

KORRAL KOOL SYSTEMS IN DESERT ENVIRONMENTS

by

XAVIER ALEJANDRO ORTIZ DE JANON

B. S., Kansas State University, 2007

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Animal Science & Industry  
College of Agriculture

KANSAS STATE UNIVERSITY  
Manhattan, Kansas

2009

Approved by:

Major Professor  
Dr. John F. Smith

## **Abstract**

A series of experiments was developed to investigate how Korral Kool<sup>®</sup> (KK) systems work in arid climates to prevent heat stress on dairy cows. These experiments were conducted during summer on a commercial dairy farm in eastern Saudi Arabia. In the first experiment, the core body temperatures (CBT) of 63 multiparous cows were evaluated when KK were operated for 18, 21 and 24h/d. Animals were housed in 9 different pens, which were randomly assigned to treatment sequence in a 3x3 Latin square design. In the second experiment, 21 multiparous and 21 primiparous cows were housed in 6 different pens, which were randomly assigned to sequence of treatments (KK operated for 21 or 24h/d) in a switchback design. In the third experiment, 7 primiparous and 6 multiparous lactating cows were assigned to one of two pens, which were randomly assigned to treatment sequence in a switchback design. Treatments in the third experiment were KK used with or without feedline soakers 24h/d. In the fourth experiment, 20 multiparous cows were randomly assigned to one of two pens, which were randomly assigned to treatment sequence in a switchback design. Treatments in this experiment were KK operated for 24h/d while feedline soakers were operated for 12h/d. In the fifth experiment, 2 different sizes of KK were compared (BIG and SMALL); 48 multiparous cows were randomly assigned to 8 pens and pens were randomly assigned to sequence of treatments (KK were operated for 21 or 24h/d) in a switchback design. Results demonstrated that for multiparous cows in desert climate conditions, it is advisable to operate KK systems continuously regardless of the size of KK system used, whereas KK operating time could potentially be reduced from 24 to 21h for primiparous cows. Reducing operation time should be done carefully, however, because CBT was elevated in all treatments. Feedline soakers complementing KK systems decreased the CBT of dairy cows housed in desert environments. However, the combined systems were not adequate to lower CBT to normal temperatures in this extreme environment.

# Table of Contents

List of Figures .....	vi
Acknowledgements .....	viii
Dedication .....	ix
CHAPTER 1 - Literature Review .....	1
Introduction.....	1
Thermo Regulatory Mechanisms.....	3
Conduction .....	4
Convection .....	4
Radiant Exchanges .....	5
Evaporation .....	5
Sweating.....	5
Panting .....	6
Heat Stress Indicators .....	6
Respiration Rates .....	7
Body Temperature .....	7
Animal Behavior .....	7
Effects of Heat Stress.....	8
Nutrition .....	8
Reproduction.....	9
Expression of estrous behavior .....	9
Follicular development .....	10
Conception rate .....	10
Endocrinology.....	11
Thyroid hormones.....	11
Progesterone.....	12
Estradiol .....	12
Prolactin .....	12
Luteinizing Hormone (LH).....	12
Follicle Stimulating Hormone (FSH).....	13

Somatotropin.....	13
Cortisol.....	13
Milk Yield.....	13
Health.....	14
Methods to Reduce Heat Stress .....	15
Genetics.....	15
Facilities .....	16
Shade.....	16
Fans .....	17
Fans and water spray.....	17
Evaporative cooling .....	18
Feedline soakers.....	18
Holding pen.....	19
Exit lane cooling.....	19
Nutritional management.....	19
Conclusions.....	21
CHAPTER 2 - Effects of Korral Kool <sup>®</sup> Running Time over Core Body Temperature on Dairy Farms in an Arid Environment .....	22
Abstract.....	23
Introduction.....	24
Materials and Methods.....	25
Experiment 1 .....	25
Experiment 2.....	26
Statistical Analysis.....	26
Results.....	26
Experiment 1 .....	26
Experiment 2.....	27
Discussion.....	27
Conclusions.....	29
CHAPTER 3 - Effect of Feedline Soakers Complementing Korral Kool <sup>®</sup> Systems on Lactating Dairy Cows in a Desert Environment.....	33

Abstract.....	34
Introduction.....	35
Materials and Methods.....	35
Experiment 1 .....	36
Experiment 2.....	36
Statistical Analysis.....	37
Results.....	37
Experiment 1 .....	37
Experiment 2.....	37
Discussion.....	38
Conclusion .....	40
<b>CHAPTER 4 - A Comparison of the Effects of Two Different Korral Kool® Systems on Dairy</b>	
Cows in a Desert Environment .....	44
Abstract.....	45
Introduction.....	46
Materials and Methods.....	47
Statistical Analysis.....	48
Results.....	48
Discussion.....	49
Conclusion .....	51
Bibliography .....	55

## List of Figures

Figure 2.1 Average ambient temperature and relative humidity by hour (Exp. 1).....	30
Figure 2.2 Mean core body temperature of multiparous cows with KK operated for 18, 21 and 24 hours per day (Exp. 1). Bars represent the SEM. Values with different letters are significantly different ( $P < 0.05$ ). .....	30
Figure 2.3 Running CBT of multiparous cows with KK operated for 18, 21 and 24 hours per day Treatment by time interaction: $P < 0.001$ . SEM=0.18 (Exp. 1).....	31
Figure 2.4 Average ambient temperature and relative humidity by hour (Exp. 2).....	31
Figure 2.5 Mean core body temperature of multiparous and primiparous cows with KK operated for 21 and 24 hours per day (Exp. 2). Bars represent SEM. Values with different letters are significantly different ( $P < 0.01$ ).....	32
Figure 2.6 Core body temperature of primiparous and multiparous cows with KK operated for 21 and 24 hours per day (Exp. 2). Treatment by time interaction for primiparous and multiparous cows: $P < 0.001$ . SEM=0.008 .....	32
Figure 3.1 Average ambient temperature and relative humidity by hour (Exp. 1).....	41
Figure 3.2 Mean core body temperature of multiparous and primiparous cows with KK operated for 24 hours per day with (ON) and without (OFF) the complementation of feedline soakers operated for 24 hours per day (Exp. 1). Bars represent SEM. Values with different letters are significantly different ( $P < 0.01$ ).....	41
Figure 3.3 Core body temperature of primiparous and multiparous cows with KK operated for 24 hours per day with (ON) or without (OFF) the complementation of feedline soakers run continuously (Exp. 1). Treatment by time interaction: $P < 0.001$ . SEM=0.061 .....	42
Figure 3.4 Average ambient temperature and relative humidity by hour (Exp. 2).....	42
Figure 3.5 Mean core body temperature of multiparous cows with KK operated for 24 hours per day with (ON) and without (OFF) the complementation of feedline soakers run for 12 h/d (Exp. 2). Bars represent SEM. Values with different letters are significantly different ( $P < 0.04$ ). .....	43

Figure 3.6 Core body temperature (CBT) of primiparous and multiparous cows with KK operated for 24 hours per day with (ON) or without (OFF) the complementation of feedline soakers run for 12 h/d (Exp. 2). Treatment by time interaction: $P < 0.02$ . $SEM=0.08$ .....	43
Figure 4.1 Diagram of the distribution of the sensors under three KK units in the SMALL and BIG KK systems measuring ambient temperature at 5-minute intervals.....	52
Figure 4.2 Average ambient temperature and relative humidity by hour. ....	52
Figure 4.3 Calorimetric distribution of the area under KK units of 1.52 m in diameter, 5 hp motors and a distance of 8 m between units (BIG).....	53
Figure 4.4 Calorimetric distribution of the area under KK units of 1.29 m in diameter, 3 hp motors and a distance between units of 6 m (SMALL). ....	53
Figure 4.5 Mean core body temperature of multiparous cows with SMALL and BIG KK systems operated for 21h and 24 hours per day. Bars represent SEM. The contrast between the BIG and the SMALL systems was not statistically significant ( $P<0.13$ ). Treatment effect in the SMALL KK system is significantly different ( $P < 0.03$ ). Treatment effect in the BIG KK system is significantly different ( $P < 0.02$ ). ....	54
Figure 4.6 Running CBT of multiparous cows with BIG and SMALL KK systems operated for 21 and 24 hours per day Treatment by time interaction: $P < 0.001$ . $SEM=0.06$ .....	54

## **Acknowledgements**

The author would like to acknowledge NADA Al-Othman, for their support in the development of these experiments. The author would also like express his appreciation to Dr. John Smith, Dr. Barry Bradford and Dr. Joe Harner for their patience, guidance and hard work putting these studies together. Without their effort this thesis would not have been possible.

## **Dedication**

I would like to dedicate this thesis to God for all the opportunities he has put in my path. To Renate Diaz Gill for giving me the strength to confront all my challenges and for allowing me to share my life with her. Finally to my family for all their unconditional support in all the decisions I have made and their effort looking after my future.

# CHAPTER 1 - Literature Review

## Introduction

In the dairy industry one of the biggest problems is the susceptibility of dairy cows to heat stress. Every year, animals are more vulnerable to changes in weather caused by global warming (Klinedinst et al., 1993). In addition, the majority of the biggest dairy farms in the US are located in regions where seasonal stressors adversely influence productivity (Collier et al., 2006). These challenges have created more interest in the development of mitigation measures and techniques that prevent heat stressed animals.

An animal in thermoneutrality, or zone of thermal comfort (ZTC), is in the range of maximum sensation comfort. At this stage the environmental factors promote maximum performance and least stress for the animal. NRC (2001) suggested that for lactating dairy cows, the ZTC is between 5 and 20°C. When temperature is beyond 20°C, environmental factors compromise the animal's zone of thermal comfort affecting the performance and maintenance requirements of animals (NRC, 2001). It has been also suggested that major physiological changes are more evident at temperatures above 25°C (McDowell 1972). It needs to be considered that relative humidity plays an important role in the variation of ZTC; as relative humidity increases, the ability of animals to exchange heat with the environment decreases, meaning that at lower temperatures animals could be under heat stress.

Heat stress is defined as the negative balance between the amount of energy an animal exchange with the environment, and the amount of heat energy produced by the animal as result of metabolic reactions. The regulation of this balance is made by environmental factors (ambient temperature, relative humidity, solar radiation, air movement, and precipitation), animal properties (rate of metabolism, moisture loss) as well as thermoregulatory mechanisms of the animal with the surrounding environment (non evaporative and evaporative) (Armstrong, 1994; Bohmanova et al., 2007; St-Pierre et al., 2003).

Researchers developed a method to estimate and control the impact of environmental conditions over livestock. This index is called Temperature Humidity Index (THI), and it takes in consideration the thermal stress of the animals related with all the environmental information available such as ambient temperature, relative humidity and solar radiation.

According to the National Research Council (1971), the formula to calculate THI for dairy cattle is:

$$\text{THI} = ((1.8 \times T_{\text{db}}) + 32) - (0.55 - 0.0055 \times \text{RH}) \times (1.8 \times T_{\text{db}} - 26)$$

$T_{\text{db}}$ : Temperature dry bulb, outdoor ambient temperature in degrees Celsius

RH: Relative humidity in percentage

New investigations have shown that each species has a different value of THI, and it should be calculated depending on the methods and characteristics of the thermoregulatory mechanisms as well as the sensitivity of each specie to environmental conditions. According to Armstrong (1994) when THI exceeds 72 an environment is considered stressful for dairy cattle.

Even though the THI values are used to estimate the impact of heat stress on animals, cows are exposed to different microenvironments within a farm created by the cooling systems and the position of the cows in the pens (Collier et al., 2006). Therefore new technology has been used to estimate if animals are adequately cooled. One approach is the use of infrared thermography guns, which measure the actual skin surface temperature of animals. If the skin surface temperature is below 35°C, the difference between the skin temperature and the core body temperature is large enough to effectively exchange heat from the body with the surrounding environment (Collier et al., 2006). Although this approach does not require restricting movements of cows and it also takes in consideration the different microenvironments that cows are exposed (Collier et al., 2006), the accuracy of the predictions can be limited by the variability in skin surface moisture at a given point in time (VanBaale, 2006).

Another alternative is the use of data loggers attached to a continuous intravaginal drug release (CIDR). These devices remain inside the cow's vagina measuring and recording core body temperature (CBT) 24h/d as they move throughout all the areas of a dairy facility (VanBaale, 2006).

During periods of heat stress, dairy cattle develop a series of changes (anatomical, physiological and behavioral), but most of these changes are the result of the animal's effort to acclimatize with the environment. This process takes place in neurons that are temperature sensitive located throughout the animal's body (Mount, 1979). These peripheral temperature receptors in the skin send information to central temperature receptors in the hypothalamus, in the midbrain, and in the spinal cord. Information from both peripheral and central receptors

influences the control of body temperature, which is centrally mediated in the hypothalamus, which invokes numerous acclimation responses (Curtis, 1983; Mount, 1979).

During heat stress, animals decrease feed intake to reduce the metabolic heat produced by fermentation. Due to the decrease in feed intake, the animal loses weight, body condition decreases, energy balance is affected, milk composition is compromised and milk production decreases.

The reproductive performance of cows decreases during thermal stress, the expression of estrus is reduced and fertility decreases in lactating dairy cows. During thermal stress, steroid hormones are affected, compromising reproduction and other functions.

Due to the change of thermal conditions, animals change their normal behavior to cope with the environment. As a result of these changes in behavior, animals are more susceptible to laminitis and hoof diseases (Cook et al., 2007).

In the United States during periods of heat stress, the diverse physiological, behavioral and nutritional changes that animals go through have a big impact on the profitability of dairy cattle. According to St-Pierre et al. (2003), across the United States, heat stress results in an estimated \$897 to \$1500 million in losses per year in the dairy industry.

Beede and Collier (1986) recommended three heat abatement management techniques to prevent losses and at the same time increase the wellbeing of dairy cows: 1) Cooling systems to modify the environment, 2) Genetic development for animals more resistant to environmental changes but without any negative effect on performance, and 3) Nutritional management practices.

### **Thermo Regulatory Mechanisms**

The equilibrium between the metabolic heat production and the heat dissipation from the cows to the environment regulates the core body temperature of animals (Hansen, 2004). Cattle can exchange heat with their surrounding environment in four ways: conduction, convection, radiation and evaporation. Conduction, convection and radiation involve differences in the temperatures of materials involved, and depend on a thermal gradient. As environmental temperature rises above a critical point, the thermal gradient is reduced and heat dissipation via conduction, convection and radiation is less effective. With increasing ambient temperature,

evaporative cooling becomes more important than non evaporative, and more heat flow is exchanged by evaporative pathways (Kibler, 1950; Maia et al., 2005).

### ***Conduction***

The definition of conductive heat exchange is the flow of heat between two media or bodies in direct physical contact. There are three types of media material: gases (air surrounding the animal), solid and liquids. If the media materials are gases or liquids, the conductive heat exchange is affected by the convective heat exchange between those materials and the animal. The flow of heat by conduction is affected by differences in media temperature as well as the thermal conductivity of the material and the area of contact. As example of this, cows will tend to stand during hot environment to reduce contact with the ground, and increase the surface area in contact with the air. The net heat exchanges via air are small due to the low thermal conductivity of air (Yousef, 1985). If air temperature or ground temperature on which the animal is lying is greater than skin temperature, then the animal will gain heat by conduction, adding to metabolic heat load (Yousef, 1985). On the other hand, if a cool wet area is available, cows will lay in it depending on the conductance of the liquid as well as the temperature difference and magnitude of the area of contact relative to the total surface area (Kadzere et al., 2002).

### ***Convection***

Convection is defined as the exchange of heat with moving air surrounding the surface of the body. Convection is a thermoregulatory mechanism which could increase or decrease the temperature of the animal's body, depending on the ambient temperature surrounding the animal and the temperature of the animal's surface. If the ambient temperature is lower than the temperature of the surface of the animal, the heat from the surface of the animal is exchanged with the temperature of the air creating a heated layer of air surrounding the surface of the body, and thereby cooling the body through the process of convection (Kadzere et al., 2002). Dairy cows in hot environments increase their skin circulation (vasodilatation) to enhance heat loss and prevent a rise in core body temperature. This method is unlikely to be major method of heat dissipation in cattle because of their large body mass, but convection helps to decrease the temperature on the surface of the body (Berman et al., 1985).

### ***Radiant Exchanges***

This method exchanges heat loads by the amount of radiation heat that an animal can receive from solar energy (short wave), and from radiation exchange between the animal and its environment (long wave) (Yousef, 1985). Long waves exchange heat away from the cow, helping the animal to decrease its temperature. According to Cena and Monteith (1975) the amount of heat gain by radiation depends on the temperature of the animal or object, and also on its color and texture. Dark surfaces radiate and absorb more heat than light colored surfaces. Stewart and Brody (1954) reported that the type and color of Brahman's coat decreases its susceptibility to solar radiation compared with Jersey and Holstein cattle.

### ***Evaporation***

This heat exchange mechanism varies by breed of cattle. Evaporation in dairy cattle is considered the most important thermoregulatory mechanism during periods of hot temperature and low relative humidity. During this process 2.43 joules of heat are lost for each gram of water that evaporates (Silanikove, 2000). Cows accomplish the process of evaporation in two ways: through the diffusion of water through the skin (sweating), and by loss of water vapor from the respiratory tract (panting). Water losses from sweating and panting can cause a critical level of dehydration, becoming a threat to thermoregulation and cardiovascular function (Silanikove, 1994). Evaporation effectiveness is compromised when relative humidity or temperature increases. According to Maia et al. (2005), under natural conditions and at temperatures between 10 and 20°C, approximately 20% of the heat is lost via sweating. At 30°C, of the total evaporative heat loss in cattle, about 85 % of the heat is lost through sweating and 15% is lost via panting.

#### ***Sweating:***

Sweating can be considered the most important thermoregulatory mechanism in high temperature environments. Cattle have apocrine sweat glands and they are associated with hair fiber (Yousef, 1985). There are two types of sweating in dairy cattle, the first one is insensible sweating of perspiration that leaves the body at all times, unless relative humidity increases. The second type of sweating occurs when ambient temperature rises and it is the principal evaporative cooling mechanism of the cow. According to Collier et al. (2008) there are physical (wind speed, ambient temperature, and relative humidity) and animal factors (sweat gland

density and function, hair coat density and thickness, hair length and color, skin color, and regulation of epidermal vascular supply) affecting the efficacy of sweating. Berman (2005) estimated the maximal sweating rate of cattle between 200 to 300 g/m<sup>2</sup> per hour.

In heat stressed cows the increase in sweating rate leads to an increase in the loss of water and ions like potassium, sodium and chlorine (Kadzere et al., 2002; Mallonee et al., 1985).

### ***Panting:***

Panting allows for the exchange of heat with the environment via respiration. It can be accomplished by two methods, through evaporation of water in the lungs and by increasing the temperature of the inhaled air (Brouk, 2001). The amount of heat exchanged via respiration depends on the number of breaths per minute and the temperature and humidity difference between the inhaled and exhaled air (Brouk, 2001). In the case of high relative humidity, sweating is limited but respiratory cooling may still be effective.

One of the consequences of panting during hot climatic conditions is the respiratory alkalosis created by the elevated blood pH. This change in blood pH is the result of a carbonic acid deficit created by carbon dioxide (CO<sub>2</sub>) expired due to panting (Dale and Brody, 1954). When the cow pants, bicarbonate (HCO<sub>3</sub>)<sup>-</sup> is converted to carbonic acid, which is broken down to carbon dioxide and water for exhalation and excretion (Dale and Brody, 1954). When panting increases, the loss of CO<sub>2</sub> via pulmonary ventilation reduces the blood concentration of carbonic acid, creating a critical imbalance between carbonic acid and bicarbonate, affecting blood pH and resulting in respiratory alkalosis (Benjamin, 1981). In their effort to maintain the blood pH equilibrium during respiratory alkalosis, cows increase urinary excretion of bicarbonate and Na, and increase the renal conservation of K. The decrease in blood bicarbonate concentration results in a decrease in the bicarbonate pool available for buffering the rumen, lowering the ruminal pH of cows during heat stress (Bandaranayaka and Holmes, 1976) and during cooler evening hours creating metabolic acidosis (West, 2003).

