

PHYSIOLOGICAL RESPONSES OF “SLICK” VERSUS NORMAL HAIRE
D HOLSTEIN X SENEPOL CROSSBRED CATTLE IN FLORIDA

By

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Holstein x Senepol crosses with “slick” (SH; short and shiny) and normal hair (NH) were utilized to account for differences in physiological responses to hot weather. A relatively small phenotypic difference in quantity of hair in very closely related animals resulted in differences in rectal temperature (RT), skin temperature (ST), and respiration rate (RR) under the same stressful environmental conditions.

Monthly measurements of RT were made over a period of a year. In the months at the end of summer, slick haired animals had lower ($P < 0.05$) rectal temperatures (e.g., September; NH = 39.7°C, SH = 39.3°C). During cooler months, difference between hair types disappeared (e.g., December; NH = 39.9°C, SH = 39.7°C). These results suggest that slick hair affects body temperature during the hot season but does not influence body temperature regulation during cooler weather in Florida.

In a subsequent experiment, a sample of the cattle from the first experiment (8 bulls and 8 heifers, four of each sex with slick and normal hair) was assigned to pens with individual Calan gates. Environmental conditions were measured and the temperature-humidity index (THI) was calculated. Physiological measurements were taken daily during the summer of 2000. Differences between slick and normal haired animals were evident in RR, ST and RT. The RR of SH animals were lower ($P < 0.05$) than NH animals (RR = 56 breaths per minute (BPM) vs. 69 BPM for NH). Skin temperatures of the slick-haired animals were lower ($P < 0.05$) than NH animals (37.5°C for SH vs. 38.0°C for NH). Slick-haired animals maintained lower ($P < 0.05$) rectal temperatures (38.9°C for SH vs. 39.3°C for NH) under hot summer conditions (average temperature-humidity index = 99).

Slick and normal-haired animals were identified visually and the difference in hair weight per skin area was quantified. Slick-haired had less ($P < 0.05$), 11.47 vs. 17.82 mg/cm², hair weight per skin area than NH animals. Hair clipped from both black and white areas of the spotted animals was also measured. The hair weight per skin area of black hair was indeed lower ($P < 0.05$), 11.02 vs. 18.28 mg/cm², than that of white hair.

The marked advantage in physiological differences in favor of SH cattle seems to confirm that cattle with this trait are less likely to experience unfavorable physiological responses when exposed to heat stress in hot, humid subtropical environments. Furthermore, inheritance of this trait as a single gene increases its potential utility.

CHAPTER 1 INTRODUCTION

Production of food and animal protein in adequate quantities and quality continues to be a major issue for more than the half of the world's population. A majority of these people live in tropical and semiarid areas of the world which constitute two thirds of the world's land. In these areas, productive breeds of cattle from temperate areas are often unable to survive. The majority of the world's widely used breeds of cattle were developed in temperate zones and were selected for production in the temperate environment, possibly resulting in animals that are more sensitive to the heat stress of tropical environments. Breeders in tropical regions, on the other hand, have been unsuccessful at improving breeds of livestock native to the tropics to adequate levels of production. Farmers in these areas of the world are often unable to provide the increased food supply required for their growing populations. The demand of livestock products in developing countries is predicted to increase by 50% from current levels by the year 2020 (Delgado et al., 1999). Livestock producers from this region will need serious improvement in total production to match the estimated demand. Increased efficiency of production will be a key component to this increased output.

The pernicious effects of thermal stress on the production of cattle have negatively affected cattle productivity for many years. Many of the enhancements to reduce heat effects require the construction of costly structures, buildings, fans, sprinklers, etc. Improvements in animal management technologies, such as artificial

insemination and embryo transfer, which increase the ease of worldwide transportation of germplasm, have had conflicting effects. On the one hand, these techniques have increase distribution of genes of highly productive animals to regions of the tropics and subtropics. On the other hand, cattle selected for increased productivity in temperate areas are likely to be genetically unadapted for hot environments.

In this study, the environment – animal interaction during thermal stress was quantified. The environmental measurements were characterized for ambient temperature, black globe temperature, relative humidity and the physiological responses (rectal temperature, skin temperature and respiration rate) of cattle enduring these environments were evaluated.

The physiological differences among animals with similar genetic composition but differentiated by the presence of a short, shiny, “slick” hair or normal Holstein type hair are quantified. This hair trait is a characteristic of many native breeds from Latin America and seems to be associated with a single gene. The objective of this study is to test the hypothesis that cattle with the slick phenotype are better able to regulate body temperature in the presence of thermal stress than cattle with normal hair.

CHAPTER 2 LITERATURE REVIEW

Cattle and Hot Environment

From a physical point of view, animals are entities through which materials and energy flow before eventually returning to the environment (Campbell and Lasley, 1985). Environmental factors affecting the flow of energy between cattle and the surroundings are sunlight, skylight, thermal radiation, air temperature, air movement and humidity of the air (Gebremedhin, 1985). One important form of energy that flows through cattle is heat, and heat is a major constraint on animal productivity, especially in tropical and arid areas (Silanikove, 2000). This is a concern because of the homeothermic condition of cattle; i.e., they need to maintain a constant body temperature over a wide range of environmental conditions. This constant body temperature, of course, is not absolute; there is a diurnal fluctuation (Finch, 1984; Robertshaw, 1985), typically in the form of a monophasic rhythm with a maximum in the late evening and a minimum in late morning (Hahn, 1989; Hahn, 1999). Environmental stressors may alter this monophasic temperature rhythm (Nienaber et al., 1999). Hot environments have been shown to cause phase shifts, increase amplitude and increase means of this diurnal rhythm (Hahn, 1999). An indication of acclimatization to heat challenges is the return to normal body temperature rhythms after heat stress displaces the normal rhythm (Nienaber et al., 1999).

Acclimatization to thermal stress occurs when an animal, as a consequence of recurrent or permanent exposure to a hotter environment, develops functional, structural

and behavioral qualities that improve its ability to withstand its hot surroundings without distress (McDowell, 1972; Curtis, 1981). Hahn (1999) found that physiological acclimation to elevated thermal conditions is reflected during the day with observed variations of body temperature on the order of 0.1°C to 0.4°C per day.

Every interaction an animal has with its thermal environment involves heat exchange, with permanent fluctuations of thermal energy in and out of the environment and the animal; the rate of exchange determines the degree to which cattle remain in thermal equilibrium with their environment. The rate at which these heat exchanges occurs is dependent on the individual resistance of each entity (the cattle and the environment). The resistances to heat exchange that affect the ability of an animal to regulate its body temperature are tissue, coat, and air resistance, as well as evaporative resistance (Finch, 1986). Furthermore, the properties of the hair coat and skin which affect the exchange of energy are its color, density, length, diameter, pelt thickness, transmissivity, and absorptivity (Gebremedhin, 1985).

The pathways of thermal exchanges between an animal and its environment are conduction as well as radiative, convective, and evaporative heat exchanges (Curtis, 1981; Gebremedhin, 1985; Finch, 1986). Thermal exchanges are meant to maintain homeothermy which requires that the amount of heat produced or gained must equal the heat loss to the environment. This concept is graphically explained in the figure 1, and indicated mathematically by the equation:

$$M = K + C + R + E$$

where M is the metabolic heat production, K equals the heat exchanged by conduction, C is the heat exchanged by convection, R is the heat portion exchange by radiation, and E is the heat removed by evaporation (Robertshaw, 1985).

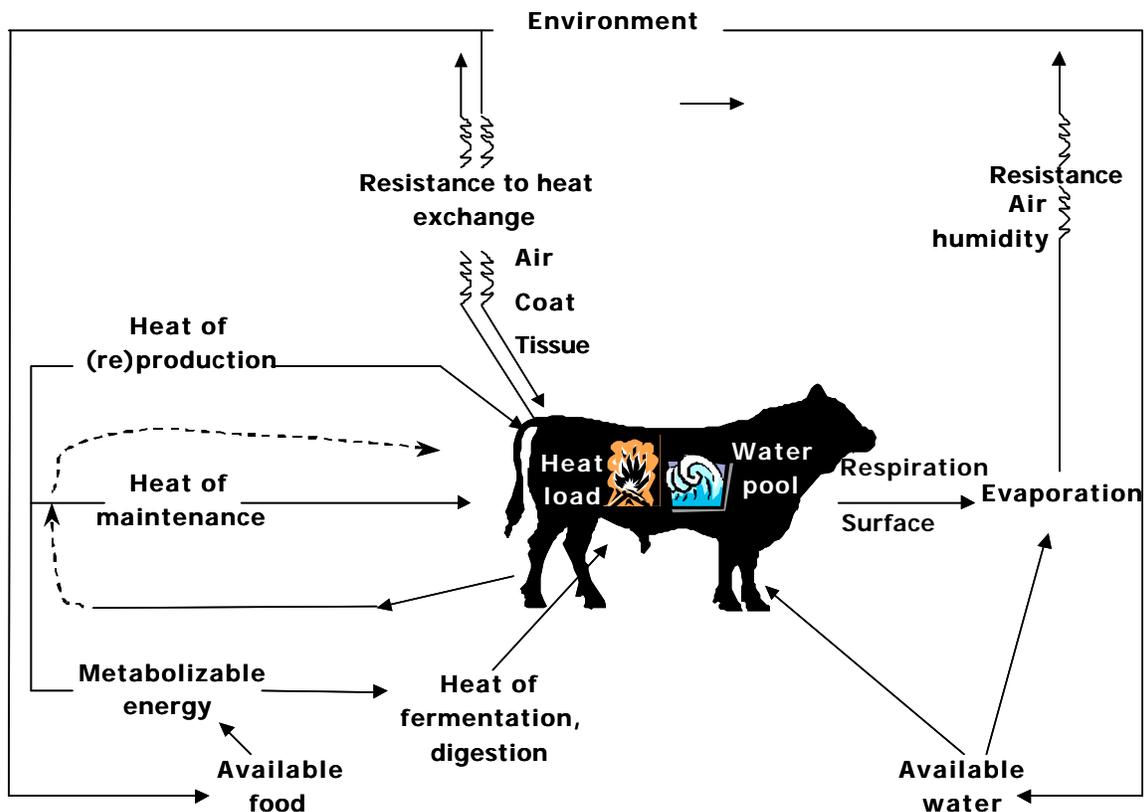


Figure 1. The interrelation of heat, water and energy metabolism in the bovine (adapted from Finch, 1986)

The rate or velocity of exchange depends on the ability of the environment to accept heat and water vapor. High ambient humidity reduces the capacity of these exchanges because the air is already saturated with moisture. Resistance to these exchanges prohibits heat loss, resulting in an increase body temperature and a reduced appetite. Finch (1986) also stated that animals which increase their capacity for

thermoregulation often do so through a diminution in energy metabolism, which probably is negatively related with their growth potential in less harsh environments.

Upon exposure to a hot environment, cattle respond initially with an acceleration of certain physiological processes to increase the rate of heat loss (McDowell, 1972). The two processes that are increased first are respiration rate and evapotranspiration rate; are mechanisms of achieving heat dissipation (Campbell and Lasley, 1985). Panting and sweating are paths of thermoregulatory water loss for heat dissipation (Silanikove, 2000) and are complementary in the sense that animals with less sweating capability normally have a higher capacity for panting (Yousef, 1985). In cattle with relatively large sweating response, skin temperature is kept cooler by sweat evaporation. The critical skin temperature that triggers panting seem to be one or two degrees higher than that for the onset of sweating, however, if the sweating response is poor, the panting reflex threshold is reached at lower temperatures (Curtis, 1981).

