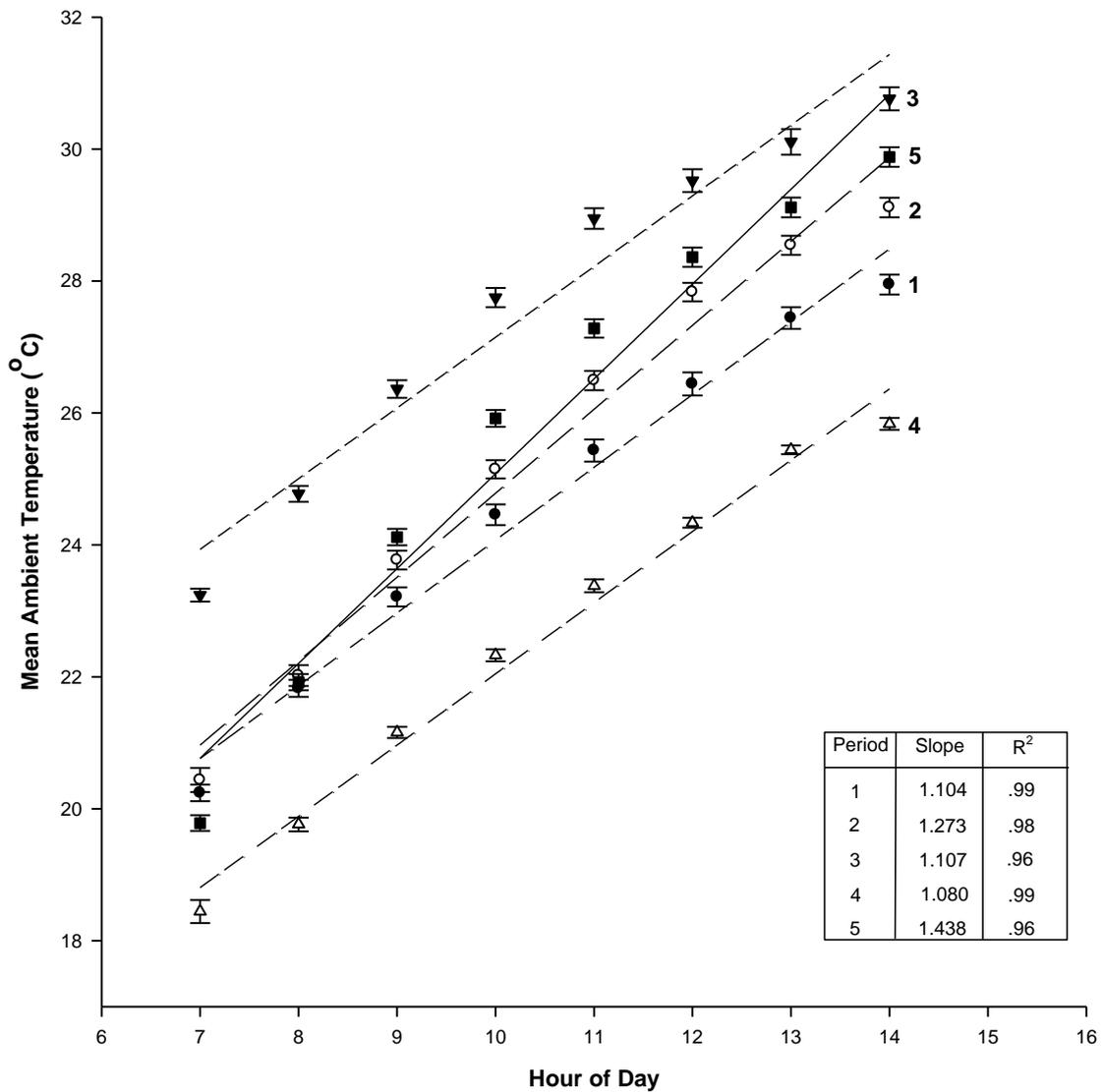


Figure 11. Ambient temperatures for the 2013 study were averaged by hour over the whole study and blocked by period (P1 through P5). Hours from 0700 to 1400 h CST were included in an attempt to capture the linear behavior of temperature rise during the first half of the day. A line was plotted for each period in 2013 to allow slope comparison, and standard error bars are included.