## **Heat Stress Indicators**

For dairy managers it is extremely important to realize when the animals are under high thermal conditions. The awareness of animals under heat stress helps producers to take heat stress preventive measures. Currently the most used heat stress indicators are: respiration rates, body temperature and animal behavior.

### ***Respiration Rates***

Respiration rate is a gross indicator of heat load in animals during hot weather, due to the high correlation between the respiration rate and the thermal condition of the animal. Thermal stress induces physiological changes, including increased respiration rates, in order to maintain a thermal equilibrium (Kadzere et al., 2002). In cool conditions the reported amount of breaths is 20 breaths/min which increases to 100 or more per minute at severe heat stress (Silanikove, 2000). Although high temperatures play a more important role in affecting the respiration rate of dairy animals, high relative humidity decreases the effectiveness of evaporative mechanisms of thermal regulation, decreasing the ability of animals to exchange heat with the environment. Respiratory behavior was considered the best indicator of climatic heat stress. According to Hahn (1999), an animal with heat stress increases the respiration rate to maintain homeothermy by dissipating excess heat as other ways of heat exchange become insufficient.

### ***Body Temperature***

An increase in body temperature is the result of the imbalance between the heat energy produced by the animal and the amount of heat dissipated. Body temperature is the best indicator to assess the physiological response to high thermal environments in dairy cows, because it is nearly constant under normal conditions. Normal body temperatures of dairy cattle vary from 38°C to 39.3°C with an average of 38.6°C (Dukes, 1947). A 1°C increase in core body temperature of 1°C or less is enough to reduce performance in most livestock species (Kadzere et al., 2002).

### ***Animal Behavior***

Heat stress in dairy cattle not only alters the physiology and performance, but it also affects the behavior of animals. According to Jones (1999), some of the behavioral changes due to heat stress are: increased water intake, seeking out shade, reduced feed intake, standing rather than lying down and increasing respiration behavior.

Drinking behavior will increase due to the dehydration of the animal; Garcia (2006) mentioned that water helps the animal to transfer heat from the body to the environment. As the temperature rises from 30 to 35°C, water intake may increase from 71 to 121 liters per day (Garcia, 2006). Cook et al. (2007) reported an increase from 0.3 to 0.5 h/d in drinking behavior at a THI of 68 units.

Cows are more likely to seek shade during elevated temperature waves. This type of behavior could be preferred by animals instead of drinking or eating behaviors (Jones, 1999).

Reduced feeding behavior is another symptom of heat stress. The animal decreases this behavior to regulate the amount of metabolic heat produced. Feed intake of a dairy cow may be compromised when ambient temperatures are above the comfort zone of the cow (5 to 20° C). When ambient temperatures go beyond 25° C, cows typically decrease dry matter intake (NRC, 2001). Perera et al. (1986) reported that eating activity in winter was 5.6 h/d and decreased to 4.2 h/d during summer months.

According to Albright (1997), resting behavior is decreased with heat stress. Cattle trying to dissipate more body heat tend to stand rather than to lie down and ruminate (Albright, 1997). Cook et al. (2007) reported a decreased in resting behavior from 10.9 to 7.9 h/d at a THI of 68 units.

## **Effects of Heat Stress**

Some of the major responses of animals to thermal stress include changes in nutrition, reproduction, health and decrease in production.

### ***Nutrition***

The main nutritional impact of hot environments on lactating dairy cows is the decrease in feed intake. This reduction in feed intake contributes to control the heat production by ruminal fermentation and metabolic processes (Sanchez et al., 1994). Feed intake begins to decline at ambient temperatures between 25 - 27°C (NRC, 1981). However, a decrease in feed consumption has been reported on dairy cows at lower temperatures and high relative humidity (Johnson, 1963).

According to Brobeck (1960), heat stress causes the rostral cooling center of the hypothalamus to stimulate the medial satiety center which inhibits the lateral appetite center, resulting in reduced feed intake and consequently lower milk production. Even though the reduction in feed intake is not completely understood, some authors have reported that the reduction in feed intake is the result of changes in elevated body temperature, the reduction in blood flow and may be related to gut fill (McGuire et al., 1989; Silanikove, 1992).

The decrease in feed intake may induce a negative nitrogen balance in the animal decreasing the protein available for production (Hassan. A., 1975; Higginbotham et al., 1989)

During thermal stress, the concentration of volatile fatty acids (VFA) in the rumen decreases (Kelley et al., 1967), due to the decrease of rumen motility (Attebery and Johnson, 1969), and decrease in fiber intake, which may lead to decreased acetate production as well the acetate and propionate ratio (Weldy et al., 1964). Despite the idea that cows have better performance on a lower fiber diet in hot weather due to the reduced heat production in the digestion of high concentrate rations, ruminal pH is reduced as consequence of propionate and lactic acid production from increased high energy feed intake (Pitt et al., 1996). The decline of pH often increases the cases of cows with rumen acidosis (Collier et al., 2006).

During hot conditions dehydration by sweating increases the need of animals to consume water. Water is one of the most important nutrients for dairy cattle due to the correlation with feed intake and milk production. Murphy et al. (1983) mentioned that water may increase by 1.2 kg/°C increase in minimum ambient temperature. Further more, the composition of cattle's sweat is high in potassium and low in sodium. It has been estimated that potassium requirements increase by as much as 12 % in heat stressed cows (Collier et al., 2006). This is especially important when diets are based on feed sources with low potassium content.

### ***Reproduction***

Heat stress has a negative impact on reproduction in dairy cattle and even though many studies have been developed to understand the physiology of the reproductive changes that animals go through during thermal stress, the knowledge is not enough to control and prevent the reproductive effects. Some of the most important consequences in dairy cows' reproduction due to heat stress are: decreased expression of estrous behavior, reduced duration of estrus, altered follicular dynamics, decreased oocyte quality for an extended interval even after thermal stress is removed, decreased conception rate, early embryonic mortality and decreased pregnancy rate.

#### ***Expression of estrous behavior:***

The reproductive performance on a dairy farm is greatly influenced by the ability to accurately detect heat. Failing to detect heat will contribute to longer calving intervals and a decrease in income (Barr, 1975). During periods of thermal stress, the duration and intensity of behavioral estrus decreases and the incidence of anestrus and silent ovulation are increased, leading to a decrease in detection of estrus (Gwazdauskas et al., 1981; Pennington et al., 1985; Thatcher, 1986). According to Rensis and Scaramuzzi (2003), the reduction in fertility due to

poor expression of estrus is a consequence of the decrease in hormonal secretion of LH and estradiol during heat stress.

***Follicular development:***

Follicular dynamics are also affected with elevated environmental temperatures. Wolfenson et al. (1995) reported impaired follicular development, a depression of follicular dominance correlated with a significant increase in large follicles, a decrease in the number of medium-sized follicles and the decline of plasma estradiol concentration in heat stressed cows. Despite the fact that the average size of dominant follicles did not differ in the first wave, the decline in size was sooner during thermal stress. On the other hand, the emergence of the preovulatory follicle, or second wave, was sooner, suggesting that the dominant follicle in the second wave may have been an aged follicle at ovulation, compromising the quality of the oocyte and follicular steroidogenesis (Howell et al., 1994; Jordan, 2003; Wolfenson et al., 1995). This reduction in oocyte quality lasts for an extended interval of 40–50 days after thermal stress is removed, which is suggested to be the reason for decreased fertility of dairy cows during cooler autumn months (Collier et al., 2006; Rensis and Scaramuzzi, 2003; Roth et al., 2001).

***Conception rate:***

Uterine blood flow helps dissipate the uterine metabolic heat and it is a source of nutrients, oxygen and water for the developing embryo. Uterine blood flow is mainly controlled by estrogens and progesterone. During periods of thermal stress, increased catecholamines and probably changes in estrogen create a decrease in blood flow going to the uterus and an increase in uterine temperature, compromising the oviductal or intrauterine environment (García-Ispuerto et al., 2007; Roman-Ponce et al., 1978). These changes in the intrauterine environment have been linked to decreased conception rates and early embryonic loss (García-Ispuerto et al., 2007). Negative effects on reproduction of heat stressed cows begin before mating; Garcia-Ispuerto et al. (2007) mentioned that cows under heat stress before artificial insemination (AI) showed a decrease in conception rate after AI. Conception rate seems to decrease from a THI of 75 units or 25.8°C, although the effects of heat stress become more obvious above 80 units of THI, when conception rate decreased from 30.6 to 23.0 % (García-Ispuerto et al., 2007). The reason for the decrease in conception rate is not well established, but one of the reasons could be that exposure of spermatozoa to elevated temperatures after AI in the uterus or oviduct of a hyperthermic

female could compromise sperm survival, fertilizing capacity, or both (García-Ispuerto et al., 2007).

Early embryonic mortality is also correlated with the decrease in uterine blood flow and the likely reason is that low uterine blood flow elevates the intrauterine temperature, resulting in increasing metabolic rate of the conceptus, altering nutrient uptake and growth (Biggers et al., 1987). On the other hand, a decrease in uterine blood flow would decrease the amount of nutrients, oxygen and water for the developing embryo. According to Biggers et al. (1987) the smaller conceptus may not develop the biosynthetic capabilities required to signal the maternal system to maintain CL function, compromising the survival of the embryo. There have been studies evaluating the effects of heat stress before and after the service of the animal. Garcia-Ispuerto et al. (2007) reported that the reproduction of cows is more sensitive to high environmental temperatures at day 3 before AI and at day 1 after AI.

### ***Endocrinology:***

The reproductive physiology of animals is controlled by hormones secreted in the organism. The concentrations of these hormones have been reported to be altered by heat stress in many studies. According to Collier et al. (2006) acclimation is under endocrine regulation and during this period there are changes not only in hormonal concentrations, but also in the target tissue responsiveness to hormonal stimuli. Additionally, the mechanisms by which heat stress alters the concentrations of circulating reproductive hormones are not entirely known; the reason is that it is difficult to separate the hormonal changes caused by the thermal strain from those caused by the rest of physiological changes, like lower feed intake (West, 2003). Many studies have been developed to improve our understanding of endocrinology during thermal stress; however, some of the major pathways are unclear. Improving our understanding of hormonal physiology may lead to decreased reproductive losses in periods of thermal stress.

### ***Thyroid hormones:***

Triiodothyronine (T3) and Thyroxine (T4) are involved in metabolic homeostasis (Perera et al., 1985). Many experiments measuring the level of T3 and T4 in heat stressed cows gave a variety of results. While Collier et al. (1982b) found an increase in T3 and a decrease in T4, Collier et al. (1982a), Mohammed and Johnson (1985) and Magdub et al. (1982), agreed that heat stressed cows showed a decrease in T3 and T4.

### ***Progesterone:***

There have been discrepancies regarding the effects of heat stress on the concentration of plasma progesterone. Even though some researchers have shown that the concentration of plasma progesterone increases in heat stressed cows (Abilay et al., 1975; Trout et al., 1998), others have shown a decrease (Howell et al., 1994; Rensis and Scaramuzzi, 2003) or no effect (Roth et al., 2000; Wise et al., 1988) on progesterone concentration. Rensis and Scaramuzzi (2003) mentioned that a probable reason for these discrepancies in progesterone concentration is the uncontrolled changes in other factors that affect blood progesterone concentration, like differences in feed intake and intensity of heat stress. A decrease in progesterone concentration during heat stress would compromise follicular development during the luteal phase, affecting oocyte maturation as well as early embryonic death (Rensis and Scaramuzzi, 2003).

### ***Estradiol:***

According to the literature, concentration of peripheral estradiol at estrus is increased by heat stress (Wilson et al., 1998; Wolfenson et al., 1995). Wolfenson et al. (1995) reported that heat stressed cattle experience an increase in estradiol  $17\beta$  concentration between day 1 and day 4 of the estrus cycle and a reduction in estradiol  $17\beta$  concentration from day 4 through 8 and 11 through 21 of the estrus cycle. Rensis and Scaramuzzi (2003) proposed that this decrease in plasma estradiol was the result of a decline in LH levels during thermal stress leading to a reduction of estradiol secretion from the dominant follicle, and to poor expression of estrus.

### ***Prolactin:***

The concentration of prolactin in several studies increased during periods of heat stress (Mohammed and Johnson, 1985; Thatcher, 1974). Thatcher (1974) associated the increase in prolactin with an alteration in the hypothalamic pituitary control.

### ***Luteinizing Hormone (LH):***

There are some inconsistencies in the literature about the influence of heat stress on LH concentration. Some studies have shown unchanged concentrations (Rosenberg et al., 1982) while others found an increase in concentration (Roman-Ponce et al., 1981), and others not only found a decrease in plasma concentration of LH, but a decrease in LH pulse frequency (between day 5 and 12 of the estrus cycle; Wise et al., 1988) and LH pulse amplitude (Gilad et al., 1993).

Rensis and Scaramuzzi (2003) mentioned in their review that these inconsistencies could be related to preovulatory estradiol levels.

#### ***Follicle Stimulating Hormone (FSH):***

The response of FSH to heat stress is not well understood, however many studies suggested an increase in FSH concentration during heat stress (Gilad et al., 1993; Rensis and Scaramuzzi, 2003). The reason for this increase in FSH, according to Rensis and Scaramuzzi (2003) and Wolferson et al. (1995), is the decrease in plasma inhibin secretion from compromised follicles in estrus.

#### ***Somatotropin:***

This metabolic hormone decreases in concentration in periods of heat stress (Igono et al., 1988; Mohammed and Johnson, 1985). Igono et al. (1988) mentioned that a decrease in metabolic hormones like somatotropin and triiodothyronine is the result of the animal's attempt to reduce heat production. Collier et al. (2006) also mentioned that the secretion of somatotropin and thyroid hormones could be inhibited by the release of somatostatin from the hypothalamus stimulated by corticotropin-releasing hormone.

#### ***Cortisol:***

This hormone allows animals to tolerate stressful conditions by inducing physiological changes. Heat stressed cows have an elevated level of cortisol as a short-term response of heat stress (Christison and Johnson, 1972; Wise et al., 1988). As cows acclimate to chronic heat stress, cortisol concentrations decrease to normal levels (Christison and Johnson, 1972).

### ***Milk Yield***

Milk production in the dairy industry is the main source of income and it is affected by high ambient temperatures. It is thought that the decrease in milk yield is not originated by one factor; instead it is the result of a combination of physiological changes that animals experience to maintain thermal equilibrium.

According to the literature, factors such as: reduced energy balance due to a decline in feed intake, increased maintenance energy requirements for the activation of thermoregulatory mechanisms, nutrient metabolism affected by the shifted blood flow to peripheral tissues, decrease metabolic rate as well as the hormonal status of the animal and changes in nutrient

partitioning (Collier et al., 2006; Hansen, 2004; Kadzere et al., 2002; West, 2003; Rhoads et al., 2009; Lough et al., 1990).

The decrease in milk yield can be predicted using THI. Ravagnolo and Misztal (2000) found that milk yield decreases 0.2 kg per unit increase in THI when THI is higher than 72 units. West et al. (2003) reported that elevated temperatures two days before the measurements had the greatest effect on milk yield and feed intake.

Besides the decrease in milk yield, there have been some discrepancies on the effect of heat stress on milk concentration. Collier et al. (1981) found in an experiment conducted in Florida that milk fat content is not affected by heat stress. This result disagrees with Rodriguez et al. (1985), who found a decrease in milk fat content in heat stressed cows. On the other hand, Ravagnolo et al. (2000) found that milk fat yield decreases 0.012kg per unit of THI when THI exceeds 72 units. Emery et al. (1965) mentioned that the reduction in fiber intake would decrease milk fat yield, thus the reduction in roughage intake during heat stress could be one of the reasons for the reduction in milk fat synthesis.

Milk protein content is not affected by heat stress. Collier et al. (1981) found no difference in the milk protein content from non shaded and shaded cows. On the other hand, Ravagnolo et al. (2000) found that milk protein yield decreases 0.009 kg per unit of THI when THI exceeds 72 units.

### ***Health***

Hot and humid environmental conditions may affect the incidence of health problems in dairy cows. According to Kadzere et al. (2002), the incidence of internal parasite populations and disease causing vectors increase during summer, thus the incidence of diseases transmitted by vectors compromise the health of animals.

Lameness of dairy cows is affected by heat stress. Cook et al. (2007) reported an increase in claw horn lesion during late summers. The increase in lameness may be related to behavioral changes associated with reduction in lying time (Cook et al., 2007), and a decrease in the rumen pH due to severe panting. When cows pant buffers are loss due to drooling of saliva, and excretion of bicarbonate to counteract for the respiratory alkalosis created (Benjamin, 1981). This decrease in rumen pH has been associated with a decrease in bacteria producing biotin, a precursor of keratin which is a key factor in the claw horn production in cattle.

The incidence of retained placenta and developed postpartum metritis were analyzed by DuBois and Williams (1980). They found a decrease in gestation time and an increase in cows suffering retained placenta and postpartum metritis during heat stress (DuBois and Williams, 1980). Dale and Brody et al. (1954) reported an increased incidence of ketosis during hot summer months as result of an energy imbalance, accelerating body fat catabolism.

## **Methods to Reduce Heat Stress**

### *Genetics*

The genetic variation for heat tolerance between breeds of cattle is large (Legates et al., 1991). Researchers, in their effort to improve the resistance of dairy cattle to hyperthermia, created crossbreeds between breeds more sensible to heat stress and high thermal resistance breeds and. The results of these crossbreeds were cows more resistant to heat stress, but with lower milk production (Collier et al., 2006). The reason for these results may be that greater milk production is associated with an increase in metabolic activity and at the same time increased heat production by the animal.

Hair coat in cattle plays an important role in the ability of cattle to regulate heat. Factors like color or density of the hair coat can affect the solar radiation absorbed by the animal, the airflow over the skin surface as well as the number of sweat glands in the skin of the cow (Collier et al., 2008). When heat load increases during summers, animals decrease their ability to dissipate heat by the non evaporative thermoregulatory mechanisms and depend mainly on evaporation to exchange heat with the environment. The desire to genetically modify the hair coat of cows to increase the ability of the thermo regulatory mechanisms to exchange heat with the environment motivated investigators to locate genes affecting the characteristics of hair color (MC1-R; Klungland and Vage, 2003) as well as hair length and density (BTA20; Mariasegaram et al., 2007; Olson et al., 2003). With the manipulation of these genes, the goal is to enhance the thermoregulatory mechanisms, especially sweating, to allow the animals to cope with the environment in heat stress.

According to Collier et al. (2008), hyperthermia in animals causes a series of abnormalities in the cellular function that begin a series of changes in the animals' physiology. Some of these changes in cellular functions take place because of changes in the gene expression of the cells. Some of the major changes in gene expression are: the activation of heat shock

transcription factor 1 (HSF1), increased expression of heat shock proteins (HSP), activation of the immune system, decreased fatty acid metabolism and increased glucose and amino acid oxidation (Collier et al., 2008). HSF1 is known for being responsible for the activation of heat shock proteins (Pirkkila et al., 2001). Increased expression of heat shock proteins (HSP) is linked with elevated cellular survival (Pirkkila et al., 2001) and prevention of circulatory shock and cerebral ischemia during heat stress (Lee et al., 2006). Research in the future may generate genetic information for the development of animals more resistant to heat stress via gene manipulation.

### ***Facilities***

To decrease the impact of heat stress in the dairy industry, some heat abatement systems have been created. Effective cooling systems need to take in consideration solar radiation, ambient temperature and relative humidity and should be based on the combination of the principal thermoregulatory mechanisms of the animals (convection, conduction, radiation and evaporation; Collier et al., 2006; West, 2003). According to VanBaale (2006) the basic mitigation strategy is to maintain the ambient temperature lower than the core body temperature of animals to allow the thermoregulatory mechanisms to exchange heat with the environment. Even though the utilization of more than one cooling system is common, the efficiency of these cooling systems is affected by their type and location. All cooling systems fit into one of two categories; they either cool the cows or cool the environment surrounding the cows.

#### ***Shade:***

By protecting animals from direct and indirect solar radiation, shade is one of the most easily implemented and economical methods to minimize heat load (West, 2003). The material of the shade may vary from trees to corrugated sheet steel. Corrugated sheet steel is more often used because of the cost, duration and low maintenance (Armstrong, 1994). The effectiveness of shades has been demonstrated by Roman-Ponce et al. (1977), who reported an increase in 10.7% in milk yield as well as a decrease in respiration rate (54 vs. 82 breaths/min) and rectal temperatures (38.9 vs. 39.4 °C) when cows were housed with a shade structure.

