MITIGATING HEAT STRESS ON DAIRY FARMS DURING THREE PHASES

OF PRODUCTION

A Thesis

by

BOONE H. CARTER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2008

Major Subject: Animal Science

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Approved by:

Chair of Committee,   Ted Friend
Committee Members,   Jason Sawyer
                       Tom Edrington
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ABSTRACT

Mitigating Heat Stress on Dairy Farms During Three Phases of Production.

(August 2008)

Boone H. Carter, B.S., Brigham Young University - Idaho

Chair of Advisory Committee: Dr. Ted Friend

Four studies were conducted in the Texas Panhandle during the summer of 2007 to evaluate methods for cooling cattle in three phases of production (unweaned calves in hutches, weaned heifers on pasture and lactating cows).

Unweaned calves (n = 20) housed in polyethylene hutches, covered with reflective aluminum and bubble film insulation, were compared to calves (n = 18) in similar, un-insulated hutches. Mean thermal heat index (THI) for the trial was 71.9 ± 5.5 (SD). Insulation treatment did not affect body weight gain (P > 0.044). Insulation affected interior hutch temperature, calf body temperature, and respiration rate (P < 0.05), indicating insulation may moderate temperature extremes within the hutch.

Weaned heifers (n = 55) on pastures with shade were compared to similar heifers (n = 62) in pastures without shade. Mean THI for the trials was 70.8 ± 6.2 (SD). Shade treatment increased body temperature (P = 0.03) and decreased body weight gain. The effect of shade on foraging behavior was dependant on THI. Shade use by heifers was dependant on THI and wind speed. Heifers utilized shade when THI was above 72, especially when wind speed was low.

Feed bunk attendance was compared among pens (n = 3) of lactating cows where the feed bunk was equipped with water sprinklers that sprayed the backs of cows and pens (n = 2) without feed bunk sprinklers. Mean THI for the trial was 70.8 ± 5.7 (SD). Feed bunk sprinklers mediated the affect of elevated THI on decreasing bunk attendance, but overall bunk attendance was not different among treatments.

Lactating dairy cows, cooled with water sprinklers and fans three times each day in the holding pen prior to milking, were compared with similar cows cooled in the holding pen by fans only. Mean THI for the trial was 69.9 ± 5.3 (SD). Body temperature, milk yield and somatic cell count were not different among treatments. Sprinkled cows had lower milk fat and total protein than control cows. Sprinkling cows in the holding pen when THI is less than 70 may negatively affect milk production.

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Thanks to the Food Animal Concerns Trust for their support of this research. Thanks to Rich Wood, their executive director for being an active participant in this project and for taking time to understand the challenges dairy farmers face.

Thanks to the DeVos family, especially Gary and to the Ruynes and the late Rick Willingham for allowing me to intrude into their daily lives and businesses and for extending a hand of friendship during my sojourn on their cap-rock prairie.

Most of all, thanks to my wife and little girls for joining me on this and the many adventures to come as we journey through this wonderful thing called life.

NOMENCLATURE

h	Hour
min	Minute
d	Day
kg	Kilogram
L	Liter
m	Meter
km	Kilometer
SD	Standard Deviation
THI	Thermal Heat Index
TMR	Total Mixed Ration
DHIA	Dairy Herd Improvement Association

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CHAPTER I

INTRODUCTION

Homeotherms, including cattle, are adapted to survive in climates with highly variable temperature ranges. They have the challenge of maintaining a narrow body temperature range in order to survive, grow and reproduce. If their external thermal environment moves outside their thermoneutral zone, their body temperature rises or falls until their environment changes, they adapt, or die.

Negative Impacts of Heat Stress on Dairy Cattle

Confining animals may limit their ability to respond to environmental pressures, and therefore producers have the moral responsibility to provide the resources necessary for animals to cope with their environment. Providing these resources is beneficial, as it will likely enhance productivity and efficiency. Animals instinctively seek conditions that are conducive to psychological and physiological comfort. The absence of such conditions induces behavioral and physical coping mechanisms that divert energy from growth and production while at the same time increasing physical strain, reducing productivity. High temperature in combination with humidity and radiant energy create an environment that is stressful for dairy cattle both physically and mentally (Beatty et al., 2006; Christison and Johnson, 1972; Hahn, 1999).

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This thesis follows the style of Journal of Animal Science.

Heat stress influences animal health, welfare and economic productivity on dairy farms (Igono et al., 1987; St-Pierre et al., 2003)

Short-term effects of coping with heat stress. In the short term, heat stress causes a decrease in feed intake (Bernabucci et al., 1999) and alters feeding patterns (Sprinkle et al., 2000). Cattle that don't feed when its is hot are prone to over consumption when it is cool, which can cause metabolic disorders such as acidosis (Krause and Oetzel, 2006; Stone, 2004). Heat stress decreases milk production (Fuquay, 1981; West et al., 1999) and behavioral signs of estrus (Her et al., 1988), while increasing early embryonic death in mature cattle (Ambrose et al., 1999; Ryan et al., 1993). Mortality rates rise during heat stress, especially during heat waves where animals are not adapted to heat (Brown-Brandl et al., 2005). In addition, increased energy utilization for heat dissapation results in less efficient conversion of feed resources to marketable product (Igono et al., 1987; Kadzere et al., 2002). Economic losses due to heat stress are often associated with the Southwest and Southeast, but cattle in most parts of the United States are affected by heat stress for varying periods of time during the course of a year (Armstrong, 1994; Roenfeldt, 1998). One study estimated the economic impact of heat stress on the dairy industry to be a loss of between $879 million to $1.5 billion dollars annually (St-Pierre et al., 2003).

Long-term effects of coping with heat stress. Residual effects of hest stress can create long-term problems. Cows with longer calving intervals due to suppressed behavioral estrus or early embryonic death (Al-Katanani et al., 1999) have shorter productive lives (Erb et al., 1985). Reducing the productive span of mature cows

requires a higher capital investment in heifers to replace culled cows. Cows with longer

calving intervals are fed more days without return on investment (McDowell, 1972).

Heifers that calve at 26 months instead of 24 months of age cost producers $90 more in

feed per heifer and require 12 more replacement heifers per hundred head of cows

annually at a cull rate of 30% (Cady as cited in Bungert (1998). This estimate does not

include the lost revenue from entering the milking herd two months later.

Necessity of These Studies

The face of the dairy industry has changed dramatically in the last thirty years

toward larger and more confined dairies. Southwest dairies are leading the trend toward

larger dairies and the dairy industry in Texas has grown dramatically. In 1987, 19% of

milk cows in the state of Texas lived on dairies larger than 500 cows (USDA, 1987). By

2002, 60% of the milk cows were on dairies larger than 500 and 66% of those were from

dairies larger than 1000 cows (USDA, 2002). Since 2002 total milk cow numbers in

Texas have increased by nearly 47,000 cows (USDA, 2007), mostly in the Panhandle

region (USDA, 2006). At the same time dairies were moving toward larger herds, the

average annual milk produced per cow almost tripled, from 8,634 lbs in 1970 to 21,328

lbs in 2006 (USDA, 2007).

The combination of increased confinement and increased milk production makes

modern dairies especially sensitive to heat stress. High producing cows are more

susceptible to heat stress (Tapki and Sahin, 2006) because of their higher metabolic

activity (Kadzere et al., 2002). Little is known about how thermoregulation in calves

differs from adults except that their heat production is less than adult cattle and certainly lactating cattle (Brody, 1956). It would follow that calves might be less sensitive to heat stress, but to what extent is unknown.

Finally, confined cows cannot respond behaviorally to heat stress by seeking out microclimates, but rely on owners to moderate their environment. High temperatures can cause production losses, but heat waves, even in moderate climates, can lead to the death of vulnerable animals (Brown-Brandl et al., 2005). Therefore, thermal environment must be carefully regulated, to prevent production losses and thermal shock.

The Texas Panhandle presents a unique challenge for dairy farmers, who are relatively new to the region. The climate is characterized by moderately warm summers marked by periodic heat waves, in comparison to the more consistently high temperatures of the major dairy producing regions of the Southwest. The rapid influx of dairy cattle to the Texas Panhandle makes heat stress in that region an important topic in terms of animal welfare and economic productivity. Cooling methods used in warmer regions may not be economically efficient in the Panhandle, but nonetheless necessary to mitigate mild chronic heat stress and the acute stress of heat waves.

Studies are needed to develop and validate adaptations of existing cooling methods for use in the southern high plains and will benefit diaries by developing cost effective ways to improve cow welfare and production. Better understanding of how cows utilize available cooling methods will enable development of more effective methods of managing environmental stress of dairy cattle, ultimately improving cow comfort and increasing production.

CHAPTER II

HEAT TRANSFER AND THERMOREGULATION

Heat Transfer

The transfer of thermal energy always flows from an area of high temperature to an area of low temperature. When an object we sense when an object heats up is the accumulation of thermal energy within that object. Thus, the goal of cooling cows has two aims, to transfer accumulated thermal energy away from the animal, and to prevent unwanted thermal energy from being transferred to the animal.

On dairy farms, heat accumulation is typically managed in one or a combination of three methods; by preventing radiant heat transfer or accumulation through shading cows, increasing convective cooling by the use of fans or by increasing evaporative cooling (transference away from target).

Thermal energy is transferred through and between objects in three ways radiation, convection, and conduction (Schmidt-Nielson, 1997). Radiation involves the transfer of energy through electromagnetic radiation. Movement of atomic particles that make up a molecule and by extension an object, creates electromagnetic radiation which radiates from the objects surface (Incropera and DeWitt, 1996). All objects absorb and radiate electromagnetic energy. Radiant energy, unlike convection and conduction does not rely on matter to transport it (Schmidt-Nielson, 1997), which allows heat from the sun to travel through space to earth. . Radiant energy excites the atomic particles that absorb it, which changes radiant energy to thermal energy and the objects temperature

rises. Objects that have a higher temperature, also radiate more energy (Schmidt-Nielson, 1997).

Convection is the flow of heat from one place to another through the actual movement of molecules from an area of higher temperature to an area of lower temperature, and is limited to fluid matter. The natural form of convection is the upward movement of a heated fluid induced by bouyancy forces (Incropera and DeWitt, 1996). As a fluid's thermal energy increases, the molecules move or vibrate more rapidly, which creates space between molecules making the fluid less dense (Incropera and DeWitt, 1996). As the molecules move upward, they lose heat to their environment, which cools them down; they become less dense and sink until they are reheated creating convection current. Artificial convection occurs when a force other than natural convection (pump or fan) moves a fluid away from an area of heat accumulation to area of heat dissipation. The major role of convection in cow thermoregulation is that convection (natural or artificial) moves heated air away from the skin surface and replaces it with cooler air.

Conduction is the flow of heat from molecule to molecule of materials by direct contact. Dense materials generally conduct heat more rapidly because their molecules are closer together and have greater contact with one another (Incropera and DeWitt, 1996). When a dense material is surrounded by less dense material the rate of conduction away from the dense object is limited by the lower level of molecular interaction from the less dense material. If the rate of heat absorption is higher than the rate of heat loss, objects accumulate thermal energy. Density plays a role in the transfer

of heat away from animals. Heat transfers relatively quickly from the body core through tissue conduction and blood convection to the skin surface, but does not transfer as rapidly to the air because air is less dense and conduction between gas molecules and the skin happens at a much slower rate than the dense molecules within the body (McDowell, 1972). As a result heat can build up within the animal.

When water changes phase from solid to liquid or liquid to gas and visa versa, relatively large (0.580 Kcal/g at 35°C) amounts of energy are lost or gained (Schmidt-Nielson, 1997). This phenomenon is used to the benefit of most mammals when they sweat. The evaporation of sweat from the body surface transfers heat from the skin to the water molecules that are vaporized, cooling the skin surface.

The effectiveness of evaporative cooling is dependant on the environmental temperature and relative humidity. When ambient temperature rises, vapor pressure decreases, and evaporation increases. As body temperature rises, the difference between environmental temperature and body temperature narrows, less energy is required to evaporate moisture from the skin, and the rate of evaporation further increases (Schmidt-Nielson, 1997). Humidity plays a role in thermoregulation by influencing the rate water is evaporated from the skin surface (Berman, 2005, 2006). Relative humidity is an expression the actual vapor density divided by the saturation density at a set temperature. Humid (dense) air has more mass than dry air and therefore exerts a larger amount of downward pressure on a liquid surface. Water molecules that vaporize must overcome this downward pressure to leave the surface of the liquid. When relative humidity is 100%, the air is saturated and condensation equals evaporation and no net energy is lost.

Unsurprisingly evaporative cooling is most efficient in semi-arid climates (Collier et al.,

2006). In most of the southwest, humidity is generally not a major inhibitor to

evaporative cooling.