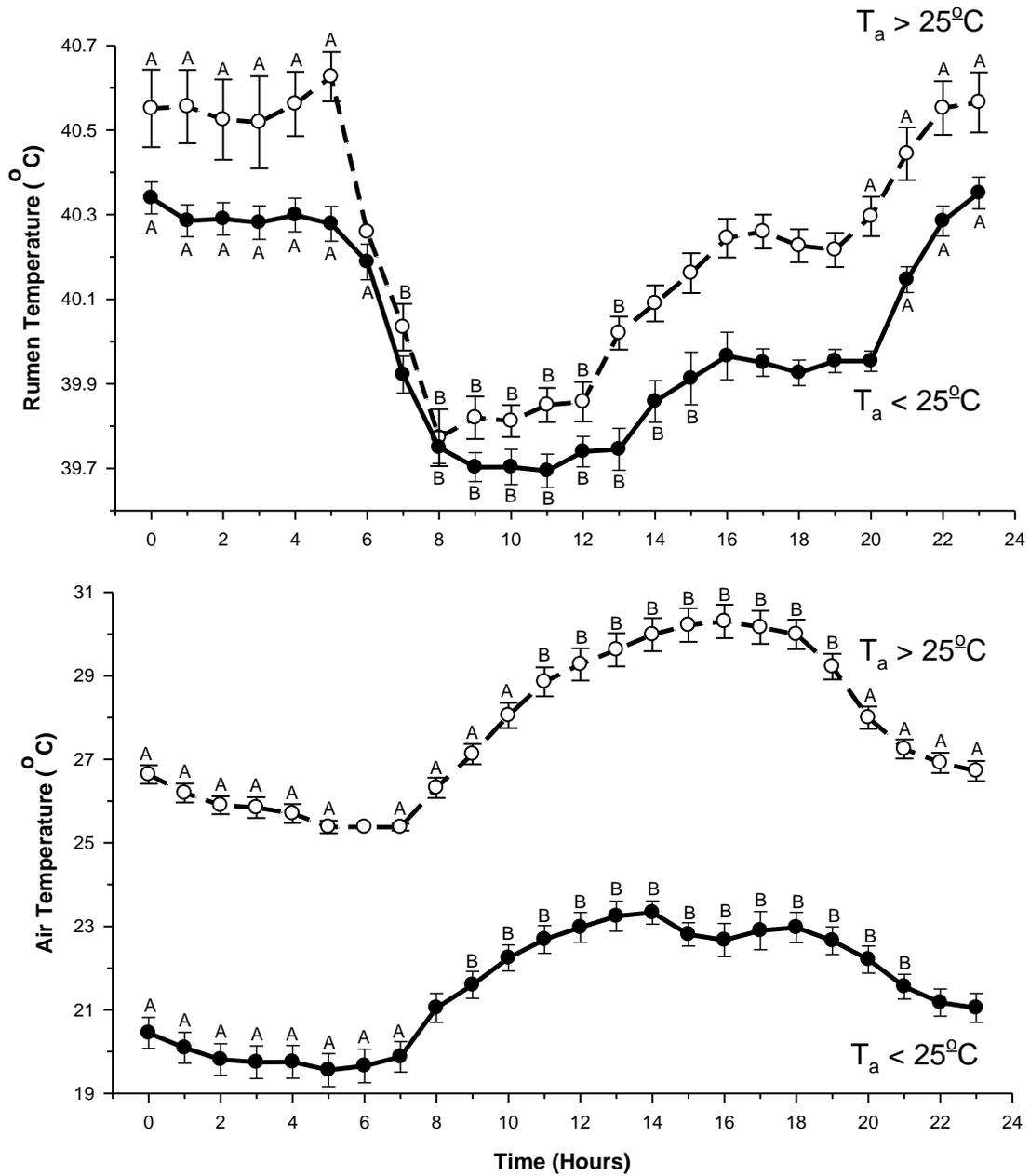


Figure 12. Average hourly air temperature for the 2013 study by hour, and separated by values greater than or less than  $25^\circ\text{C}$ . Standard error bars are included. Hourly values that are not connected by the same letter (i.e. "A" or "B") are significantly ( $p < 0.05$ ) different.