For most effective shade, the upper surface of the shade roof should be painted white, and the shade roof should be 3.5 to 4.5 m high to minimize radiation from the shade roof to the cow (Armstrong, 1994). Steeply pitched shades are frequently utilized. These roofs commonly have

vents that will encourage cross ventilation from wind movement (West, 2003). The amount of shaded area that should be provided to animals depends on the climate. Wiersma (1982) recommended for arid climates 3.5 to 4.5 m<sup>2</sup> of shade area per lactating cow and Buffington (1983) recommended 4.2 to 5.6 m<sup>2</sup>, which provides more ventilation for humid climates.

The ideal orientation of the shade depends on the weather of the region and the type of ground used beneath the shade. In hot conditions and high rainfall areas, an orientation north to south is recommended (Armstrong, 1994). This orientation will allow the sun to dry the ground beneath the shade if cows are housed on a dirt surface (West, 2003). If the animals are located in a hot and low rainfall (10 cm) environment, an east to west orientation is recommended, providing the animals with more shade, but the ground will need additional maintenance (Armstrong, 1994).

***Fans:***

Fans are used to cool cows by moving air around the animal, exchanging heat with the animal via convection. Fans are effective only if the air temperature is less than the cow's body temperature.

***Fans and water spray:***

This method consists of injecting low pressure water into the air stream created by fans suspended from the roof (Armstrong, 1994). The installation of curtains to prevent the mobilization of cooled air due to the natural wind is needed. This system is normally used in the feed area of dry and semi humid regions (Armstrong, 1994). Igono et al. (1987) reported an increase in milk production of 2 kg/day per cow when cows were cooled with fans and mist compared to cows in shade alone. The efficacy of this system is correlated with the length of time cows are cooled. Flamenbaum et al. (1986) reported that cooling the animals with a fan and spray system for 15, 30 and 45 minutes decreased rectal temperature 0.6, 0.7 and 1°C, respectively.

The inconvenience of this system is the large quantity of water needed for cooling the cows. There are two methods used to inject low pressure water into the air. The first one is sprinklers which produce large water droplets and completely wet the cow by soaking through the hair coat to the skin, cooling the animal's skin as the water evaporates (Flamenbaum et al., 1986). The second method is the use of misters which produce tiny water droplets that stay

suspended in the air and evaporate before being deposited on the ground, thus cooling the surrounding air and cooling the animal by convection. Even though Armstrong (1994) mentioned that the use of sprinklers is recommended because the large water drops provide a direct evaporative cooling, Lin et al. (1998) reported that the use of misters had the same effect, increasing feed intake and milk yield as the sprinklers did. However, Lin et al. (1998) recommended that positioning the misters low near the cow is more effective than if positioning the misters higher in the barn.

### ***Evaporative cooling:***

The ability of cows to dissipate heat through evaporation is compromised as ambient temperature exceeds the core body temperature of cows. Therefore, cooling the environment surrounding the cows may be necessary to mitigate heat stress. With evaporative cooling systems it is recommended to have an air velocity of 1 to 1.5 m/s in the proximity of the animals to prevent the stress associated with high humidity (Berman, 2006). The Arizona Manufacturing Company (Mesa, AZ), found a method (Korral Kool<sup>®</sup>) which consists of the injection of very fine fog into the air using large fans to drive air through vanes and creating a cyclonic motion of air down to the cows (Armstrong, 1994; Ryan et al., 1992). The atomized droplets in the air stay suspended, but evaporate before reaching the ground cooling the air surrounding the animals. Curtains need to be installed on the side of the barns to keep the cooled air beneath the shade.

Ryan et al.(1992) demonstrated that cows under an evaporative cooling system had better reproductive performance, pregnancy rate (35% vs. 23%), postpartum interval (117.6 d vs. 146.7 d) and milk production by 0.98 kg/d per cow compared to cows cooled with spray and fan systems. The disadvantage of a Korral Kool evaporative cooling system compared to spray and fan systems is the initial cost and the higher daily cost (VanBaale, 2004).

According to Smith (2007), evaporative cooling can achieve desirable temperatures to reduce heat stress in dry climates. However, evaporative cooling will reduce heat stress in humid environments (Brown, 1974; Smith et al., 2006).

### ***Feedline soakers:***

Evaporation of heat from the skin is the most effective heat exchange mechanism in dairy cows. Feedline soakers have been successfully utilized in arid and humid environments (Armstrong, 1994; Strickland, 1989). Completely wetting the skin surface is essential for the

success of feed line soakers. Previous experiments have shown increases in milk production and reproduction efficiency of cows housed with feedline soakers (Schultz, 1988).

Feedline soakers are more effective when combined with fans, creating air movement. By complementing feedline soakers with fans, the core body temperature, respiration rate and body surface temperature of cows decreased compared to feedline soakers alone (Brouk et al., 2003).

### ***Holding pen:***

Even though some authors believe that cooling the holding pen is not necessary because of the short amount of time that cows spend there (West, 2003), other authors believe that the holding pen is the most stressful area for dairy cows (Armstrong, 1994; Smith, 2006). Armstrong (1994) mentioned that the hot and humid environment in the holding pen can improve if ventilation is added. Collier et al. (2006) reported an increase in milk production and a reduction in core body temperature with the addition of sprinklers and fans in the holding pen. Armstrong (1994) recommended the use of roofs at 4.5m height and the utilization of fans and sprinklers to maintain an adequate ambient temperature, Smith (2006) recommended a density of 1.39 m<sup>2</sup>/cow for groups of less than 200 cows, and a density between 1.48 and 1.57 m<sup>2</sup>/cow for groups greater than 200 cows.

### ***Exit lane cooling:***

The purpose of this system is to prolong the cooling period after milking. It consists of nozzles that wet the hair coat of the cows as they exit the parlor. If it is properly installed, the udder will remain dry as the top and the sides of the animal get wet (Armstrong, 1994). Depending on the weather conditions, this system provides additional cooling for 15 to 25 minutes after the cows return to the corrals (Collier et al., 2006). Collier et al. (2006) recommended that soakers should be located 0.3m behind the control switch and it should deliver 30 liters of water per minute at 35 to 40 psi.

## ***Nutritional management***

The increase in knowledge of the negative effects of heat stress on nutrient requirements have resulted in specific diets for dairy animals during different weather conditions (Collier et al., 2006). It is important to understand that modifications in nutrition management typically do not prevent heat stress, but rather are attempts to support homeostasis of the cow. There are

several key areas of nutritional management which should be considered during hot weather conditions. These include reformulation to account for reduced DMI, requiring increased nutrient density, altered mineral and water requirements, altered digestive tract function and avoiding nutrient excess (Collier et al., 2006; West, 2003).

Water is heavily demanded to maintain homeostasis and homeothermy during periods of heat stress. Abundant water must be available at all times for dairy cows regardless of the ambient temperature.

During summers a common practice is to increase the protein content of diets to account for a reduction in protein intake. However, supplementing excessive protein in the diet is associated with an energetic cost. According to Tyrrell et al. (1970) approximately 7.2 Kcal/g of N, are required to catabolize excessive N in the diet. This extra energy associated with synthesizing and excreting urea will create a reduction in milk yield and an increase in metabolic heat production (Hassan and Roussel, 1975; Oldham, 1984). The level of degradability of dietary protein is important under heat stress conditions. Even though diets with high RUP (39.2% of CP) do not have an effect on feed intake, they may increase milk yield as well as decrease blood urea N (Belibasakis, 1995).

The approach of using some dietary ingredients to decrease the total heat production of the cow has been studied before. According to Maynard and Loosli (1956) fats are a high efficiency product that decreases the dietary heat increment of the animal. Coppock (1985) mentioned that the utilization of fats during heat stress as a dietary ingredient is undervalued by feed evaluation systems. However, Drackley et al. (2003) mentioned that supplementing rumen-active fat have limited benefits if compared to starch-based concentrate to increase energy density of diets for lactating cows during hot summer months.

One of the most common methods to increase energy intake during heat stress is increasing energy density by reducing forage and increasing concentrate content in the diet. Less fiber in the diet may decrease heat production, and increase energy density and feed intake. West (2003) mentioned that intake of high fiber diets has a substantial effect on heat production; therefore increasing the concentrate level of the diet must be considered in designing a nutritional program during thermal stress. Even though low fiber diets may decrease dietary heat production and increase energy intake, the consumption of high concentrate diets by the animal is associated with an increase in rumen acidosis. Collier et al. (2006) mentioned that to reduce

rumen acidosis due to high concentrate diets, it is necessary to increase the buffering of the rumen during thermal stress.

During heat stress the demand for dietary minerals increases due to alterations in mineral metabolism. Potassium is the primary cation in bovine sweat, and its secretion increases during periods of heat stress. Panting, on the other hand, increases the levels of urinary Na excreted to balance the pH level of the blood due to respiratory alkalosis. While some studies have shown good results by supplementing individual minerals in the diets of heat stressed cows (Mallonee et al., 1985; West et al., 1987), there are others that believe that the dietary cation-anion difference equation is more significant than the increase of individual mineral concentrations in the diet (West, 2003; West et al., 1992).

## **Conclusions**

The negative responses of dairy cattle due to heat stress are well documented by research. Losses in productivity, reproduction and health are commonly seen during summer months. Each year these negative effects accentuate the economic losses in the livestock production. Changes in nutrition, selection for more heat resistant genetics, and cooling systems that help animals cope with the environment are common strategies used in the dairy industry. However, all of these techniques are useless if producers do not realize the susceptibility of animals to climatic conditions and the importance of using such methods to mitigate heat stress.

## **CHAPTER 2 - Effects of Korral Kool<sup>®</sup> Running Time over Core Body Temperature on Dairy Farms in an Arid Environment**

X.A. Ortiz<sup>1</sup>, J.F. Smith<sup>1</sup>, B.J. Bradford<sup>1</sup>, J.P. Harner III<sup>2</sup>, and A. Oddy<sup>3</sup>

<sup>1</sup>Department of Animal Science and Industry, Kansas State University, Manhattan, KS 66502

<sup>2</sup>Biological and Agricultural Engineering, Kansas State University, Manhattan, KS 66502

<sup>3</sup>NADA Al-Othman, Al Ahsa, Saudi Arabia

## Abstract

Two experiments were developed on a commercial dairy farm to understand the effects of a reduction in the operating time of Korral Kool® (KK) on the core body temperature (CBT) of primiparous and multiparous cows. In the first experiment, KK systems were operated for 18 (18h), 21 (21h) and 24 (24h) hours per day while CBT of 63 multiparous Holstein dairy cows were monitored. All treatments started at 0600 h and systems were turned off at 0000 h and 0300 h for the 18h and 21h treatments respectively. Animals were housed in 9 different pens, which were randomly assigned to treatment sequence in a 3x3 Latin square design. In experiment 2, 21 multiparous and 21 primiparous cows were housed in 6 different pens, which were randomly assigned to sequence of treatments (KK operated for 21 [21h] or 24 [24h] hours per day) in a switchback design. All treatments started at 0600 h and KK were turned off at 0300 h for the 21h treatments. Results in Exp. 1 showed that cows had lower mean CBT ( $P < 0.05$ ) with 24h compared to 18h and 21h treatments (38.97°C, 39.08°C, and 39.03°C respectively). There was a significant treatment by time interaction ( $P < 0.001$ ), with greatest treatment effects occurring at 0600 h; treatment means at this time were 39.43°C, 39.37°C and 38.88°C for 18h, 21h and 24h, respectively. These results demonstrate that a reduction in the running time of KK cooling systems for 3 or more hours per day will lead to an increase in CBT. Results in Exp. 2 showed a significant parity by treatment interaction; multiparous cows on the 24h treatment had a lower mean CBT ( $P < 0.007$ ) than cows on the 21h treatment (39.23°C, 39.45°C respectively), but treatment had no effect on mean CBT of primiparous cows (21h and 24h treatments: 39.50°C and 39.63°C, respectively). There was a significant treatment by time interaction ( $P < 0.001$ ), with greatest treatment effects occurring at 0500 h; treatment means at this time were 39.57°C, 39.23°C, 39.89°C and 39.04°C for 21h primiparous, 24h primiparous, 21h multiparous, and 24h multiparous cows, respectively. These results demonstrate that multiparous and primiparous cows respond differently when running time of KK cooling systems decreases from 24h to 21h. Based on these results, we conclude that for multiparous dairy cows in these climate conditions, it is advisable to operate the KK system continuously to decrease heat stress, whereas KK operating time could potentially be reduced from 24 to 21 hours for primiparous cows. Reducing operation time should be done carefully, however, because CBT was elevated in all treatments.

**Key words:** Heat stress, evaporative cooling, arid environments

## Introduction

Ambient temperatures exceeding the thermalneutral zone (TNZ) of dairy cows have detrimental effects on milk production, reproduction and the susceptibility of animals to diseases. Therefore, heat stress is considered one of the major causes of economic losses in the dairy industry (Collier, 2007, St-Pierre et al., 2003). An indicator to assess the physiological response to high thermal environments in dairy cows is core body temperature (CBT), because it is nearly constant under thermoneutral conditions. The average CBT of dairy cows in the TNZ range between 38°C to 39.3°C with an average of 38.6°C (Dukes, 1947).

Recently, dairy production has increased in arid climates. That is especially the case in places like Saudi Arabia where farms are rapidly growing in size to meet the demand for milk. In Saudi Arabia, the demand for milk and milk products increases during the summer (Ryan et al., 1992), and because summer months are the period when ambient temperatures exceed the thermoneutral zone for dairy cows, producers need to find cooling systems to decrease the detrimental effects of heat stress on dairy cows.

Evaporative cooling systems have been tested in arid climates, showing improvement in performance of dairy cows (Correa-Calderon et al., 2004, Ryan et al., 1992). However, little research has been done evaluating methods of operating these different cooling systems in arid environments. Korral Kool<sup>®</sup> (KK) is a cooling system used by producers to decrease the temperature of the air surrounding dairy cows. It injects fine fog into the air using fans to drive air through vanes and create a cyclonic motion of air down to the cows (Armstrong, 1994). Because of the evaporative and convective mechanisms that this system uses to cool the animals, KK are used in places with high temperatures and low humidity. On most farms, KK are set to come on at an ambient temperature of 27°C, but at this temperature the TNZ of a dairy cow has already been exceeded. Suggesting that that KK should be set to turn on based on the TNZ of dairy cows. However because in arid environments ambient temperature is often higher than TNZ, it is hypothesized that KK should work based on operation time.

Primiparous cows respond differently than multiparous cows to evaporative cooling when housed together. Ryan et al. (1992) hypothesized that this difference in response might be the result of dominant older cows demanding better places under the cooling systems, pushing primiparous cows away from the cooling area. However, little research has been conducted to evaluate this hypothesis.

Our objectives for these experiments were to investigate the effects of Korral Kool operating time on core body temperature of multiparous and primiparous Holstein cows.

## **Materials and Methods**

Two experiments were conducted on a commercial dairy farm located in eastern Saudi Arabia in July and August of 2008. Cows were housed in desert barns with a covered area of 10 m<sup>2</sup> per cow covering the feeding area as well as part of the dry lot. All pens had Korral Kool evaporative cooling systems (Korral Kool<sup>®</sup>, Mesa, AZ) located at 6 m intervals. Each unit was 1.30 m in diameter with a 3 hp motor. Weighted curtains were placed on the side of the roof to keep the cooled air inside of the barn. For the purpose of these experiments, to simulate the effect of KK working based on ambient temperatures above the TNZ, KK were operated based on operation time.

Ambient temperature and relative humidity were measured every 15 minute intervals with 6 weather stations located throughout the farm. Weather stations were comprised with a sensor (HOBO Pro H8<sup>®</sup> Onset Computer Corporation, Bourne, MA) and a solar radiation shield (M-RSA Onset Computer Corporation, Bourne, MA).

Core body temperature measurements were obtained at 5-minute intervals using data loggers (HOBO U12<sup>®</sup>, Onset Computer Corporation, Bourne, MA) attached to blank continuous intravaginal drug release (CIDR<sup>®</sup>, Pfizer Animal Health, New York, NY) devices. Each experiment lasted 6 days, with 3 periods of 2 days each. Cows had 1 day to acclimate to each treatment and only the CBT data from the second day was analyzed to minimize carry over effects between treatments.

All animals were milked 4 times per day at 0600, 1200, 1800, and 0000 h. Cows were cooled in the holding pen with KK operated continuously and in the exit lane with soakers. Because of the short duration of these experiments dry matter intake and milk yield of the animals were not analyzed.

### ***Experiment 1***

KK systems were operated for 18 (18h), 21 (21h) and 24 (24h) hours per day while CBT of 63 multiparous (mean milk production = 44 ± 20 kg/d and days in milk = 120 ± 85) Holstein dairy cows was monitored. All treatments started at 0600 h and systems were turned off at 0000 h and 0300 h for the 18h and 21h treatments, respectively. The animals were housed in 9

different pens, which were randomly assigned to the treatment sequence in a 3x3 Latin square design.

### ***Experiment 2***

Twenty one multiparous (mean milk production =  $36 \pm 17$  kg/d and days in milk =  $144 \pm 56$ ) and 21 primiparous Holstein dairy cows (mean milk production =  $36 \pm 16$  kg/d and days in milk =  $94 \pm 38$ ) were housed in 6 different pens. Cows were housed by parity with 3 pens per parity and 7 cows per pen. Within parity, pens were randomly assigned to a sequence of 2 treatments, 21 (21h) or 24 (24h) hours per day in a switchback design. All treatments started at 0600 h and KK were turned off at 0300 h for the 21h treatment.

### ***Statistical Analysis***

Vaginal temperature data in both experiments were analyzed using a repeated measures model of SAS (Version 9.1, SAS Institute, Cary, NC) and significance was declared with a *P* value < 0.05. For the first experiment time of day, day, treatment, and time of day by treatment were included as fixed effects. Cow and pen were assigned as random effects.

For the second experiment, data were analyzed by parity with time of day, treatment, and time of day by treatment included as fixed effects. Animal, pen, and day were assigned as random effects.

## **Results**

### ***Experiment 1***

Mean ambient temperature and relative humidity of this experiment are shown in Figure 2.1. During the experiment, the average ambient temperature was 37°C and the average relative humidity was 24 %.

Cows had a lower mean CBT (*P* < 0.05) with 24h compared to 18h and 21h treatments (38.97°C, 39.08°C, and 39.03°C respectively, Figure 2.2). There was a significant treatment by time interaction (*P* < 0.001), with greatest treatment effects occurring at 0600 h; treatment means at this time were 39.43°C, 39.37°C, and 38.88°C for 18h, 21h and 24h, respectively (Figure 2.3).

## **Experiment 2**

Mean ambient temperature was 35°C and average relative humidity was 49 % during this experiment (Figure 2.4). Multiparous cows on the 24h treatment had a lower mean CBT ( $P < 0.007$ ) than 21h multiparous cows (39.23°C and 39.45°C, respectively), but treatment had no effect ( $P > 0.19$ ) on mean CBT of primiparous cows (39.50°C and 39.63°C for 21h and 24h, respectively; Figure 2.5). There was a significant treatment by time interaction for both multiparous and primiparous cows ( $P < 0.001$ ), with greatest treatment effects occurring at 0500 h; treatment means at this time were 39.57°C, 39.23°C, 39.89°C and 39.04°C for 21h primiparous, 24h primiparous, 21h multiparous, and 24h multiparous cows, respectively (Figure 2.6). These results demonstrate that multiparous and primiparous cows respond differently when running time of KK cooling systems decreases from 24h to 21h.

## **Discussion**

Saudi Arabia is one of the regions with greatest growth in milk production in the world. In 2004, the food and agriculture organization of the United Nations estimated 1,149,000 tons of milk production per year in Saudi Arabia (FAO, 2006). However, the higher consumption of milk and milk products during summer months has led to a seasonal peak production of milk during the hottest months of the year. To accomplish this, producers synchronize cows to calve before the summer months and then become pregnant during summer to maintain milk production for the subsequent lactation.