Thermoregulation in Cattle

Cattle maintain their body temperature within a narrow range in the presence of a

highly variable environment. The thermoneutral zone is the range of environmental

conditions where heat is dissipated at near an equilibrium rate with heat production and

gain without initiating adaptive coping mechanisms to maintain body temperature within

a normal range (Figure 2.1). Within the thermoneutral zone, body temperature is mostly

regulated by vasoconstriction or dilation of peripheral blood vessels (Van Someren et al.,

2002). A drop in ambient temperature increases the rate of body heat loss and requires

an animal to increase metabolic rate to maintain its body temperature. If the rate of body

heat loss increases faster than metabolic heat production, body temperature drops.

Conversely, if metabolic heat production and environmental heat gain outpaces heat

dissipation, body temperature rises (Figure 2.1). If environmental temperature rises

above an animal's upper critical temperature (Curtis, 1983; Hahn, 1999), they are no

longer capable of maintaining a normal and their body temperature rises (Figure 2.1).

LLT   LCT   Thermoneutral zone   UCT   ULT

A   A

Thermal comfort zone

Death

Core body temperature

Death

Environmental temperature
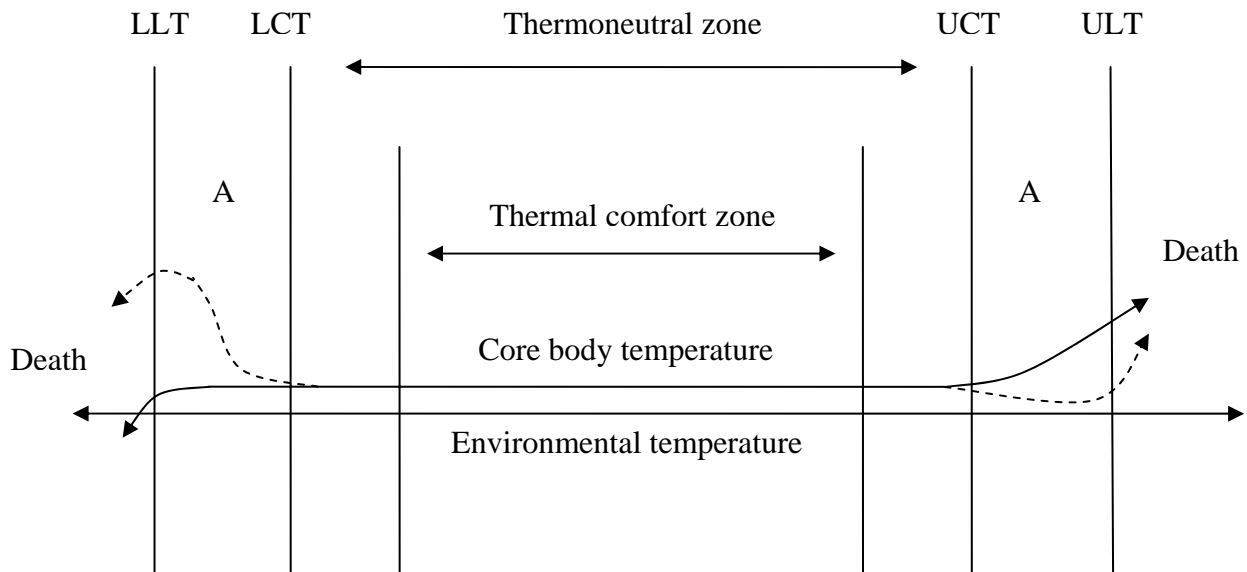
Figure 2.1. The relationship of the animal's core body temperature, heat production and environmental temperature. As environmental temperature decreases below the thermoneutral zone, cattle adapt by increasing metabolic heat production until it maximizes after which point body temperature begins to fall. The environmental temperature below which an animal is not capable of thermo-regulating is considered its lower lethat temperature (LLT). As environmental temperature increases beyond the thermoneutral zone, cattle adapt by seeking cooler microclimates to decrease heat gain, decreasing feed intake and physical activity to reduce metabolic heat production and increasing sweating rate and respiration rate to increase heat dissipation. When cooling mechanisms are out paced by heat gain, body temperature rises. The environmental temperature at which the animal becomes unable to thermo-regulate is considered the upper lethal temperature (ULT), above that critical threshold, metabolic rate increases as a result of increased body temperature (adapted from Curtis, 1981; Kadzere et al., 2002).
A = Zone of adaptation
LCT = Lower critical temperature
UCT = Upper critical temperature
- - - -   Metabolic heat production

Sources of heat. Cattle accumulate heat from two sources, heat produced by the animal and heat absorbed from the environment. Heat is produced from within cattle by digestion and metabolism of energy. When the chemical bonds that hold molecules together are broken during digestion and metabolism, energy is released. In humans, 60-75 percent of the total daily energy from metabolism is lost as heat (Poehlman, 1993). Of the heat that is generated by metabolism (in humans), 56 percent comes from internal organs such as the lungs and heart, 18 percent comes from the skin and muscle and 16 percent is generated by the brain (Aschoff, 1958 as cited in Van Someren, (2002).

Metabolic heat is only one source of heat; heat is also absorbed from the environment. If the skin temperature becomes hotter than the body core, the animal becomes a heat sink (Finch, 1986; VanBaale et al., 2006). Animals absorb radiant energy regardless of environmental conditions, because radiant energy is not dependant on temperature gradients for transfer, therefore radiant energy is always a component of body temperature(Schmidt-Nielson, 1997). In hot thermal environments, radiant energy contributes significantly to heat stress (Finch, 1986).

Preventing heat gain. Because heat has two sources, cattle act to prevent heat gain in two ways. Cattle seek out cooler microclimates to prevent heat gain from the environment and they decrease metabolic heat production.

 Seeking microclimates that have a higher level of thermo-comfort (e.g, sunning when it is cold and seeking shade and wind when it is hot) is a common behavior among most animals (Van Someren et al., 2002). Hensel et al. (1981) showed that warming the pre-optic and anterior-hypothalamic area of the brain induced heat loss behavior. Heat

loss behavior includes increasing water intake (Mitlohner et al., 2002), which prevents

dehydration and directly decreases body temperature. Stermer et al. (1986) reported that

drinking chilled water decreased body temperature in lactating dairy cows by 1°C,

though it did not improve production due to the short duration of the effect. Cattle

voluntarily seek out water sources to cool themselves; this behavior has been utilized in

dairies by creating cooling ponds in which cattle may stand (Jones and Stallings, 1999;

Tomaszewski et al., 2005).   The production of endogenous body heat is crucial for

thermoregulation in cold environments, but is a liability in hot environments. Cattle

decrease metabolic heat production by decreasing feed intake and physical activity

(Curtis, 1983; Mader et al., 2002; McDowell, 1972). Decreases in feed intake and

changes in energy partitioning are the causes of decreased milk production in lactating

cattle and reduced growth rates in growing cattle. It is estimated that half of the decrease

in milk production associated with heat stress can be attributed to changes in energy

partitioning, a physiologic response to heat stress. The other half is attributed to

decreased feed intake (Baumgaurd as cited in Quaife (2007)).

When the environmental temperature rises above their thermoneutral zone, cattle

adapt to the environmental change by increasing their rate of heat loss by panting and

sweating, decreasing their metabolic heat production by decreasing feed intake and

physical activity and seeking out cooler microclimates such as shade or ponds (Curtis,

1983; Jones and Stallings, 1999; Tomaszewski et al., 2005).

Dissipating heat. Thermoregulation in animals achieved through both behavioral and autonomic mechanisms. Autonomic mechanisms work in conjunction with behavioral activities to dissipate heat and reduce heat accumulation.

The lower thermo-neutral threshold for dairy cattle varies depending on their level of production, but the upper threshold is consistently estimated to be between 24-25°C (Burt, 2002; Hahn, 1999; West et al., 2003). When environmental temperature is near the thermal neutral zone, body temperature is primarily controlled by vasoconstriction or dilation of the peripheral vasculature (Van Someren et al., 2002). Sympathetic thermo receptors in both the body core and periphery initiate blood perfusion of the skin when body temperature rises above its set point. Maximum perfusion of the skin in humans (8-fold increase) with warm blood can consume 50% of cardiac out put, which requires redistribution of blood to the extremities, and increases heat transfer to the skin (Guyton, 1991).

In a study of tissue heat conduction in different breeds of cattle, Finch (1985), found that tissue heat conduction peaked at an environmental temperature of 41°C for all types of cattle and remained constant in *Bos indicus* cattle up to 45°C. In *Bos taurus*, cattle tissue conductance declined above 41°C. The authors suggested that the effect might be due do variation in ability to redirect blood flow from the core to the skin. Increased blood flow to the skin increases the skin temperature, which raises the vapor pressure of moisture on the skin and increases the rate of conductive and evaporative cooling.

When environmental temperature exceeds body temperature, the direction of heat movement reverses and the body gains heat instead of dissipating heat. Several studies in rats, sheep and humans, indicate that negative feedback mechanisms exist to induce peripheral vasoconstriction at least in some parts of the body to reduce heat inflow when environmental temperatures exceed core temperature (Hales et al., 1985; Nagasaka et al., 1987, 1986).

When environmental temperature rises above body temperature, evaporation becomes the main source of cooling and must dissipate not only metabolic heat generated by the animal, but heat load absorbed from the environment as well. The evaporation of water from the skin surface releases heat that was on the skin surface into the air. At 25°C, fifty to sixty-five percent of heat loss is non-evaporative as temperature rises non evaporative cooling decreases proportionally, making up less than twenty-five percent of all cooling (Finch, 1985).

Sweating rate is regulated by temperature and radiant energy. As temperature increases, rate of sweating increases. Radiant energy induces more profuse sweating than high thermal temperature alone (Finch, 1986, 1985). Bos Taurus cattle exhibit an increase in sweating rate as temperature rises but sweating rate plateaus. However the sweating rate of Bos Indicus cattle increases exponentially as temperature rises (Finch, 1986).

Heat loss from evaporative cooling occurs not just on the skin surface, but in the lungs and nasal passages as well. Respiration rates in cattle rise (Hahn, 1999; Van

Someren et al., 2002; West, 2003) when the thermal environment becomes hotter than blood perfusion of the skin alone mitigate.

While internal mechanisms increase both rate and efficiency of heat transfer from the body core to the skin surface, the effectiveness of heat transfer from the animal to its environment is dependant on environment's relative humidity, temperature and air movement. Vaporization of sweat creates a zone of saturated air surrounding the animal which slows the rate of evaporation (West, 2003). Air movement through natural convection or forced ventilation removes saturated air from the body surface and replaces it with unsaturated air, maintaining or increasing the rate of evaporation (Berman, 2006).

Cattle are well adapted to thermoregulating in hot environments as long as the resources they need to prevent heat gain and promote heat loss are available. Determining how cooling requirements differ among cattle in different phases of production will facilitate the development of new cooling methods as well as the modification of existing cooling methods to more efficiently cool cattle at each phase of production.

CHAPTER III

USING REFLECTIVE INSULATION TO REDUCE HEAT STRESS ON

CALVES IN POLYETHYLENE HUTCHES

Introduction

The objective of this study was to determine how insulating polyethylene calf hutches affected interior hutch temperature, calf body temperature, health (disease incidence), weight gain, and activity state. Calves are an often-overlooked component of dairy production and generally receive minimal attention in terms of heat stress alleviation. However, there may be substantial need and possible economic incentive to address heat stress in young calves (Bungert, 1998).

Preliminary data collected by this lab indicated that the interior temperature of polyethylene calf hutches (Calf-Tel Pro®, Hampel Corp., German town WI) can reach temperatures of 45 to 47°C when ambient temperatures are 36 to 40°C, probably due to radiant energy absorption. Shading the hutches and associated pens with 80% shade cloth was effective in reducing their interior temperature by blocking radiant energy (B. H. Carter, unpublished data). Because direct sunlight kills bacteria and other pathogens (Reed et al., 2004), we designed a radiant insulation cover for the hutches that reflected radiant energy away from individual hutches while leaving the uncovered portion of the pen exposed to sunlight.

Materials and Methods

  Animals. Heifer calves of predominantly Holstein-Friesian decent were placed

alternately into one of two types of hutches by order of birth over a period of 10 days, so

that age distribution was similar for both groups (5 ± 2.6 (SD); $P = 0.97$). All calves

were bottle fed 1.9L of pasteurized waste milk twice daily until they would drink from a

bucket (1 to 3 d), after which, they were fed 7.6 L of pasteurized waste milk twice daily

in buckets at the front of their hutch's pen. At 56 d of age, calves milk was no longer

offered. For the entire trial, water and Startena [®] (Purina Mills, St Louis MS) calf starter

were available *ad libitum* in the same area milk was fed. All procedures were conducted

in compliance with Texas A&M University's animal care and use guidelines.

  Treatments. All hutches were made of thermoformed opaque polyethylene

(Calf-Tel Pro [®], Hampel Corp., German town WI). Insulated hutches (n = 20) were

covered with a 2.2 x 2.5 m sheet of Tempshield [TM] (Innovative Insulation Inc., Arlington

TX) reflective insulation consisting of a double layer of polyethylene bubble film

laminated between a layer of aluminum foil and white polyethylene. Grommets were

placed along the short edges of each insulation sheet, and were used in attaching the

insulation sheets to the base of the hutch in 3 places on each side with bungee cord.