Unlike man, cattle increase the rates of respiration, pulmonary ventilation, and respiratory vaporization with increasing environmental temperature (Worstell and Brody, 1953). Nonetheless, when the environmental temperature reaches in average 26.7°C for *Bos taurus*, and, 35.0°C for *Bos indicus*, these mechanisms become incapable of dissipating all of the excess heat (Brody, 1956). At higher ambient temperatures the temperature gradient between an animal's body and the surroundings is reduced with a consequent reduction in convective and radiative cooling, and heat loss is swung towards evaporative cooling. When the ambient temperature approaches the body surface temperature, convective and radiative cooling approach zero (Worstell and Brody, 1953)

In addition to the environmental heat load, cattle also must cope with the heat production of the rumen (Brody, 1956), part of the heat increment of feeding. The heat increment of feeding is heat produced by an animal during fermentation in the gastrointestinal tract and during the processing and use of nutrients by the body. Heat is released during the metabolism of the nutrients absorbed from the gut. The nutrients undergo chemical transformations related to productive and reproductive activities that are not totally efficient, and as a result they are accompanied by heat increment. Estimations of the components of the heat increment of feeding should be carefully interpreted as they are influenced by numerous factors (Curtis, 1981). Furthermore, nutritional imbalance and deficiencies may aggravate the impact of heat stress, i. e. higher levels of dietary protein (West, 1999)

Another factor that contributes to heat load into the core temperature of a bovine body is the level of production, (e.g. daily milk production). Higher levels of production supply an extra thermal input and are reflected in the stress indices (Seath and Miller, 1946b; Silanikove, 2000). Similar increases in heat load arise with pregnant cows and water-deprived cattle (Silanikove, 2000). Vulnerability to environmental forces is also influenced by life stage, conditioning, and nutritional and health status (Worstell and Brody, 1953; Hahn, 1999).

Under the challenge of several forces, homeotherms maintain their body temperature within a relatively narrow range (Das et al., 1999; Frisch, 2000) and slight variations in internal temperature may disrupt normal processes and, as a result, their productive performance. The affected processes that have been studied the most are growth (McDowell, 1972; Turner, 1982; Finch, 1986; Hammond et al., 1998), milk

production (McDowell, 1972; Armstrong, 1993; Valtorta et al., 1997; Ravagnolo et al., 2000) and reproduction (McDowell, 1972; Wolfenson et al., 2000; Hansen et al., 2001).

Growth under heat stress conditions appears to be directly related to the level of animal resistance to stressors which include high temperatures (Turner, 1982), low nutritional inputs, disease outbreak, and parasite infestation (Frisch, 1981). Cattle with better growth under harsh hot environments are those with lower respiration rates and rectal temperatures (Hammond et al., 1998). Animals might also reduce their metabolism to compensate for the excessive external heat load. Cattle eat more frequent meals of smaller sizes in hot environments, perhaps trying to avoid peaks of heat load (Hahn, 1999). West (1999) stated that the reduction of dry matter intake caused by heat stress in dairy cattle reduces the availability of nutrients for absorption, and that the portion that is absorbed is done so less efficiently. Reduction in growth hormone and insulin levels in blood is also probable in cattle under heat stress (Parker, 1984).

Milk production is another trait that is negatively influenced by higher ambient temperatures, humidity and/or THI (Brody, 1948; Ravagnolo et al., 2000). One cause as suggested by Seath and Miller (1946a) was the reduction of grazing time during the day that is only partially compensated in part by an increase during the night. The components of the milk are also affected by hot weather (Valtorta et al., 1997). Studies have confirmed that a reduction of the protein content of milk from dairy cattle occurs under heat stress. Moreover, hot weather peaks that occur during heat waves reduce milk production not only on the day of the peak, but also for several days afterwards (Harris et al., 1960; Valtorta et al., 1997)

Reproductive traits are readily influenced by many factors, both genetic and environmental. Environmental stressors can easily disrupt an animal from homeostasis, upsetting physiological functions such as reproduction. Reproduction is deleteriously influenced by hot weather due to reduction of estrus behavior and conception rates (Turner, 1982) and also by lower embryonic survival (Hansen, 1997; Hansen et al., 2001). In addition, hot weather during pregnancy lowers calf birth weight (Collier et al., 1982) and may also disrupt male fertility by diminishing semen motility and increasing the incidence of sperm abnormalities (Meyerhoeffler et al., 1985; Hansen and Arechiga, 1999). Timed insemination (de la Sota et al., 1998; Wolfenson et al., 2000, Cartmill et al., 2001), embryo transfer (Hansen et al., 2001) and in-vitro fertilization appear to be modern reproductive techniques that may help to overcome deleterious effects of heat stress on cattle fertility (Rutledge, 2001).

Cattle producers over a long period of time have tried many approaches to reduce the pernicious effects of hot weather on cattle. The provision of shelter, for example, reduces the impact of the forces of the environment. In particular, shade reduces the impact of high heat load from the atmosphere. The effects of shade on cattle thermoregulation have been intensively studied, especially in dairy cattle, and most reports agree that the build up of body temperature and respiration rate are lower when animals are in shaded areas as compared with animals in the sun (Gaalaas, 1945; Roman-Ponce, 1977; Roman-Ponce et al., 1978; Spain and Spiers, 1996). Providing shade altered the animals' microenvironment and improved milk yield and reproductive performance (Roman-Ponce, 1977). The coolest shade is provided by trees due to of the cooling effect

of the evapotranspiration from leaves, which, additionally, do not interfere with air circulation (Brody, 1948).

Heat Stress

Bos taurus cattle, especially dairy cattle, withstand long periods of exposure to cold temperatures, even arctic cold, without much difficulty; but they are not as able to deal with high heat loads (Regan and Richardson, 1938; Brody, 1948; Curtis, 1981). The depressing effect of hot weather on physical activity, hot weather “laziness”, in animals is homeostatically viewed as a biological mechanism to avoid overheating of the body (Brody, 1948) and occurs when the first reaction (higher respiration rate and sweating) fails (McDowell, 1972). In hot climates high ambient temperatures, high direct and indirect solar radiation, lack of air movement, and humidity are the main sources of environmental factors that impose strains on animals. Strain in animal production most commonly refers to adverse physiological effects that eventually result in a decline in production, such as weight loss or infertility (Finch, 1984). Physiologists adopted the stress-strain relationship from the physical sciences as a concept applicable to animals. Accordingly, strain refers to an internal displacement from the resting or basal state brought about by external stress (Finch, 1984; Silanikove, 2000). Probably the most important sources of stress are ambient temperature and solar radiation, and to a lesser extent, humidity (Seath and Miller, 1946b; Ragsdale et al., 1953; Williams et al., 1960).

Heat stress which induces hyperthermia in cattle is deleterious to any form of productivity and occurs regardless of breed and stage of adaptation (CSIRO, 1983; Finch, 1984). The general homeostatic responses to thermal stress in mammals include

augmentation of respiration rate (Yousef, 1982, 1985), panting, drooling, reduced heart rates, profuse sweating (Brody, 1956), and decreased feed intake (McDowell, 1972).

The thermoregulatory process also affects behavior of cattle. Domestic animals are mainly diurnal in their habits, being active during daylight hours and inactive at night. In tropical and semi-arid regions, however grazing cattle tend to reduce activity and seek shade in the daylight hours during hot weather. Instead, they graze in the late afternoon, at dawn and during the night (Gaalaas, 1945; Seath and Miller, 1946a; Silanikove, 2000). Seath and Miller (1946a) also reported that cows grazing during hot weather reduced their daytime grazing and tripled their grazing time at night. Similar findings were reported based on research conducted at STARS; tropically adapted cattle (Brahman, Senepol and Tuli) grazed more at midday while non-adapted *Bos taurus* cattle (Angus) were more active at night during hot summer weather (Hammond et al., 1998). Other behavioral responses include avoidance of the font of heat, e.g., seeking shade, looking for water, and wallowing in mud (Robertshaw, 1985). This range of behavioral responses affects the heat exchange between the animal and its environment by reducing heat gain from radiation and by increasing heat loss by convection and conduction (Hafez, 1968).

Stress from hot weather also causes a reduction in daily feed consumption which primarily occurs through a reduction in meal size, and sometimes even meal frequency (Nienaber et al., 1999). One of the reasons why these changes in nutritional activities may occur is the exchange of blood flow that occurs between the thermoregulatory and the non – thermoregulatory tissues. Under the pressure of heat stress, blood flow tends to be shunted toward superficial tissues and respiratory muscles, diverting blood away from the gut (Christopherson, 1985, Beede and Collier, 1986). The increase of blood flow to

the surface occurs very readily through vasodilatation of the arterioles near the skin (McDowell, 1972). Other studies have reported diminution of rumen motility and rumination when cattle are subjected to higher environmental temperatures, with opposite effects occurring under cold stress (Christopherson, 1985; West, 1999). Of course, the diminution of the blood flow to the gut and reduced rumen motility and rumination may be a cause-effect relationship.

In response to stress, mammals react with physical, biochemical, and physiological processes to try to counteract the negative effects of heat stress and to maintain thermal equilibrium. Most of the adjustments made by an animal involve dissipating heat to the environment and reducing the production of metabolic heat (Silanikove, 2000). The eminent environmental physiologist Samuel Brody (1948) stated this action-reaction as: “The chain reaction relating climate, successively, to the nervous system, to the endocrine system, to the enzyme system, to metabolic levels, to metabolic rates and, therefore, to the rates of all productive processes”.

Indicators of Heat Stress and Strain

Thermal stress is reflected assessable as changes in pulse rate, respiration rate, and rectal temperature. The whole body, including nerves, hormones, enzymes, metabolites and metabolic rates, responds to thermal stress by an elaborate series of chain reactions (Brody, 1948). However, Seath and Miller (1946b) found that pulse rate was not affected by ambient temperature, but agreed that ambient temperature did have deleterious effects on other physiological responses. Heat stress indicators may even measure the extent of a physiologic displacement from the normal equilibrium or ground state, appropriately called homeostasis (Curtis, 1981; Yousef, 1982, 1985). Physiological

measurements (heart rate, body temperature, respiration rate, etc.) can quantify the extent of the physiological displacement from the normal state; the greater the physiological response, the nearer the animal is to collapse (Yousef, 1985). From an economic standpoint, weight gains (beef cattle) and milk production (dairy cattle) probably are the best indicators of the effects of heat stress during the summer. Production measurements are not the only factors to consider during the summer, but are very important and may be related to others (e.g., physiological indices) (Cartwright, 1955).

Extensive collection of environmental indices and milk production in Georgia allowed Ravagnolo et al. (2000) to find a specific environmental threshold where excessive heat load is evident by lowered milk output. Temperature-humidity index (THI) values above 72 seem to be the threshold where the effects of heat stress begin to be evident in reduced milk production (Ravagnolo et al., 2000). Besides performance prediction, climatic records can also be used to quantify expected death or morbidity losses (Nienaber et al., 1999).