However, this type of seasonal production system has a great impact on milk production and reproduction due to the high ambient temperatures in this area. The average ambient temperature during summer months in Saudi Arabia (36°C) is above the TNZ of dairy cows (20°C; NRC, 2001) demonstrating that cows could be negatively affected by heat stress. Previous research has shown that heat stressed cows have a decrease milk production as result of reduced nutrient intake and a shift in postabsorptive metabolism and nutrient partitioning (Rhoads et al., 2009). Heat stress will also compromise reproduction in dairy cattle by decreasing the intensity and duration of estrus (Hansen and Arechiga, 1999, Younas et al., 1993), as well as reducing the manifestations of estrus (Hansen and Arechiga, 1999). Heat stress also decreases conception rates (Morton et al., 2007) and compromises early embryonic development (Hansen et al., 2001).

Genetic and management advances in dairy production have increased the ability of cows to produce milk. However, this increment in milk yield is accompanied by increases in heat production, making more difficult the regulation of body temperature of dairy cows during heat stress (Berman, 2005). It has been estimated that at 30°C, of the total evaporative heat loss in cattle, approximately 85 % of the heat loss of lactating cows is through evaporation from the skin (Maia et al., 2005).

In arid climates like in Saudi Arabia, many cooling systems have been tested (Armstrong, 1993, Correa-Calderon et al., 2004, Ryan et al., 1992) to alleviate the negative effects of heat stress on dairy cows. Of all these systems, evaporative cooling seems to provide the greatest benefit because it decreases the ambient temperature surrounding the cow and increases the heat exchange between the cow and the environment.

On dairy farms, KK cooling systems are often controlled by ambient temperature. Typically fans are turned on at 27°C. At 30°C, high pressure misters start injecting fine moisture into the air and the amount of water injected increases along with the ambient temperature. However, by the time this system starts working the ambient temperature has already exceeded the TNZ of dairy cows (20°C; NRC, 2001) and the cows have already been exposed to the negative effects of heat stress. Based on this information, it is suggested that KK should be set to turn on based on the TNZ of dairy cows. However, because the ambient temperature in arid environments is often higher than the TNZ, it is hypothesized that KK should be based in operation time.

Core body temperature is a good indicator of the severity of heat stress on cows. An increment in CBT is a physiologic response of dairy cows to heat stress as result of the imbalance between the heat energy produced by the animal and the amount of heat dissipated. The normal CBT of dairy cows has a range between 38.0°C and 39.3°C with the average of 38.6°C in the TNZ (Dukes, 1947). Results from both experiments showed a significant increase in CBT of multiparous cows when KK decreased from 24h of operating time. This response was not observed in primiparous cows. These results demonstrate that a reduction in the operating time of KK cooling systems for three or more hours per day will lead to an increase in CBT of multiparous cows as result of heat stress.

In the second experiment, primiparous cows had numerically higher CBT than multiparous cows for all treatments. In a previous experiment the same response was observed

when KK cooled primiparous and multiparous cows housed together (Ryan et al., 1992). From that experiment it was suggested that the difference in response was the result of dominant multiparous cows pushing primiparous cows away of the cooling area. Because primiparous and multiparous cows were housed separately and we still observed a difference in CBT, it might be possible that primiparous cows have physiological differences compared to multiparous cows during heat stress. It has been suggested that multiparous cows have higher feed intake and milk production compared to primiparous cows (Bucklin, 1991, Chebel et al., 2004) which lead to an increase in metabolic heat production and an increased susceptibility to heat stress.

Results in these experiments also demonstrated that even with a 24h operating time, the CBT of multiparous and primiparous lactating dairy cows exceeded the mean CBT of dairy cows under thermoneutral conditions, suggesting that the complementation of KK with a different cooling system might be advantageous in these climatic conditions.

## **Conclusions**

On the basis of these results, we conclude that for multiparous dairy cows in desert climate conditions, it is advisable to operate the KK system continuously to decrease heat stress, whereas KK operating time could potentially be reduced from 24 to 21 hours per day for primiparous cows. Reducing operation time should be done carefully, however, because CBT was elevated in all treatments. To decrease the CBT of multiparous and primiparous cows to thermoneutral conditions it may be necessary to complement the KK system with an additional cooling system.

Figure 2.1 Average ambient temperature and relative humidity by hour (Exp. 1).

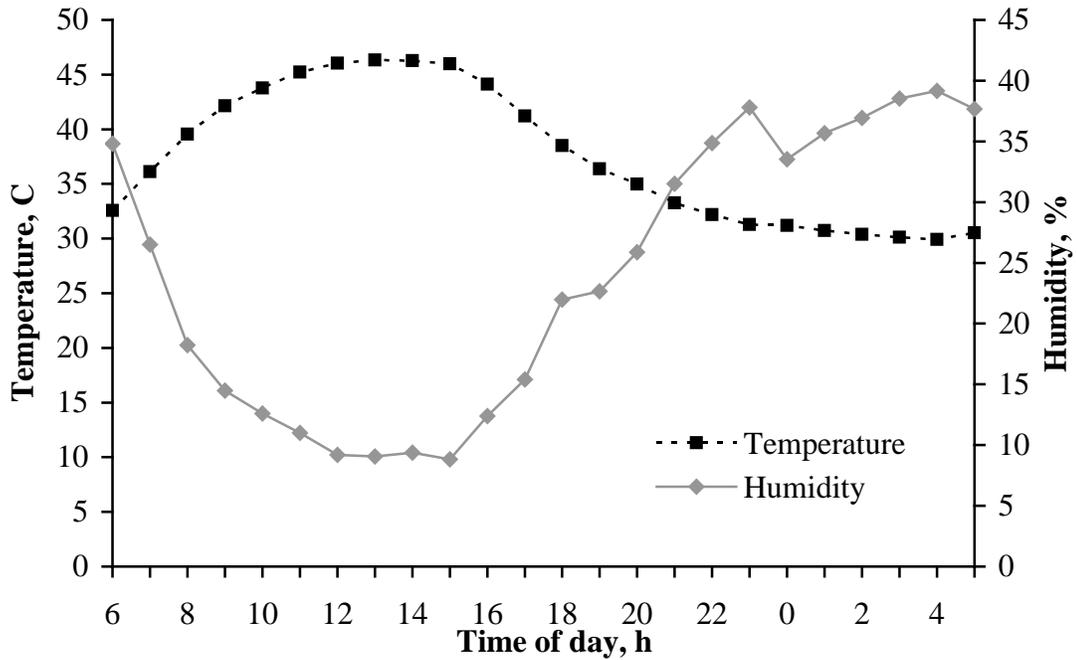
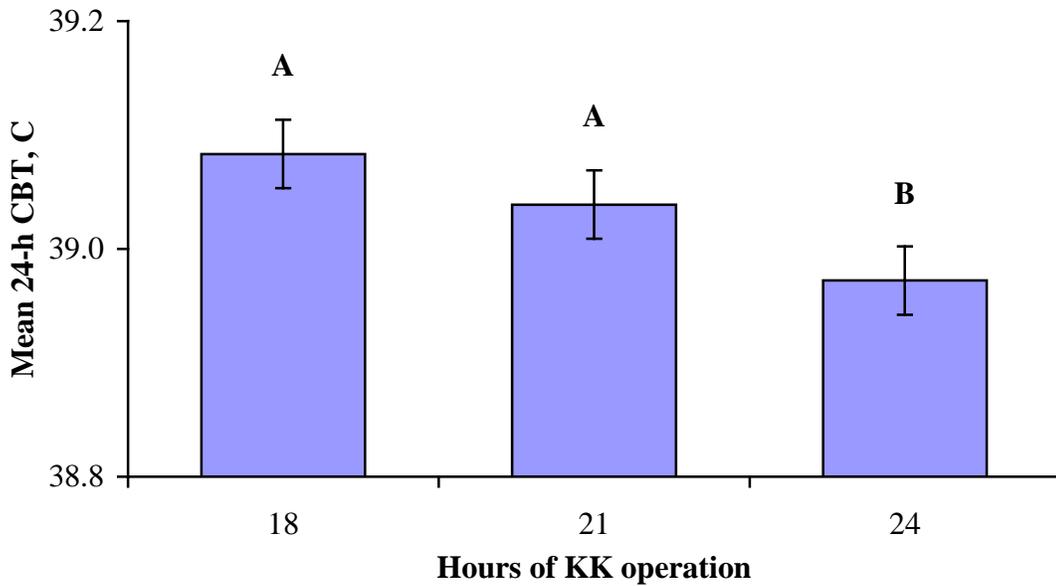
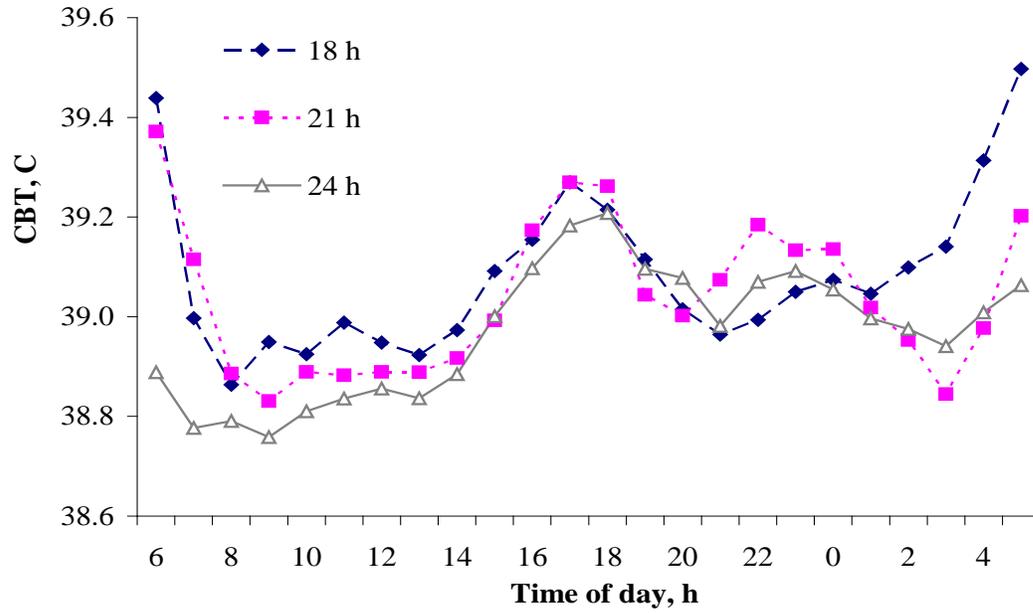


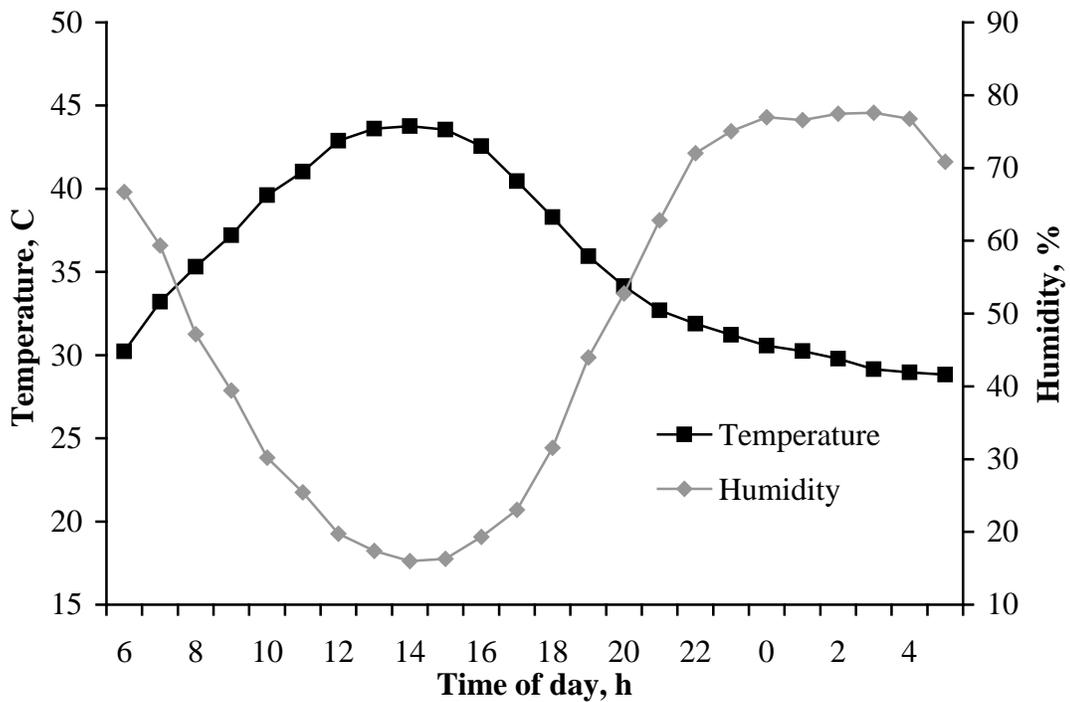
Figure 2.2 Mean core body temperature of multiparous cows with KK operated for 18, 21 and 24 hours per day (Exp. 1). Bars represent the SEM. Values with different letters are significantly different ( $P < 0.05$ ).



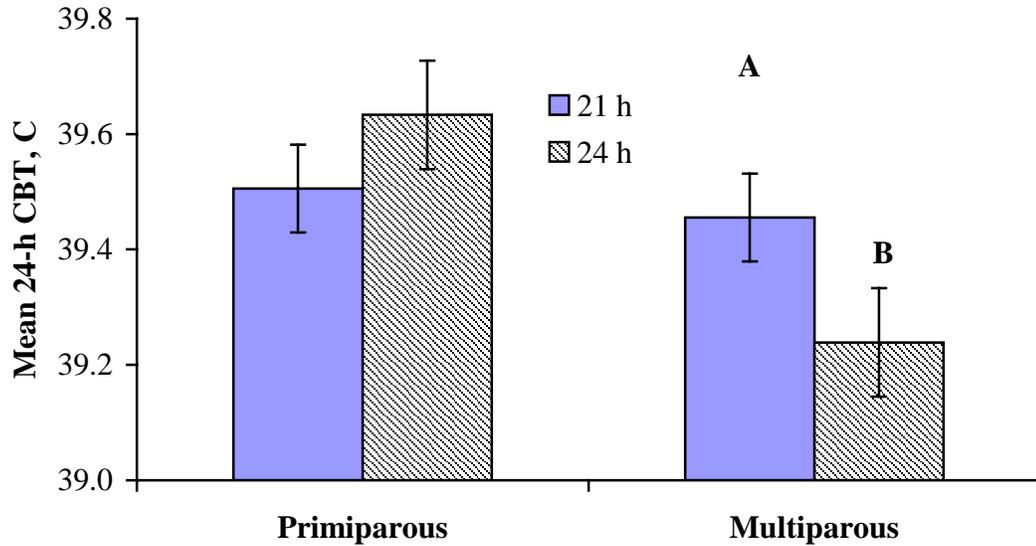
**Figure 2.3 Running CBT of multiparous cows with KK operated for 18, 21 and 24 hours per day Treatment by time interaction:  $P < 0.001$ . SEM=0.18 (Exp. 1).**



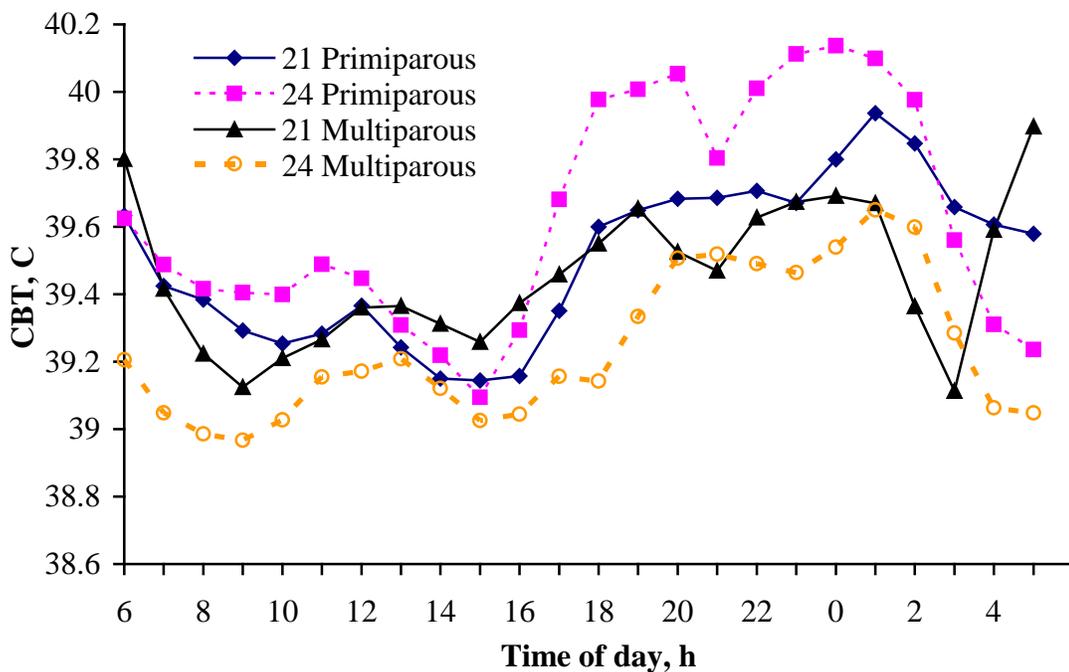
**Figure 2.4 Average ambient temperature and relative humidity by hour (Exp. 2).**



**Figure 2.5 Mean core body temperature of multiparous and primiparous cows with KK operated for 21 and 24 hours per day (Exp. 2). Bars represent SEM. Values with different letters are significantly different ( $P < 0.01$ ).**



**Figure 2.6 Core body temperature of primiparous and multiparous cows with KK operated for 21 and 24 hours per day (Exp. 2). Treatment by time interaction for primiparous and multiparous cows:  $P < 0.001$ . SEM=0.008.**



# **CHAPTER 3 - Effect of Feedline Soakers Complementing Korral Kool<sup>®</sup> Systems on Lactating Dairy Cows in a Desert Environment**

X.A. Ortiz<sup>1</sup>, J.F. Smith<sup>1</sup>, B.J. Bradford<sup>1</sup>, J.P. Harner III<sup>2</sup>, and A. Oddy<sup>3</sup>

<sup>1</sup>Department of Animal Science and Industry, Kansas State University, Manhattan, KS 66502

<sup>2</sup>Biological and Agricultural Engineering, Kansas State University, Manhattan, KS 66502

<sup>3</sup>NADA Al-Othman, Al Ahsa, Saudi Arabia

## Abstract

Two experiments were conducted on a commercial dairy farm in eastern Saudi Arabia to investigate the effects on core body temperature (CBT) of dairy cows when Korral Kool® (KK) units were complemented with feedline soakers. In the first experiment 7 primiparous and 6 multiparous lactating Holstein dairy cows were assigned to one of 2 pens, which were randomly assigned to treatment sequence over 4 days in a switchback design. Treatments in this experiment were KK operated for 24 h per day while feedline soakers were on (ON) or off (OFF) for 24 h per day. For the second experiment, 20 multiparous lactating Holstein cows were randomly assigned to one of 2 pens, which were randomly assigned to treatment sequence in a switchback design. This experiment lasted 4 days, in which KK were operated for 24 h per day while alternately feedline soakers remained off (OFF) or stayed (ON) for 12 h per day. The average ambient temperature during experiment 1 was 30°C and average relative humidity was 44 %. Feedline soakers complementing KK for 24 h decrease the mean CBT of lactating dairy cows (38.80 vs. 38.98°C;  $P < 0.001$ ). There was a significant treatment by time interaction ( $P < 0.001$ ), with greatest treatment effects occurring at 2100 h; treatment means at this time were 39.26°C and 38.85°C for OFF and ON treatments, respectively. The average ambient temperature during experiment 2 was 35°C and the average relative humidity was 33 %. Feedline soakers running for 12 h per day significantly decreased the mean 24-h CBT from 39.16 to 38.99°C ( $P < 0.04$ ). Treatment by time interaction was also significant ( $P = 0.02$ ), with greatest treatment effects at 1500 h, when ON reduced CBT from 39.38 to 38.81°C. These results demonstrate that the use of feedline soakers complementing the KK cooling systems decreased the CBT of dairy cows housed in desert environments. However, the combined systems were not adequate to lower CBT to normal temperatures in this extreme environment.