Insulated hutches (n = 20) were alternated with the control hutches (n = 19) forming a

single row of 39 hutches. All hutches had a 1.2 x 1.8 m outdoor pen made from a

welded wire panel bent at a 90° angle in two places.

  Parameters measured. Starting on d 32 and again on d 53, ear canal temperature

was recorded for 72 h at 10-min intervals using iButton [®] (Model 1921h, Maxim

Integrated Products, Sunnyvale CA) temperature data loggers. Data loggers were placed in the tip of a polyester child's stocking that was partially filled with polyester pillow batting. The stocking and data logger were inserted into the ear canal of the calf with the batting packed tightly against the opening to insulate the ear canal and data logger from environmental influence. The pinna of the ear was then wrapped around the batting and tapped shut using 5.2 cm wide ElastiKon[®] (Johnson and Johnson, New Brunswick NJ) tape to hold the batting in place.

When calves were 32 d of age, 6 control hutches and 7 insulated hutches were fitted with Hobo[®] , (model H08-003-02) temperature and humidity data loggers (Onset Computer Corp., Bourne MA), which recorded interior hutch temperature at 10-min intervals for 72 h. Data loggers were installed on the interior sidewall 0.25 m from the ground, mid way between the front and rear of the hutch using a wire cage that was attached to the hutch with screws. A layer of Tempshield[®] reflective insulation was placed between the hutch and the data logger to insulate the data logger against temperature influence from the hutch wall.

On d 32 and 53, activity states and respiration rates were recorded by visual observation at 1and 2-h intervals respectively for 48 h. Each calf was weighed within 72 h of birth and at an average of 35, 56 and 73 days of age. The number of times each calf was treated for diarrhea, respiratory or "other" health problems was recorded. Activity states were location (inside or outside of the hutch) and posture (standing or lying down).

Hourly ambient temperature and dew point were obtained from the National Oceanic and Atmospheric Administration weather station located 28 km to the southeast at the Hale County Airport. Ambient temperature and dew point data were converted to a thermal heat index (THI) using the formula THI = Temperature (°C) + (.36 * Dew point (°C)) + 41.2 (Collier and Zimbelman, 2007; Tapki and Sahin, 2006)

Statistical analysis. Effects of THI on ear canal temperature and interior hutch temperature were modeled for each calf and hutch using linear regression. The resulting slopes (rate of change in calf or hutch temperature per unit increase in THI) for ear canal and hutch temperature were compared among treatments using 2-sample t-tests.

Studies reviewed by West (2003) reported that below 25°C or a THI of 72, heat stress is negligible. In order to separate thermal conditions that were potentially stressful from those that were not, mean respiration rate, ear canal temperature and interior hutch temperature data from each calf were separated into observations made at low (< 72) THI and at moderate (> 72) THI. Effects of insulation treatment on respiration rate, ear canal temperature and hutch temperature were tested within low and moderate THI categories using 2-sample t-tests.

Weight gain for periods of growth between weighings and total body weight gain were analyzed for treatment effects using analysis of variance. Medical treatment data was too sporadic to analyze statistically and were summarized by number of calves requiring treatment and the mean number of treatments received per calf treated with their standard deviation. All other means are presented with their standard errors unless otherwise stated.

Treatment effects on the proportion of calves in each activity state were determined using a generalized linear mixed model (GLIMMIX procedures, SAS Inst., Inc., Carr, NC). Activity state was the dependent variable, treatment was a classification variable, and THI was a covariate. In this model, the binomial response (activity state) was automatically transformed using a logit transformation for hypothesis testing. Activity state proportions were then estimated for each dependant variable using the logit function at THI of 71, 79 and 63, which represent the mean THI and 1.5 SD above and below the mean. Estimates and their standard errors were back transformed into original units with the inverse of the logit link function. Treatment means were separated at each THI using 2-tailed t-tests.

Results

Thermal conditions during the trial ranged from 62.6 to 82.6. Overall mean THI for the trial was approximately 72 (Table 3.1). Thirty-eight percent of all observations made were associated a THI greater than 72.

Table 3.1. Mean thermal heat index [a] (THI) which occurred during the trial, grouped into low (< 72) and moderate (> 72) THI categories, and pooled over all periods.

Category	Mean	SD	Minimum	Maximum
Low	67.34	2.90	62.60	71.96
Moderate	76.60	3.08	72.32	82.68
Overall	71.86	5.511	62.60	82.68

[a] THI = Temperature °C + (.36 * dew point °C) + 41.2

Ear canal temperature increased as THI increased, but insulation had minimal effect on the rate of ear canal temperature change (P = 0.11, Figure 3.1). The rate of hutch interior temperature change was less for insulated hutches than control hutches (P < 0.01, Figure 3.2) with changing THI.

Mean ear canal temperature was 0.27 °C lower for calves in control hutches at low THI (P = 0.05), but was not different at moderate THI (Table 3.2). Covering hutches reduced (P < 0.01) interior temperatures by 1.4 ± 0.14°C at moderate THI but increased (P < 0.01) interior temperatures by 0.58 ± 0.09°C at low THI. Respiration rates were lower (P = 0.04) for calves in insulated hutches at moderate THI, but were similar among treatments (P = 0.17) at low THI (Table 3.2).

There was no difference in body weight gain between treatment groups for any growth period (P > 0.44; Table 3.3). The number of calves receiving medical treatment was similar among hutch treatments for all symptoms (Table 3.4). However, calves in insulated hutches required fewer treatments per calf. Insulation did not affect the proportion of calves in either activity state (Table 3.5). A greater proportion of calves were inside their hutch and lying down as THI increased (Table 3.5).
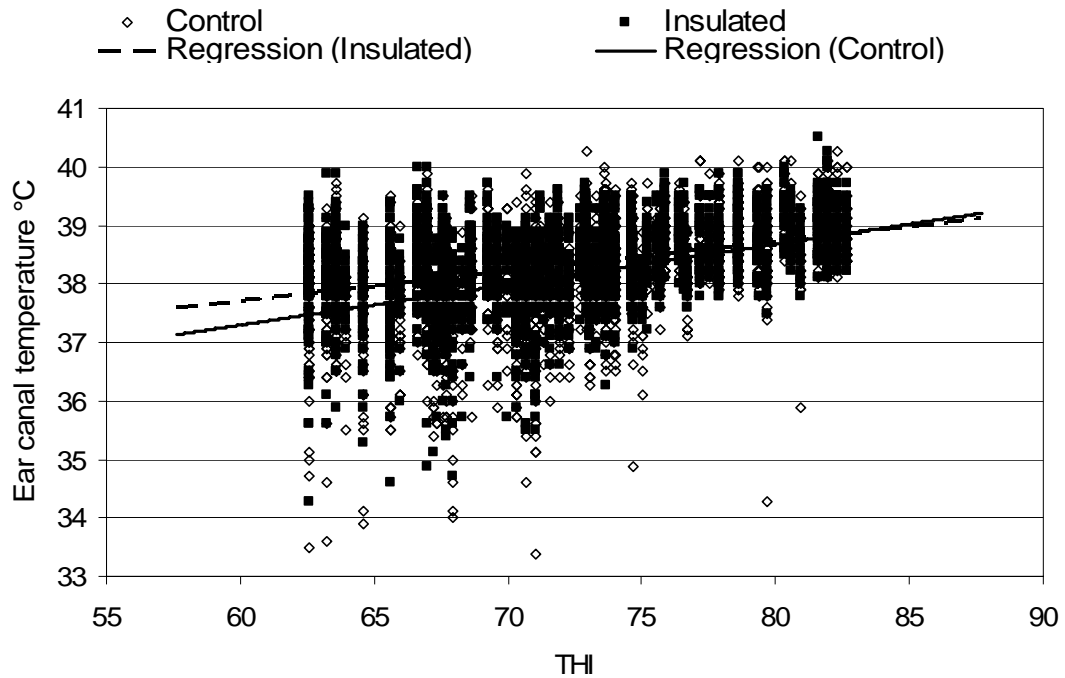
Figure 3.1 The relationship between ear canal temperature and thermal heat index (THI) for calves in control or insulated hutches. The rate of ear canal temperature change for calves in control hutches (Slope = 0.069) was not different (P = 0.11) from calves in insulated hutches (Slope = 0.054).
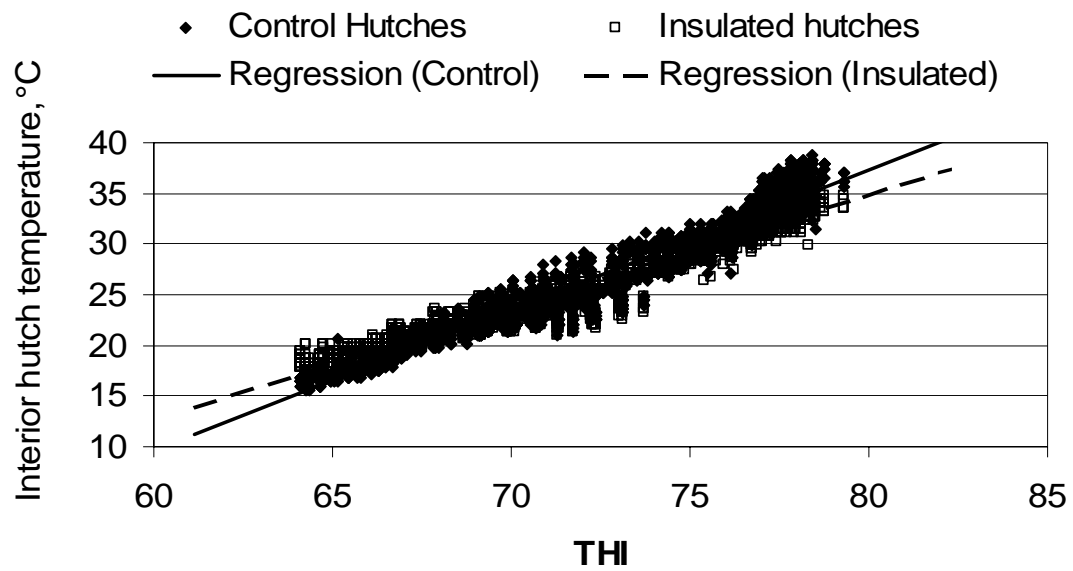
Figure 3.2 The relationship between interior hutch temperature and thermal heat index (THI) for control or insulated hutches. The rate of interior hutch temperature change for calves from insulated hutches (Slope = 1.11) was less (P < 0.01) than calves from control hutches (Slope = 1.38).

Table 3.2. Estimated mean interior hutch temperature, ear canal temperature and respiration rate during low (< 72) and moderate (> 72) thermal heat index[a] (THI) for calves housed in control and insulated hutches.

Variable	Low		Moderate		P - Value	
	Control Hutches	Insulated Hutches	Control Hutches	Insulated Hutches	Low	Moderate
Interior hutch temperature, °C	20.97 ± 0.04	21.55 ± 0.08	31.85 ± 0.09	30.42 ± 0.11	< 0.001	< 0.001
Ear canal temperature, °C	37.76 ± 0.10	38.03 ± 0.08	38.47 ± 0.07	38.60 ± 0.05	0.051	0.157
Respiration rate, beats / min	49.76 ± 2.42	45.69 ± 1.76	60.07 ± 2.32	54.37 ± 1.46	0.177	0.041

[a] THI = Temperature °C + (.36 * dew point °C) + 41.2

Table 3.3. Least squares mean for weight gain (kg) during three periods of growth and total gain for calves housed in control and insulated hutches.

Growth period (d)	Control hutches	Insulated hutches	P - Value
0 to 35	24.0 ± 1.06	24.1 ± 1.01	0.93
36 to 56	14.3 ± 1.21	13.7 ± 1.15	0.74
57 to 73	16.4 ± 1.82	14.8 ± 1.82	0.52
Total gain	54.7 ± 2.0	52.6 ± 2.0	0.44

Table 3.4. Number of calves that received medical treatment and mean number of treatments administered ± SD per calf receiving treatment by symptom for calves housed in control and insulated hutches.

