PRODUCTION AND PHYSIOLOGICAL RESPONSES OF LACTATING HOLSTEIN DAIRY COWS TO THE PROVISION OF SHADE IN SUB-TROPICAL ZIMBABWE

by

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Abstract

The objective of this study was to establish production and physiological benefits of shade provision to lactating Holstein cows under hot summer conditions in Zimbabwe. Different shading materials providing shade at different levels were used so that a recommendation could be made as to the effectiveness of the shading materials in providing a comfortable thermoneutral micro-environment during periods of heat stress.

Three experiments were conducted at the University of Zimbabwe Farm, Harare, Zimbabwe. The Holstein dairy breed which is the main dairy breed making the University of Zimbabwe Farm dairy herd was used in Experiments 1 and 2 whose main objectives were centered on evaluating production and physiological responses of lactating cows to different levels of shading during periods of intense solar radiation and high ambient temperatures. Three levels of shading were provided: 100%, 80% and 30% shade. Experiment 3 involved a comparison of radiation balances under the three shading materials which were used in Experiment 2 which were; Hessian 30% shade cloth, Hessian 80% shade cloth and corrugated iron sheets.

Cows under corrugated iron sheets (100% shade) had significantly ($P < 0.05$) lower skin surface temperature, respiration rate, rectal temperature and water intake compared to those under Hessian 30% shade cloth (Experiment 1). Milk yields increased significantly ($P < 0.05$) in cows under 100% shade compared to those under 30% shade. Skin surface temperature of cows under Hessian 80% shade cloth were not significantly ($P > 0.01$) different from skin surface temperatures of cows under corrugated iron sheets (Experiment 2). In Experiment 3, corrugated iron sheets completely cut off direct solar radiation but emitted the highest amount of thermal radiation.

These results indicate that shade provision to lactating cows during the summer is of great benefit. In addition, corrugated iron sheets provide 100% shade but they release a significant amount of thermal radiation and considering this substantial amount of direct long wave radiation the Hessian 80% shade cloth can be used as an effective alternative shading material.

Dedication

To Mrs. T. Gwatibaya, Mrs. M. Mlambo and the late Mr. W. T. Gwatibaya.

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List of Abbreviations

λE	latent heat flux density (Wm^{-2})
ΔQ_S	net energy storage; rate per unit volume (per unit horizontal area) (J; Wm^{-3} (Wm^{-2}))
ANOVA	analysis of variance
C	flux of heat per unit area by convection in air
CL	chlorine
CP	crude protein
FSH	follicle stimulating hormone
G	flux of heat by conduction, per unit area
GnRH	gonadotrophin releasing hormone
HSI	heat stress index
K	potassium
LCT	lower critical temperature
L_d	downward long wave radiation (Wm^{-2})
LH	lutenising hormone
L_u	long wave radiation emitted by the ground (Wm^{-2})
M	rate of heat production by metabolism per unit area of body surface
ME	metabolisable energy
N.R.C	National Research Council
Na	sodium
Q^*	net all-wave radiation flux density (Wm^{-2})
Q_E	turbulent latent heat flux density (Wm^{-2})
Q_G	sub-surface heat flux density (Wm^{-2})
Q_H	turbulent sensible heat flux density (Wm^{-2})
Q_M	metabolic heat production by animals (Wm^{-2})
RH	relative humidity (%)
R_n	net radiation flux density (Wm^{-2})
RR	respiration rate (breaths/minute)
RT	rectal temperature (^oC)
S	sulphure
S_d	downward solar radiation (Wm^{-2})
SST	skin surface temperature (^oC)
S_u	solar radiation reflected by the ground (Wm^{-2})
T_d	dry bulb temperature (^oC)
T_{dew}	dew point temperature (^oC)
THI	temperature-humidity index
T_w	wet bulb temperature (^oC)
UCT	upper critical temperature
UZ	University of Zimbabwe
VFA	volatile fatty acids
W.M.O	World Meteorological Organisation

CHAPTER 1

INTRODUCTION

1.1 The problem

When European breeds of farm animals are introduced to tropical and sub-tropical countries they face many problems relating to the hot climate, particularly conditions of heat stress (Piggins and Phillips, 1992). A vast array of physiological and biochemical changes are induced in such animals. Cattle milk production is significantly impaired in hot climates (Charlotte and Madsen, 1998). In tropical and sub-tropical regions, cattle coming from temperate climates fail to adapt and become unproductive (McDowell, 1972) and dairy cattle breeds have been the worst affected by this scenario. The failure to adapt has been attributed to the harsh conditions associated with the tropical and sub-tropical climates, especially those in Africa which are characterized by intense solar radiation, high ambient temperatures and high relative humidity. Zimbabwe is one of the countries which are in the hot climatic regions of the world.