**Key words:** Heat stress, evaporative cooling, feedline soakers

## **Introduction**

In 2003, it was estimated that heat stress causes a loss of \$897 million in the US dairy industry annually (St-Pierre et al., 2003). These losses are the result of extreme weather conditions and cows being inadequately cooled. In arid regions, the utilization of a cooling system to cool the cows is necessary in order to mitigate the negative effects of heat stress. In arid climates, with high ambient temperatures and low humidity, evaporative cooling is a good option to control the environment of cows.

The Korral Kool<sup>®</sup> (KK) system is 1 type of evaporative cooling, which decreases the temperature of the air surrounding dairy cows. Previous experiments have demonstrated that in arid regions even with continuous operation of KK, the core body temperature (CBT) of primiparous and multiparous cows was higher than the mean CBT of cows in thermoneutral conditions (Ortiz et al., 2009). These results suggested that additional mitigation measures may be required in order to decrease the negative impact of high ambient temperatures.

As temperature increases the evaporation mechanism of heat flow from the cow to the environment becomes more important. It has been estimated that at 30°C, of the total evaporative heat loss in cattle, approximately 85 % of the heat loss of lactating cows is through evaporation from the skin (Maia et al., 2005). Feedline soakers wet the back of the cows and then turn off to provide enough time for the water to evaporate. Therefore, using feedline soakers may provide a logical complement to evaporative cooling by increasing the cows' heat exchange through evaporation. Complementing evaporative cooling with feedline soakers has been shown to decrease the CBT, increase feed intake, and increase milk production in tropical climates (Armstrong, 2007; Brouk, 2005), but little research has been conducted evaluating the combination of evaporative cooling with feedline soakers in arid climates.

Two experiments were conducted to investigate the effects of feedline soakers complementing KK systems on the CBT of lactating cows housed in arid environments.

## **Materials and Methods**

Two experiments were developed on a commercial dairy farm located in eastern Saudi Arabia. The first experiment was conducted during September of 2007 and the second experiment was performed in August 2008. Cows were housed in desert barns with a covered area over the feeding area as well as part of the dry lot and it provided shade with an area of 10

m<sup>2</sup> per cow. All pens had Korral Kool evaporative cooling systems (Korral Kool<sup>®</sup>, Korral Kool, Inc. Mesa, AZ) located in openings on the roof. Korral Kool units were located at 6 m intervals between each other. Each unit was 1.29 m in diameter with a 3 hp motor. Weighted curtains were placed on the side of the roof to keep the cooled air inside of the barn. Feedline soakers were installed on the feed line of the pens and operated with a controller (C- 440S<sup>®</sup> Edstrom Industries, Inc. Waterford, WI). Feedline soakers were set to run with a frequency of 5 minutes (36 sec. on and 264 sec. off). During every cycle, 1 L of water was sprayed over 61 cm of feedline.

In both experiments, CBT measurements were obtained at 5-minute intervals using data loggers (HOBO U12<sup>®</sup>, Onset Computer Corporation, Bourne, MA) attached to blank continuous intravaginal drug release (CIDR<sup>®</sup>, Pfizer Animal Health, New York, NY) devices.

All animals were milked 4 times per day at 0600, 1200, 1800, and 0000 h. Cows were cooled by KK operated continuously in the holding pen and soakers placed in the exit lane. Because of the short term of these experiments dry matter intake and milk yield of the animals were not analyzed.

### ***Experiment 1***

Seven primiparous (mean milk production = 41 kg/d and 53 days in milk) and 6 multiparous (mean milk production = 48 kg/d and 28 days in milk) Holstein dairy cows were housed in one of 2 pens. Cows were assigned to pens by lactation number and pens were randomly assigned to a sequence of treatments in a switchback design. KK were operated continuously while feedline soakers were alternately turned on (ON) and off (OFF) for 24 hour periods over 4 days. Ambient temperature, relative humidity, and temperature humidity index (THI) were collected hourly from a weather station located on the farm.

### ***Experiment 2***

Twenty multiparous Holstein dairy cows (67 days in milk and 44 kg/d of milk production) were assigned to one of 2 pens. Pens were randomly assigned to a sequence of treatments in a switchback design. Treatments in this experiment consisted in KK operated continuously while feedline soakers remained off (OFF) in 1 of the pens while the feedline soakers in the other pen were (ON) for 12 h per day. Treatments started at 0600 h and feedline soakers were operated from 1200 h to 2400 h for the ON treatment.

Ambient temperature and relative humidity were measured every 15 minute intervals with 6 weather stations located throughout the farm. Weather stations were comprised with a sensor (HOBO Pro H8<sup>®</sup> Onset Computer Corporation, Bourne, MA) and a solar radiation shield (M-RSA Onset Computer Corporation, Bourne, MA).

### ***Statistical Analysis***

For the first experiment, CBT data were analyzed with a mixed model of SAS (Version 9.1, SAS Institute, Cary, NC) and significance was declared with a  $P$  value  $< 0.05$ . Pen, treatment, day within treatment, time of day and treatment by time of day interactions were included as fixed effects. Cow within pen was assigned as random effect. Repeated measures over time were modeled with a variance component covariance structure, and denominator degrees of freedom were estimated using the Kenward-Roger method.

Core body temperature data in the second experiment were analyzed using a repeated measures model of SAS (Version 9.1, SAS Institute, Cary, NC) and significance was declared with a  $P$  value  $< 0.05$ . Time of day, treatment, and time by treatment were included as fixed effects. Cow within pen and day were assigned as random effects.

## **Results**

### ***Experiment 1***

Average ambient temperature and relative humidity of this experiment are shown in Figure 3.1. During the experiment, the average ambient temperature was 30°C and the average relative humidity was 44 %. The mean THI during this experiment was 76 units.

Cows showed a lower mean 24-h CBT ( $P < 0.001$ ) with KK complemented with feedline soakers compared to KK alone (38.80°C vs. 38.98°C, Figure 3.2). There was a significant treatment by time interaction ( $P < 0.001$ ), with greatest treatment effects occurring at 2100 h; treatment means at this time were 39.26°C and 38.85°C for OFF and ON treatments, respectively (Figure 3.3).

### ***Experiment 2***

Average ambient temperature and relative humidity of this experiment are shown in Figure 3.4. During the experiment, the average ambient temperature was 35°C and the average relative humidity was 33 %.

Cows showed a lower mean 24-h CBT ( $P < 0.04$ ) with KK complemented with feedline soakers for 12 hours compared to KK alone (38.99°C and 39.16°C, respectively; Figure 3.5). There was a significant treatment by time interaction ( $P = 0.02$ ), with greatest treatment effects occurring at 1500 h; treatment means at this time were 39.38°C and 38.81°C for OFF and ON treatments respectively (Figure 3.6).

## Discussion

The relocation of dairy farms due to population expansion and availability of resources has led producers to overlook the climatic conditions where dairies are being built. In many cases producers end up in arid regions where the climatic conditions exceed the thermoneutral zone (TNZ) for dairy cows. In addition, when producers are unaware of the negative impact of heat stress on dairy cattle, cows are often improperly cooled, therefore compromising milk production, reproduction and the health of the herd.

The negative effects of heat stress on dairy cattle depends on the ambient temperature to which cows are exposed and the amount of time that cows spend under ambient temperatures above their TNZ. As temperature rises, the losses in dry matter intake and milk production increases (Rhoads et al., 2009). In the same way, reproduction is compromised by elevated temperatures and long periods of ambient conditions above a temperature humidity index (THI) of 72 (Hansen and Arechiga, 1999; Morton et al., 2007). Others have reported that animals are more susceptible to diseases and infections during summer months (Kadzere et al., 2002). Lameness increases during periods of heat stress as result of behavioral changes (Cook et al., 2007) and a decrease in the rumen pH as result of respiratory alkalosis (Benjamin, 1981), and drooling of saliva at severe panting.

Heat stress is the result of ambient conditions preventing cows to dissipate heat through the 4 routs of heat exchange (convection, radiation, conduction, and evaporation). As ambient temperature approaches the core body temperature, evaporation becomes the primary route of heat exchange between the animal and the environment. When ambient temperatures exceed the core body temperature of dairy cows, heat flow reverses and cows become heat sinks. Dukes (1947) reported that cows in thermoneutrality have a mean body temperature of 38.6°C, but when climatic conditions exceed the upper limit of the comfort zone, the core body temperature of cows start rising as a physiological response of heat stress.

To prevent heat stress many different cooling systems have been utilized in arid climates. However, only evaporative cooling has been shown to improve the environment of cows housed in this type of climatic conditions (Correa-Calderon et al., 2004; Ryan et al., 1992). This system decreases the air temperature surrounding the cow, and increases the heat exchange between cows and the environment.

Korral Kool is an evaporative cooling system widely used in desert environments. Previous research showed that by operating KK continuously, the CBT of primiparous and multiparous lactating Holstein dairy cows was decreased; however the CBT of these cows still exceeded the CBT of cows in thermoneutral conditions (Ortiz et al., 2009). These results suggested that an additional cooling system complementing KK may help cows dissipate more heat into the environment, therefore counteracting the negative effects of heat stress during summer months.

Feedline soakers have been used before to wet the skin of cows in the feeding area (Armstrong, 1994). Schultz (1988) showed an increase in milk yield and reproduction of cows with feedline soakers. Each cycle in this system consists of a short phase of spraying water on the animals and then a long phase when the water absorbs heat and then evaporates. It takes approximately 2.43 Joules to evaporate 1 ml of water from the skin (Silanikove, 2000). Previous studies showed that wetting the skin of Holstein cows increased the evaporation rate from  $68 \pm 8$  g/m<sup>2</sup>-h to  $508 \pm 114$  g/m<sup>2</sup>-h (Gebremedhin, 2008).

The frequency of each cycle has a great impact on the efficiency of heat abatement. Brouk et al. (2003) reported that feedline soakers set at 5 min cycles were more efficient at decreasing skin temperatures, respiration rates, and CBT of cows compared to feedline soakers set at 10 or 15 min cycles.

During these experiments, high ambient temperatures were observed. With the use of feedline soakers complementing the KK system for 12 and 24 hours, the CBT of these cows significantly decreased. Additionally, the biggest difference in the CBT of these cows was observed during peaks of heat stress. Thus, complementing KK with feedline soakers maintained a more constant core body temperature and may prevent physiological changes due to elevated CBT.

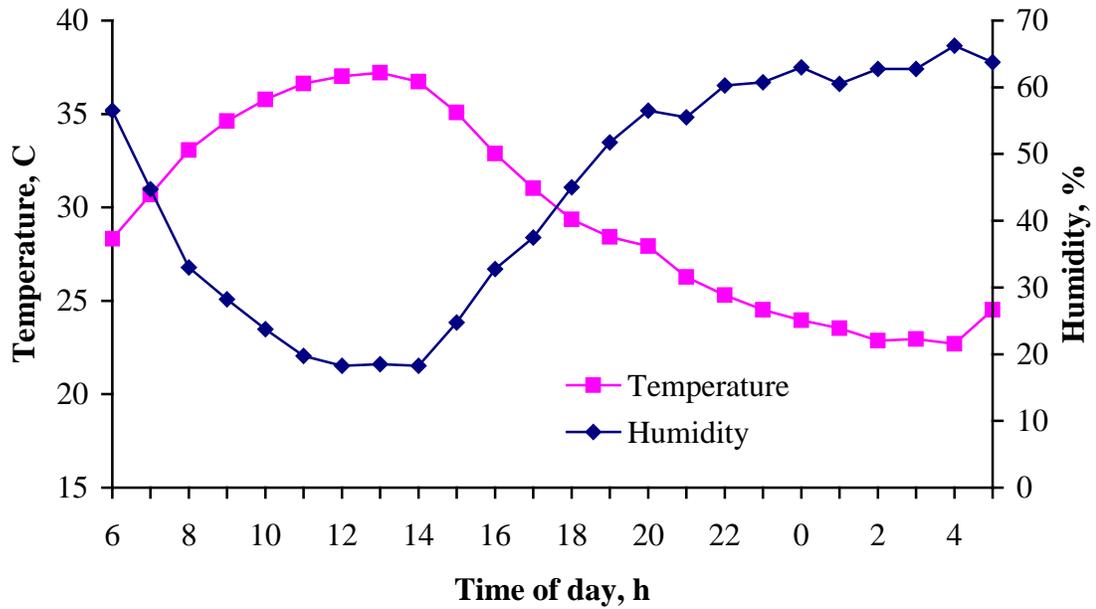
Even though feedline soakers complementing KK decreased the CBT of lactating dairy cows, the mean CBT of these cows exceeded the CBT of cows in the TNZ. Using fans on the

feedline with soakers may help reduce CBT. Brouk et al. (2003) showed that fans and soakers caused a bigger decrease in CBT, skin temperature, and respiration rates of 16 lactating dairy cows compared to fans or soakers alone. Future research is needed to investigate the effect of supplementing KK with feedline soakers and fans on cows housed in desert environments.

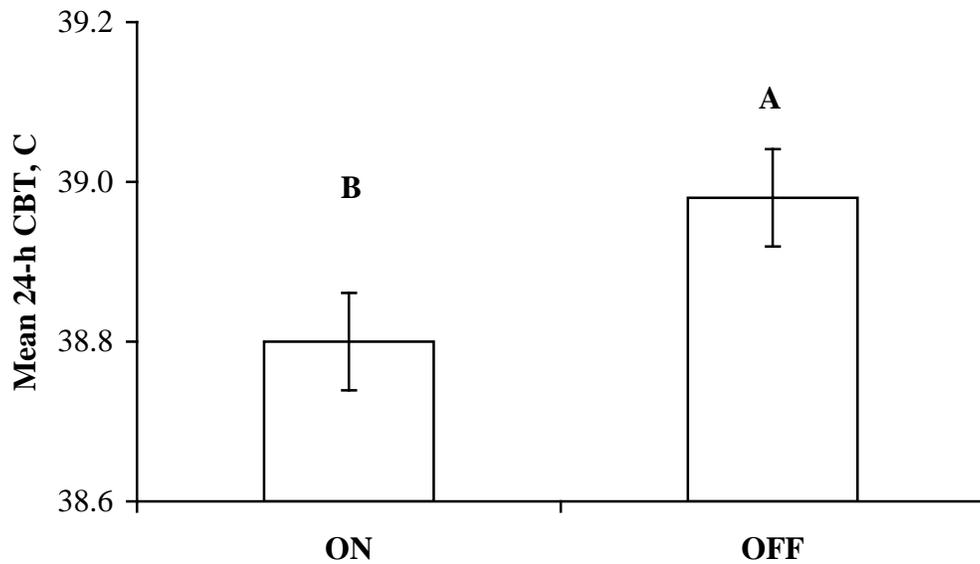
### **Conclusion**

Results of these experiments showed that complementing KK with feedline soakers for at least 12 hours per day during peak heat stress times is a good alternative to decrease the CBT of lactating dairy cows in desert environments. However, the combined systems were not adequate to lower the CBT to normal temperatures in this extreme environment.

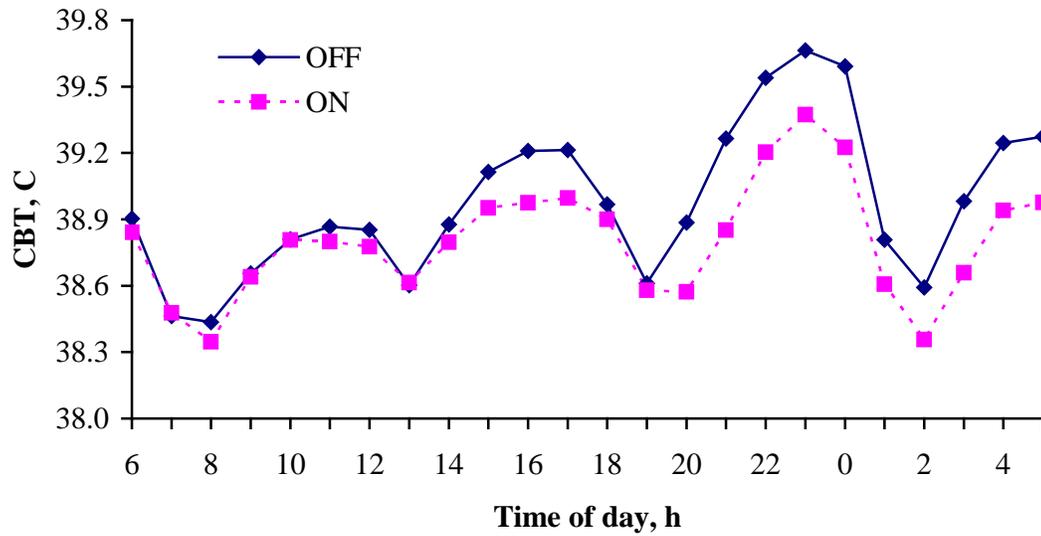
**Figure 3.1 Average ambient temperature and relative humidity by hour (Exp. 1).**



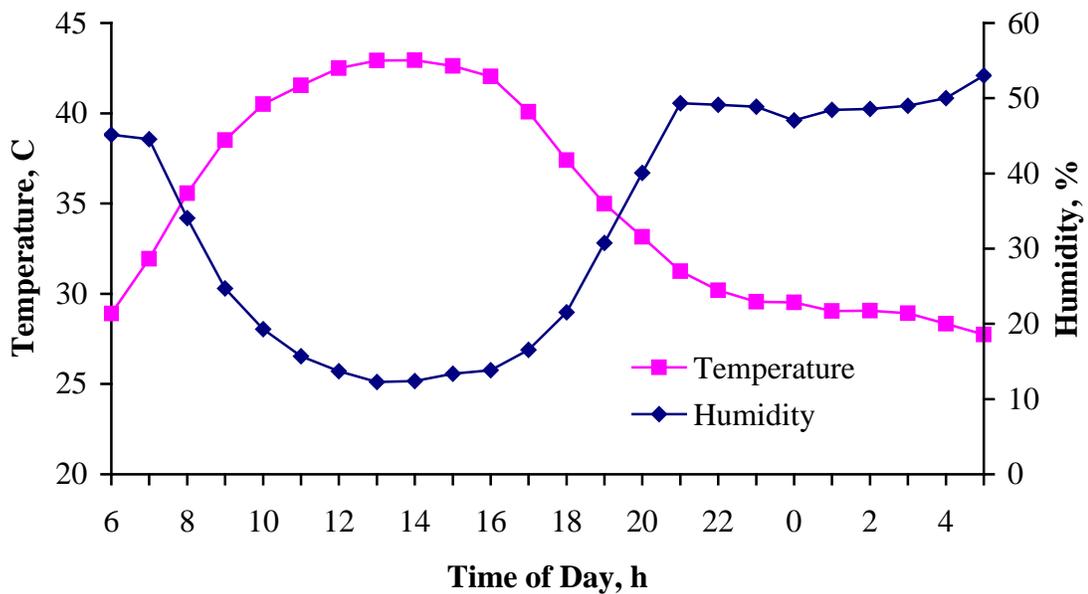
**Figure 3.2 Mean core body temperature of multiparous and primiparous cows with KK operated for 24 hours per day with (ON) and without (OFF) the complementation of feedline soakers operated for 24 hours per day (Exp. 1). Bars represent SEM. Values with different letters are significantly different ( $P < 0.01$ ).**



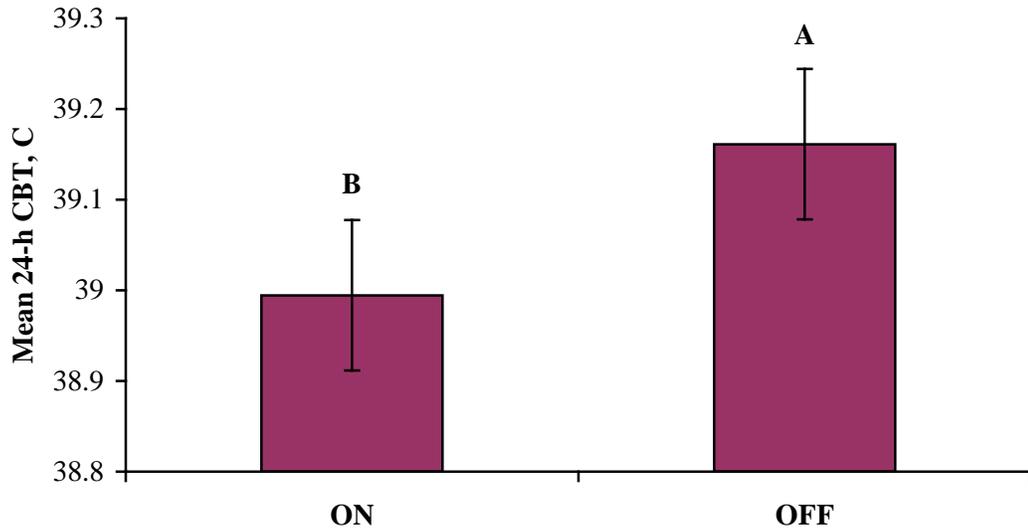
**Figure 3.3 Core body temperature of primiparous and multiparous cows with KK operated for 24 hours per day with (ON) or without (OFF) the complementation of feedline soakers run continuously (Exp. 1). Treatment by time interaction:  $P < 0.001$ .  $SEM=0.061$ .**