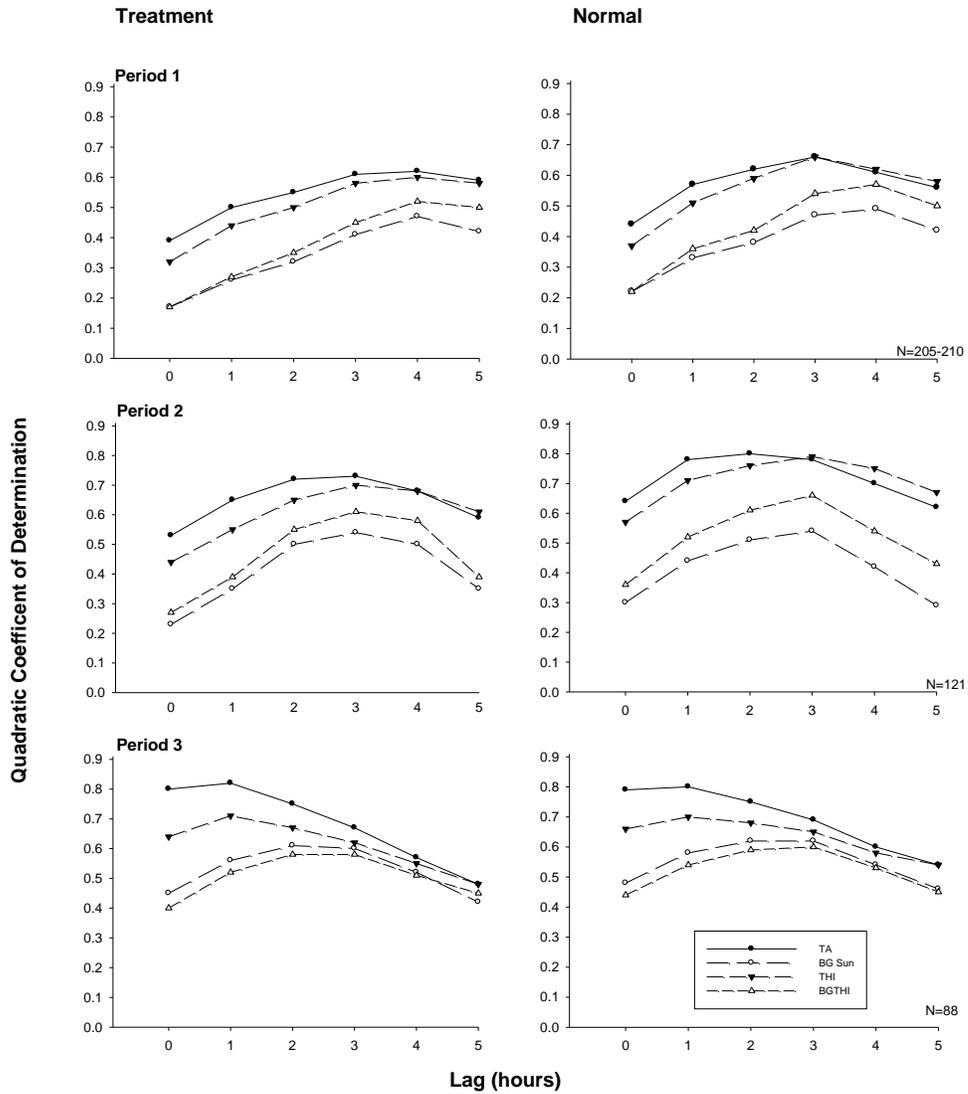


Figure 13. Periods 1 through 3 coefficients of determination for the 2013 study were calculated by plotting the effect of ambient conditions on mean core body temperature. The effect of delayed response was considered by incorporating hourly lags ranging from 0-5 hours. Ambient values were averaged by day and hour and core values were averaged by day, hour, and treatment. Only values gathered from hours 0700 to 1700 h CST were considered.