Symptom	Control hutches (n = 18)	Insulated hutches (n = 20)
Diarrhea		
No. of cases	16	18
No. of treatments	1.4 ± 0.62	1.7 ± 0.76
Respiratory		
No. of cases	3	5
No. of treatments	4.3 ± 2.5	1.6 ± 0.89
Other		
No. of cases	1	0
No. of treatments	2	0
Total treatments		
No. of cases	16	18
No. of treatments	2.25 ± 2.14	2.22 ± 1.16

Table 3.5. Estimated mean proportion of calves lying or inside their hutch at three thermal heat indexes [a] (THI) by treatment

Activity state	Control hutches			Insulated hutches			P – Value [b]	
	THI = 63	THI = 71	THI = 79	THI = 63	THI = 71	THI = 79	Treatment	THI
Lying	0.854 ± 0.01	0.868 ± 0.01	0.881 ± 0.01	0.847 ± 0.02	0.861 ± 0.01	0.874 ± 0.01	0.414	0.022
Inside	0.849 ± 0.01	0.904 ± 0.00	0.940 ± 0.00	0.849 ± 0.01	0.903 ± 0.00	0.940 ± 0.00	0.955	< 0.001

[a] THI = Temperature °C + (.36 * dew point °C) + 41.2
[b] P- Values indicate that changes in activity state were non-zero but that there were no differences among treatments

Discussion

 Thermal conditions. Covering polyethylene calf hutches with reflective insulation had mixed effects on the parameters measured, possibly because ambient thermal conditions were not stressful enough to elicit a measurable response in all parameters. A daily mean THI of 72 is the point at which heat stress has been reported to be induced in lactating dairy cattle (VanBaale et al., 2005; West et al., 2003). While most days had periods where environmental conditions were greater than 72, only 8 d had a mean THI greater than 72 and none were over 75. Because the thresholds for different levels of heat stress in the thermal heat index were developed on adult cattle (West, 2003), they may not accurately reflect the thresholds of heat stress for calves. Relationships between THI and the physiological parameters measured in this study suggest that THI may influence calves at THI not normally associated with heat stress in adult cattle.

 Interior hutch temperature and physiologic responses. Normal body temperature in cattle under thermoneutral conditions is estimated to have a mean of 38.6 °C with a range of 1°C (McDowell, 1972). The mean ear canal temperature was not above 38.6°C for either treatment, which indicates that heat load did not exceed calves' ability to dissipate. Initial regression analysis showed that ear canal temperature for both control and insulated calves rose as THI increased, but rates of increase were not different among treatments (Figure 3.1). However, when mean ear canal temperature were sorted into low (THI < 72) and moderate THI categories, calves in control hutches had lower ear canal temperatures (P = .05) than calves in insulated hutches at low THI

and ear canal temperature was not different at moderate THI. This result was surprising as insulation was hypothesized to reduce body temperature at higher THI. Brown-Brandl et al (2005) found that respiration rates increase as ambient temperature increases but ambient temperature has a non linear influence on body temperature suggesting that other parameters influence body temperature as well.   Insulation may have helped calves retain body heat during lower THI which increased ear canal temperature a low THI. This effect was probably not shown at moderate THI because the effect of ambient thermal conditions were more influential on calf body temperature than the heat being retained by the insulation, in effect increasing ear canal temperature in control calves and moderating ear canal temperature in calves in insulated hutches so they were not different.

While body temperature may not have been different, thermal heat load probably was, as respiration rates were higher in control calves at moderate THI, which as indicated earlier are more directly influenced by THI, rising in response to an increase in heat load (Berman, 2005; Carvalho et al., 1995). It seems under the thermal conditions of this trial, little change in ear canal temperature was produced, because the increase in respiration rate was sufficient to compensate for increases in heat load.

The interaction of calf body heat and radiant heat with insulation was more prominent when the interior temperatures of the calf hutches were compared among treatments. The regression model of THI and Interior hutch temperature estimated that interior temperature of control hutches were lower than insulated hutches at low THI and higher than insulated hutches at moderate THI (Figure 3.2). Subsequent analysis of the

actual temperature observations sorted into low and moderate categories supported the regression analysis. Insulated hutches averaged 1.4 ± 0.14°C lower than control hutches when THI was less than 72 but were 0.58 ± 0.09°C higher when THI was below 72. These data further indicate that insulated hutches retain calves' body heat, which becomes evident when THI is low, as well as effectively reducing interior temperature by reflecting solar radiation which is more influential when THI is high.

Mean body weight gain for calves from insulated hutches were not different from control calves at any point (Table 3.3). These results show no benefit in weight gain from insulating hutches when THI is low to moderate, presumably because metabolic rate was not affected by insulation treatment at these THI.

Calves in this study were limit-fed pasteurized waste milk twice a day and always consumed all milk offered. Calf starter consumption was not measured, but procedures on the dairy where the study took place called for weaning after calves began consuming approximately 1kg, which historically occurred around 56 d. Calves in this study were weaned at day 56 and probabliy consumed less than 1 kg of starter per day prior to that.

Reduction in feed intake is one of the first responses observed in cattle under heat stress (Collier et al., 1982; Hahn, 1999; West, 2003). If heat stress affected the calves' appetites, it was not to the extent that they did not consume all their milk. Additionally, feed intake as measured by milk consumption may have confounded by an opposing mechanisms during this trial, the desire to increase liquid (water in adult cattle) consumption and a decreased appetite (Fuquay, 1981). Calves under heat stress may

increase milk consumption, rather than decrease as hypothesized, especially if they are at the age where milk constitutes a major portion of their diet. To this author's knowledge, the relationship between milk intake and heat stress has not been quantified.

It was hypothesized that larger differences in weight gain might become evident after calves were weaned because feed reduction due to heat stress has been associated with dry matter intake; however, this was not the case. Weight gain was greatest for both treatments from 0 to 35 d, and was similar for the rest of the study (Table 3.3), indicating that weaning did not have a large effect on weight gain and therefore insulation was not more beneficial to calves after weaning than before.

Activity states. Activity states were not different among treatments, but calves spent more time inside their hutches lying down as temperature increased (Table 3.5). It is not surprising that calves would prefer the inside of their hutches for a majority of time, but it is somewhat surprising that the proportion of calves lying down increased as THI increased. In adult cattle, standing behavior increases during high THI (Berman, 2005; Tapki and Sahin, 2006) presumably so cattle can increase body surface exposure to the air and increase evaporative cooling. In a study of heat loss a low temperature (< 18°C) Schrama et al. (1994), reported that low ambient temperature had minimal effects on calf posture (standing or lying), but in an earlier study, the same author reported that standing behavior did increase the rate of body heat loss (Schrama et al., 1993). The calves studied at cool temperatures in Schrama et al. (1994), spent less (74%) time lying than calves in this study who spent greater than 84% of the time lying down. The difference in heat reduction behavior observed in calves and cows might be explained by

differences in stamina. Calves in both studies spent a large proportion of the time lying down possibly due to having less stamina than adult cattle and increased heat load alters energy metabolism to decrease muscle energy reserves.

The overall change in activity states was unexpectedly low with times of highest activity occurring around the morning feeding; the mean proportion of calves observed outside the hutch was never greater than 15% for any time except the two hours surrounding morning feeding time. All calves were receiving nearly double the standard amount of milk, suggesting that reduced activity was not due to energy restriction. Curtis (1983) attributed decreased activity in cattle during the beginning stages of heat stress to reduce metabolic heat production. According to Curtis, this behavior precedes an actual rise in body temperature.

Implications.   Under thermal conditions that would not normally be considered stressful to calves covering polyethylene hutches with reflective insulation moderated interior hutch temperature and reduced respiration rate of calves but did not affect the rate of ear canal temperature change. Insulation both retained calf body heat and reflected radiant energy resulting in insulated hutches being warmer at low THI and cooler at moderate THI. Variables of economic relevance, such as weight gain and disease incidence were not affected by insulating hutches under the thermal conditions of this trial and none of the cost ($15.00) of insulating the hutches was recovered. Future studies at higher and more stressful THI may demonstrate economic benefits of increased weight gain and lower body temperature.

CHAPTER IV

SHADE UTILIZATION BY WEANED DAIRY HEIFERS IN A PASTURE SETTING

Introduction

Shade is often used as the primary method in reducing heat load on cattle housed in dry-lot dairies. Kendall (2006) found that shade improved milk yield and decreased body temperature for lactating cows even in mild summer conditions. Preliminary research by this lab measuring the body temperatures of groups of shaded lactating and unshaded dry cows indicated that lactating cows had higher body temperature than dry cows even though the dry cows had no access to shade (B. H. Carter, unpublished data). This reinforces the findings of Holter (1976) that lactating cows produce more metabolic heat than dry cows or heifers, which would make them more sensitive to heat stress than dry cows (Kadzere et al., 2002). Under heat stress, milk production is reduced (Collier and Zimbelman, 2007), the major production metric in dairy cows.

The most important parameter of production in dairy heifers is weight gain, because body weight is negatively correlated to onset of puberty (MacDonald et al., 2005). Heifers that grow faster can ultimately enter production earlier requiring less capitol investment per cow (Bungert, 1998). In addition to reducing the rate of gain, sever heat stress can alter body composition. Kamal and Johnson (1971) reported that 6 month-old calves exposed to 32°C temperature at 50% relative humidity lost 15% of

their body solids, mostly fat, over the course of three days. The loss of body solids was

offset by an increase in body water so that weight loss was not detectable.

Heat stress increases energy expenditure while reducing feed intake (Beatty et

al., 2006; Bernabucci et al., 1999) and by extension rate of gain, and shade has been

shown to mitigate heat stress in lactating cows. We hypothesized therefore, that heifer

calves would utilize and benefit physiologically from shade in a pasture setting when

thermal heat index (THI) was greater than 72, an often cited threshold for heat stress

(Jones and Stallings, 1999; Kadzere et al., 2002; West, 2003).

Materials and Methods

Animals and treatments. Holstein-Friesian heifers averaging 137 ± 15 (SD) kg

were divided into two groups. Shade treatment heifers (n= 55) were kept in a 120 x 150

m pasture that contained a 3 x 24 m shade structure that was made of 80 % black

polyethylene shade cloth (Farmtek, Dyersville IA) suspended 2.4 m above the ground on

a galvanize pipe frame. The control group (n = 62) was kept in a pasture of similar size

with no access to shade.   All procedures were conducted in compliance with Texas

A&M University's animal care and use guidelines.

Originally, heifers in both pastures had equal access to a total mixed ration in

unshaded portable feed bunks with 3.6 m of bunk space on two sides. During the trial

farm workers fed refused TMR from a set of calves not under investigation to the heifers

in the unshaded pasture. The refused TMR was the same as the subject heifers were

receiving so the effect was to increase bunk space. Heifers in both groups had access to triticale hay in round bales and mixed grass pasture.

Parameters measured. After an18 d acclimation period, behavioral observations were made for 47 h at hourly intervals. Behaviors were recorded as the proportion of heifers "at bunk", "foraging", "under shade" or "other". Heifers were considered at the bunk if they were within 1m of the bunk. They were considered to be foraging if they were walking, drinking, eating hay or grazing. Heifers were under the shade if some part of their body were under the shadow of the shade. If heifers were not involved in one of the other behaviors, they were considered "other".

Ear canal temperature was measured for a subset (n = 7) of each group during the same 47 h period using using iButton® (Model 1921h, Maxim Integrated Products, Sunnyvale CA) temperature data loggers set to sample at 10-min intervals. Resulting data were subsequently averaged to hourly means. Data loggers were place in the ear canal of each heifer by first placing it in the tip of a polyester child's stocking that was filled with a small amount of polyester pillow batting. The stocking and data logger were inserted into the ear canal of the heifer with the batting packed tightly against the opening to insulate it from environmental influence. The pinna of the ear was then wrapped around the batting and tapped shut using 5.2 cm wide ElastiKon® (Johnson and Johnson, New Brunswick NJ) tape to hold the batting in place.

Heifers were weighed on day 0 of the trial and again on day 21. Hourly ambient temperature and dew point were obtained from the National Oceanic and Atmospheric Administration weather station located 28 km miles to the southeast at the Hale county

airport. Ambient temperature and dew point data were converted to a thermal heat index (THI) using the following formula THI = Temperature °C + .36 * Dew point °C + 41.2 (Collier and Zimbelman, 2007; Tapki and Sahin, 2006).

The trial was replicated one month later with two different groups of heifers at the same average age and weight. Ear canal temperature and final body weight were not recorded for the second trial.

Statistical analysis. Ear canal temperature data were analyzed using mixed model analysis of covariance with ear canal temperature as the dependant variable, treatment (a class variable), THI (a covariate) and their interaction as fixed effects. Ear canal temperature was compared for the first trial only.

The effect of shade on total weight gain was determined using a 2 sample t-test. Weight gain was compared among treatments for the first trial only, as final weight data was not available for the second trial.

Feeding behavior data from both trials were pooled and analyzed with trial as a random effect. Because there was no equivalent category to "under shade" in the control group, and cattle under the shade were neither foraging or at the bunk, "under shade" was pooled with "other" for behavioral comparisons across treatment. A generalized linear mixed model (GLIMMIX procedures, SAS Inst., Inc., Carr, NC) was used in which the proportion of subjects performing a given behavior was the dependent variable, treatment was a classification variable, and THI was a covariate. In this model, the binomial response is automatically transformed using a logit transformation for hypothesis testing. Due to significant treatment by THI interactions, response

proportions were then estimated using the previously mentioned model for each dependant variable using the logit function at THI values of 71, 79 and 63, which represent the mean THI and 1.5 SD above and below the mean. Estimates and their standard errors were back transformed into original units with the inverse of the logit link function. Treatment means were separated for each behavior at each THI for using 2-tailed t-tests.