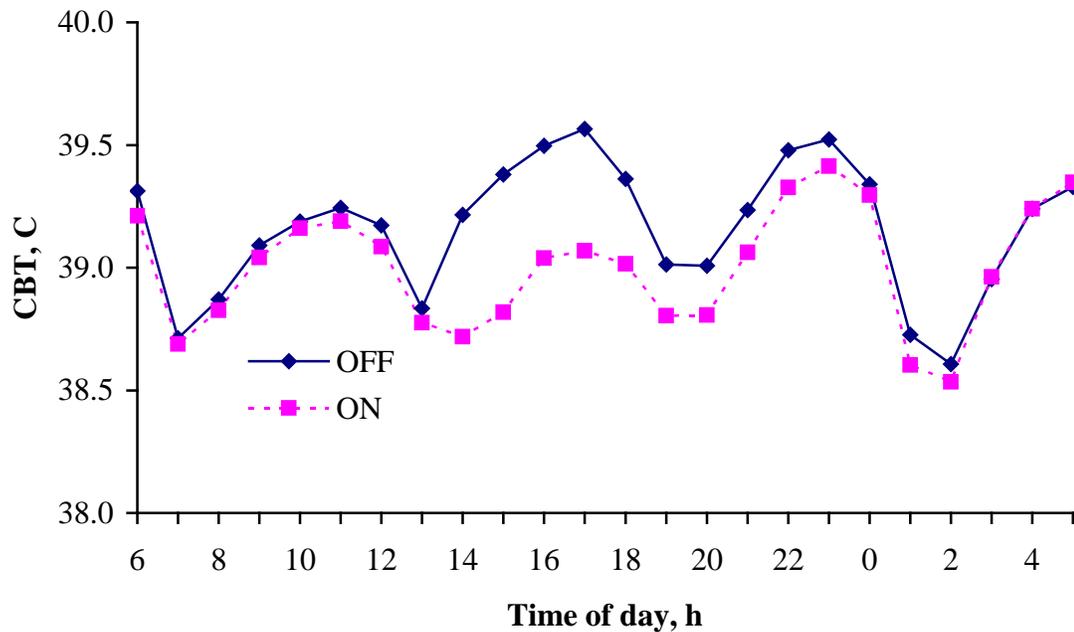
**Figure 3.4 Average ambient temperature and relative humidity by hour (Exp. 2).**



**Figure 3.5 Mean core body temperature of multiparous cows with KK operated for 24 hours per day with (ON) and without (OFF) the complementation of feedline soakers run for 12 h/d (Exp. 2). Bars represent SEM. Values with different letters are significantly different ( $P < 0.04$ ).**



**Figure 3.6 Core body temperature (CBT) of primiparous and multiparous cows with KK operated for 24 hours per day with (ON) or without (OFF) the complementation of feedline soakers run for 12 h/d (Exp. 2). Treatment by time interaction:  $P < 0.02$ . SEM=0.08.**



# **CHAPTER 4 - A Comparison of the Effects of Two Different Korral Kool<sup>®</sup> Systems on Dairy Cows in a Desert Environment**

X.A. Ortiz<sup>1</sup>, J.F. Smith<sup>1</sup>, B.J. Bradford<sup>1</sup>, J.P. Harner III<sup>2</sup>, and A. Oddy<sup>3</sup>

<sup>1</sup>Department of Animal Science and Industry, Kansas State University, Manhattan, KS 66502

<sup>2</sup>Biological and Agricultural Engineering, Kansas State University, Manhattan, KS 66502

<sup>3</sup>NADA Al-Othman, Al Ahsa, Saudi Arabia

## Abstract

An experiment was conducted to investigate the effects of 2 different operation times and 2 Korral Kool<sup>®</sup> (KK) systems on core body temperature (CBT) of dairy cows. Two different KK systems were compared; a system with 1.29 m diameter, 3 horse power fans and spaced at 6 m (SMALL), and a system with 1.52 m diameter, 5 horse power fans spaced at 8 m (BIG). Forty eight multiparous Holstein cows were randomly assigned to 8 pens (4 BIG, 4 SMALL) and pens were randomly assigned to sequence of treatments (KK were operated for 21 [21h] or 24 [24h] hours per day) in a switchback design. A complementary calorimetric analysis was developed to investigate the cooling area under the KK units of the BIG and the SMALL systems. Twenty five sensors were equally distributed under the units of KK measuring ambient temperature at 5 minutes intervals for 2 hours. Average ambient temperature was 35°C and relative humidity was 45 %. Results showed significant treatment effects on mean CBT; cows on the SMALL 24h treatment had a lower mean CBT ( $P < 0.03$ ) compared to the SMALL 21h treatment (39.22°C vs. 39.36°C), and cows on the BIG 24h treatment had a lower mean CBT ( $P < 0.02$ ) compared to the BIG 21h treatment (38.95°C vs. 39.09°C). The contrast between the BIG and the SMALL systems was not statistically significant ( $P < 0.13$ ). There was a significant treatment by time interaction ( $P < 0.001$ ), with greatest difference between systems occurring at 0100 h; treatment means at this time were 39.05°C, 39.01°C, 39.72°C and 39.89°C for BIG 24h, BIG 21h, SMALL 24h and SMALL 21h, respectively. Results demonstrated that at certain times of the day the BIG system reduce CBT as compared to the SMALL system. These results showed that CBT of multiparous cows decreases when KK running time is increased from 21h to 24h, regardless the size of the KK cooling system used. The calorimetric analysis showed that even though the BIG system had lower mean ambient temperatures than the SMALL system, the distance between units in the BIG system should be decreased to reduce the variation in temperature under the BIG units.

**Key words:** heat stress, dairy cow, evaporative cooling

## Introduction

The negative effects of heat stress on dairy cattle are well documented by previous authors (Kadzere et al., 2002; West, 2003). In past years a great effort has been made to evaluate different cooling systems for heat stressed cows. However, little research has been conducted comparing different methods of operating these cooling systems on commercial dairy farms in arid climates.

In desert environments, evaporative cooling is an efficient cooling method due to the high ambient temperatures and low relative humidity. The Korral Kool<sup>®</sup> (KK) system is a type of evaporative cooling, which consists of high pressure misters injecting fine fog into the air and fans driving air through vanes to create a cyclonic motion of air down to the cows. This system uses convection and evaporation pathways to increase the dissipation of heat from the cow to the environment.

On most dairy farms, KK systems are set to come on at an ambient temperature of 27°C. At this temperature the thermoneutral zone (TNZ) of a dairy cow (20°C; NRC, 2001) has already been exceeded. Suggesting that KK systems should be set to work based on the TNZ of dairy cows. However because in arid environments ambient temperature is often higher than TNZ for dairy cows, it is hypothesized that KK should be based in operation time.

On the other hand, there are 2 sizes of KK systems available in the market; a small system with 1.29 m diameter and a big system with 1.52 m diameter. Because of the difference in size of these systems, they have a different expected decreases in the air temperature surrounding the cows. The small system has an expected drop in temperature between 8°C and 16°C while the big system is between 8°C and 19°C.

In previous experiments it was demonstrated that in arid climates the CBT of multiparous cows was reduced with continuous operation of KK units with 1.29 m in diameter (Ortiz et al., 2009). Core body temperature (CBT) is an indicator to assess the physiological response to high thermal stress in dairy cows. Under normal conditions, the mean CBT of dairy cows is 38.6°C (Dukes, 1947)

The objectives of this experiment were to investigate the effects of two different sizes of Korral Kool systems and two operating times on core body temperatures (CBT) of lactating Holstein dairy cows.

## Materials and Methods

An experiment was conducted on a commercial dairy farm located in eastern Saudi Arabia. Cows were housed in desert barns with a covered area of 10 m<sup>2</sup> per cow covering the feeding area as well as part of the dry lot.

Pens had either of 2 types of Korral Kool systems (Korral Kool<sup>®</sup>, Mesa, AZ) located in openings on the roof. The first system (SMALL) had 1.29 m diameter, 3 hp motors, and units were placed at intervals of 6 m. The second system (BIG) had 1.52 m diameter, 5 hp motors, an interval between units of 8 m. Weighted curtains were placed on the side of the desert barns of all pens to keep the cooled air inside of the shade.

Ambient temperature and relative humidity were measured every 15 minute intervals with 6 weather stations located throughout the farm. Weather stations were comprised with a sensor (HOBO Pro H8<sup>®</sup> Onset Computer Corporation, Bourne, MA) and a solar radiation shield (M-RSA Onset Computer Corporation, Bourne, MA).

Core body temperature measurements were obtained at 5-minute intervals using data loggers (HOBO U12<sup>®</sup>, Onset Computer Corporation, Bourne, MA) attached to blank continuous intravaginal drug release (CIDR<sup>®</sup>, Pfizer Animal Health, New York, NY) devices. This experiment lasted 6 days, with 3 periods of 2 days each. Cows had 1 day to acclimate to each treatment and only the CBT data from the second day was analyzed to minimize carry over effects between treatments.

Because of the short term of these experiments, dry matter intake and milk yield of the animals were not analyzed. All animals were milked 4 times per day at 0600, 1200, 1800, and 0000 h. In this experiment, 2 milking parlors were utilized. Cows with SMALL units in the housing area were milked in a milking parlor cooled by SMALL units in the holding pen, operated continuously. Cows housed in pens with BIG units were milked in a milking parlor cooled by BIG units in the holding pen, operated continuously. Both parlors were cooled in the exit lanes by a soaker system activated as cows exited the milking parlors. Milking parlors had the same milking times for cows in both systems.

Two sizes (SMALL and BIG) of Korral Kool units were operated for 21 (21h) and 24 (24h) hours per day while CBT of 48 multiparous (mean milk production = 33 kg/d and days in milk = 112) Holstein dairy cows was monitored. Animals were housed in 8 different pens, with 6 cows per pen and 4 pens per Korral Kool system. Pens were randomly assigned to a treatment

sequence in a switch back design. All treatments started at 0600 h and systems were turned off at 0300 h for the 21h treatments.

Simultaneous to this study, a calorimetric analysis was conducted to compare the cooling areas under the KK units of the BIG and the SMALL systems. Twenty five sensors (HOBO Pro H8<sup>®</sup>, Onset Computer Corporation, Bourne, MA) measuring ambient temperature at 5-minute intervals were placed based on a grid distribution (Figure 4.1) under 3 SMALL units and 3 BIG units operated continuously. These sensors were placed at 1 m above the bedding area and they measured ambient temperature for a period of 2 hours in each of the systems. Because both studies were conducted simultaneously, the KK units used for the calorimetric analysis were not the same units used for the operation time study. Ambient temperature data were analyzed using Surfer software (Surfer 8<sup>®</sup>, Golden Software, Inc, Golden, CO) to create calorimetric graphs of both systems.

### ***Statistical Analysis***

Vaginal temperature data in this experiment was analyzed using a repeated measures model of SAS (Version 9.1, SAS Institute, Cary, NC) and significance was declared with a *P* value < 0.05. Time, treatment, and time by treatment were included as fixed effects and cows within pen, day and pen were included as random effects.

## **Results**

Mean ambient temperature and relative humidity for this experiment are shown in Figure 4.2. During the experiment, the average ambient temperature was 35°C and the average relative humidity was 45 %.

Based on the distribution grid utilized on the calorimetric analysis, the area analyzed in the SMALL system was 108 m<sup>2</sup> and 192 m<sup>2</sup> for the BIG system. This study showed that the mean ambient temperature inside the desert barn cooled with the SMALL system was 29.5°C compared to 26.8°C for the BIG system.

The calorimetric distribution of the area under the BIG system is illustrated in Figure 4.3. The maximum ambient temperature recorded was 31.8°C and the minimum 23.9°C. The lowest temperatures were registered at 2 m around the KK units. The highest temperatures were observed at 4 m around the units and at the area next to the curtains. Based on this information each KK unit in the BIG system provides 7.77 m<sup>2</sup> of cooling area under 25°C.

The calorimetric distribution of the area under the SMALL KK system is illustrated in Figure 4.4. The maximum ambient temperature recorded was 32.86°C and the minimum 26.86°C. Based on the results of this analysis the SMALL system did not provide an area under 25°C. However, these results need to be interpreted carefully, because of the temperature variation observed in the SMALL KK system.

Treatment effects on CBT are shown on Figure 4.5. Results showed significant treatment effects on mean CBT; cows on the SMALL 24h treatment had a lower mean CBT ( $P < 0.03$ ) compared to the SMALL 21h treatment (39.22°C vs. 39.36°C), and cows on the BIG 24h treatment had a lower mean CBT ( $P < 0.02$ ) compared to the BIG 21h treatment (38.95°C vs. 39.09°C). The contrast between the BIG and the SMALL systems was not statistically significant ( $P < 0.13$ ).

There was a significant treatment by time interaction ( $P < 0.001$ ), with greatest treatment effects occurring at 0100 h; treatment means at this time were 39.05°C, 39.01°C, 39.72°C and 39.89°C for BIG 24h, BIG 21h, SMALL 24h, and SMALL 21h, respectively (Figure 4.6). Results demonstrated that at certain parts of the day the BIG system had a better performance compared to the SMALL system.

## Discussion

It is estimated that the thermoneutral zone for dairy cows is between 5 - 20°C (NRC, 2001). The negative effects on dry matter intake and maintenance requirements are observed at ambient temperatures as low as 21°C (NRC, 2001) and are accentuated at 25°C (McDowell, 1972). It is suggested that the decreases in milk production are the result of a reduction in dry matter intake in combination with changes in nutrient partitioning (Rhoads et al., 2009).

On commercial dairy farms located in arid climates, the ambient temperature during summer months exceeds thermoneutral conditions, meaning that appropriate mitigation measures need to be considered to alleviate heat stress. However, at high ambient temperatures the heat dissipation from the cow to the environment depends on evaporation. It has been estimated that at 30°C, of the total evaporative heat loss in cattle, approximately 85 % of the heat loss of lactating cows is through evaporation from the skin and 15 % is lost by panting (Maia et al., 2005).

The KK system has been used to improve the environment of dairy cows housed in desert environments. Ryan et al. (1992) observed an increase in reproductive performance and milk yield of cows housed with the KK system. Even though this system is widely used on dairy farms around the world, little is known about how this system should be operated on commercial dairy farms. Previous research showed that 1.29 m KK systems should be operated continuously to decrease the CBT of multiparous cows (Ortiz et al., 2009).

The results from this experiment showed a significant decrease in CBT when both KK systems were operated 24 h vs. 21 h per day. These results suggest that KK systems in arid environments should be operated continuously for multiparous cows when ambient conditions exceed the TNZ.

Additionally, a significant treatment by time interaction was observed between the two KK systems. This difference might be explained by the additional cooling in the holding pen in the BIG system. It has been previously reported that holding pens are the most stressful area in a dairy farm because of the lack of ventilation and the amount of time cows spend waiting to be milked (Armstrong, 1994). In this experiment, the ambient temperature in the holding pens was not measured; however, the major differences in the CBT of animals under the SMALL and the BIG systems were observed after cows were milked. During this experiment, cows were milked 4 times per day at 0000, 0600, 1200 and 1800 hours. At each milking, cows remained at the milking parlor for approximately one hour before returning to their respective pens. Based on Figure 4.6, the differences in CBT between SMALL and BIG systems occurred during and after milking time, suggesting that at milking times, the BIG system reduced the CBT as compared to the SMALL system.

Results from the calorimetric analysis demonstrated that the lowest temperatures in the BIG system were reached at 2 m around the units. The highest temperatures in this system were observed at 4 m between the units, suggesting that it might be advantageous to place units in the BIG system at intervals less than 8 m to have a more homogeneous cooled area under the shade.

In the analysis it was observed that the SMALL system had a higher mean ambient temperature compared to the BIG system. These results may be biased by the variation observed in the SMALL system. This temperature variation could be created by the age and maintenance of the SMALL system as compared to a new BIG system. Without appropriate maintenance high

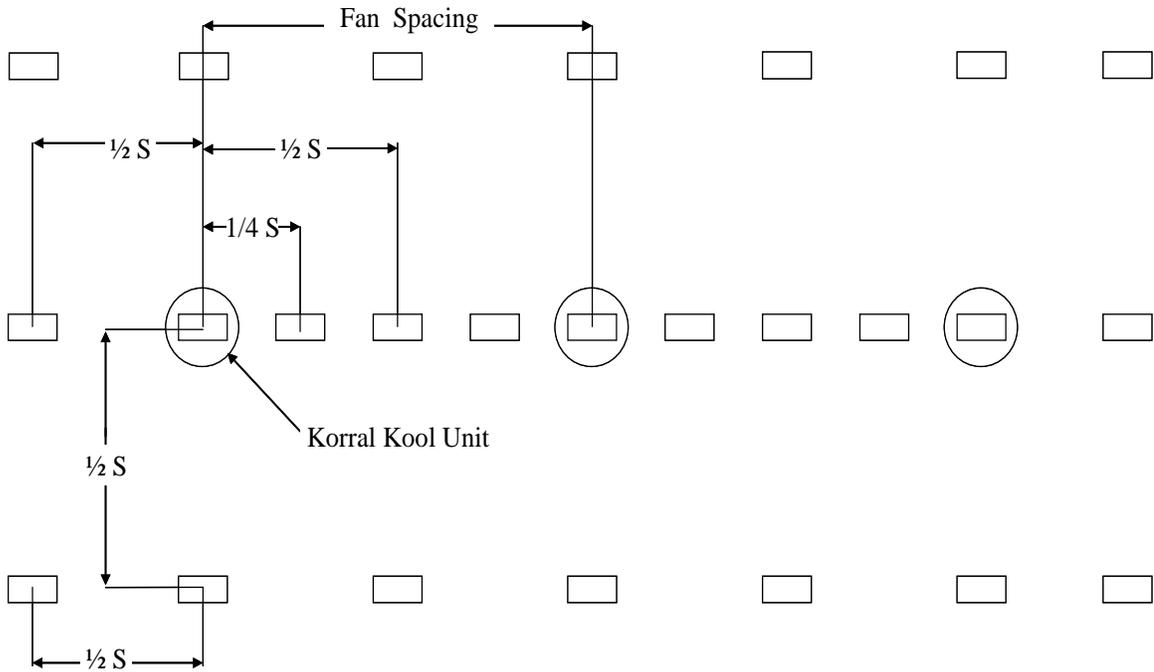
pressure misters in KK units could plug decreasing the amount of water sprayed to the environment compromising the effectiveness of the systems to decrease the ambient temperature.

It is important to emphasize the maintenance of KK units and curtains in this type of evaporative cooling systems. The malfunction of these systems will result in an increment in the ambient temperature inside the desert barns, thus, compromising cows to the negative effects of heat stress.

### **Conclusion**

Results of this experiment showed that CBT of multiparous cows decrease when KK operating time is increased from 21h to 24h, regardless of the size of the KK cooling system. The BIG system showed lower mean ambient temperature compared to the SMALL system. In the BIG system it might be advantageous to reduce the distance between units to 7 m to reduce the variation in temperature between units.