According to Svotwa (2001), an understanding of an animal's climatic environment is an essential part of livestock management. It is the nature of the climatic environment that determines productivity of domestic animals in terms of milk yield, egg production and growth rate. Hot weather can strongly affect animal bioenergetics, with adverse effects on the performance and well being of livestock (Hahn, 1999). Such understanding of the climatic environment is necessary in designing animal housing and feeding programmes both of which counteract the effects of an adverse climatic environment. Livestock managers therefore need information about how and why their animals respond to environmental challenges to make decisions on strategies and tactics to reduce losses during hot weather (Hahn, 1999). According to the World Meteorological Organization (WMO) (1989), cattle that are exposed to adverse environmental conditions have reduced feed conversion efficiency to meat and milk.

The dairy animal is a milk-producing factory which converts nutrients derived from a variety of dietary constituents into a complex, marketable and highly nutritious product. There are a number of elements in the environment which must be overcome by *Bos taurus* breeds of dairy cattle if they are to reproduce and be efficient and highly productive in tropical and sub-tropical regions. Major environmental constraints to high productivity in the tropics and sub-tropics are ambient temperature, intense solar radiation and humidity, annual and seasonal availability of feed resources, internal and external parasites and a variety of bacterial and viral infections (Vercoe, 1990). The effect of climate, parasites and diseases on production can be minimized either through the use of resistant genotypes or through managerial interventions to the animals' environment. In most cases a combination of these two basic strategies is used. Of these constraints, the most difficult to combat are those associated with high ambient temperature and humidity encountered in most tropical areas.

According to Johnson (1980), the introduction of Holstein dairy cattle into tropical and sub-tropical countries results in moderate to severe limitations in milk yield due largely to the effect of temperature and humidity and related nutritional factors. Bray *et al.* (1994) noted that the primary sources of heat gain from the environment which results in heat stress which is of major concern in dairy cows in tropical and sub-tropical regions are solar radiation and elevated ambient temperatures. These are significantly complicated by high relative humidity, a lack of air movement and poor night cooling. Of these two factors, solar radiation is the major factor that contributes to heat stress and it increases heat gain by both direct and indirect means. Studies in lactating dairy cattle have shown reductions in milk production of 10 to 25% due to heat stress (Atkeson and Bickert, 1997).

With management concerns for cow comfort and the effects of heat stress in the holding pens and feed-lots, the use of shade cloth can be an economic benefit for cow comfort and milk response (Atkeson and Bickert, 1997). Blocking the effects of the sun with properly constructed shade structures alone increased milk production by 10 to 19% in studies conducted in Florida. Shade covering over the feedlot area and the holding pen area is an economical method of altering the effects of summer environmental conditions which is of major importance to dairy farming in Zimbabwe.

1.2 Justification

The seasonal effects of heat stress have tremendous impact on dairying in tropical and sub-tropical climates. *Bos taurus* dairy cattle breeds introduced in the warm tropics are highly susceptible to heat stress mainly due to the intense solar radiation and elevated ambient temperatures that are characteristic of the climate in these regions. Adjustments in nutrition and feeding management can alleviate some of the negative effect of heat stress on performance, but compared with environmental modification, manipulation of the cow's diet specifically for heat stress, has little effect on productivity. The primary sources of heat gain from the environment are solar radiation and elevated ambient air temperature (Shearer *et al.*, 2002). Primary methods for altering the environment include the provision of shade, evaporative cooling with water in the form of fog, mist or sprinkling with natural or forced air movement, and possibly cooling ponds. The incorporation of these methods into an integrated environmental management system which protects cows from the primary sources of heat gain from the environment and takes advantage of opportunities to enhance evaporative heat loss have the best potential for successful abatement of heat stress. Shade provision is probably the best heat stress abatement programme in tropical and sub-tropical regions where solar radiation is the main meteorological factor that significantly contributes to heat stress especially during the hot summer season.