Body Temperature

The most obvious index of thermal strain is the response in body temperature (Brody, 1948). The temperature of a homeothermic animal's body is relatively uniform and constant, but various parts of the body do have different temperatures. Variations of temperature from site to site in the body are caused by a disparity in the insulation of each part (Curtis, 1981). Core or body temperature may be measured at several locations. The most frequently used site is the rectum which is perfectly adequate for steady – state conditions (Robertshaw, 1985), and RT is a very useful index of heat tolerance under field conditions (Hammond et al., 1998). Deviation from the normal rectal temperature

implies that the animal is under stress and that its homeothermic mechanisms are overtaxed (Brody, 1948).

Body temperature of homeothermic animals is maintained within a relatively narrow range (Das et al., 1999; Frisch, 2000) and slight fluctuations may upset the normal production processes. The efficiency of the body machine weakens rapidly even with slight increases in core temperature (Brody, 1948). A rise in body temperature of only 4.4°C above normal is often quickly fatal. This concept is even clearer when we acknowledge that 38.5°C is normal temperature (Campbell and Lasley, 1985) and that most mammals die at core temperature of 42°C - 45°C (Brody, 1948; Silanikove, 2000).

The temperature of the central nervous system, in particular the brain, appears to be the most closely regulated deep body temperature as the function of the brain is very susceptible to temperature change. Tympanic temperature has been used as an indication of core temperature because the origin of the blood supply to the tympanic membrane and to the brain is the same (Robertshaw, 1985). Also, a high degree of association between tympanic temperatures and the feeding activities of cattle in thermoneutral environments has been reported by Hahn (1999). The use of measurement of tympanic temperatures with the infrared thermometer, as is done in humans could be of value considering the similarity between tympanic temperature and core body temperatures (Robertshaw, 1985). Tympanic temperatures are also known to be associated with feeding activities in cattle (Hahn, 1999). An appropriate procedure to take tympanic measurement with the infrared thermometer might improve body temperature records in cattle.

Blood temperature at the aorta is probably the best single indicator of average body temperature because it corresponds to a mixture of the blood from all over the body

(Curtis, 1981) and responds much more rapidly to sudden changes of body temperature (Robertshaw, 1985). Rectal temperatures estimate average body temperature less accurately, especially when the temperature is changing. In addition, RT changes more slowly than does body temperature (Curtis, 1981). However, RT is an indicator of thermal balance and may be effective in quantifying the harshness of the thermal environment (Silanikove, 2000). The body temperature of homeotherms tends to be higher in the late afternoon and early evening than during the morning. In cows, body temperatures also vary with the stage of the estrous cycle (Curtis, 1981).

The rise in rectal temperature reflects or coincides with the cessation of increase in evaporative cooling and with rising environmental temperature. A decrease in the gradient between rectal and skin temperature causes a reduction of heat loss and rectal temperature increases (Worstell and Brody, 1953).

Skin Temperature (ST)

Mammals have the homeothermic ability of maintaining their body core temperature within narrow limits despite wide fluctuations in AT. The various parts of the body, however, have different temperatures. Tissues from organs in the core have higher temperatures than do skeletal muscles in the body shell (Curtis, 1981). The outermost surface of the skin, fur, or feathers, the shell of an animal, is the transducing surface across which the environment interacts with the internal physiology of the animal (Gebremedhin, 1985). The temperature of the shell fluctuates more than does that of the core, as it tends to reflect more closely changes in environmental temperature. Much of the change in heat content occurs in the body shell. Indeed, changes in heat content of the shell form an important part of body-temperature regulation; the shell is a thermal buffer

protecting the core from large changes of temperature (Curtis, 1981; Robertshaw, 1985). The heat flow from the body interior to the body surface tends to be proportional to the conductance of the peripheral tissues which are vasocontrolled by the blood flow (Worstell and Brody, 1953).

Cattle under heat stress lose part of the heat load through the respiratory tract. Another substantial portion is transferred to the skin where it is then dispelled by various mechanisms. A cow reaches thermal balance under hot conditions first by vasodilatation, primarily on the trunk (Ehrlemark and Sallvik, 1996), and then by increasing evaporative heat loss from the skin surface through sweating. The dissipation of heat through the skin depends on the amount of heat conducted by the blood from the body core to the hide and the variance of temperature between these points. As the skin temperature approaches core temperature, the flow of heat to the environment decreases and heat amasses, elevating body temperature (Finch 1986). The relationship between environmental temperature and skin temperature in cattle is closer with the skin of the limbs than the skin of thorax, where variation in blood flow to the skin seems to be minimal. The skin on the limbs seems to be much more active in heat dissipation as compared with that of the hide of the trunk (Robertshaw, 1985).

Respiration Rate (RR)

Respiration is a form of convective heat transfer. The inhaled air closely corresponds to the body temperature by the time it reaches the trachea due to the heat and moisture exchange (Yousef, 1985). The greater the volume of air inhaled, warmed, and moisturized, the greater the resultant heat lost (McDowell, 1972). Respiration rate (RR) is a useful indicator of an animal's thermal load (Gaughan et al., 2000); moreover, in

panting animals which include cattle, it is an excellent index and the first visible sign of thermal stress (Brody, 1948; McDowell 1972). The transference of heat through respiration is an important pathway of heat transfer for most mammals over a wide range of environmental conditions (Eigenberg et al., 2000).

Homeothermia under higher heat loads is easier to maintain when the respiration rate increases or panting begins, although they are not as effective as sweating for evaporative cooling (Robertshaw, 1985; Hahn et al., 1997; Silanikove, 2000). A high respiration rate may be a useful means of increasing heat loss for short periods of time, but if the high rates continue for several hours, may cause serious problems for the animal. Continued panting may affect the efficiency of rumination and feeding and may lead to a reduction in the CO₂ combining capacity of the blood plasma because of hyperventilation. Hyperventilation normally is the origin of respiratory alkalosis which occurs when the CO₂ in the alveoli fails to reach the normal rate of diffusion (McDowell, 1972).

Measuring respiration rate appears to be the most accessible and easiest approach for evaluating the degree of heat stress in farm animals (low: 40 – 60 breaths per min, medium high: 60 – 80, high: 80 – 120, and severe stress: above 150 breaths per minute in cattle). All it requires is direct observation of the animal and a watch (Silanikove, 2000). As RR reaches 160 breaths per minute or higher, emergency actions should be activated to reduce heat loads (e. g., providing shade and/or wetting the animals) (Hahn et al., 1997). Another type of breathing often observed in cattle under heat stress is open-mouth breathing, where drooling is present. This water loss mechanism of dealing with heat stress is very inefficient and is a cause of important mineral loss. “Open-mouth” breathers

often show the poorest tolerance of heat, and normally, breeders in the tropics use this sign as a culling factor in selection for adaptation. Usually, a low respiratory rate under hot weather identifies animals with lesser discomfort. This fact is evident when comparing respiration rates of *Bos taurus* versus *B. indicus* under hot summer weather conditions where *Bos indicus* (Zebu) cattle maintain lower respiration rates (McDowell, 1972; Gaughan et al., 1999).

Respiration rate can be a valuable physiological parameter in conjunction with additional information such as ambient temperature, humidity, radiation heat loads, and air velocity (Eigenberg et al., 2000; Silanikove, 2000). Highlighting the importance of RR, Brody (1948) commented that RR in *B. taurus* cattle is probably the most sensitive simple index of thermal stress, especially in conjunction with rectal temperature. Moreover RR reacts faster than RT (Seath and Miller, 1946b) and may be useful when a rapid assessment of the heat load condition of cattle is needed.

Physiological responses of cattle have been studied intensively and RR has been shown to behave predictably, increasing with rising ambient temperature. However, the RR response is non linear. As ambient temperature increases beyond a threshold, RR increases more rapidly; this threshold occurs near heat stress conditions for cattle (Hahn et al., 1997). A slight reduction in the respiration frequency during the days with highest environmental strains could be related to a shift in RR dynamics from rapid panting to a deep phase, open mouth panting which is slower (Gaughan et al., 2000).

The major stressor affecting respiration rate is ambient temperature, which has much more influence on RR than does humidity (Seath and Miller, 1946). Some researchers have described specific relationships between ambient temperature and

respiration rate indicating that increasing AT resulted in an approximate doubling of RR in adult lactating dairy cows for each 10°C rise in AT over the range from 4.4°C to 37.8°C (Regan and Richardson, 1938). Gaalaas (1945) suggested a quadratic relationship between RR and AT for mature lactating cows, as did Spain and Spiers (1996) for young dairy calves. The response of respiration rate to AT in lactating cows over a series of AT increasing from 10°C to 41°C in constant temperature environments was reported to be sigmoidal by Kibler and Brody (1950), and Worstell and Brody (1953). The sigmoidal function was a consequence of repeated changes in respiratory activity, from normal breathing at ground state, cool temperatures, to fast shallow breathing at moderately higher heat loads to a slower deep-phase of open mouth panting in hot conditions. The RR to AT relationship may help to define the threshold temperatures from which action to minimize the effect of higher heat loads will be needed (Hahn et al., 1997).

Many researchers have attempted to identify the stress thresholds where homeothermal mechanisms are triggered and when heat balance is disrupted. Responses to high environmental temperatures that are reported in the literature include: intensification of the respiration rate and anorexia between 26.7°C and 29.9°C (Regan and Richardson, 1938), to increase respiration rate at 21.3°C of AT and to decline in feed intake at 25.0°C (Hahn, 1999), to decrease milk production at 24.0°C or 72 THI (Ravagnolo et al., 2000; Ravagnolo and Misztal, 2000), and to die at body temperature of 42.7°C (Brody, 1948).

The development of biological response functions and their dynamic analyses will help to better understand the cause of the problem and recognize animals with problems.

Moreover, they may lead to the establishment of standards for proactive environmental management of cattle during hot weather (Hahn, 1999).

Environmental Indices

The main environmental stressors that cause strain in animals are air temperature, solar radiation and humidity (Curtis, 1981; Finch, 1984) and they should be quantified to correlate them with the physiological responses. In the Northern hemisphere, the most severe heat stress is expected during the months of July – August, because in many instances the temperature does not drop below 21 °C at night, and the capacity to completely dissipate heat gained during the preceding day is severely hampered (Silanikove, 2000).

Indices of environmental measurements that have been developed to characterize their effects on animal physiology range from simple measurements of air temperature and humidity to weighted indices (Finch, 1984) like temperature humidity index and milk production (Ravagnolo et al., 2000; Ravagnolo and Misztal, 2000). Other important and commonly used parameters are the black globe thermometer (BGT), which accounts not only for air temperature, but also wind and radiation (Finch, 1984) and the wet bulb thermometer which, through comparison with the dry bulb thermometer and using the psychometric chart, allows determination of the humidity of the air (Curtis, 1981; Finch, 1984).

Coat

The coat is composed of hair. Hair covers the animal's shell and insulates the animal from environmental variations. The insulation of this cover is associated with air captured amongst the hairs which retards heat flow from the skin to the outer edge of the

cover (Curtis, 1981). Heat transfer processes across animal coats are complex and difficult to quantify but they decisively influence the thermal balance (Finch, 1984). The rate of evaporation from the coat surface is inversely proportional to the length of the hair; in hotter climates a fast convection-evaporation rate is desired, therefore, a shorter hair should be preferable (McDowell, 1972).