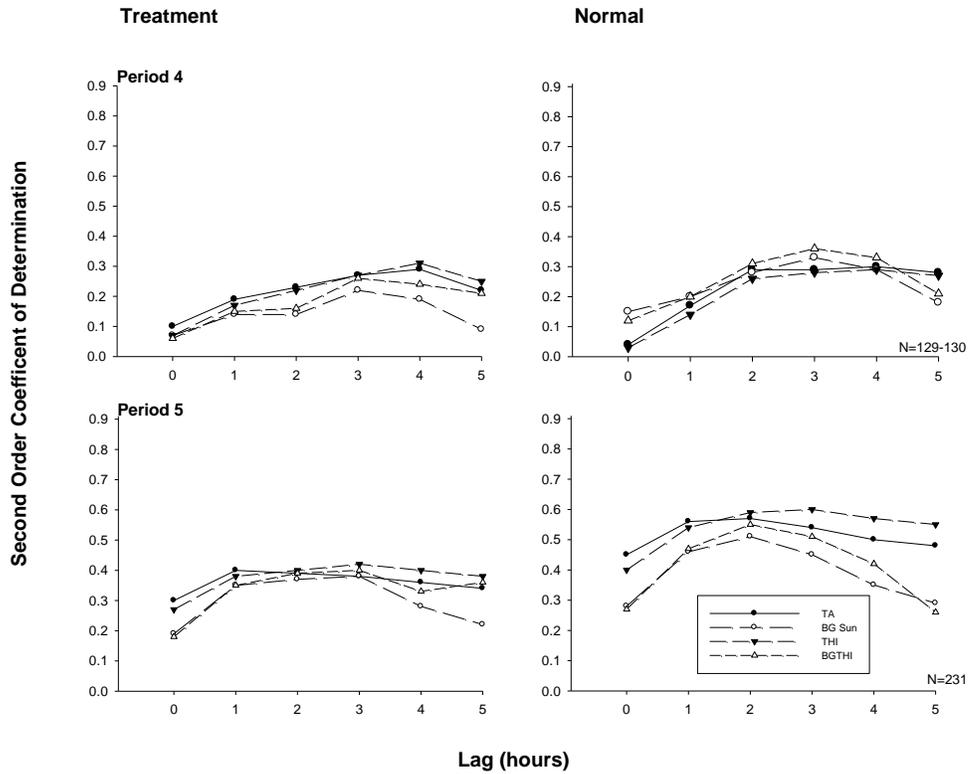


Figure 14. Periods 4 and 5 coefficients of determination for the 2013 study were calculated by plotting the effect of ambient conditions on mean core body temperature. The effect of delayed response was considered by incorporating hourly lags ranging from 0-5 h. Ambient values were averaged by day and hour and core values were averaged by day, hour, and treatment. Only values gathered from hours 0700 to 1700 h CST were considered.