The effect of environmental conditions on shade use was only determined for the pen with access to shade, observations were not pooled with "other" for this analysis. To elucidate the interaction between wind speed and THI on shade use, observations below THI = 72 were excluded from analysis. VanBaale et al. (2005)and West et al. (2003) found that below a THI of 72 there is little or no heat stress. Additionally, a preliminary regression analysis of wind speed on THI demonstrated that these variables were related for observations when THI was less than 72 ($P = 0.001$; $r^2 = 0.60$), but were not related above THI of 72 ($P = 0.893$; $r^2 < 0.001$).

Shading behavior was analyzed utilizing the same model used to analyze feeding behavior. The proportion of heifers under the shade was the dependant variable with THI, wind speed and their interaction as covariates. The proportion of heifers "under shade" was estimated for three THI (74, 77 and 80) at three different wind speeds (15.1, 24.3 and 5.8 km/h) using the same logit transformation procedures. THI levels were representative of the range of observations where THI was above 72 and wind speeds corresponded to the mean wind daily speed and ± 1.5 SD. The proportion of heifers

under the shade was also estimated at the mean THI of 72 and mean wind speed of 15.1 km/h.

Results

THI ranged from 62.6 to 78.6 during the period observations were made in the first trial and ranged from 62.2 to 82.6 during the period observations were made for the second trial. Mean daily THI was 69.3 and 72.0 for the first and second trial respectively (Table 4.1.)

 Ear canal temperature was significantly affected by THI ($P < 0.01$) and treatment ($P = 0.03$). Heifers in the pasture with shade had 0.32 ± 0.07 °C higher ear canal temperatures than controls (Table 4.2). Heifers with access to shade gained 2.79 ± 1.51 kg less body weight than heifers without shade in the pasture (Table 4.2). The proportion of heifers observed at the feed bunk was influenced by THI ($P < 0.021$) but not treatment (Table 4.3). Overall, foraging behavior increased with THI, but the rate of increase was greater for heifers without access to shade (Table 4.3). The proportion of heifers involved in other behavior (which included shade use) decreased as THI increased, and decreased at a greater rate among heifers without access to shade (Table 4.3).

The proportion of heifers under the shade increased as THI increased ($P < 0.001$) and decreased as wind speed increased ($P < 0.001$; Figure 4.1). Below a THI of 72, no heifers were observed under the shade. At mean THI (72) and wind speed (15.1 km / h), 26.6 ± 0.03 % of the heifers were estimated to be under the shade.

Table 4.1. Mean thermal heat index[a] (THI) for the periods of time when behavior and ear canal temperature data were obtained.

Trial	Mean	SD	Minimum	Maximum
One	69.62	4.89	62.60	78.60
Two	72.00	6.22	62.24	82.68

[a] THI = Temperature °C + (.36 * dew point °C) + 41.2

Table 4.2. Least squares mean ear canal temperature and body weight gain by treatment for heifers on pasture

Treatments	Control	With access to shade
Ear canal Temperature, °C	38.15 ± 0.05	38.48 ± 0.05*
Body weight gain, kg	30.22 ± 8.98	27.42 ± 6.01[†]

Within row, means differ by [†] $P < 0.10$ * $P < 0.05$

Table 4.3.Estimated proportion of control heifers and heifers with access to shade engaged in feeding behaviors at different thermal heat index (THI).

Behavior	Pasture with no access to shade			Pasture with shade			P - Values		
	63	71	79	63	71	79	Treatment	THI	Interaction
At Bunk	0.07 ± 0.01	0.09 ± 0.01	0.12 ± 0.02	0.09 ± 0.01	0.12 ± 0.02	0.15 ± 0.02	0.697	0.021	---[a]
Foraging	0.11 ± 0.03	0.24 ± 0.05	0.44 ± 0.06	0.14 ± 0.03	0.22 ± 0.05	0.32 ± 0.06	0.023	---[b]	< 0.001
Other	0.81 ± 0.02	0.65 ± 0.03	0.45 ± 0.03	0.77 ± 0.02	0.66 ± 0.03	0.52 ± 0.03	<0.001	---[b]	<0.001

[a] slopes were not different among treatments , therefore interaction effect was dropped so the effect of THI was estimated with a single slope
[b] slopes differed among treatments, therefore the main effect was dropped so that the slope was estimated by treatment
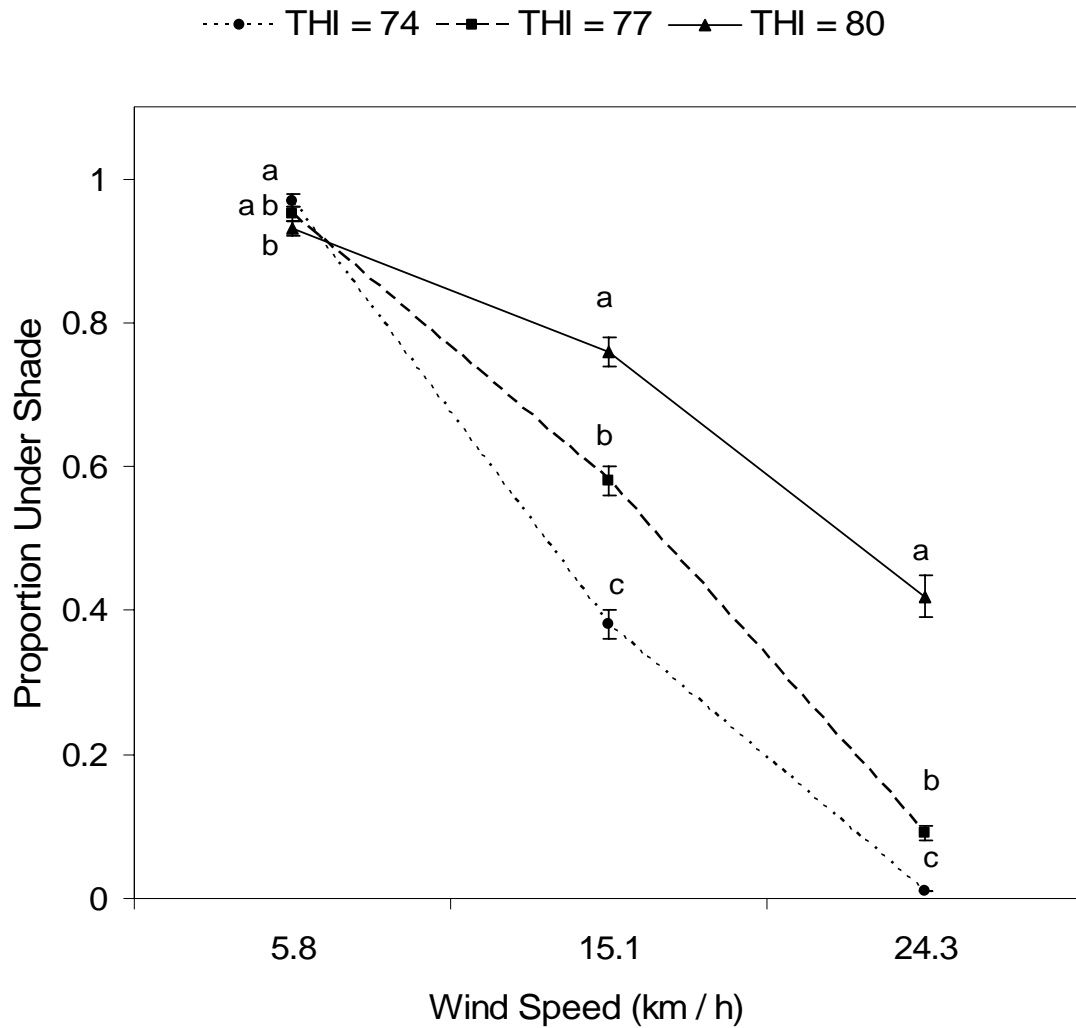
Figure 4.1. The estimated effect of wind speed on the proportion of heifers under the shade at three different thermal heat index (THI). The proportion of heifers under the shade decreased as wind speed increased for all three THI values.
[a b c] Within a wind speed category, means without common superscript differ (P < 0.05)

Discussion

      Thermal conditions. Offering shade to weaned heifers had varying responses for the parameters measured. It is possible that ambient thermal conditions were not stressful enough during the periods of observation to have a definitive influence on the parameters measured. Mean daily THI exceeding 72 is generally considered the threshold for initiating heat stress in lactating cows (VanBaale et al., 2005; West et al., 2003). The mean THI for both periods of behavioral observation in this study were less than 72 (Table 4.1). Although 45 % of the observations of the study had THI of over 72, the maximum THI for all observations of the trial was 83.

      Physiology. Heifers in pastures with shade treatment had slightly higher mean ear canal temperatures (Table 4.2). While the difference (0.32 ± 0.07 °C) in ear canal temperature wass statistically significant, it is doubtful that it was biologically meaningful because both groups of heifers were within the normal ear canal temperature range for cattle in thermoneutral conditions (McDowell, 1972; Sprinkle et al., 2000).

      Heifers that had no access to shade weighed 2.79 ± 1.51 kg more than heifers with access to shade (Table 4.2). Two possible explanations are offered. First, heifers with access to shade may have been reluctant to leave the shade to eat and drink when THI exceeded their thermal comfort zone and therefore had lower feed intake. A second and more likely explanation is that because of the extra bunk space, calves in the pasture without shade had less competition for feed resources and therefore had higher intake and better gain. Definitive conclusions about weight gain differences are impossible to make because the extra feed received by the control calves confounds body weight gain.

Feeding behavior and shade use. Heifers feeding on the refused TMR fed by the farm workers were counted as "foraging." Even if heifers feeding on the refused TMR were correctly counted as "at bunk", a larger proportion of heifers would have been able to attend the bunk in the control group than the shade group, further confounding the results. Therefore, only inferences comparing general feeding behavior to the "other" category can be made among the treatments.

The proportion of heifers engaged in the feeding behaviors observed were dependant on THI. Interestingly, the proportion of heifers "At Bunk" and "Foraging" increased with increasing THI in both treatment groups while the proportion of heifers engaged in "other" behavior decreased with increasing THI (Table 4.3). These results are contrary to the results of Sprinkle et al. (2000) which showed that cattle sought out shade during the hot part of the day which decreased grazing behavior during those times. When pressured not to graze during the day cattle typically shift their feeding pattern to night time feeding (Kilgour and Dalton, 1984). It is possible that because THI was moderate, and cattle are mostly daytime feeders (Albright, 1993; Kilgour and Dalton, 1984), circadian feeding behavior was more influential on grazing pattern than THI. Heifers may also be less susceptible to heat stress than adult cattle, which have greater feed intake and produce greater metabolic heat (Holter, 1976). Therefore, THI that would be stressful to lactating cattle may have less influence on the behavior of growing heifers. However, above a THI of 72 some portion of the heifers utilized the shade whereas, below a THI of 72 heifers were never observed to be under the shade. This response when considered in relation to previously mentioned data might indicate

that the threshold of thermal discomfort for heifers might be approximately 72, while the threshold for heat stress is probably higher.

As THI increased, the proportion of heifers under the shade increased, indicating that rising THI was perceived as a thermal stressor. THI has been used for decades as an indicator of heat load in lactating cattle (Berman, 2005; Collier and Zimbelman, 2007; Igono et al., 1985; Lacetera et al., 2002; McDowell, 1972; Tapki and Sahin, 2006) and is based on the affect of ambient temperature and relative humidity have on cow physiology and production. However, THI may not completely describe the level of heat stress an animal is subject to in the absence of shade, as it does not take into account the cooling effect of wind speed (air movement) or the proportion of heat absorbed by animals as solar radiation, which are not directly represented by ambient temperature (Gaughan et al., 2008; Mader et al., 2006).

Wind speed and THI had opposing influences on the proportion of heifers estimated to be under the shade. As wind speed increased the proportion of heifers estimated to be under the shade decreased (P < 0.001) for all THI. Even at relatively high THI, when wind speed was high, less than 50% of the heifers would be expected to utilize the shade based on our statistical model. However, at relatively low wind speeds, over 90% of the heifers would be expected to be under the shade if THI was moderate (Figure 4.1). This trend suggests that wind at moderate speeds sufficiently cooled some proportion of heifers (dependant on THI) to the extent that solar radiation had little effect on them and they did not seek shade. These results are not surprising, because air movement across the body of lactating dairy cattle has been reported to have a cooling

effect in numerous studies (Collier et al., 1982; Collier et al., 2006; Collier et al., 1981; Flamenbaum et al., 1986; Igono et al., 1985; Kendall et al., 2006; Mader et al., 1999).

   Implications.   When THI was above 72, some portion of heifers sought shade presumably because they perceived that shade was beneficial to them for cooling. However, shade seeking behavior was strongly influenced by wind speed. The presence of shade did not benefit the heifers observed, in terms of lowering ear canal temperature and increasing weight gain, which might offset the cost of shade installation. These results indicate that when mean daily THI is less than 72, weaned heifers do not benefit physiologically from shade although heat load for portions of the day may exceed their thermal comfort threshold and heifers do utilize shade for those periods. Future research should focus on defining the environmental conditions at which heifers become stressed and might benefit from shade.