Perhaps the environmental stressor most important for cattle not confined to buildings is solar radiation (Shrode et al., 1960; Williams et al., 1960; Curtis, 1981; Finch, 1984). This was readily apparent when researchers found that 32°C outdoors was equivalent to 50°C in a temperature-controlled chamber based on their impact on the physiological processes of animals maintained under these conditions (Finch, 1984). Solar radiation reaching a surface is reflected, transmitted, or absorbed by that surface. Dense hair coats reflect more incident solar radiation than do sparse ones (Curtis, 1981). Finch (1986) also mentioned that a dense flat coat, when exposed to solar radiation, provides greater resistance to heat transfer to the skin. This is because a smooth surface reflects at or near the surface; dense flat coats with a well-defined surface resist heat flow to the skin through their entire depth (Finch, 1984).

Medullated¹ hairs result in a smooth, glossy coat, whereas non-medullated hairs give a dull, woolly coat (Curtis, 1981). Woolly coats accept radiation between the hairs; therefore, the absorption is within the coat and the resistance to environmental heat is impaired (Finch, 1984). Summer coats tend to have a greater proportion of medullated hairs. Degree of medullation is a less important determinant of solar-radiant exchange than is coat color, but glossy coats do have higher solar albedos² (Curtis, 1981). Coat

¹ Medulla: Inner portion of the hair.

² Albedo: reflective power; specifically: the fraction of incident radiation that is reflected by a body.

depth also seems to be very important, as Turnpenny et al. (2000) reported that the increase from 3 to 10 mm diminished the sensible heat loss (heat loss by convection and conduction) by 17%.

Researching *B. taurus*, *B. indicus* and Sanga cattle, Peters et al. (1982) found that correlations among coat type and growth rate were low at most of the ages analyzed, except as yearlings where the values were relatively higher. The higher correlation between wooly, long hair and poor performance (CSIRO, 1983) as yearlings validates the empirical knowledge of farmers from tropical areas who use the hair length at weaning as an indicator of future grazing performance (T. Olson, personal communication).

The total number of hair follicle in an animal's skin is relatively constant from birth to adulthood, but since skin area increases with growth, hair follicle density generally declines with age (Curtis, 1981). Since it has been found that cattle have a sweat gland at a base of each hair follicle, the density of follicles per area will have a relationship with the potential effectiveness of heat loss by sweating (McDowell, 1972, Curtis, 1981). Tropical breeds have a higher density of hair follicles than is the case of non-adapted *B. taurus* breeds (Silanikove, 2000), as can be seen in table 1.

TABLE 1. Hair follicle density, length, and diameter reported for several types of cattle and buffalo.

Breed	Approximate no./cm ²	Follicle		Source
		Diameter (μ)	Length (mm)	
Buffalo (Egypt)	394	-	-	McDowell, 1972.
Zebu (India)	1400 to 2600	54.2	3.6	McDowell, 1972.
Jersey (U. S.)	600 to 1100	56.1	5.1	McDowell, 1972.
Holstein (U. S.)	550 to 1095	55.7	4.9	McDowell, 1972.
Brahman (U.S.)	2390	-	-	Steelman et al. 1997
Chianina (U.S.)	1587	-	-	Steelman et al. 1997
Sanmartinero (Colombia)	6.000 to 7.000	-	5.0	Martinez Correal, 2000.

Zebu breeds have about twice the density of hair follicles compared with breeds from temperate areas (McDowell, 1972).

Frisch (1981) mentioned that cattle selected for growth rate under stressful tropical conditions had sleeker coats; such cattle are known to have more efficient sweating and cooling mechanisms (Turner, 1964). The hair coat may vary from region to region, among breeds, and with age, season, health, and nutritional status of the animal (Curtis, 1981).

Campbell and Lasley (1985), mentioned that a coat with a smooth, glossy texture is best to minimize the adverse effects of solar radiation. The consensus is that a short, sleek or glossy hair coat over a pigmented skin that is kept soft and flexible is most appropriate for warm climates. Native cattle from tropical areas normally exhibit this type of hair and skin, whereas temperate zones stocks do not (McDowell, 1972).

Moreover, hot weather acclimated cattle are known to reduce the insulation of the hair coat by coat shedding (Robertshaw, 1985). The shedding occurs largely in response of variation in daylength and to temperature changes to a lesser extent (Curtis, 1981); it is an adaptive mechanism to promote heat loss (McDowell, 1972, Robertshaw, 1985). The adaptation to heat stress of cattle could be modified by clipping woolly hair from non-adapted cattle;¹ this practice considerably improves the heat resistance of animals, although not to the extent of that of genotypes with sleek coats (Finch, 1984; Hammond et al., 1996)

Resistance of the animal coat to environmental heat-flow is of great importance to the control of body temperature. Therefore, it is not surprising that coat type is correlated with body temperature and with productivity of cattle in the tropics; sleek, dense and

¹ Clipping *B. taurus* cattle for exhibition is a common practice in the tropics.

short coats being associated with lower body temperatures and higher growth rates (Turner and Schleger, 1960; Curtis, 1981; Peters et al., 1982; Finch, 1984). If the coat is short, white and shiny, it will reflect away perhaps 30 to 50% of the radiant energy. If the coat is woolly and black, on the other hand it may reflect only 10% of the incoming energy (Finch, 1984; Allen, 1997). The conclusion is that those animals with woollier coats required more shade, grazed less and gained less weight (CSIRO, 1983).

Peters et al. (1982) noticed that hair coat color of cows did not affect either their own body weight or the weaning weight of their offspring in a research trial conducted in South Africa, but, that the hair coat type did have highly significant effects on cow body weight. Conclusions from other researchers including McDowell (1972) and Yousef (1985) corroborate the importance of hair type, however, Finch, (1984) believed that hair coat color did have an influence on overall heat resistance of livestock. Hansen (1990) found that hair coat color predominance (black or white) influenced milk production and physiological responses of Holstein cows under hot weather in Florida.

Contrary to most reports Peters et al. (1982) declared that coat type was not so much the cause of weight performance but rather was its result. The researchers based these conclusions on:

- a) The measurements of growth of young animals, at different ages (12, 15 and 18 months), which showed low correlations between weight gain within age period and coat type at the beginning and end of each period. However, closer correlations were found between weight gain and coat type at the end of the period.

- b) Young stock with a higher proportion of *Bos taurus* genes showed considerable variation in coat type. Some calves remain hairy from weaning to yearling, while others decrease the quantity of hair, however, none of the changes in HT affected growth.

Peters et al. (1982) agreed on the important role that the coat type could play in avoiding ectoparasitic infestations, which is important in many tropical regions of the world. Observations made in the field show that Zebu and Criollo (shorter haired) cattle, suffer less tick infestation than European *Bos taurus* cattle (longer haired) (Bonsma, 1981).

Hair density is quantified as the number of hairs per unit of skin surface area. Some authors have classified a hair coat with more than 1,000 hairs per cm² as dense; if fewer than that, as sparse (Curtis, 1981). Criollo breeds of cattle from Latin America and Zebu breeds have denser coats than Holstein cattle (see table 1). The density of the hair coat has been demonstrated to be an important factor in resistance to the attack of ectoparasites. Studies conducted in Arkansas found that an increase of hairs per cm² and the corresponding increase in the amount of sebum present on cattle skin and hair help to reduce horn fly infestation in steers from different breeds under feedlot conditions. (Steelman et al., 1997).

Hair weight is the weight of hair clipped from a unit of skin surface area. The fibers of hair themselves can be classified as to length, diameter, medullation, and presence of air cells (Curtis, 1981). The short hair and abundance of sweat glands are also commonly seen in many breeds adapted to a tropical environment, breeds from both *B. taurus* and *B. indicus* origin.

Several researchers have mentioned that short and glossy hair is a common characteristic of Criollo breeds of cattle from the tropical Americas. Some such breeds are the Barroso from Guatemala (Melgar et al., 1984); the Romosinuano, the Blancorejinegro, and the Sanmartinero from Colombia (Martinez Correal, 1992, 1998; Martinez Correal and Gonzales Henao, 2000), the Yacumeño in Bolivia (Wilkins, 1985) and the Tropical Dairy Criollo from Costa Rica described by De Alba as cited by Wilkins (1985)

Genetics of Adaptation

There are two options to decrease the effects of heat stress on cattle: one is to modify the environment, which is expensive and not permanent and the other is to selectively bred cattle that are most adapted and productive (Finch, 1984). Genetic adaptation is defined by Yousef (1985) as a genetically fixed condition of a species or subspecies, or its evolution, which favors survival in a particular total environment. The success of this endeavor has been a goal of farmers and scientists alike for a long time. Selection for resistance to thermal stress involves the use of physiological and production measurements; use of such quantitative measures may allow us to better understand the inheritance of the fitness (Brody, 1948). Examples of quantitative traits that may be related to adaptation to heat stress include rectal temperature, respiration rate, feed intake, weight gain, reproduction (McDowell, 1972), and other traits.

Turner (1982) researched the genetics of cattle in the tropics and found heritabilities of rectal temperature between .25 and .33 and genetic correlations of rectal

temperature to female fertility and growth of $-.76$, and $-.86$, respectively. Burrow (2001) found a lower heritability for rectal temperature ($.17$) with a repeatability of $.27$. Finch et al. (1986) confirmed the existence of genetic control over body temperature and mentioned that selection within breeds for thermoregulatory characteristics would be a sound strategy for increasing productivity in the tropics. This idea is obvious when we consider that within a cattle population individuals have different levels of response or degree of adaptability to the environmental forces, such differences are likely related to the genetic diversity within the population that could be exploited through selection.

It is possible to select for specific traits related to heat stress but the potential advantages of such an approach are diminished by the reduced selection pressure for traits of economic importance such as milk production. Perhaps it would be better to select for production in the hot climate itself (Hansen, 1997). The same belief was shared by Brody (1948) and Cartwright (1955), and was used by Frisch (1981) in Australia in the selection of beef cattle. Also in Australia, Burrows (2001) found that most of the traits connected with environmental resistance in the tropics are correlated with growth rates; therefore, when beef cattle are selected for production under tropical conditions, resistance to the prevailing environmental forces should improve. Cartwright (1955) found a heritability of $.19$ for summer weight gain and considered it a useful selection tool for cattle that would resist hot weather. However, estimation of genetic parameters for growth and resistance to heat and other stresses in tropical cattle is not easy as it is complicated by various environmental interactions. Studying the genetics of tropical cattle in Australia, Burrows (2001) stated that in the tropics, growth is controlled not only of genes for direct growth, but also by genes for resistance to environmental stressors,

and even that males and females may have different genes controlling growth and traits affecting insect resistance.

Frisch (1981) selected Hereford x Shorthorn cattle mainly for growth rate under conditions of moderate to high environmental stress beginning in 1966 as compared to an unselected line. Ten years later, the lines (selected *vs.* control) were compared and the selected line was shown to be more heat tolerant, to have lower nutritional requirements and greater resistance to infections and endo parasites and hence, better growth under the presence of these stressors. However, the selected line did not express improved growth rate at low levels of stress. Finally, Frisch (1981) concluded that selection under stress appears not to increase growth rate *per se*, rather, the improvement of growth rate was achieved through increases in resistance to environmental strains that affected growth rate. This concept seems to be applicable for dairy cattle as well (Hansen, 1997; Pinheiro et al., 1998). In recent studies under tropical conditions in Brazil, Pinheiro et al. (1998) found genetic correlations of 0.56 between hair length and milk production in Holstein cattle. Upon consideration at these results, they concluded that selection for milk production under their environmental conditions results shortened hair length which was also expected to improve performance in subsequent generations.