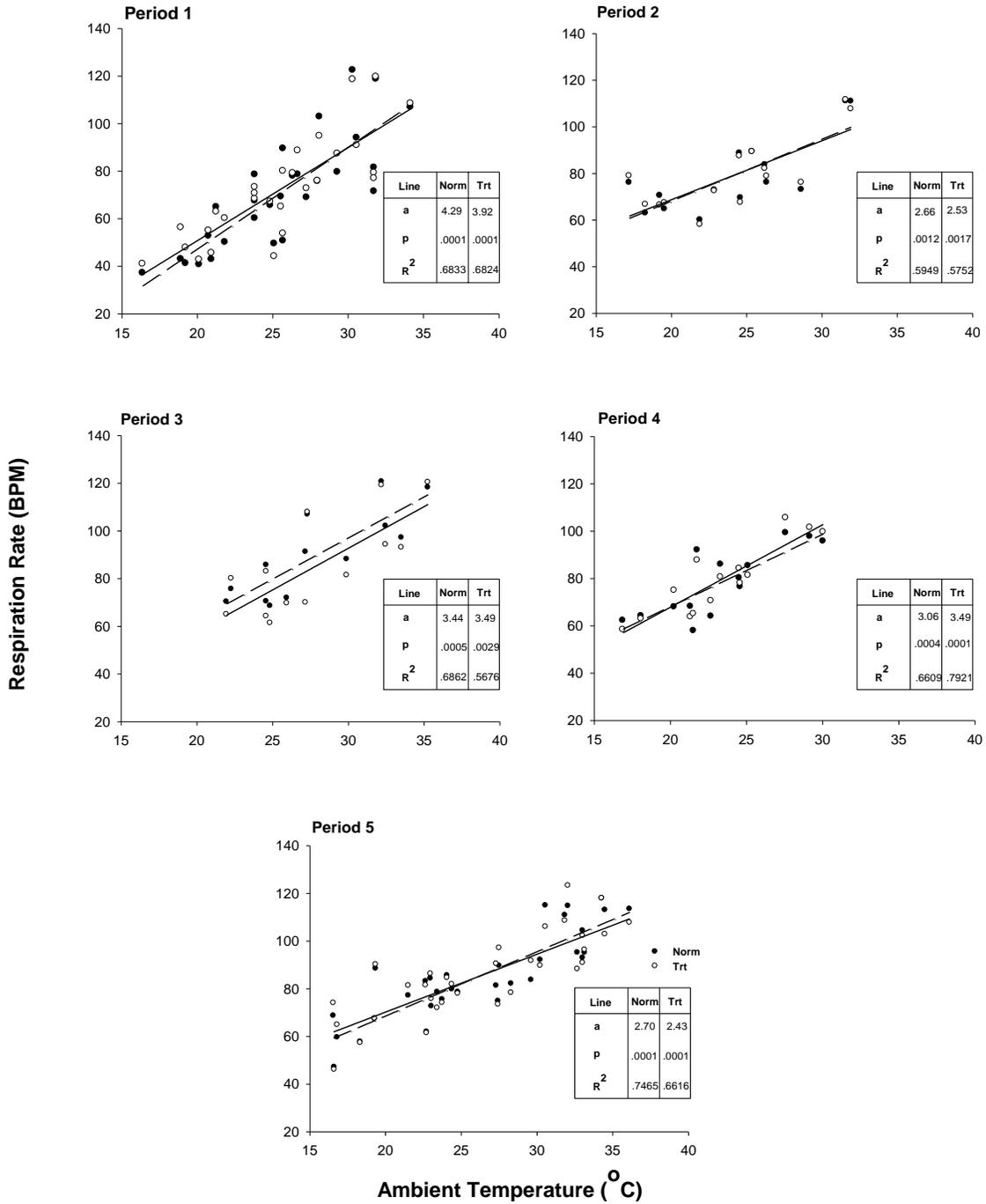


Figure 15. Respiration values for the 2013 study for all animals were averaged for each day within each period, treatment (Trt) and normal (Norm) groups, and hour of recording (i.e. 0800 and 1700 h). Values are plotted by temperature and include linear regression for comparison between treatments and among periods.