CHAPTER V

AFFECT OF FEED BUNK SPRINKLERS ON ATTENDANCE AT UNSHADED FEED BUNKS IN DRY-LOT DAIRIES

Introduction

Feed bunk sprinklers serve the dual purposes of cooling cattle and attracting them to the feed bunk, potentially increasing feed intake. In management systems where the feed lane and free stalls were under one shade structure, feed bunk sprinklers have been used effectively to cool cows as they feed (Collier et al., 2006; Her et al., 1988; Igono et al., 1985). Cows in these systems have been observed to stand in the feed lane simply to cool themselves rather than to eat (Igono et al., 1987). Cattle that were sprayed with water and exposed to fans produced 2 kg more milk per cow daily than cows that had access shade only (Igono et al., 1987). A study of the effects of fan-forced air reported that in hot humid conditions, sprinklers alone were not as effective for improving milk production as they were when used in combination with fans (Armstrong, 1994). The aforementioned studies demonstrated the benefit of combined application of water and fans on milk production, but did not evaluate the effect of sprinklers on increasing feed bunk attendance, although they certainly are related.

Most dry-lot dairies are designed with shade structures transecting the center of the pen parallel to separate unshaded feed bunks. In such a system, cattle must choose between having access to food while being exposed to solar radiation or remaining in the shade, without access to food. Our primary objective was to determine whether feed

bunk sprinklers were successful at attracting cows to an unshaded bunk in a dry-lot management system. A secondary objective was to determine the affect of THI and wind speed on bunk attendance at sprinkled and un-sprinkled feed bunks. The economic and physiological benefits of animal cooling systems are related to the level of use by the animals. Even if feed bunk sprinklers work well to cool the cows that utilize them, they may not be an effective or economical choice if the majority of cows choose to remain in the shade.

Materials and Methods

Animals. The subjects of the experiment were five pens of predominantly Holstein- Friesian dairy cows. Pens contained shade structures that were 45 m from the feed bunk running parallel to it from north to south. Shade structures were 4.26 m h and 6.7 m wide, which exposed all of the ground underneath them to sunlight as the shade traveled through out the day. The total number of cows in each pen varied from 135 and 391, but total cows were similar among treatments. Average days in milk ranged from 11 to 140 among pens, and number of lactations per cow varied from 1 to 6 within pens. All procedures were conducted in compliance with Texas A&M University's animal care and use guidelines.

Mean pen density and feed bunk space were 64 m^2 $\pm$ 4.9 (SD) and .65m $\pm$ 0.2 (SD) per cow respectively. Pen size varied from 107 x 244 m to 76 x 107m (Figure 5.1). Feed bunks had a 2 m wide concrete alley behind them with a .15 m curb on the back of

Feed alley without
back fence

Feed alley with back fence
(gaps are open gates)

Legend

A, B, C = Pens with
feed bunk sprinklers
D, E = Pens without
sprinklers

A

D

B

Alley to
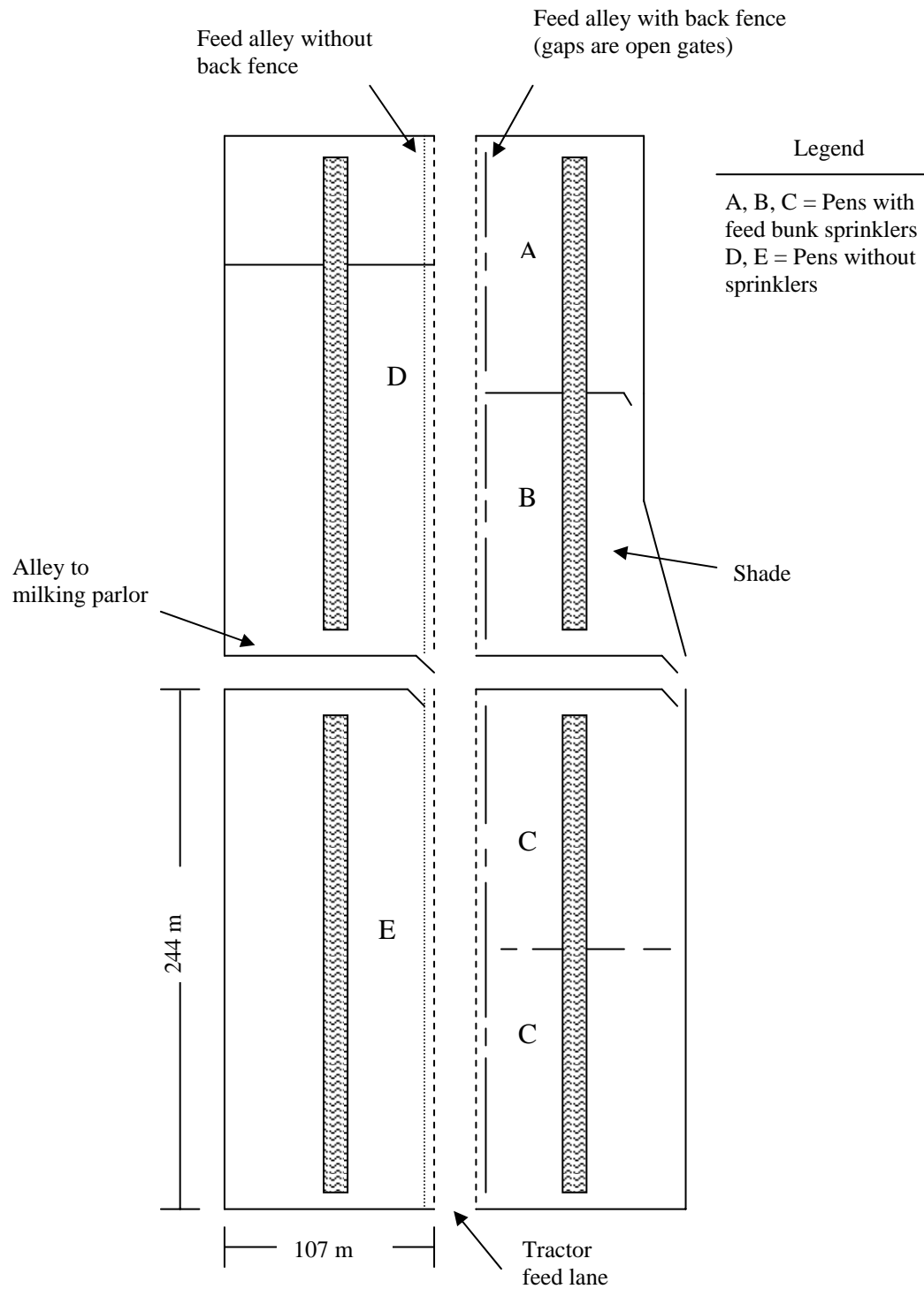milking parlor

Shade

244 m

E

C

C

107 m

Tractor
feed lane

Figure 5.1. Diagram of pens where feed bunk attendance observations were made
(approximate scale).

the alley to keep water from running onto the lot. There was a back fence on top of the curb, dividing the lot and the feed bunk, but gates positioned at each end of the alley and evenly spaced along the feed ally, were kept open at all times. Pens without sprinklers were not equipped with a curb or back fence on the feed alley (Figure. 5.1)

Treatments. Three pens were equipped with sprinklers above the bunk that sprayed the backs of the cows as they fed. The sprayer nozzles (Tee-jet[®], D8055, Carol Stream, IL) were mounted every 2 m and covered a 120° radius area, delivering 2.65 L / min at 20 PSI. Droplet size was > 200 microns. Water application was controlled using a multi-stage controller, model number C-440S (Edstrom Industries, Waterford WI), that activated the system when ambient temperature rose above 22.2°C. At 22.2°C, the interval cycle was 1.5 min on and 10 min off. For every 1.1°C that ambient temperature increased, the controller lengthened the on cycle by 15 sec and shortened the off cycle by 30 sec up to 26.6°C, above which it maintained a 2 min on 8 min off cycle. Two similar pens without feed bunk sprinklers directly across the feed lane from the sprinkled pens served as controls.

Measurements. The number of cows attending the feed bunk for each pen was recorded for 48 h at 2-h intervals. Cows were counted as in attendance if they were within 2m of the bunk. Observations for pens made at time points where the pens were evacuated for milking were excluded from analysis. Cows were fed a TMR in the morning at 0600 h and in the afternoon at 1600 h.

Hourly ambient temperature, dew point and wind speed data were obtained from the National Oceanic and Atmospheric Administration weather station located 28 km to

the south-east at the Hale County Airport and were used to calculate a thermal heat index

(THI) using the formula: THI = Temperature °C + .36 * Dew point °C + 41.2 (Collier

and Zimbelman, 2007; Tapki and Sahin, 2006).

Statistical analysis. Observational data were analyzed as repeated measures with

sprinkler treatment, time, and their interaction as effects in a mixed model with pen

(treatment) as the subject. Differences among means associated with time by treatment

interactions were separated using t-tests. Relationships between bunk attendance,

thermal heat index (THI) and wind speed within treatment were evaluated using linear

regression, with bunk attendance as the response variable and THI and wind speed as

independent predictor variables.

Results

THI for the trial ranged from 62.2 to 82.6 with a mean of 74.26 ± 6.14 (SD). The

effect of feed bunk sprinklers on bunk attendance was dependant on time of observation

(treatment by time interaction, $P < 0.01$). Bunk attendance was greater for pens with

sprinklers at 1700 h during each 24-h period ($P < 0.02$), corresponding to peak daily

THI. Bunk attendance was greater for pens without sprinklers at 0300 h ($P = 0.09$) and

0900 h ($P = 0.008$) of the first 24-h period and 2100, 0300 and 1100 h of the second 24-h

period ($P < 0.02$) which occurred during the cooler parts of the day (Figure 5.2). Bunk

attendance was similar among treatments at all other times ($P > 0.09$).
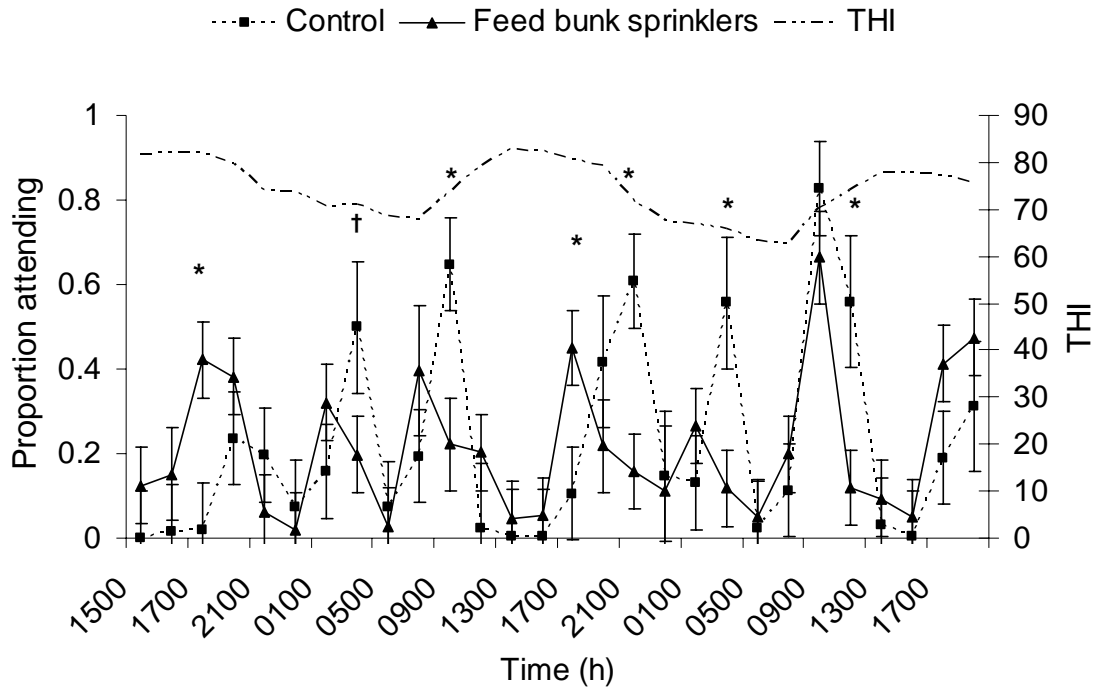
Figure 5.2. Least square mean proportion of cows attending the feed bunk during 2, 24-h periods by treatment (with or without feed bunk sprinklers that sprayed cows' backs). Cows from pens with feed bunk sprinklers began feeding earlier in the afternoon. Cows from pens without sprinklers fed later in the afternoon, and in the early morning before THI increased above 72. Peak attendance appeared to be greater for cows in control pens than cows in pens with feed bunk sprinklers but was not tested.
Observations made at the same times differ by * P < 0.05, † P < 0.10