Antagonisms exist between some components of adaptation and production potential. Al-Katanani et al. (1999) showed that when the milk yield increases the reproductive problems during the summer are magnified. It may be impossible to create an animal which has both high production potential coupled with a high level of adaptation (Frisch and Vercoe; 1979). This concern was shared by Ravagnolo et al. (2000) and Ravagnolo and Misztal (2000) who believe that Holstein cattle which have

been selected intensively for improved milk production in temperate areas are now more susceptible to heat. They intend to validate the idea using extensive production and atmospheric data from producers and state weather stations, respectively. This could be one of the reasons why the difference between adapted and non-adapted animals disappears when the environmental conditions are not stressful enough and, in fact, the growth or production advantage could reverse in favor of non-adapted animals under such conditions (Frisch, 1981).

Zebu cattle are undoubtedly more heat tolerant than non-adapted *B taurus*; part of this advantage is because *B. indicus* breeds have lower metabolic rates and energy levels which are closely related with reduced productivity levels (Worstell and Brody, 1953; McDowell et al., 1955; Gaughan et al., 1999). However, in many tropical regions around the world, the most common system to improve production of beef cattle is crossbreeding. Crossbred cattle (*Bos taurus* X Zebu breeds or *Bos taurus* X Sanga breeds) respond to heat stress similarly to the adapted parental breed (Seath and Miller, 1946b; Hammond et al., 1996, 1997, 1998; Gaughan et al., 1999) but with levels of production that are intermediate between both progenitors (Cartwright, 1955). The difference is rather constant through the stages of life (Seath and Miller, 1946b). Crossbreeding is a useful tool, particularly since heat tolerance is dominant (Hammond et al., 1998).

Cattle indigenous to tropical areas have shorter hair compared to those that originated in temperate regions (McDowell, 1972), such as cattle of the European *Bos taurus* breeds. Also, all indigenous breeds of livestock in tropical areas have pigmented skin that avoids sunburn caused by solar radiation. There is abundant proof that longer

hair cattle in the tropical areas can result in lower milk production (Lucena and Olson, 2000; Pinheiro et al., 1998), lower weight gains, and higher levels of tick infestation (Bonsma, 1981; Frisch, 1981). The *Bos taurus* breeds of Criollo cattle of Latin America, found in tropical areas probably have the shortest hair coat of any cattle. McDowell (1972) believed that only $\frac{1}{8}$ to $\frac{1}{4}$ of Zebu or Criollo genes are needed to insure a short coat.

Evidence for a Major Gene Controlling Hair Length

A completely new approach to developing cattle adapted to heat stress was suggested by findings reported by Olson et al. (1997a, b). They report that a major gene appears to be present in the Senepol breed and in some Criollo breeds, which causes expression an extremely short hair type called the slick hair coat (Olson et al., 1997a). This gene seems to be responsible, at least in part, for the greater heat tolerance of animals with this trait. The increased tolerance to higher heat loads of cattle with this hair type was evident in cattle with better growth rates (Olson et al., 1997a, b) and higher milk production compared to cattle of the same breed composition but with normal hair (Lucena and Olson, 2000). Weight gain from July to December of twenty-eight $\frac{1}{4}$ Senepol: $\frac{1}{4}$ Hereford: $\frac{1}{2}$ Angus calves, normal-haired and slick-haired was evaluated by Olson et al. (1997a). They found the slick-haired animals heavier ($P < 0.02$) by 13 kg than the contemporaneous normal-haired ones at the end of the trial.

A somewhat analogous situation apparently exists with the so-called “rat-tail” syndrome. This is a syndrome controlled by interacting genes at two loci and whose effects are observed in crossing of Continental breeds with cattle that are black in color (Schalles and Cundiff, 1999). In Simmental crosses with black breeds, calves with both

the black (E^d) and rat-tail gene that are also spotted have normal hair in the white areas and limited quantity of abnormal hair in the dark areas. Contrary to the slick hair gene, the rat-tail gene does not have an effect on red hair (Olson, personal communication).

Hair coat types of progeny of Senepol x Angus and Senepol x Hereford F_1 dams breed were examined to analyze the segregation of the short hair trait. The short sleek hair coat and the normal *Bos taurus* hair type appeared to be segregating into two definite categories, perhaps without intermediate categories as would be expected if the trait were inherited quantitatively (Olson et al., 1997a, b). In the literature, Martinez Correal (1992) reported similar hair segregation with low frequency of hairy animals in the progeny of Blancoorejinegro cattle, a Criollo breed from Colombia. The greatest importance of these findings is that short hair and heat tolerance seems to be controlled by a single, dominant gene. A trait expressed as a single gene may allow the incorporation the characteristic easily through upgrading into highly productive, non-adapted breeds (Olson et al., 1997a, b).

CHAPTER 3 MATERIALS AND METHODS

Data for this study were collected from thirty Senepol X Holstein crossbred heifers and bulls which were used to measure variation in rectal temperature (RT), respiration rate (RR) and live weight (LW). The breed composition of the cattle included nine Senepol X Holstein F₁ and 21 $\frac{3}{4}$ Holstein: $\frac{1}{4}$ Senepol animals. The $\frac{3}{4}$ Holstein: $\frac{1}{4}$ Senepol were produced from two Senepol X Holstein F₁ cows via embryo transfer and were the progeny of two purebred Holstein bulls.

The data collection of the first experiment took place from August 1999 to June 2000 at the Subtropical Agricultural Research Station (STARS; 28° 37' N, 82 ° 22' W) located near Brooksville, Florida. The topography at STARS is gently rolling hills with the highest elevation being 84 meters. Average annual rainfall is 1370 mm, over half of which occurs in June, July, August and September. The average temperature is 22.2°C with several frosts occurring from November through March (Hammond et al. 1996).

The second experiment was conducted at the Beef Research Unit (BRU; 82° 17' W, 29° 45' N) of the University of Florida which is located 12 miles NE of Gainesville, Florida. The unit is situated in a flatwoods area where the primary forage is bahiagrass (*Paspalum notatum*) with forested areas interspersed within the pastures. The average annual rainfall and average year-round temperature are similar to those described above for STARS.

In the first experiment, rectal temperatures (RT) were measured at 1:30 PM once a month beginning August 1999 and ending June 2000 (11 measurement dates). Rectal

temperature measurements were made with a microprocessor thermometer (Omega model HH21) using a 21 mm probe. Respiration Rate (RR) data were collected at the same time. Breaths per minute (BPM) calculations were made from the measurements of movements of the flanks in a given period of time as recorded with a chronometer, and were standardized to a minute. The relative humidity (RH) of the air was calculated using a sling psychrometer (Ertco®). Dry bulb temperature (AT) was registered with a dry bulb thermometer in an area adjacent to that where the records were taken. A temperature-humidity index (THI) was used to characterize the heat load (Armstrong, 1993). The THI was calculated as follows: $THI = .8AT + RH \times [(AT - 14.3) + 46.3]$, where RH is expressed in decimal form (NOAA, 1976). This index is a common indicator of heat stress used in several weather stations throughout the United States (Table A-1). Black globe thermometers were placed in sunny and shaded areas to register the black globe temperature (BGT). This measurement is important because it not only accounts for environmental temperature, but also for radiation and air movement. It is a good integration of ambient temperature, solar radiation and wind. The THI equation could also be use to calculate the Black Globe Humidity Index (BGHI), substituting the AT by the BGT in the formula (Gaughan et al., 1999).

At STARS the cattle grazed throughout the year on improved pastures, which were primarily bahiagrass (*Paspalum notatum*). Supplemental feeding is normally practiced during the winter period, and because of an extremely dry spring in 2000, supplementation lasted through May.

At the BRU, the cattle used in the trial 2 were a sample of the $\frac{3}{4}$ Holstein: $\frac{1}{4}$ Senepol described in page 33. They were sorted by sex into groups and placed in feedlot

pens with individual feeders. The pens had a shaded portion over the feeders. However, this shaded area was not large enough to have all the animals sheltered at the same time. The corral where the animals were penned was surrounded and shaded by vegetation, and the chute where the measurements were taken was roofed. Each individual feeder was equipped with a Calan® gate (American Calan, Inc., Northwood, NH). Each Calan® gate could be opened only by a single animal as determined by a transmitter suspended from its neck. This allowed the consumption of each animal to be quantified. Individual consumption was calculated from the difference between the weight of the feed offered and the refused portion. The composition of the feed is described in Table A-2. The cattle were fed early in the morning to avoid any extra heat load caused by the feed to the animals at the time of data collection in the afternoon.

The hair coat was evaluated visually and classified into two types (HT) as “slick” (SH), short and shiny, typical of that of the Senepol breed, and as normal (NH), similar to that of Holsteins. The classifications for hair used in the research varied from other similar studies where the investigators used several grades to classify the hair (Olson et al., 1997). The HT was also measured objectively from the weight of samples clipped from each animal. The hair was clipped from an area of 57 cm² on the right loin, 12 cm below the spine. The hair sample was taken with an electric clipper (Stewart Shearmaster®, model 510A head). Separate weight hair samples for each color were collected from the black and white areas of spotted cattle. The same location was used to measure skin temperature in the second experiment. The infrared thermometer used was from Cole Palmer Int®. Model 39650-02 and the measurements were taken directly from

the shaved area to record the skin temperature without hair interference. The shaving of these areas was repeated at least once a week.

The second experiment was conducted during the summer of 2000, beginning July 14, and ending August 27th, 2000. The cattle had a one-week adaptation period before data were collected. The data collection occurred between 2:00 PM and 3:00 PM, Tuesday through Saturday. All environmental conditions were recorded in the same fashion as in the first experiment. The black globe temperatures from sunny areas were classified in four classes, Black Globe Temperature Class (BGTC) 1, less than 40.0°C; BGTC 2, between 40.0°C and 44.9°C; BGTC 3, between 45.0°C and 50.0°C; and BGTC 4, more than 50.0°C. Each class was formed to have similar numbers of observations. This time frame was chosen for the study as summer weather conditions were expected to provide the heat stress necessary to fulfill the objectives of the experiment.

All data were analyzed using the General Linear Models (GLM) procedure of the Statistic Analysis System (SAS). Sex effects were not significant ($P < 0.01$) in the initial analyses; therefore, sex was not included in the final model. The RT data from the first experiment were analyzed with hair type as the only independent effect, and data from each month were evaluated as a separate dataset. The RT, ST and BPM analyses of the second experiment were accomplished using a Repeated Measurements model (Littell et al., 1998) from the GLM of SAS. Least squares means are reported for each variable. The final model of these data included the fixed effects of hair (H), BGTC and the interaction between H and BGTC.

Furthermore, correlations among different climatic and physiological measurements were calculated using the procedure CORR of SAS (1996). Pearson

correlation coefficients and their probabilities were obtained for data from NH and SH animals, respectively.

CHAPTER 4 RESULTS AND DISCUSSION

Experiment 1 STARS

Environmental Conditions

Weather conditions were recorded while the physiological information was being obtained and the highest ambient temperature during the trial at STARS was 35.5 °C in June 2000. The same day THI reached 103 and the relative humidity was 44%. The lowest ambient temperature was 21°C at the end of February of the same year; the temperature-humidity index (73) that day was also the lowest measured during the study. Detailed meteorological information from the STARS is shown in Table A-3.