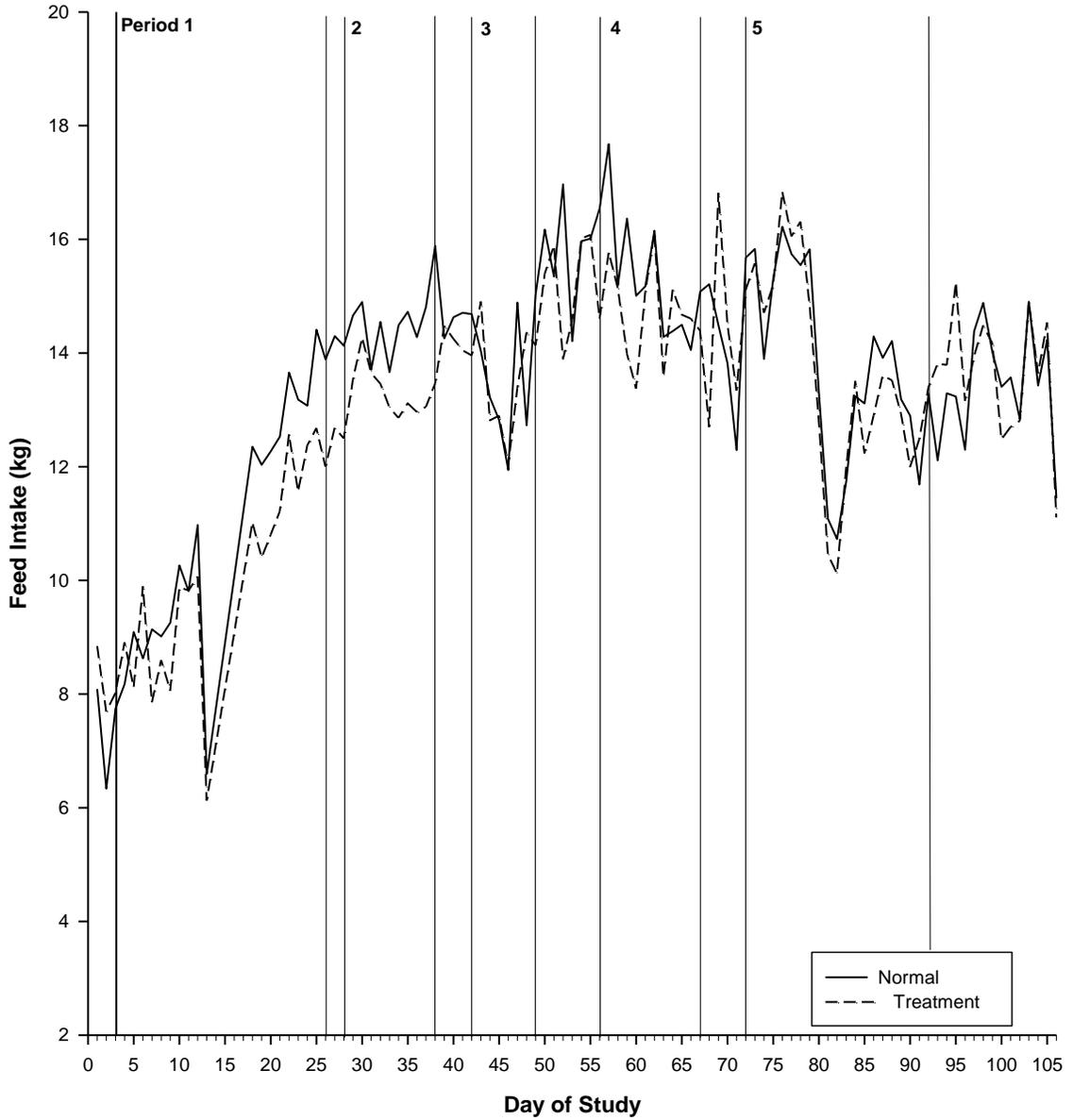


Figure 16. Feed intake values for the 2013 study were averaged by day and treatment and plotted by day of study. Individual periods are partitioned, and values are separated by TRT and NORM groups.

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