Wind speed did not affect bunk attendance for either treatment (P > 0.10). Bunk attendance decreased with increasing THI in pens without sprinklers (P = 0.02), but was not influenced by THI for pens with sprinklers (P = 0.54) as shown in Figure 5.3. Sprinklers altered the timing of bunk attendance but did not alter overall mean bunk attendance (P = 0.91).
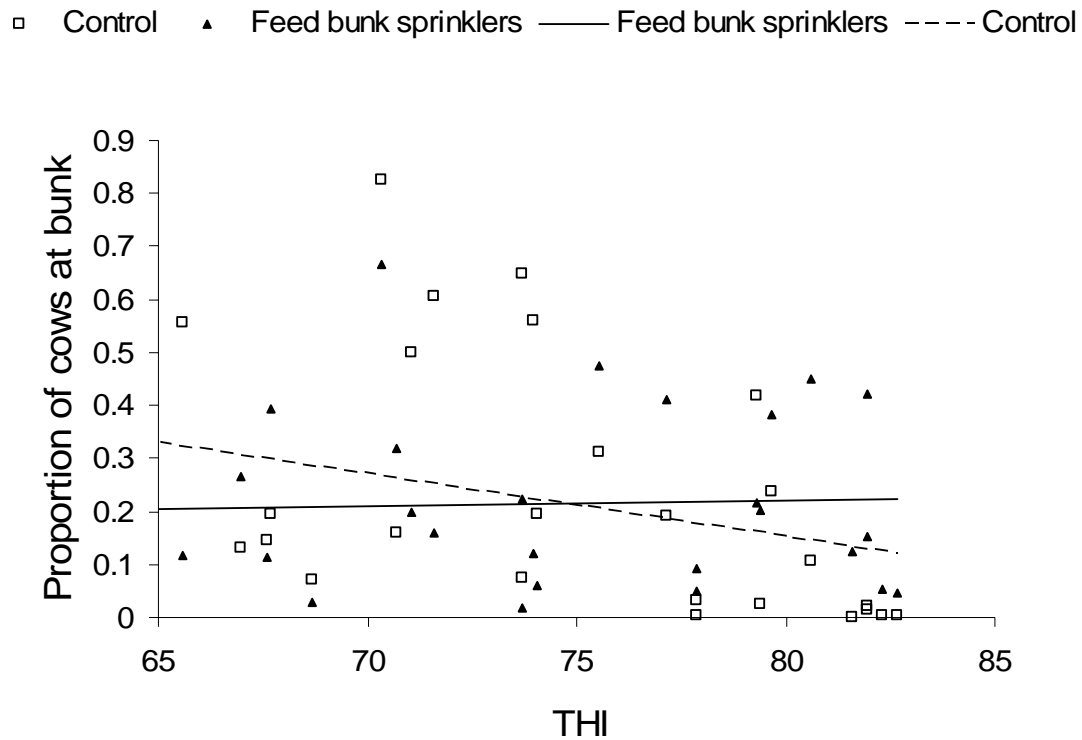
Figure 5.3. The relationship between thermal heat index (THI) and the proportion of cows attending the feed bunk for cows in pens with or without sprinklers mounted on the feed bunks. The proportion of cows at the bunk in pens equipped with sprinklers was not related to THI (slope = -0.003; P = 0.54). The proportion of cows at the bunk in control pens decreased as THI increased (slope = -0.018; P = 0.02)

Discussion

Influence of THI. Cattle tend to exhibit crepuscular feeding patterns supplemented by daytime and late night feeding bouts dependant on energy demands or environmental influences (Kilgour and Dalton, 1984). While THI was probably only moderately stressful, it did affect the feeding pattern of cows in pens not equipped by sprinklers, to the extent that bunk attendance decreased as THI increased (P = 0.02).

This trend is similar to grazing patterns of grazing beef cattle reported by Sprinkle et al. (2000). The most distinguishing response observed was a shift in feeding pattern where cows in pens equipped with sprinklers began feeding earlier in the afternoon (1700 h) when THI was still near its daily high, while cows in pens without sprinklers increased in bunk attendance later, between 1900 and 2100 h in the evening when THI had began to drop. Cows in pens without sprinklers had their highest bunk attendance between 0300 and 1100 in the morning (Figure 5.2), suggesting a compensatory feeding behavior which is consistent with the change in grazing behavior of cattle when daytime temperatures are high (Kilgour and Dalton, 1984).

High THI has been reported to cause cattle to refuse to leave shade for food and water (Jones and Stallings, 1999), inducing over consumption when cattle feed after THI decreases, which contributes to acidosis and laminitis (Beatty et al., 2006; Stone, 2004). Feed bunk sprinklers are intended to moderate the influence of temperature on feeding pattern and encourage multiple small feeding bouts, which have been shown to reduce risk of acidosis and increase dry matter intake (Krause and Oetzel, 2006). The frequency when a large ($>$ .0.20) proportion of cows were at the bunk appear to be similar (Figure 5.3) and mean bunk attendance was not different among treatments (P = 0.91). These results indicate that while feed bunk sprinklers eliminated the relationship between feed bunk attendance and THI they did not increase the overall frequency in which a large proportion of the cows attended the bunk. This suggests that feed bunk sprinklers in this study may not have increased the frequency of bunk attendance (feeding bouts) as intended. However, informal evaluation of cattle during observations

indicated that a small number of individual cows may have attended the bunk more frequently than the rest of the group, but this effect could not be detected because observations were made at a group level. At higher THI than the conditions of this study, feed bunk sprinklers may prove more beneficial.

Influence of wind speed. Air movement has been shown to play an important role in cow cooling by increasing the rate of evaporation and removing hot humid air from the animal's body surface (Finch, 1986; Fuquay, 1981). Surprisingly, wind speed did not play a significant role in predicting bunk attendance for either treatment (P > 0.10), which may indicate that thermal conditions were stressful enough that wind by its self did not increase the cows' thermal comfort enough to leave the shade structures. However, wind speed may have reduced heat load in ways not measured in this study, such as body temperature, respiration rate and milk yield, which other studies have determined are affected by THI (Armstrong, 1994; Brown-Brandl et al., 2005; Gaughan et al., 2008). Specifically, Armstrong (1994) showed that when fans were used in combination with sprinklers to cool cows milk yield was greater than when cows were cooled by sprinklers alone.

Economic benefits. To be economically beneficial, income from increased yield or reduced acidosis would have to exceed the estimated cost of $4.50 per cow to install feed bunk sprinklers. Installation cost alone is not representative of the true cost of sprinklers. The cost of pumping the water and managing the wastewater generated by the sprinklers are additional costs that should be considered when evaluating the economic benefit of feed bunk sprinklers but were unavailable. Because milk yield and disease

incidence was not measured, an economic benefit of installing feed bunk sprinklers at unshaded bunks could not be established although the minimal differences among treatments suggest that such a benefit might not exist.

Implications. Feed bunk sprinklers mounted on unshaded feed bunks eliminated the influence of THI on bunk attendance and attracted cows to the bunk earlier in the afternoon while temperatures are still high, leading to a shift in feeding pattern. The frequency at which large proportions of the group fed were similar and overall attendance was not different. Feed bunk sprinklers may have encouraged individual cows to engage in more frequent feeding bouts but treatments were similar at a group level.

CHAPTER VI

COOLING DAIRY COWS WITH SPRINKLERS IN ADDITION TO FANS IN

THE HOLDING PEN

Introduction

Armstrong (1994) and Flamenbaum et al. (1986) identified the holding pen of the

milk parlor as a place were cows are subjected to heat stress. They hypothesized that

this is due to cows being crowded together in the holding pen for a period of time before

milking. Under such circumstances, the cattle absorb heat from each other and are less

able to dissipate heat because their bodies have limited exposure to air movement. Van

Baale et.al., reported in 2006 that overhead sprinkling in combination with forced air

from fans, transformed the holding pen into a place where heat build up was dissipated

rather than gained. In dry-lot dairy systems, sprinkling in existing holding pens is a

promising method for cooling cows, as all lactating cows pass through that location two

to four times per day and a water management system already exists to manage parlor

waste water.

Reducing heat stress has been shown to improve milk production and

reproductive performance (Ryan et al., 1992; Thatcher et al., 1974). Improving

evaporative cooling through sprinkling or misting cattle has proven to be an effective

means of cow cooling in several situations (Berman, 2006; Collier et al., 2006;

Flamenbaum et al., 1986; Igono et al., 1985; Ryan et al., 1992). Her et al. (1987), in a

study similar to this one, reported that cooling cattle with sprinklers and fans nine times

per day for ten days post insemination increased milk yield by eight percent but did not

alter conception rates, possibly due to the short time of the trial.

The objective of this experiment was to build on previous investigations by

designing a trial in which one treatment group of cows were sprinkled in the holding pen

in combination with forced air and another group was cooled by forced air only. The

hypothesis was that cooling cows by sprinklers in the holding pens would lower cow ear

canal temperature; increase cow comfort and improve milk yield during the summer

climatic conditions of the panhandle region.

Materials and Methods

Animals. Holstein- Friesian cows were housed in two groups, one group

(n=142) was cooled with fans only while in the holding pen. The other group, (n= 181)

was cooled with overhead sprinklers and fans. The cows were housed in soil surfaced

dry-lots measuring 82 x 122 m with a shade structure that measured 8 m wide 4.8 m tall

and 107 m long. The shade structures transected the center of the pens lengthwise from

north to south to take advantage of shade movement during the day. All procedures

were conducted in compliance with Texas A&M University's animal care and use

guidelines.

Treatments. The holding pen of the milk parlor measured 11.2 m wide and 20 m

long and was enclosed on three sides and covered with a metal roof. The two sides had

1.5 m ventilation gap between the eaves and the wall so air could flow freely across the

holding pen. The sprinklers were 2.4 m above holding pen floor, descending from the

holding pen roof, and were arranged in 3 rows of 6. The rows ran parallel to the longest

side of the holding pen and were 3 m apart with 3 m between sprinklers in the same row

so that spray patterns overlapped 50%. The average flow rate for each sprinkler in the

center row00 was 5.49 L / min with a spray radius of 4.9 m at 10 PSI (LDN #8,

Senninger Irrigation Inc., Orlando FL). The sprinkler in the center row that was closest

to the milking parlor was shut off because it sprayed into the milk parlor. The sprinklers

on the two side rows had an average flow rate of 3.10 L / min and a spray radius of 4.2

m at 10 PSI (LDN #6, Senninger Irrigation Inc., Orlando FL). Water pressure was

controlled at each sprinkler by 10-PSI Pressure Master® regulators (Senninger Irrigation

Inc., Orlando FL). Panel fans (Aerotech inc., Pittsburg PA) measuring 1.3 m in

diameter were mounted 3 m above the floor in banks of 4 on either side of the holding

pen. Fans within banks were 4m apart and delivered air at 26,500 cfm.

Sprinklers and fans were controlled by a Programmable logic controller (Cole-

Parmer, Vernon Hill IL) that was programmed to turn the sprinklers and fans on and off

based on milking schedule. The sprinklers ran on a 1 min on 9 min off cycle. In the

interval where sprinklers were off, fans were turned on. Cows spent 5 to 60 min in the

holding pen depending on what order they were milked. When control cows were in the

holding pen the fans ran continuously.

Parameters measured. Milk production data was measured on d 7, 21 and 35 of

a 35 d trial period using DHIA milk test procedures. The most recent pre-treatment milk

test was used as a baseline for comparing milk yield. Only cows represented in all four

milk tests for the fan only (n = 86) and sprinkler and fan (n = 113) group were used in

the analysis of milk yield. Pre trial data were not available for somatic cell count, percent milk fat or percent total protein. Cows present in the three tests conducted during the trial period were used in milk component analysis for the fan only group (n = 97) and for the sprinkler and fan group (n = 133).

Vaginal temperatures were recorded at 10-min intervals on a random subset (n = 12) of each group starting on the first day sprinklers were turned on (d 1) for 93 h and again on day 20 for 123 h. Temperature was measured using iButton[®] temperature data loggers (Model 1921h, Maxim Integrated Products, Sunnyvale CA). Each iButton was fitted in the empty slot in a CIDR, an inter-vaginal hormone administration device (DEC manufacturing; Hamilton, New Zealand) that contained no hormones. A CIDR was then placed in each cow's vaginal canal caudal to the cervix.

Hourly ambient temperature and dew point readings were obtained from the National Oceanic and Atmospheric Administration weather station located 28 km miles to the southeast at the Hale County Airport. Ambient temperature and dew point data were used to calculate a thermal heat index (THI) using the following formula THI = Temperature °C + .36 * Dew point °C + 41.2 (Collier and Zimbelman, 2007; Tapki and Sahin, 2006).

Statistical analysis. Cow vaginal temperature data were analyzed by analysis of covariance in a mixed model where vaginal temperature was the dependant variable and treatment (classification variable) and THI (covariate) and their interaction were fixed effects, with period of temperature measurement as a random effect.

Milk yield (kg / d) was first analyzed using analysis of variance for repeated measures and found to be different among treatments at the pre-trial test (Table 6.1). Because pre-trial differences confounded treatment affects, a new variable, "change in yield" was calculated to facilitate comparisons across treatments. Milk yield is not presented in the results and discussion.