Physiological Response

The rectal temperatures for slick-haired animals were lower than those of normal-haired animals on several measurements from August through November (e.g. September: NH= 39.7, SH= 39.4°C; $P < 0.05$ and October: NH= 39.8, SH= 39.3°C; $P < 0.05$), while the difference was not significant from November (NH= 39.9; SH= 39.7°C; $P=0.31$) through June in the yearlong experiment at STARS (Table 2). The final statistical model included only the hair effect.

Correlations

Environmental conditions, including THI, did not affect the physiological responses of cattle during the STARS trial. This fact was evident when we calculated the

TABLE 2. Least squares means of rectal temperature (°C) influenced by hair type. STARS experiment.					
Date	AT (°C)	Hair type	LS means	SEM	P
9/30/99	31.1	S ¹	39.3	0.118	P < 0.05
		N ²	39.7	0.096	
10/14/99	29.0	S	39.8	0.119	P < 0.05
		N	40.1	0.088	
10/21/99	29.0	S	39.3	0.151	P < 0.05
		N	39.8	0.111	
11/18/99	23.5	S	39.4	0.105	P < 0.05
		N	39.7	0.077	
12/14/99	25.0	S	39.7	0.171	P= 0.38
		N	39.9	0.134	
2/4/00	21.5	S	39.5	0.109	P= 0.30
		N	39.6	0.085	
2/25/00	21.0	S	39.5	0.106	P= 0.65
		N	39.4	0.083	
3/24/00	29.0	S	39.0	0.082	P= 0.12
		N	39.2	0.064	
4/28/00	27.5	S	39.3	0.146	P= 0.41
		N	39.4	0.103	
6/2/00	35.5	S	39.1	0.103	P= 0.10
		N	39.4	0.070	
6/30/00	24.7	S	39.3	0.060	P= 0.36
		N	39.4	0.470	

¹ S = Slick-haired.

² N = Normal-haired.

correlation between THI and RT. The correlations between THI and RT for NH and SH animals were -0.100, $P=0.77$; and -0.350, $P=0.30$, respectively.

Experiment 2 BRU

Environmental Conditions

Environmental conditions throughout the experiment at the BRU were harsh, considering that the average ambient temperature at the time of the measurements was 32.7°C and the average THI was 99.7. The highest dry bulb temperature, 36°C, the highest THI, 107, and the highest BGT in an unshaded area, 56.5°C all occurred, on August 9th, 2000 (Table A-4).

Physiological Responses

In spite of the similar genetic makeup (half-sibs and closer relationships) of the SH and NH animals, the environmental forces imposed by the weather at BRU were sufficient to produce differences in their physiological responses. Slick-haired cattle had lower ($P<0.05$) rectal temperatures, 38.9 vs. 39.3°C ($P<0.05$), skin temperatures, 37.5 vs. 38.0°C ($P<0.05$), and respiration rates, 56.6 vs. 69.0 BPM ($P<0.05$), than the NH cattle (Table 3). ANOVA results for RT, ST, feed intake and RR are detailed in tables A-5, A-6, A-7 and A-8, respectively.

The RR of SH animals were medium high, and medium high to high in NH animals (Silanikove, 2000). The differences in RR between SH and NH animals were similar (about 11 BPM) at each level of BGTC, as is shown in Table 4. The RR of the animals during the trial appeared to be more affected by variations in BGT than changes in THI. Both NH and SH elevated ($P<0.01$) respiration rate as BGTC increased from 1 to 4; (NH, 64.0 to 77.1; SH, 53.4 to 64.9), but the rise of the RR of NH animals appeared to be more pronounced than that of SH animals.

TABLE 3. Least square means of the physiological traits influenced by hair type - BRU experiment.					
Trait	N	Hair type	LS means	SEM	P
Rectal temperature (°C)	16	Slick	38.9	0.03	P < 0.05
		Normal	39.3	0.03	
Skin temperature (°C)	16	Slick	37.5	0.07	P < 0.05
		Normal	38.0	0.07	
Intake (g of feed/g of live wt/day)	16	Slick	27.0	0.47	P= 0.789
		Normal	26.7	0.47	
Respiration rate (BPM)	15	Slick	56	0.81	P < 0.05
		Normal	69	0.86	

BGTC	Rectal temperature (°C)		Skin temperature (°C)		Respiration rate (BPM)	
	Normal-haired	Slick-haired	Normal-haired	Slick-haired	Normal-haired	Slick-haired
1	39.35	39.09	37.55	36.98	64.39	53.72
2	39.29	39.04	37.83	37.50	65.53	51.89
3	39.28	38.80	38.63	37.82	72.66	58.20
4	39.38	39.02	38.12	37.82	73.47	62.62

Other authors have reported that lactating cows begin to suffer from heat stress at THI 72, but such threshold was not evident in our analyses. The RR increased inconsistently in both NH and SH animals as THI varied from 91 to 107. Perhaps the lack of a clear threshold value is due to the fact that the THI was substantially higher than 72 each day of the experiment. Alternatively this lack of a clear threshold may have been caused by the use of non-lactating animals in our study.

Open-mouth panting was not observed at the time (2:30 PM) of the measurements, in spite of the fact that animals had high respiration rates and ambient temperatures were very high at the BRU on certain days. Respiration rates of animals from each hair type were compared from the days with the highest (107) and the lowest (91) THI, although even 91 is considered stressful. The respiration rate of NH animals only tended to respond to increasing THI ($P < 0.10$) as their highest RR (78) occurred on the day the THI reached 107 and correspondingly their lowest RR (60.5) occurred on the day when the THI reached 91. The slick-haired animals, on the other hand, increased ($P < 0.05$) their respiration rate from a low 47 at THI= 91 to 61 (essentially the same as the RR of the NH animals at THI= 91) when the THI was its highest at 107. Similar results were observed at various levels of BGTC (Table 4). Respiration rate of SH varied from 52 at BGTC 2 to 64.9 at BGTC 4; while RR of NH increased in a similar fashion from 65.5 at BGTC 2 to 77.14 at BGTC 4 ($P < 0.01$). Figure 2 illustrates the relationship between respiration rate and black globe temperature.

Skin temperature measured at the BRU trial also revealed differences between SH and NH animals. Skin temperature of SH was lower ($P < 0.05$) than NH animals, 37.5 vs. 38.0°C, a difference of 0.5°C between the means of cattle of each HT (Table 3).

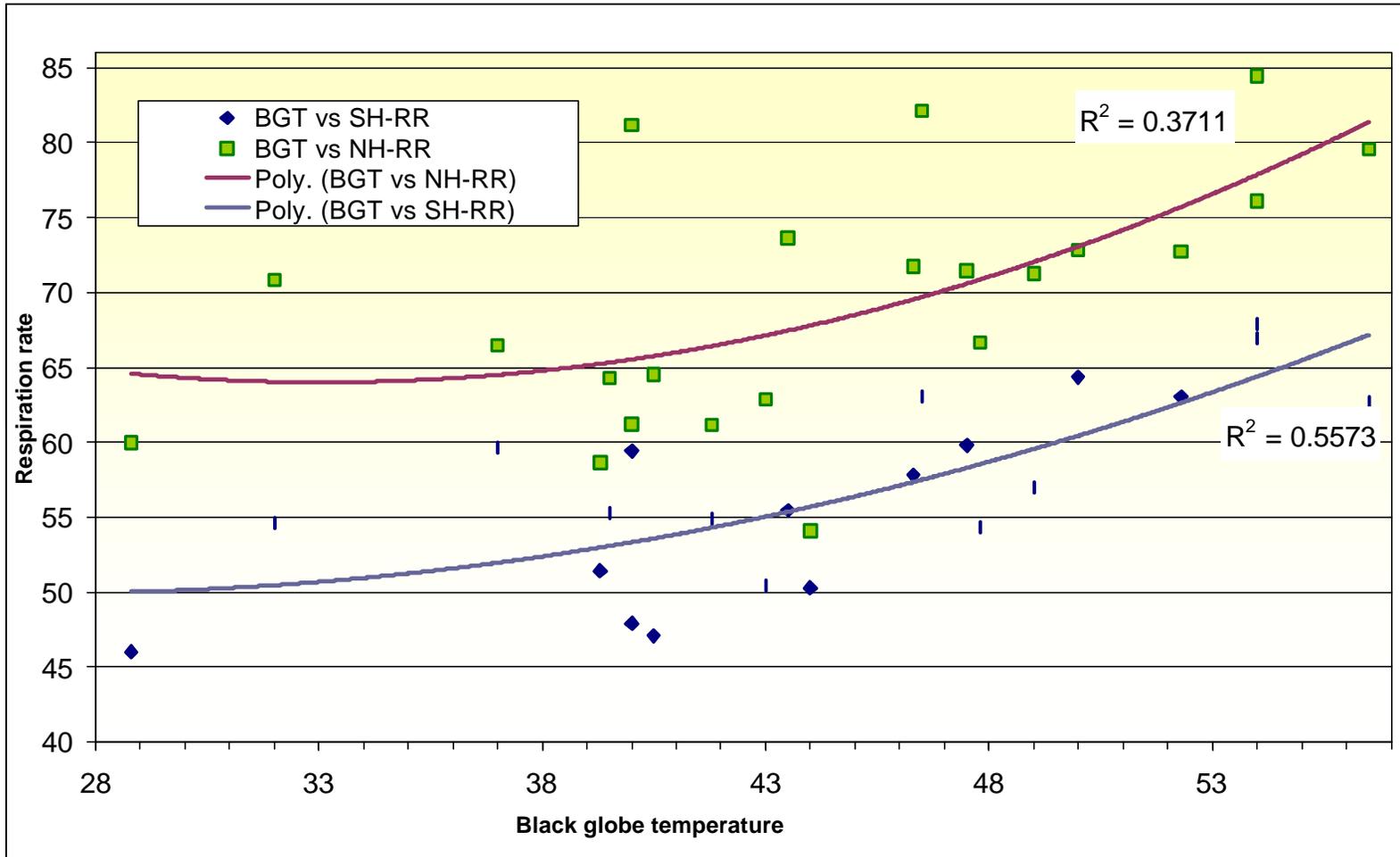


Figure 2. Variation of respiration rate at different black globe temperature

The skin temperature within each hair type varied more than 1°C from BGTC 1 to 4 ($P < 0.01$). The values of skin temperature of SH and NH animals when BGTC was the lowest were, 36.9°C and 37.4°C, respectively; while at the hottest BGTC were; 38.0°C and 38.5°C, respectively (Table 4). Thus, the difference between the skin temperature of SH and NH cattle did not vary across black globe temperature classes.

Slick and normal-haired animals were identified visually and the difference in hair weight per skin area was quantified. Slick-haired had less ($P < 0.05$), 11.47 vs. 17.82 mg/cm², hair weight per skin area than NH animals (Table 5). We also measured the weight of hair clipped from both black and white areas of the spotted animals, as it appeared visually that the white areas possessed longer hair. The hair weight per skin area of black hair was indeed lower ($P < 0.05$), 11.02 vs. 18.28, than that of white one. This difference between black and white hairs was very similar to the one reported between hair weights of SH and NH animals (Table 5). Hair weight per skin area by color of each animal in the BRU experiment is detailed in Table A-9. From the individual data is observable that only one animal had more white hair than black hair weight per skin area.