**Figure 4.1 Diagram of the distribution of the sensors under three KK units in the SMALL and BIG KK systems measuring ambient temperature at 5-minute intervals.**



**Figure 4.2 Average ambient temperature and relative humidity by hour.**

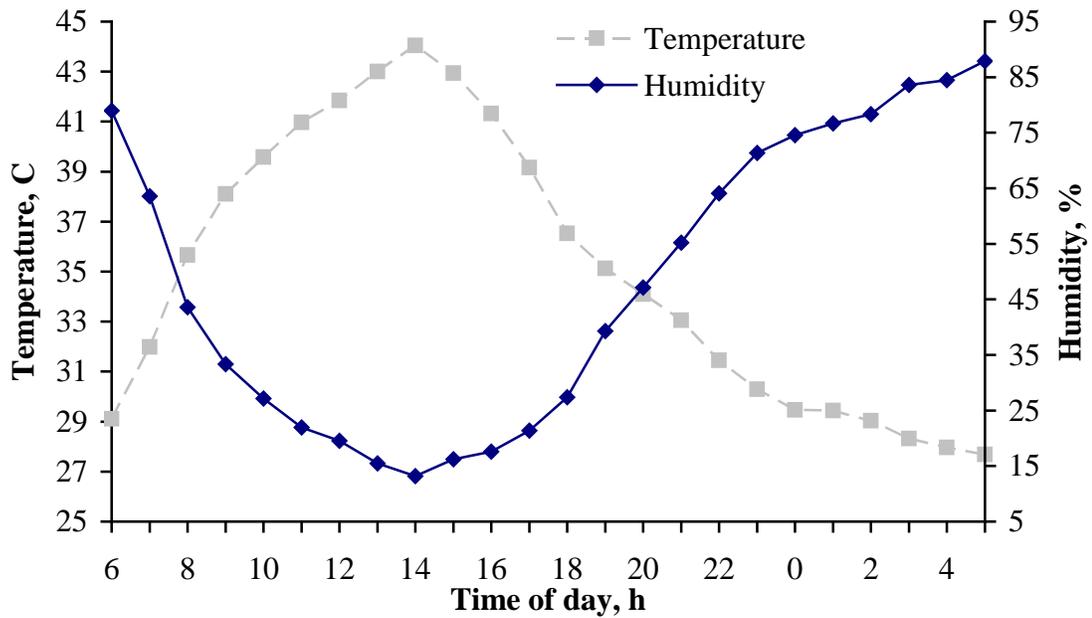


Figure 4.3 Calorimetric distribution of the area under KK units of 1.52 m in diameter, 5 hp motors and a distance of 8 m between units (BIG).

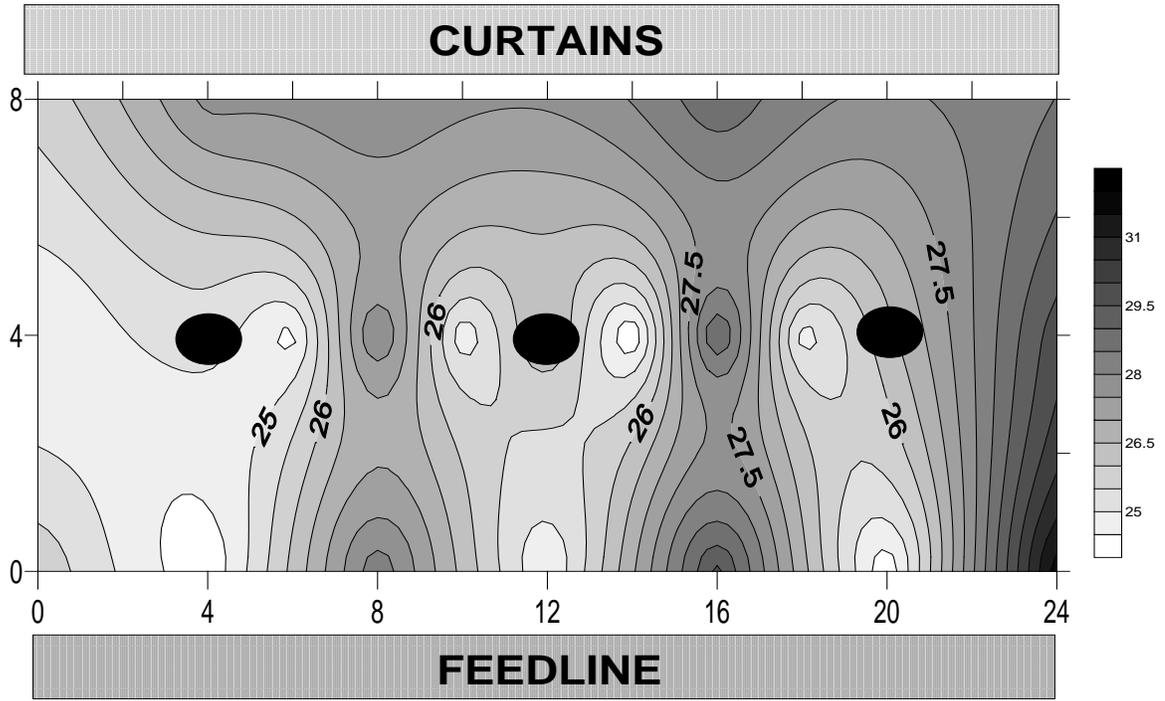
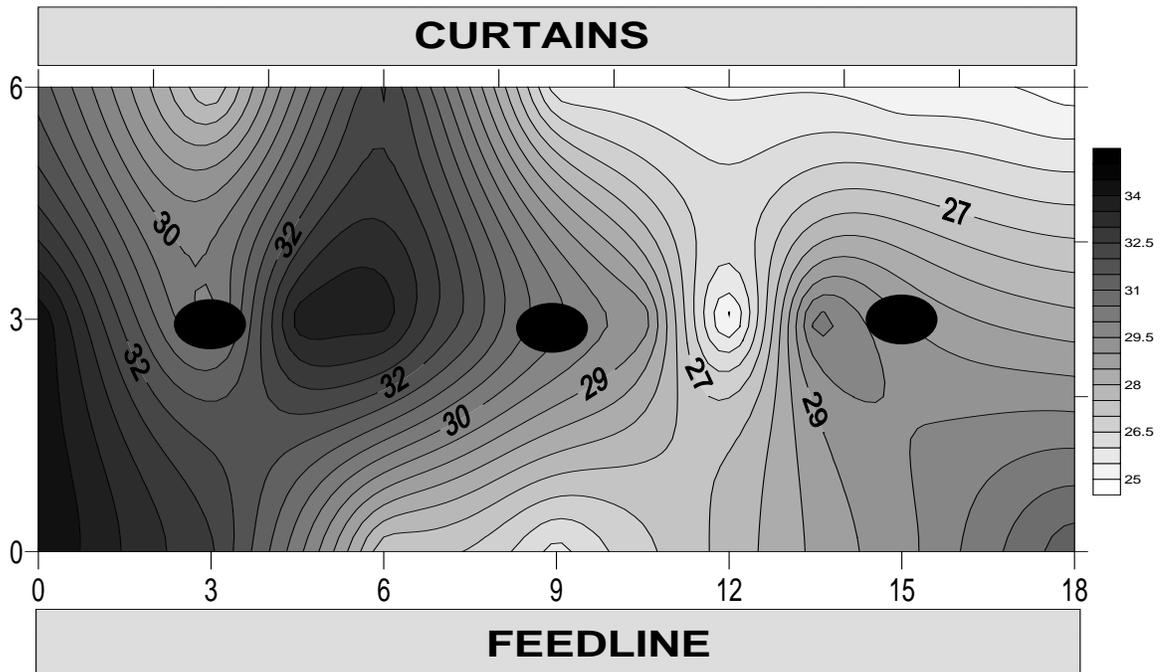
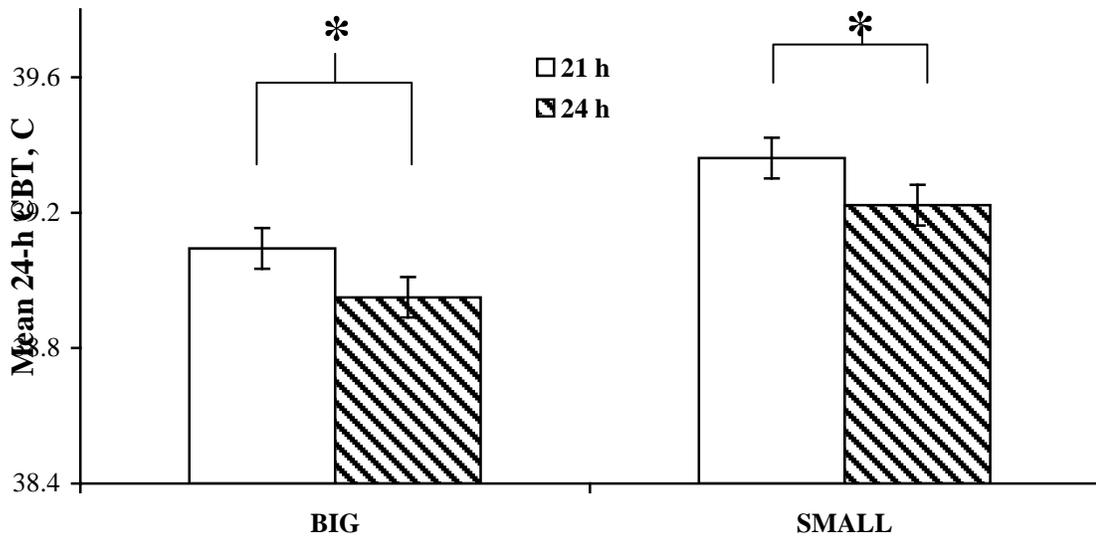


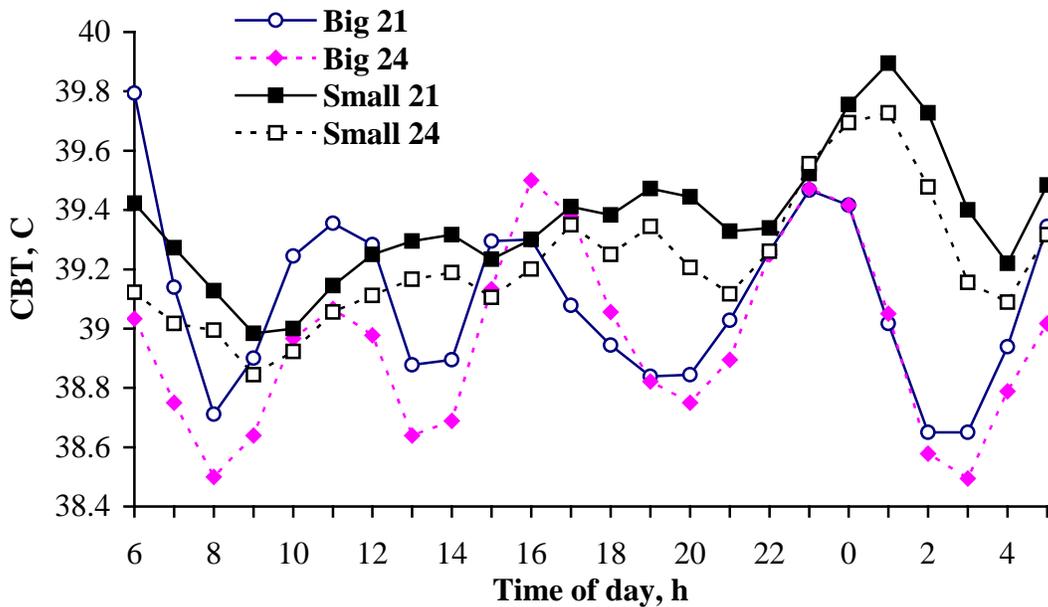
Figure 4.4 Calorimetric distribution of the area under KK units of 1.29 m in diameter, 3 hp motors and a distance between units of 6 m (SMALL).



**Figure 4.5 Mean core body temperature of multiparous cows with SMALL and BIG KK systems operated for 21h and 24 hours per day. Bars represent SEM. The contrast between the BIG and the SMALL systems was not statistically significant ( $P < 0.13$ ). Treatment effect in the SMALL KK system is significantly different ( $P < 0.03$ ). Treatment effect in the BIG KK system is significantly different ( $P < 0.02$ ).**



**Figure 4.6 Running CBT of multiparous cows with BIG and SMALL KK systems operated for 21 and 24 hours per day Treatment by time interaction:  $P < 0.001$ . SEM=0.06.**



## Bibliography

- Abilay, T. A., H. D. Johnson, and M. Madan. 1975. Influence of environmental heat on peripheral plasma progesterone and cortisol during the bovine estrous cycle. *J. Dairy Sci.* 58: 1836-1840.
- Albright, J. L., and C. W. Arave. 1997. *The behaviour of cattle*. CAB Int., Wallingford, Oxon, UK.
- Armstrong, D. 1993. Environmental modification to reduce heat stress. Pages 2-7 in Proc. Western large herd management conference. Las Vegas, Nevada.
- Armstrong, D. V. 1994. Heat stress interaction with shade and cooling. *J. Dairy Sci.* 77: 2044-2050.
- Armstrong, D. V., M.J. VanBaale, S. Rungruang, V. Wuthironarith, M. J. Brouk, and J. F. Smith. 2007. Effect of soaking dairy cows at the feed line on animal body temperature in a tunnel ventilated barn equipped with evaporative pads located in a tropical climate, Thailand. *Journal of Dairy Science* 90 (Suppl. 1): 239 (Abstr.).
- Attebery, J. T., and H. D. Johnson. 1969. Effects of environmental temperature, controlled feeding and fasting on rumen motility. *J. Anim. Sci.* 29: 734-737.
- Bandaranayaka, D., and C. Holmes. 1976. Changes in the composition of milk and rumen contents in cows exposed to a high ambient temperature with controlled feeding. *Tropical Animal Health and Production* 8: 38-46.
- Barr, H. L. 1975. Influence of estrus detection on days open in dairy herds. *J. Dairy Sci.* 58: 246-247.
- Beede, D. K., and R. J. Collier. 1986. Potential nutritional strategies for intensively managed cattle during thermal stress. *J. Anim. Sci.* 62: 543-554.
- Belibasakis, N. G. 1995. Effects of degradability of dietary protein on milk production and blood components of dairy cows in hot weather. *World review of animal production* 30: 21-26.
- Benjamin, M. M. 1981. Fluid and electrolytes. Page 213 in Proc. Outline of Veterinary Clinical Pathology. Iowa State Univ. Press, Ames.
- Berman, A. 2005. Estimates of heat stress relief needs for Holstein dairy cows. *J. Anim. Sci.* 83: 1377-1384.
- Berman, A. 2006. Extending the potential of evaporative cooling for heat-stress relief. *J. Dairy Sci.* 89: 3817-3825.
- Biggers, B. G., R. D. Geisert, R. P. Wetteman, and D. S. Buchanan. 1987. Effect of heat stress on early embryonic development in the beef cow. *J. Anim. Sci.* 64: 1512-1518.
- Bohmanova, J., I. Misztal, and J. B. Cole. 2007. Temperature-humidity indices as indicators of milk production losses due to heat stress. *J. Dairy Sci.* 90: 1947-1956.
- Brobeck, J. R. 1960. Food and temperature. *Recent Prog. in Horm. Res.* 16:439-459.
- Brouk, M. J., J. F. Smith, and J. P. Harner, III. 2001. Efficiency of modified evaporative cooling in Midwest dairy freestall barns. Pages 412-418 in Proc. Sixth International Symp. Livestock and Environment., Louisville, KY. ASAE., St. Joseph, MI.
- Brouk, M. J., J. F. Smith, and J. P. Harner III. 2003. Effect of sprinkling frequency and airflow on respiration rate, body surface temperature and body temperature of heat stressed dairy cattle. Pages 263-268 in Proc. Fifth International Dairy Housing., Forth Worth, TX.

- Brouk, M. J. 2005. Evaluating and selecting cooling systems for different climates. Pages 33-40 in Proc. Western Dairy Management Conference. Reno, NV.
- Brown, W. H., J.W. Fuquay, W.H. McGee and S.S. Iyengar 1974. Evaporative cooling for Mississippi dairy cows. Transactions of the ASAE 17(3):513-515.
- Bucklin, R. A., L. W. Turner, D. K. Beede, D. R. Bray, R. W. Hemken. 1991. Methods to relieve heat stress for dairy cows in hot, humid climates. Appl. Eng. Agric. 7(2):241.
- Buffington, D. E., R. J. Collier, and G. H. Canton. 1983. Shade management systems to reduce heat stress for dairy cows. Trans. Am. Soc. Agric. Eng. 26(6):1798
- Cena, K., and J. L. Monteith. 1975. Transfer processes in animal coats. I. Radiative transfer. Proceedings of the Royal Society of London. Series B, Biological Sciences 188: 377-393.
- Chebel, R. C., J. E. P. Santos, J. P. Reynolds, R. L. A. Cerri, S. O. Juchem, and M. Overton. 2004. Factors affecting conception rate after artificial insemination and pregnancy loss in lactating dairy cows. Animal Reproduction Science 84(3-4):239-255.
- Christison, G. I., and H. D. Johnson. 1972. Cortisol turnover in heat-stressed cows. J. Anim. Sci. 35: 1005-1010.
- Collier, R. J., D. K. Beede, W. W. Thatcher, L. A. Israel, and C. J. Wilcox. 1982a. Influences of environment and its modification on dairy animal health and production. J. Dairy Sci. 65: 2213-2227.
- Collier, R. J., J. L. Collier, R. P. Rhoads, and L. H. Baumgard. 2008. Invited review: Genes involved in the bovine heat stress response. J. Dairy Sci. 91: 445-454.
- Collier, R. J., G. E. Dahl, and M. J. VanBaale. 2006. Major advances associated with environmental effects on dairy cattle. J. Dairy Sci. 89: 1244-1253.
- Collier, R. J., S. G. Doelger, H. H. Head, W. W. Thatcher, and C. J. Wilcox. 1982b. Effects of heat stress during pregnancy on maternal hormone concentrations, calf birth weight and postpartum milk yield of Holstein cows. J. Anim. Sci. 54: 309-319.
- Collier, R. J., R. M. Eley, A. K. Sharma, R. M. Pereira, and D. E. Buffington. 1981. Shade management in subtropical environment for milk yield and composition in Holstein and Jersey cows. J. Dairy Sci. 64: 844-849.
- Collier, R. J. 2007. Heat stress effects on cattle: What we know and what we don't know. Pages 76-83 in Proc. 22nd Annual southwest nutrition and management conference. Tempe, AZ.
- Cook, N. B., R. L. Mentink, T. B. Bennett, and K. Burgi. 2007. The effect of heat stress and lameness on time budgets of lactating dairy cows. J. Dairy Sci. 90: 1674-1682.
- Coppock, C. E. 1985. Energy nutrition and metabolism of the lactating dairy cow. J. Dairy Sci. 68: 3403-3410.
- Correa-Calderon, A., D. Armstrong, D. Ray, S. DeNise, M. Enns, and C. Howison. 2004. Thermoregulatory responses of Holstein and Brown Swiss heat-stressed dairy cows to two different cooling systems. International Journal of Biometeorology 48(3):142-148.
- Curtis, S. E. 1983. Environmental management in animal agriculture. The Iowa State Univ. Press., Ames, IA.
- Dale, H. E., and S. Brody. 1954. Thermal stress and acid-base balance in dairy cattle. Missouri Agric. Exp. Stn. Res. Bull. 562.
- Drackley, J. K., T. M. Cicela, and D. W. LaCount. 2003. Responses of primiparous and multiparous Holstein cows to additional energy from fat or concentrate during summer. J. Dairy Sci. 86: 1306-1314.