"Change in yield" was the difference between pre-trial yield and yield for each of the three in-trial milk tests and was also analyzed using analysis of variance for repeated measures. Change in yield was the dependant variable. Sprinkler treatment, sample time, and their interaction were fixed effects with cow nested within treatment as the subject of the repeated measures. The average days in milk (DIM) at the pre-trial milk test were 53 ± 52 (SD) for the sprinkler + fans group and 61 ± 44 (SD) for the fans only group. In order to adjust for its large variation, DIM was used as a covariate in the analysis of "change in yield" to scale the data.

Table 6.1. Mean milk yield (kg / d) by treatment group for cows cooled by fans or fans and sprinklers while in the holding pen

Milk test on (d)	Fan only	Sprinkler and Fan	P - Value
Pre trial	38.43 ± 0.61	41.02 ± 0.80	0.036
7	38.47 ± 0.93	40.46 ± 0.80	0.105
21	42.23 ± 0.92	43.40 ± 0.81	0.337
35	38.34 ± 0.95	38.15 ± 0.82	0.788

Somatic cell count, percent total fat and percent total protein were analyzed as dependant variables using analysis of variance with repeated measures. Sprinkler treatment, sample time, and their interaction were fixed effects with cow nested within treatment as the subject of the repeated measures. Pre-trial data were not available for somatic cell count, percent fat and percent total protein.

Results

THI ranged from 56.8 to 82.6 during the trial. Mean THI for the periods of time before each milk test ranged from 64.6 to 70.0 and decreased as the trial progressed (Table 6.2). The THI for the periods during which vaginal temperature was recorded ranged from 56.8 to 82.6 (Table 6.2). Mean vaginal temperature in cows that were cooled by sprinkler and fans in the holding pen was 37.26 ± 1.02 while cows that were exposed to fans only were 37.11 ± 1.02 and did not differ (P = 0.18).

Table 6.2. Mean thermal heat index[a] (THI) for the periods of time before each milk test that are most influential on milk yield, and for the periods of time during which cow vaginal temperature was recorded

Period (d)	Mean	SD	Minimum	Maximum
		Milk test		
5 to 7	70.95	5.69	61.88	79.60
19 to 21	70.08	4.81	62.60	78.6
33 to 35	64.64	4.31	56.80	71.30
		Vaginal temperature		
1 to 4	72.59	5.94	62.24	82.68
21 to 24	68.29	4.58	56.80	78.60

[a] THI = Temperature °C + (.36 * dew point °C) + 41.2

Change in yield tended to be different among treatments (P = 0.091). Sprinkler and fans tended to cause an overall decrease in yield of 0.38 ± 0.61 kg while cows cooled with fans only exhibited an overall increase of 1.18 ± 0.69 kg (P = 0.091). The effect of time on change in yield was significant (Table 6.3). Mean change in yield was -0.29 ± 0.58 between the pre-trial test and d 7, 3.59 ± 0.59 between the pre-trial test and d 21 and -0.42 ± 0.64 between the pre-trial and d 35. Change in yield between the pre-trial test and d 7 was different from change in yield between the pre-trial test and d 21(P < 0.001), but was not different from change in yield between the pre-trial test and d 35 (P = .847). Change in milk between the pre-trial test and d 21 was also different from change in yield between the pre-trial test and d 35 (P < 0.001).

Milk components tended to differ over time (P > 0.06). Mean somatic cell count was 226.0 ± 27.8 for cows cooled with fans only. Mean somatic cell count was 163.7 ± 30.5 for the sprinklers and fans group which did not differ from the mean of the cows cooled by fans alone (P = 0.132). Somatic cell count tended to differ over time (Table 6.3). Percent total protein was 2.67 ± 0.024 for the cows cooled with fans only, while the mean for cows cooled with sprinklers and fans was 2.77 ± 0.026 which was greater than the cows cooled with fans alone (P = 0.010). Percent milk fat was dependant on time and treatment (Table 6.3).

Table 6.3 Least squares means of milk production data over time for lactating cows cooled by fans or fans and sprinklers in the holding pen prior to being milked

Variable	Fans Only			Fans and Sprinklers			P - Values		
	Day 7	Day 21	Day 35	Day 7	Day 21	Day 35	Treatment	Time	Interaction
Change in yield, kg	0.17 ± 0.89	4.51 ± 0.89	1.16 ± 0.92	-0.76 ± 0.77	2.67 ± 0.77	-2.02 ± 0.81	0.091	< 0.001	0.244
Somatic cell count [1]	264.5 ± 42.6	172.3 ± 41.3	241.2 ± 40.1	160.0 ± 36.8	128.0 ± 37.8	203.6 ± 38.5	0.132	0.057	0.533
Total protein, %	2.79 ± 0.04	2.73 ± 0.04	2.80 ± 0.03	2.67 ± 0.03	2.67 ± 0.03	2.69 ± 0.03	0.010	0.200	0.601
Milk fat, %	3.24 ± 0.07^{b}	3.10 ± 0.07^{bc}	2.95 ± 0.07^{cd}	2.76 ± 0.06^{a}	2.69 ± 0.07^{a}	2.82 ± 0.07^{ad}	< 0.001	0.080	0.009

[a b c d] Within "Milk fat", means without a common superscript differ (P < 0.05)

[1] Units = thousands of cells per ml

Discussion

  Thermal conditions. Ambient heat stress was minimal for the period of the study as define by research reviewed in VanBaale (2005) and West (2003), which reported that below a mean daily THI of 72 lactating dairy cattle are under no heat stress. The greatest mean daily THI for the study was 74.3 ± 1.05 and there were only three days of the experiment where mean daily THI was above 72 (data not shown). Spiers et al. (2004) and West et al. (2003) both indicated that the effects of heat stress are maximal 48 hr after its onset. Mean THI for the 48 h before and day of the milk test were never stressful, although parts of those three days may have been moderately stressful (Table 6.2). Because of the moderate thermal conditions throughout this trial, these results may characterize the effect of the cooling treatments during low heat load better than heat stress.

  Body temperature. A rise in body temperature signals that an animal's mechanisms for coping with heat influx are not able to keep up with the rate of accumulation (Schmidt-Nielson, 1997). Body temperature remained in the normal range for lactating cows (McDowell, 1972) during the periods of time it was measured in this study, indicating that neither treatment experienced significant heat stress.

  Milk production. Change in milk yield tended to be different among treatments, and varied between milk tests (Table 6.3). Cows that were cooled with sprinklers and fan had a tendency toward an overall decrease in yield of 0.38 ± 0.61 kg, whereas cows cooled with fans only, had an increase in yield by 1.18 ± 0.69. However, the variability between cows was such the means were minimally different statistically ($P = 0.09$). The

tendency for sprinkled cows to decrease in milk yield may be due to the novelty of the treatment or variation in days in milk. It may also be possible that ambient thermal conditions were cool enough that sprinkling cows had a negative impact on yield.

Somatic cell count tended to change over time (P = .057), but cooling cows with sprinklers in addition to fans in the holding pen did not affect somatic cell count (P = 0.13). Interestingly, somatic cell count for both groups of cows was lowest during the period when milk yield increased the most (Table 6.3). The cause of this simultaneous increase in yield and decrease in somatic cell count is unknown. High somatic cell counts have been associated with sub clinical mastitis (Macmillan et al., 1983). These results indicate that wetting the cows with water to cool them does not pose additional risk to mastitis. It should be noted that cows in this study were sprinkled with the goal of wetting the skin without reaching the point where water ran down their sides, but achievement was not measured or quantified.

Percent total protein in cows cooled with sprinklers and fans in the holding pen was lower than in cows cooled with fans alone (P = 0.01). The affect of treatment on percent milk fat was dependant on the date of milk test, although the trend of change was similar among treatments. Lin et al. (1998), in a similar comparison of cooling systems reported that cooling system did not affect protein content in milk and affect on milk fat was dependant on year. Fuquay (1981), in a review, reported that reduction in milk protein has been associated with heat stress in the past. It is doubtful that heat stress was the cause of the differences in milk fat and protein between treatments in this trial. Pre-trial data for milk fat and protein were not available for this study. Because differences

in those milk components exhibited little change over time (Table 6.3), it may be reasonable to assume those differences existed before the study and are not direct affects.

Economic benefits. Any improvement to milking facilities must be offset by an increase in production to be economically beneficial. The cost of installing the fans which were installed when the diary was built was estimated at $4500.00, but because we compared cooling cows with fans to cooling cows with fans and sprinklers there is no way to establish an economic benefit for the use of fans alone. The economic benefit of sprinklers in additions to fans can be evaluated to some extent. The sprinklers were installed as part of this project cost $1500.00, which does not include labor or operating costs. If the cost of the sprinklers were averaged over the whole dairy the cost per cow would be approximately $1.00 per cow, which was not recovered because cooling cows with sprinklers in addition to fans did not improve yield. Under greater heat load changes in yield may be detectable.

Implications. Sprinkling cows in the holding pen in addition to cooling with fans alone may provide benefits to cows during periods of moderate to high heat stress, but no benefits were discernable for the minimally stressful conditions of this study. On the contrary, cooling cows with sprinklers in the holding pen in addition to fans tended to reduce milk yield and change milk composition during thermal conditions of this study. Further research is warranted to define the environmental conditions at which cooling cows with sprinklers in the holding pen becomes beneficial.

CHAPTER VII

GENERAL CONCLUSIONS

The highly variable climate of the Texas Panhandle leave studies of animal-environment interactions at the mercy of the environment. The results for all the parameters measured, indicate that thermal conditions for the duration of this study were moderately stressful at the most and non-stressful on average. Such conditions are not ideal for the study of heat stress. However, several general conclusions can be made from these studies about environmental interactions, thermal tolerance and potential solutions for more challenging thermal environments.

Environmental Interactions

The environmental variables that create heat stress interact in dynamic and sometimes opposing ways. The correlation between THI and the physiological responses to heat stress have been used for decades as an indicator of the magnitude of influence that ambient temperature and relative humidity have on animal production (Berman, 2005; Collier and Zimbelman, 2007; Igono et al., 1985; Lacetera et al., 2002; McDowell, 1972). However, THI may not accurately describe the level of heat stress an animal is under, especially when animals have no access to shade because THI does not take into account wind or the proportion of heat absorbed by animals as solar radiation (Gaughan et al., 2008; Mader et al., 2006).

Several factors in the studies reported in this thesis support the suggestion that solar radiation and wind speed should be incorporated into heat stress indices. First, covering polyethylene hutches with reflective insulation moderated ambient temperature and its change within hutches and reduced respiration rate of calves, suggesting that solar radiation may negatively affect calves in such hutches at relatively low THI. Future studies at higher and more stressful THI may demonstrate additional benefits to using reflective insulation to block solar radiation that this study was unable to detect.

Second, wind speed played a major role in whether weaned heifers utilized the shade. As wind speed increased, the proportion of heifers in the shade decreased at all estimated THI levels. These results are consistent with the findings of Mader et al (2006) who, in modeling heat stress in feedlot cattle, showed that wind speed moderated the effects of thermal temperature and solar radiation.

Thermal Tolerance

These results indicate that while weaned calves may perceive heat load at similar thresholds as adult cattle (Hahn, 1999), they are better able to cope with it. The presence of shade did not benefit the heifers in pastures, in terms of lowering body temperature and increasing weight gain, but the observed heifers did utilize the shade for periods of the day when lack of wind and higher THI may have induced moderate heat load. Thus, it seems that while the heifers felt thermal discomfort and responded by seeking shade, the conditions of this trial were not stressful enough to induce a physiological response.

Future research should focus on defining the environmental conditions at which growing heifers might benefit physiologically from shade.

Potential Solutions for More Challenging Environments

The application of radiant insulation to polyethylene hutches was successful at moderating the hutch temperature and reducing calf respiration rates. Other physiological benefits may be discernable at higher THI. Calf body temperature was slightly higher in calves from insulated hutches at low THI indicating that similar application may benefit calves by retaining heat in cooler temperatures. Application of reflective insulation may be beneficial to cattle when used in other shading methods as well.

Feed bunk sprinklers removed the affect of THI from influencing the timeing of attendance at feed bunk, but did not induce major changes in feeding pattern or overall bunk attendance. Additionally, because observations were made at a group level, the effect of feed bunk sprinklers on the frequency that cows ate at an individual level could not be determined. Further research is also needed to determine the effect of feed bunk sprinklers on the duration of attendance and feed intake.

Previous studies using sprinklers and fans to cool cows found marked increases in milk production and conception rates (Collier et al., 2006; Thatcher et al., 1974). Sprinkling cows in the holding pen in addition to cooling with fans alone may provide benefits to cows during periods of moderate to high heat stress, but no benefits were discernable for the minimally stressful conditions of this study. On the contrary, cooling

cows with sprinklers in the holding pen in addition to fans, may reduce milk yield and change milk composition during non-stressful thermal conditions, indicating that until mean daily THI is above 72 fans are adequate for cooling cows in the holding pen.

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