One of the objectives of the experiment was to determine if there was any difference between the feed intake of SH and NH animals while under heat stress. Feed intake has critical effects on productivity. The intakes of SH and NH animals were not different ($P = 0.78$; SH = 27.0, NH = 26.7 g of feed/kg live wt/day). Our results might have been different, however, if the cattle had been fed *ad libitum* throughout the experiment.

TABLE 5. Least square means of hair weight per area influenced by hair type and color - BRU experiment.					
Trait	N	Hair	LS means	SEM	P
Hair type	5	Slick	11.47	0.0162	P < 0.05
	8	Normal	17.82	0.0149	
Hair color	13	Black	11.02	0.0150	P < 0.05
		White	18.28	0.0150	

From 16 animals in the experiment, 3 were not measured because the absence of white and/or black hair spots.

Correlations

Some of the correlations of physiological data with THI were similar to those from the STARS data. The correlation between THI and RT, however, was low and negative in the SH (-0.071; $P=0.75$) but low and positive in NH animals (0.135; $P=0.55$). However, the relationship between THI and RR at the BRU was high for both SH (0.534; $P<0.05$) and NH animals (0.617; $P<0.01$) (Table 6).

Correlations between BGT taken in unshaded areas adjacent to the pens and RR in both SH (0.722, $P<0.001$) and NH (0.562, $P<0.01$) animals were very high. The relationship was curvilinear (Fig. 2). Respiration rate was rather stable at black globe temperatures less than 40, but rose in an increasing manner as BGT surpass 40. Rates increases were similar although respiration rate for normal hair animals were much higher. The results were similar for the effect of black globe temperature on skin temperature. Skin temperatures had a significant correlation with BGT (0.692, $P<0.001$) in SH animals and also in NH animals (0.640, $P<0.01$). Surprisingly, the correlation between BGT and RT was negative (-0.226; $P=0.31$) in SH animals and positive in NH animals (0.105; $P=0.64$), and both were not significant (Table 6).

Discussion

The low negative correlations between weather and physiological data at STARS may be due to the fact that the physiological data were measured only once per month, without consideration of previous days' conditions. Since climatic variations, such as heat wave peaks, can affect animals for several days (Harris et al., 1960; Valtorta et al., 1999), perhaps this is responsible for the low unexpectedly negative correlation between temperature-humidity index and rectal temperature in the STARS data. The temperature-

TABLE 6. Pearson correlation coefficient and probability levels among environmental and physiological measurements in SH and NH cattle - BRU experiment. (N=16)								
Variable	BGT	THI	Normal Hair			Slick Hair		
			RR	ST	RT	RR	ST	RT
BGT	1	0.464	0.562	0.640	0.105	0.722	0.692	-0.226
		P<0.05	P<0.01	P<0.01	P=0.64	P<0.001	P<0.001	P<0.31
THI	-	1	0.617	0.298	0.135	0.534	0.407	-0.071
	-		P<0.01	P=0.18	P=0.55	P<0.05	P<0.10	P=0.75
Normal Hair	RR	-	1	0.690	0.399	0.821	0.498	-0.123
		-		P<0.001	P<0.10	P<0.001	P<0.05	P=0.59
	ST	-	-	1	0.338	0.622	0.779	-0.125
		-	-		P=0.12	P<0.01	P<0.001	P=0.58
	RT	-	-	-	1	0.312	0.211	0.629
		-	-	-		P=0.16	P=0.35	P<0.01
Slick Hair	RR	-	-	-	-	1	0.589	-0.086
		-	-	-	-		P<0.01	P=0.70
	ST	-	-	-	-	-	1	0.037
		-	-	-	-	-		P=0.87
	RT	-	-	-	-	-	-	1
		-	-	-	-	-	-	

humidity index is used as an indicator of stress in humans and livestock. Its efficacy as a stress value under our conditions, however, is arguable considering that the black globe temperatures appeared to be more closely associated with physiological responses of animals under direct sun than were the THI value. The most evident weakness of the THI classification is its use of only a few indicators to calculate the index; in this study we used only dry bulb temperature and relative humidity. Dry bulb temperature and RH do not measure the known stressful effects of solar radiation, which has a great effect on animals under sunlight. Gaughan et al (1999) used a combination of both, the black globe temperature humidity index (BGTHI), but its utility still needs to be determined.

The dissimilar reaction of slick and normal-haired animals during the different seasons of the year at STARS was not particularly surprising, as the advantage of shorter hair should manifest itself during hot weather. Frisch (1981) reported that under a lack of heat stress there was no advantage in productivity of animals with greater heat tolerance.

The fact that NH animals were able to maintain RT similar to those of SH animals during cool weather suggests that their productivity should not be different in these conditions. The pastures utilized at STARS all included shade and this may have allowed the animals to avoid excessive heat load. In addition the chute where the measurements were taken was roofed and the corral where the cattle were penned prior to the measurement included shaded areas which should have helped to alleviate any extreme environmental stress.

Cattle which are less affected by higher heat loads and thus able to maintain lower respiration rates are more efficient and require less metabolic energy (McDowell, 1972). Since SH animals were able to maintain lower RT while at the same time

breathing more slowly across BGT levels (Figure 2), they appear to have a more efficient mechanism for maintaining homeostasis. Furthermore, it is of interest that the RR of SH animals at the highest black globe temperature class (64.9) is very similar to that of the NH animals at the lowest BGTC (64.0) (Figure 3). Nienaber et al (1999) reported that respiration rate has certain maximum levels, and after that open-mouth panting begins. Our data suggest SH animals will be able to withstand substantially higher levels of thermal stress before they begin open-mouth panting.

Slick-haired animals had rectal temperatures that was 0.4°C lower than that of normal-haired cattle, which may not seem to be substantial. However, body temperature in cattle can vary only from 38.5°C (normal) to 42.7°C (when death occurs) (Brody, 1948), a range of only of 4.2°C. Thus, the advantage of the slick-haired animals accounts for almost 10% of this possible variation. In addition small variations in RT have been reported to be able to upset complex productive and reproductive processes (Brody, 1948). Differences between diurnal tympanic temperatures of acclimated and non-acclimated cattle have been reported to be between 0.1 and 0.4°C (Hahn, 1999). Therefore, the magnitude of the advantage in RT under high thermal load of the slick-haired animals over their normal-haired half and full sib contemporaries is substantial and may be responsible for important variations of productivity under heat stress.

It was quite apparent from the physiological data that rectal temperature, in contrast with respiration rate and skin temperature, did not respond to increased black globe temperature. Rectal temperature may have responded differently because it is slower to react to changes in thermal load (Curtis, 1981) or because, by increasing RR,

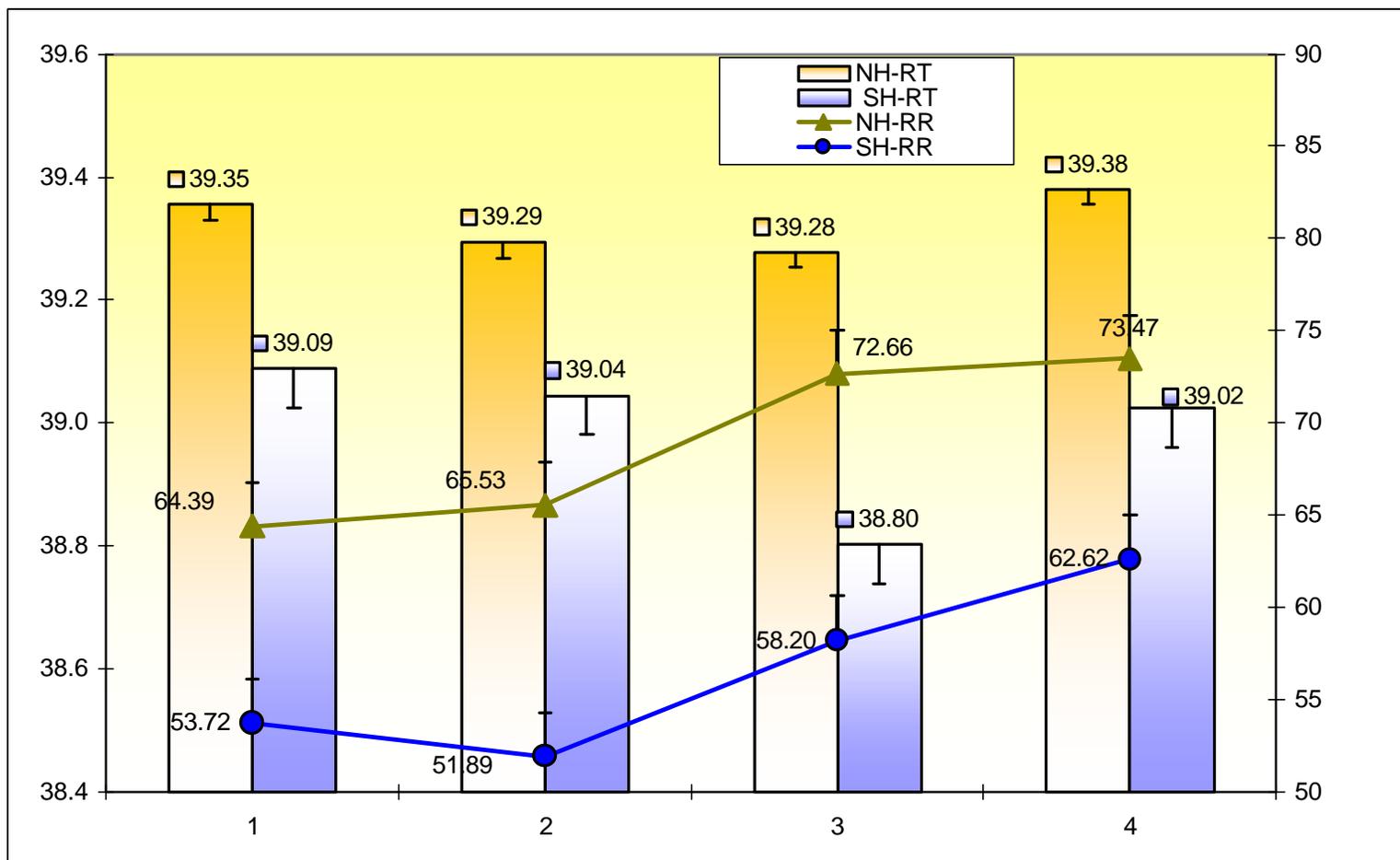


Figure 3. Rectal temperature and respiration rate means of both SH and NH animals at different BGTC.

the animals in this study were able to dissipate the rise in body temperature associated with the increased black globe temperature.

The differences in RT between SH and NH animals did not differ among BGT classes. Both SH and NH animals maintained similar RT across the BGTC and the advantage of the lower RT of SH over NH animals was consistent, as shown in figure 3. The skin temperature was clearly influenced by the changes of black globe temperature classes; of course this response is logical when we understand that black globe thermometer as well as the skin of the animals are affected by solar radiation. The skin is the part of the external layer of the animals in contact with the environmental stressors, and solar radiation is one of the most important external stressors.