- DuBois, P. R., and D. J. Williams. 1980. Increased incidence of retained placenta associated with heat stress in dairy cows. *Theriogenology* 13: 115-121.
- Dukes, H. H. 1947. *The physiology of domestic animals*. 6th ed. Comstock publishing company, Inc, Ithaca, NY.
- Emery, R. S., L. D. Brown, and J. W. Bell. 1965. Correlation of milk fat with dietary and metabolic factors in cows fed restricted-roughage rations supplemented with magnesium oxide or sodium bicarbonate. *J. Dairy Sci.* 48: 1647-1651.
- Flamenbaum, I., D. Wolfenson, M. Mamen, and A. Berman. 1986. Cooling dairy cattle by a combination of sprinkling and forced ventilation and its implementation in the shelter system. *J. Dairy Sci.* 69: 3140-3147.
- Food and Agriculture Organization of the United Nations. 2006. *FAO Statistical Yearbook*. Stats. division. Food and Agriculture Organization of the United Nations.
- Fuquay, J. W., A. B. Zook, J. W. Daniel, W. H. Brown, and W. E. Poe. 1979. Modifications in freestall housing for dairy cows during the summer. *J. Dairy Sci.* 62: 577-583.
- García-Ispuerto, I., F. López-Gatius, G. Bech-Sabat, P. Santolaria, J. L. Yániz, C. Nogareda, F. De Rensis, and M. López-Béjar. 2007. Climate factors affecting conception rate of high producing dairy cows in northeastern Spain. *Theriogenology* 67: 1379-1385.
- Garcia, A. 2006. Dealing with heat stress in dairy cows. South Dakota University Cooperative Extension Service. Extension Extra 4024.
- Gebremedhin, K. G., P. E. Hillman, C. N. Lee, R. J. Collier, S. T. Willard, J. Arthington, and T. M. Brown-Brandl. 2008. Sweating rates of dairy and feedlot cows under stressful thermal environments. ASABE paper No. 701P0408.
- Gilad, E., R. Meidan, A. Berman, Y. Graber, and D. Wolfenson. 1993. Effect of heat stress on tonic and GnRh-induced gonadotrophin secretion in relation to concentration of oestradiol in plasma of cyclic cows. *J Reprod Fertil* 99: 315-321.
- Gwazdauskas, F. C., W. W. Thatcher, C. A. Kiddy, M. J. Paape, and C. J. Wilcox. 1981. Hormonal patterns during heat stress following pgf<sub>2</sub> $\alpha$ -tham salt induced luteal regression in heifers. *Theriogenology* 16: 271-285.
- Hahn, G. L. 1999. Dynamic responses of cattle to thermal heat loads. *J. Anim. Sci.* 77: 10-20.
- Hansen, P. J. 2004. Physiological and cellular adaptations of zebu cattle to thermal stress. *Animal Reproduction Science* 82-83: 349-360.
- Hansen, P. J. and C. F. Arechiga. 1999. Strategies for Managing Reproduction in the Heat-Stressed Dairy Cow. *J. Anim Sci.* 77(E-Suppl\_2):36-50.
- Hansen, P. J., M. Drost, R. M. Rivera, F. F. Paula-Lopes, Y. M. Al-Katanani, C. E. Krininger, and C. C. Chase. 2001. Adverse impact of heat stress on embryo production: causes and strategies for mitigation. *Theriogenology* 55(1):91-103.
- Hassan, A., and J. D. Roussel. 1975. Effect of protein concentration in the diet on blood composition and productivity of lactating Holstein cows under thermal stress. *J. Agric. Sci. (Camb.)* 85:409-415.
- Higginbotham, G. E., M. Torabi, and J. T. Huber. 1989. Influence of dietary protein concentration and degradability on performance of lactating cows during hot environmental temperatures. *J. Dairy Sci.* 72: 2554-2564.
- Howell, J. L., J. W. Fuquay, and A. E. Smith. 1994. Corpus luteum growth and function in lactating Holstein cows during spring and summer. *J. Dairy Sci.* 77: 735-739.

- Igono, M. O., H. D. Johnson, B. J. Steevens, W. A. Hainen, and M. D. Shanklin. 1988. Effect of season on milk temperature, milk growth hormone, prolactin, and somatic cell counts of lactating cattle. *International Journal of Biometeorology* 32: 194-200.
- Igono, M. O., H. D. Johnson, B. J. Steevens, G. F. Krause, and M. D. Shanklin. 1987. Physiological, productive, and economic benefits of shade, spray, and fan system versus shade for Holstein cows during summer heat. *J. Dairy Sci.* 70: 1069-1079.
- Johnson, H. D., A. C. Ragsdale, I. L. Berry, and M. D. Shanklin. 1963. Temperature-humidity effects including influence of acclimation in feed and water consumption of Holstein cattle. *Univ. Missouri Agric. Exp. Stn. Res. Bull.* 846. Columbia.
- Jones, G. M., and C. C. Stallings. 1999. Reducing heat stress for dairy cattle. *Dep. Dairy Sci., Virginia Tech. Univ. Publication Number* 404-200.
- Jordan, E. R. 2003. Effects of heat stress on reproduction. *J. Dairy Sci.* 86: E104-114.
- Kadzere, C. T., M. R. Murphy, N. Silanikove, and E. Maltz. 2002. Heat stress in lactating dairy cows: A review. *Livestock Production Science* 77: 59-91.
- Kelley, R. O., F. A. Martz, and H. D. Johnson. 1967. Effect of environmental temperature on ruminal volatile fatty acid levels with controlled feed intake. *J. Dairy Sci.* 50: 531-533.
- Kibler, H., and S. Brody. 1954. Influence of wind on heat exchange and body temperature regulation in Jersey, Holstein, Brown Swiss and Brahman cattle. *Mo Agric. Exp. Stn. Res. Bull.* 552:39. Columbia.
- Kibler, H. H., and S. Brody. 1950. Influence of temperature, 5° to 95°F, on evaporative cooling from the respiratory and exterior body surfaces in Jersey and Holstein cows. *Univ. of Missouri Agric. Exp. Res. Bull.* 461, Columbia.
- Klinedinst, P. L., D. A. Wilhite, G. L. Hahn, and K. G. Hubbard. 1993. The potential effects of climate change on summer season dairy cattle milk production and reproduction. *Climatic Change* 23: 21-36.
- Klungland, H., and D. I. Vage. 2003. Pigmentary switches in domestic animal species. *Ann. N.Y. Acad. Sci.* 994: 331-338.
- Lee, W. C., H. C. Wen, C. P. Chang, M. Y. Chen, and M. T. Lin. 2006. Heat shock protein 72 over expression protects against hyperthermia, circulatory shock, and cerebral ischemia during heatstroke. *J Appl Physiol* 100: 2073-2082.
- Legates, J. E., B. R. Farthing, R. B. Casady, and M. S. Barrada. 1991. Body temperature and respiratory rate of lactating dairy cattle under field and chamber conditions. *J. Dairy Sci.* 74: 2491-2500.
- Lin, J. C., B. R. Moss, J. L. Koon, C. A. Floyd, R. L. Smith III, K. A. Cummins, and D. A. Coleman. 1998. Comparison of various fan, sprinkler, and mister systems in reducing heat stress in dairy cattle. *Appl. Eng. Agric.* 14:177-182.
- Lough, D. S., D. L. Beede, and C. J. Wilcox. 1990. Effects of feed intake and thermal stress on mammary blood flow and other physiological measurements in lactating dairy cows. *J. Dairy Sci.* 73: 325-332.
- Magdub, A., H. D. Johnson, and R. L. Belyea. 1982. Effect of environmental heat and dietary fiber on thyroid physiology of lactating cows. *J. Dairy Sci.* 65: 2323-2331.
- Maia, A. S. C., R. G. daSilva, and C. M. Battiston Loureiro. 2005. Sensible and latent heat loss from the body surface of Holstein cows in a tropical environment. *International Journal of Biometeorology* 50: 17-22.

- Mallonee, P. G., D. K. Beede, R. J. Collier, and C. J. Wilcox. 1985. Production and physiological responses of dairy cows to varying dietary potassium during heat stress. *J. Dairy Sci.* 68: 1479-1487.
- Mariasegaram, M., C. C. Chase, J. X. Chaparro, T. A. Olson, R. A. Brenneman, and R. P. Niedz. 2007. The slick hair coat locus maps to chromosome 20 in senepol-derived cattle. *Animal Genetics* 38: 54-59.
- Maynard, L. A., and J. K. Loosli. 1956. *Animal nutrition*. 4th ed. McGraw-Hill Book Co., Inc., New York, NY.
- McDowell, R. E. 1972. *Improvement of livestock production in warm climates*. W. H. Freeman & Co., San Francisco.
- McGuire, M. A., D. K. Beede, M. A. DeLorenzo, C. J. Wilcox, G. B. Huntington, C. K. Reynolds, and R. J. Collier. 1989. Effects of thermal stress and level of feed intake on portal plasma flow and net fluxes of metabolites in lactating Holstein cows. *J. Anim. Sci.* 67: 1050-1060.
- Mohammed, M. E., and H. D. Johnson. 1985. Effect of growth hormone on milk yields and related physiological functions of Holstein cows exposed to heat stress. *J. Dairy Sci.* 68: 1123-1133.
- Morton, J. M., W. P. Tranter, D. G. Mayer, and N. N. Jonsson. 2007. Effects of environmental heat on conception rates in lactating dairy cows: critical periods of exposure. *J. Dairy Sci.* 90(5):2271-2278.
- Mount, L. E. 1979. *Adaptation to thermal environment, man and his productive animals*. University Park Press, Baltimore, MD.
- Murphy, M. R., C. L. Davis, and G. C. McCoy. 1983. Factors affecting water consumption by Holstein cows in early lactation. *J. Dairy Sci.* 66: 35-38.
- National Research Council. 1971. *A guide to environmental research on animals*. Natl. Acad. Sci., Washington, DC.
- National Research Council. 1981. *Effect of environment on nutrient requirements of domestic animals*. Natl. Acad. Sci., Washington, DC.
- National Research Council. 2001. *Nutrient requirements of dairy cattle*. 7th ed. Natl. Acad. Sci., Washington, DC.
- Oldham, J. D. 1984. Protein-energy interrelationships in dairy cows. *J. Dairy Sci.* 67: 1090-1114.
- Olson, T. A., C. Lucena, C. C. Chase, Jr., and A. C. Hammond. 2003. Evidence of a major gene influencing hair length and heat tolerance in *bos taurus* cattle. *J. Anim. Sci.* 81: 80-90.
- Ortiz, X. A., J. F. Smith, B. J. Bradford, J. P. Harner III, and A. Oddy. 2009. Effects of Korral Kool® running time on core body temperature of dairy cows in an desert environment. *J. Dairy Sci.* 92: 2356-2357. (Abstr.).
- Pennington, J. A., J. L. Albright, M. A. Diekman, and C. J. Callahan. 1985. Sexual activity of Holstein cows: Seasonal effects. *J. Dairy Sci.* 68: 3023-3030.
- Perera, K. S., F. C. Gwazdauskas, R. M. Akers, and R. E. Pearson. 1985. Seasonal and lactational effects on response to thyrotropin releasing hormone injection in Holstein cows. *Domestic Animal Endocrinology* 2: 43-52.
- Perera, K. S., F. C. Gwazdauskas, R. E. Pearson, and T. B. Brumback, Jr. 1986. Effect of season and stage of lactation on performance of Holsteins. *J. Dairy Sci.* 69: 228-236.
- Pirkkka, L., P. Nykanen, and S. Lea. 2001. Roles of the heat shock transcription factors in regulation of the heat shock response and beyond. *FASEB J.* 15: 1118-1131.

- Pitt, R. E., J. S. Van Kessel, D. G. Fox, A. N. Pell, M. C. Barry, and P. J. Van Soest. 1996. Prediction of ruminal volatile fatty acids and pH within the net carbohydrate and protein system. *J. Anim. Sci.* 74: 226-244.
- Ravagnolo, O., and I. Misztal. 2000. Genetic component of heat stress in dairy cattle, parameter estimation. *J. Dairy Sci.* 83: 2126-2130.
- Ravagnolo, O., I. Misztal, and G. Hoogenboom. 2000. Genetic component of heat stress in dairy cattle, development of heat index function. *J. Dairy Sci.* 83: 2120-2125.
- Rensis, F. D., and R. J. Scaramuzzi. 2003. Heat stress and seasonal effects on reproduction in the dairy cow – a review. *Theriogenology* 60: 1139-1151.
- Rhoads, M. L., R. P. Rhoads, M. J. VanBaale, R. J. Collier, S. R. Sanders, W. J. Weber, B. A. Crooker, and L. H. Baumgard. 2009. Effects of heat stress and plane of nutrition on lactating Holstein cows: I. Production, metabolism, and aspects of circulating somatotropin. *J. Dairy Sci.* 92(5):1986-1997.
- Rodriguez, L. A., G. Mekoimnen, C. J. Wilcox, F. G. Martin, and W. A. Krienke. 1985. Effects of relative humidity, maximum and minimum temperature, pregnancy, and stage of lactation on milk composition and yield. *J. Dairy Sci.* 68: 973-978.
- Roman-Ponce, H., W. W. Thatcher, D. E. Buffington, C. J. Wilcox, and H. H. Van Horn. 1977. Physiological and production responses of dairy cattle to a shade structure in a subtropical environment. *J. Dairy Sci.* 60: 424-430.
- Roman-Ponce, H., W. W. Thatcher, D. Caton, D. H. Barron, and C. J. Wilcox. 1978. Thermal stress effects on uterine blood flow in dairy cows. *J. Anim. Sci.* 46: 175-180.
- Roman-Ponce, H., W. W. Thatcher, and C. J. Wilcox. 1981. Hormonal interrelationships and physiological responses of lactating dairy cows to a shade management system in a subtropical environment. *Theriogenology* 16: 139-154.
- Rosenberg, M., Y. Folman, Z. Herz, I. Flamenbaum, A. Berman, and M. Kaim. 1982. Effect of climatic conditions on peripheral concentrations of LH, progesterone and oestradiol-17 $\beta$  in high milk-yielding cows. *J. Reprod. Fertil.* 66: 139-146.
- Roth, Z., R. Meidan, R. Braw-Tal, and D. Wolfenson. 2000. Immediate and delayed effects of heat stress on follicular development and its association with plasma fsh and inhibin concentration in cows. *J. Reprod. Fertil.* 120: 83-90.
- Roth, Z., R. Meidan, A. Shaham-Albalancy, R. Braw-Tal, and D. Wolfenson. 2001. Delayed effect of heat stress on steroid production in medium-sized and preovulatory bovine follicles. *Reproduction* 121: 745-751.
- Ryan, D. P., M. P. Boland, E. Kopel, D. Armstrong, L. Munyakazi, R. A. Godke, and R. H. Ingraham. 1992. Evaluating two different evaporative cooling management systems for dairy cows in a hot, dry climate. *J. Dairy Sci.* 75: 1052-1059.
- Sanchez, W. K., M. A. McGuire, and D. K. Beede. 1994. Macromineral nutrition by heat stress interactions in dairy cattle: Review and original research. *J. Dairy Sci.* 77: 2051-2079.
- Schultz, T. A. 1988. California dairy corral manger mister installation. Paper No. 88-4056, Am. Soc. Agric. Eng., St. Joseph, MI.
- Silanikove, N. 1992. Effects of water scarcity and hot environment on appetite and digestion in ruminants: a review. *Livest. Prod. Sci.* 30, 175-194
- Silanikove, N. 1994. The struggle to maintain hydration and osmoregulation in animals experiencing severe dehydration and rapid rehydration: The story of ruminants. *Exp. Phys.* 79: 281-300.

- Silanikove, N. 2000. Effects of heat stress on the welfare of extensively managed domestic ruminants. *Livestock Production Science* 67: 1-18.
- Smith, J. F., J. P. Harner III. 2007. Comprehensive evaluation of a low-profile cross-ventilated freestall barn. Pages 127-147 in *Proc. Western dairy management conference.*, Reno, NV.
- Smith, J. F., M.J. Brouk, J. P. Harner III, and K. C. Dhuyvetter. 2006. Issues with dairy facilities located in the high plains. Pages 1-13 in *Proc. High plains dairy conference.*, Albuquerque, NM.
- Smith, T. R., A. Chapa, S. Willard, C., Jr. Herndon, R. J. Williams, J. Crouch, T. Riley, and D. Pogue. 2006. Evaporative tunnel cooling of dairy cows in the southeast. Ii: Impact on lactation performance. *J. Dairy Sci.* 89: 3915-3923.
- St-Pierre, N. R., B. Cobanov, and G. Schnitkey. 2003. Economic losses from heat stress by us livestock industries. *J. Dairy Sci.* 86: E52-77.
- Steward, R. E., and S. Brody. 1954. Effect of radiation intensity on hair and skin temperatures and on respiration rates of Holstein, Jersey and Brahman cattle at air temperatures of 45°, 70° and 80°F. *Mo. Agri. Expt. Sta. Res. Bull. No. 561.*
- Strickland, J. T., R. A. Bucklin, R. A. Nordstedt, D. K. Beede, and D. R. Bray 1989. Sprinkler and fan cooling systems for dairy cows in hot, humid climates. *Appl. Eng. Agric.* 5:231-236.
- Thatcher, W. W. 1974. Effects of season, climate, and temperature on reproduction and lactation. *J. Dairy Sci.* 57: 360-368.
- Thatcher, W. W., and R. J. Collier. 1986. Effects of climate in reproduction. In: *Current Therapy in Theriogenology 2*, Philadelphia, PA. p 301-309.
- Trout, J. P., L. R. McDowell, and P. J. Hansen. 1998. Characteristics of the estrous cycle and antioxidant status of lactating Holstein cows exposed to heat stress. *J. Dairy Sci.* 81: 1244-1250.
- Tyrrell, H. F., P. W. Moe, and W. P. Flatt. 1970. Influence of excess protein intake on energy metabolism of the dairy cow. Pages 69-71 in *Proc. 5th Symp. Energy Metab. Farm Anim. EAAP Publ.* 13:69.
- VanBaale, M., J. Smith, C. Jamison, R. Rodriguez, and L. Baumgard. 2006. Evaluate the efficacy "Heat stress audits" of your cooling system through core body temperature. Pages 174-180 in *Proc. 21st Annual Southwest Nutrition and Management Conference.* Tempe, AZ.
- VanBaale, M. J., D. Ledwith, R. Burgos, R. J. Collier, D. V. Armstrong, J. F. Smith, M. J. Brouk, and L. H. Baumgard. 2004. Evaluation of advanced dairy systems shade tracker (ads-st) fans and Korral Kool (kk) coolers on a commercial dairy in Buckeye, Arizona. *J. Dairy. Sci.* 88 (Suppl. 1):42. (Abstr.)
- Weldy, J. R., R. E. McDowell, P. J. Van Soest, and J. Bond. 1964. Influence of heat stress on rumen acid levels and some blood constituents in cattle. *J. Anim. Sci.* 23: 147-153.
- West, J. W. 2003. Effects of heat-stress on production in dairy cattle. *J. Dairy Sci.* 86: 2131-2144.
- West, J. W., C. E. Coppock, K. Z. Milam, D. H. Nave, J. M. Labore, and L. D., Jr. Rowe. 1987. Potassium carbonate as a potassium source and dietary buffer for lactating Holstein cows during hot weather. *J. Dairy Sci.* 70: 309-320.
- West, J. W., K. D. Haydon, B. G. Mullinix, and T. G. Sandifer. 1992. Dietary cation-anion balance and cation source effects on production and acid-base status of heat-stressed cows. *J. Dairy Sci.* 75: 2776-2786.

- West, J. W., B. G. Mullinix, and J. K. Bernard. 2003. Effects of hot, humid weather on milk temperature, dry matter intake, and milk yield of lactating dairy cows. *J. Dairy Sci.* 86: 232-242.
- Wiersma, F. 1982. Shades for dairy cattle. Univ. Ariz. Ext. Serv., WREP 51. Univ. Arizona, Tucson.
- Wilson, S. J., R. S. Marion, J. N. Spain, D. E. Spiers, D. H. Keisler, and M. C. Lucy. 1998. Effects of controlled heat stress on ovarian function of dairy cattle. 1. Lactating cows. *J. Dairy Sci.* 81: 2124-2131.
- Wise, M. E., D. V. Armstrong, J. T. Huber, R. Hunter, and F. Wiersma. 1988. Hormonal alterations in the lactating dairy cow in response to thermal stress. *J. Dairy Sci.* 71: 2480-2485.
- Wolfenson, D., W. W. Thatcher, L. Badinga, J. D. Savio, R. Meidan, B. J. Lew, R. Braw-Tal, and A. Berman. 1995. Effect of heat stress on follicular development during the estrous cycle in lactating dairy cattle. *Biology of Reproduction* 52: 1106-1113.
- Younas, M., J. W. Fuquay, A. E. Smith, and A. B. Moore. 1993. Estrous and endocrine responses of lactating Holsteins to forced ventilation during summer. *J. Dairy Sci.* 76(2):430-436.
- Yousef, M. K. 1985. Stress physiology in livestock. CRS Press, Boca Raton, FL.