Infrared thermometers have rarely been used in animal research but are widely used for ear temperature measurement in human medicine (Stavem et al., 1997). Skin temperatures, as well, are scarcely reported in the literature (Hansen, 1990; Goodwin, 1998), however, we think they were useful for identification of differences between SH and NH animals. Skin temperature might have a substantial impact on several processes that affect energy flow between the environment and cattle. The flow of heat from an animal's core to its surroundings (i.e. from the core to the skin and then to the environment) is facilitated when the gradient of temperature between the different points (core, skin and environment) is greater (Worstell and Brody, 1953). Slick-haired animals were able to maintain a lower ST which increased the difference with the internal (RT) temperature. Thermodynamics equilibrium law (Zeroth law) tells us that temperature naturally flows from hotter to cooler areas, in this case from the hotter internal parts to the cooler skin. On the other hand, higher skin temperatures could indicate that the

superficial tissues are receiving more blood flow. Increment of the blood flow to peripheral, thermoregulatory tissue during heat stress is normally accomplished by diverting blood flow from the gut (Christopherson, 1985; Beede and Collier, 1986) and this diversion may be related to a slow-down in rumen motility and decreased feed intake.

Variation in feed intake caused by heat stress normally occurs when homeostasis is disrupted (Hahn, 1999). At higher levels of stress, the difference in feed intake between heat tolerant (SH) and non-tolerant animals (NH) might have been greater. Comparison of the feed intake of normal and slick-haired adult cows during lactation or intense production process would likely be useful. Cows that are lactating may produce twice as much heat as non-lactating cows of the same size (Worstell and Brody, 1953).

Slick-haired animals also appeared to have a shinier and glossier coat compared with their normal-haired sibling and half-siblings from the BRU trial.

The black and white spots also had different skin colors at their base, as the white spots had pink skin and black spots had mostly black skin underneath, as do purebred Holsteins. Additional questions are raised because of this difference: Does the gene controlling spotting also influence hair length or is another gene involved? Is a completely black-pigmented coat superior for some traits to a spotted coat, especially one for tropical cattle with large areas of black?

External temperature receptors are located in the external layers (shell) of the body, and this layer buffers thermal exchange with the surroundings. Robertshaw, (1985) mentioned that the skin of various parts of the body varies in its heat exchange ability, for example the skin of the limbs is more effective in heat exchange than the skin of the

trunk. Future studies of ST measurements of different areas of the body may enhance our understanding of the relative utility of this measurement as compared to RT as an indicator of heat stress.

Hair density and hair medullation are also topics of potential future research based on previously cited data. Increase of hair density seems to be related to better resistance to horn fly attacks (Steelman et al., 1997), and medullated hair appears to be associated with smooth, glossy coats in cattle (Curtis, 1981). Perhaps, the presence of medullated hairs could be useful as an early indicator of sleek, smooth hair, and non-medullated hairs of wooly coats. Native breeds of cattle from harsh environments normally have smooth, short, shiny hair that often facilitates the noteworthy attribute of a relatively high tolerance to parasites (internal and external). Changes in consumer preferences toward higher environmental standards call for “organic” (i.e. residue free) products might create appropriate conditions to open niche markets where beef from cattle with these characteristics could be sold at a premium.

Implications

Research focused on the creation of accurate heat stress indices will help to generate more proactive responses to avoid excessive thermal stress effects on livestock productivity. Skin temperature measurements and the infrared thermometer are tools that have been available for several years but not yet utilized in cattle research, but which have potential for use in environmental physiology research. Tympanic temperature can be measured with an infrared thermometer to obtain one of the closest temperatures to the core temperature.

Investigation to clarify the importance of different hair coat characteristics could facilitate the understanding of more efficient mechanisms of heat dissipation present in some adapted breeds. Ecto-parasites are a serious constraint in most of the tropical and subtropical areas where livestock are bred; the slick hair trait may also be a positive attribute to enhance resistance to insect infestation. Investigation of hair and sweat gland density of slick-haired animals could also aid in recognizing a broader spectrum of characteristics conferred to cattle by the SH trait. The hair density difference found between black and white hairs in cattle with Holstein type spotting requires more study to clarify its origins and potential influences in heat stress management.

The different response to environmental conditions that were found between half and full sibs with normal and slick-hair suggest potential benefits of slick-haired cattle in hotter regions. Thermal stress resistance could be readily improved through the incorporation of slick hair gene into un-adapted breeds. The opportunity for improved productivity through use of the slick hair gene is greatest in cattle under severe heat load from the weather and production environment, such as in dual-purpose cattle and high producing milking cattle from tropical and subtropical regions.

The slick hair trait is characteristic of many criollo breeds of Latin America. Most of the native breeds of cattle of the world are endangered or threatened by genetic pollution and many have never been properly characterized. The finding of a particular beneficial trait such as the slick hair gene in these cattle is a reminder of potential losses we may suffer if these breeds are lost.

APPENDIX

TABLE A-1. Temperature Humidity Index (THI) for Dairy cows.*

DEG	RELATIVE HUMIDITY																				
F	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
75														72	72	73	73	74	74	75	75
80							72	72	73	73	74	74	75	75	76	76	77	78	78	79	80
85			72	72	73	74	75	75	76	77	78	78	79	80	81	81	82	83	84	84	85
90	72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88	89	90
95	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
100	77	78	79	80	82	83	84	85	86	87	88	90	91	92	93	94	95	97	98	99	
105	79	80	82	83	84	86	87	88	89	91	92	93	95	96	97						
110	81	83	84	86	87	89	90	91	93	95	96	97									
115	84	85	87	88	90	91	93	95	96	97											
120	86	88	89	91	93	94	96	98													
No stress				Mild Stress				Medium Stress				Severe Stress				Death					
THI= (Dry-Bulb Temp. °C) + (0.36 dew point Temp.,°C) + 41.2)																					

* Modified from Dr. Frank Wiersma (1990), Department of Agricultural Engineering, University of Arizona.

TABLE A-2. Composition and ingredients of the feed* - BRU experiment.	
Feedstuff	Percentage (%)
Soybean hulls	23.92
Ground Corn	13.96
Citrus pulp	11.96
Cottonseed hulls	24.92
Soybean meal	3.99
Soybean meal	3.99
Alfalfa hay	19.94
Mineral mix	0.92
Trace Mineral Supplement	0.40
Total	100.0

*The formulation of the diet made by Dr. Charles Staples.

TABLE A-3. Ambient conditions - STARS experiment.					
Date	Ambient temp., °C	Black Globe temperature		Relative humidity, %	THI
		Shade, °C	No shade, °C		
9/30/99	31.1	33.5	42.7	68	99
10/14/99	29.0	32.0	35.5	65	89
10/21/99	23.5	23.0	22.0	89	73
11/18/99	25.0	27.5	35.5	59	79
12/14/99	21.5	21.5	27.7	66	75
2/4/00	19.0	20.0	33.0	51	78
2/25/00	21.0	27.0	39.7	73	73
3/24/00	29.0	30.5	47.5	56	87
4/28/00	27.5	28.0	35.5	53	83
6/2/00	35.5	36.5	45.5	44	103
6/30/00	24.7	24.5	25.5	95	76
Avg.	26.1	27.6	35.5	65.4	83.2

TABLE A-4. Ambient conditions - BRU experiment.					
Date	Ambient temp., °C	Black Globe temperature		Relative humidity, %	Temp.–humidity index
		Shade, °C	No shade, °C		
7/25/00	35.6	38.9	48.9	42	97
7/26/00	32.0	33.5	44.0	57.0	100
7/27/00	32.5	34.0	43.0	59.0	96
7/28/00	32.5	32.5	40.0	51.0	102
7/29/00	33.0	33.8	41.8	58.5	99
8/1/00	30.8	32.5	40.5	70.0	96
8/2/00	31.0	32.0	39.5	63.0	99
8/3/00	29.8	28.5	37.0	80.0	105
8/8/00	35.0	37.0	54.0	49.0	106
8/9/00	36.0	37.0	54.0	45.5	103
8/10/00	33.5	35.5	50.0	57.0	100
8/11/00	32.8	34.8	46.3	56.5	93
8/12/00	29.8	30.5	39.3	68.0	99
8/14/00	33.3	34.5	47.5	50.5	94
8/15/00	33.0	37.0	52.3	44.0	94
8/16/00	32.5	33.3	47.8	47.5	106
8/17/00	34.8	36.5	49.0	52.5	106
8/18/00	35.3	38.0	56.5	49.5	107
8/19/00	33.8	34.8	43.5	60.5	102
8/20/00	30.5	31.3	32	78.5	99
8/21/00	32.3	33.5	-	59.0	90
8/22/00	28.0	27.0	28.8	82.5	104
8/24/00	34.3	34.5	40.0	53.0	99
8/25/00	33.5	35.0	46.5	50.0	97
AVG	32.7	34.0	44.4	57.7	99.7

TABLE A-5. ANOVA of RT between slick and normal hair with the source of variation hair type – BRU experiment.				
Source	Df	MS	P	Error term
Model	21	1.975	$P < 0.001$	Residual
Hair	1	10.401	$P < 0.05$	ID (Hair)
ID (Hair)	14	2.058	$P < 0.001$	Residual
ETC	3	0.562	$P < 0.05$	Residual
Hair*ETC	3	0.242	$P = 0.224$	Residual
Residual	354	0.165		

TABLE A-6. ANOVA of ST between SH and NH with the source of variation hair type – BRU experiment.				
Source	Df	MS	P	Error term
Model	21	5.679	P < 0.001	Residual
Hair	1	22.862	P < 0.05	ID (Hair)
ID (Hair)	14	3.764	P < 0.001	Residual
ETC	3	13.589	P < 0.001	Residual
Hair*ETC	3	1.221	P= 0.286	Residual
Residual	354	0.965		

TABLE A-7. ANOVA of feed intake between SH and NH with the source of variation hair type – BRU experiment.				
Source	DF	MS	P	Error term
Model	21	0.000212	P < 0.001	Residual
Hair	1	0.00001	P= 0.623	ID (Hair)
ID (Hair)	14	0.00013	P < 0.001	Residual
ETC	3	0.00083	P < 0.001	Residual
Hair*ETC	3	0.00001	P= 0.769	Residual
Residual	354	0.00004		

TABLE A-8. ANOVA of RR between SH and NH with the source of variation hair type – BRU experiment.				
Source	DF	MS	P	Error term
Model	20	2645.79	P < 0.001	Residual
Hair	1	13311.33	P < 0.05	ID (Hair)
ID (Hair)	13	2555.77	P < 0.001	Residual
ETC	3	1948.59	P < 0.001	Residual
Hair*ETC	3	78.31	P= 0.583	Residual
Residual	332	120.42		

TABLE A-9. Hair weight and hair weight per cm ² from black and white spots - BRU experiment.				
Identification	Hair color	Net weight (mg)	Weight per area (mg/cm ²)	Hair type
954	Black	597.8	10.49	S
	White	1330.4	23.34	
993	Black	132	2.316	S
	White	741.2	13.00	
957	Black	158.2	2.78	S
	White	508.6	8.92	
995	Black	205.4	3.60	S
	White	537.2	9.42	
968	Black	472.2	8.28	S
	White	1144.7	20.08	
956	Black	300.4	5.27	S
	White	955.7	16.77	
952	Red	1176.2	20.64	N
	White	1438.6	25.24	
950	Black	1175.1	20.62	N
	White	1649.2	28.93	
975	Black	513.4	9.01	N
	White	1070.6	18.78	
969	Black	607.1	10.65	N
	White	1112.9	19.52	
955	Black	1679.1	29.46	N
	White	660	11.58	
949	Black	845.7	14.84	N
	White	1292.1	22.67	
965	Black	548.3	9.62	N
	White	1217.3	21.36	

S = Slick; N = normal.

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BIOGRAPHICAL SKETCH

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