Simple shade is the basic method of protecting animals from direct solar radiation during the day (Kurihara *et al.*, 2003). Research data are limited as to the benefit of shade, but in one Arizona study, shade over the feed bunk improved milk production by 7.5% as compared to a control situation with no shade (Epperson, 2002). Some research has been carried out on nutritional, disease and management effects on dairy production in Zimbabwe but very little research has been carried out to evaluate in detail the effects of selected meteorological parameters on dairy cattle productivity. Svotwa (2001), observed that ambient temperature affected the grazing behaviour of free range grazed cattle in Tanda communal lands. No further research has been carried out in Zimbabwe to establish the effects of extreme meteorological factors on cattle production traits like milk production and live weight gain and hence establish methods which can be instituted to maintain productivity during warm weather. There is need to investigate the effect of intense solar radiation, high ambient temperature and high relative humidity on feed intake and milk production particularly under feedlot conditions and explore the benefits of providing shade under such conditions. An evaluation of the production and physiological responses of lactating cows to both heat stress and shading is important in the context of establishing criteria for proactive environmental management for cattle during hot weather. There is need to evaluate and quantify the benefits of heat stress abatement programmes like the provision of shade particularly to lactating *Bos taurus* dairy breeds exposed to intense solar radiation and high ambient temperatures in the tropics and sub-tropics and also come up with materials that can be recommended as suitable for providing shade.

1.3 Objectives

The main objective of the study was to see how the provision of shade to lactating dairy cows affects their thermal bioenergetics and milk yields. The specific objectives were to:

- measure skin surface temperatures, rectal temperatures, respiration rates and water intake for dairy cows kept under different shading materials.
- monitor the feeding behaviour of dairy cows under different shading materials and measure the total daily milk yield/cow.
- determine radiation balances under different shading materials.

CHAPTER 2

LITERATURE REVIEW

DAIRY CATTLE PRODUCTION AND THE MICRO-METEOROLOGICAL ENVIRONMENT

2.1 Introduction

Dairy production is a biologically efficient system that converts large quantities of roughage, the most abundant feed in the tropics, to milk, the most nutritious food known by man (Leeuw *et al.,* 2001).The dairy animal is a milk producing factory which converts nutrients, derived from a variety of dietary constituents, into a complex, marketable and highly nutritious product (Vercoe, 1990). Milk yields are a product of animal genetic and environmental interactions. Milk yield for a specific genotype, especially in tropical environments or ecosystems, is a function of climate and its interactive influences on the quantity and quality of feed, the presence of disease and parasites and the utilization of technology to alleviate nutritional, thermal and health limitations (Johnson, 1990). Zones of the world between the Tropics of Cancer and Capricon include the majority of the cattle and buffalo of the world and the climate in these regions is especially limiting to milk yields, growth and reproduction when both the temperature and humidity are high.

According to Johnson (1990), the introduction of Holsteins into tropical and sub-tropical countries results in moderate to severe limitations in milk yield due largely to temperature-humidity interactions and related nutritional factors. Adaptable but low yielding indigenous cattle like the Tuli and Mashona breeds in Zimbabwe have been used as sources of meat, milk and fibre in the tropical and sub-tropical zones. Hot environments affect the performance of dairy cattle both directly and indirectly (Kurihara *et al.*, 2003). To attain full genetic performance, environmental conditions and diets should be modified. Thermal factors mainly consist of air temperature, humidity, air movement and radiation rate. A decline in milk yield, fertility and growth rate in hot environments is closely related to an increase in body temperature often measured as rectal temperature. Body temperature results from the balance between heat production and heat loss. Since humidity affects heat loss from an animal under high temperature conditions, dairy cattle performance falls markedly in hot, humid conditions (Kurihara *et al.*, 2003). Moreover, heat production is associated with feed intake level, which in turn affects the production level. In high producing cows like Holsteins, the heat production is high and the effect of a hot environment is significantly pronounced.

Dairy cattle, like other warm-blood animals, function most efficiently in environments where they can maintain body temperature at around 38^{o}C (Vercoe, 1990). Normal physiological processes which include tissue and cellular metabolism and the underlying biochemical reactions that sustain life and productive functions need body temperature to be maintained within very narrow limits. In lactating Holstein cows, the comfortable ambient temperature is within the range 4 to 24^{o}C (Hahn, 1981). When environmental temperatures are moderate (18 to 20^{o}C), physiological demands for body cooling or warming are minimal and optimal performance can occur (Shearer *et al.*, 2002). However, in the face of environmental temperature extremes, thermoregulatory activities increase and performance is proportionally reduced. According to Shearer *et al.* (2002), heat stress has been observed to cause reductions in milk production of 10 to 25%. The effects of heat stress on Holstein cows begin to be observed above 24^{o}C, and milk yield decreases markedly above 27^{o}C (Johnson, 1965). Relatively small increases in body temperature, for example 1^{o}C or less, result in detectable, deleterious effects on metabolism and tissue integrity, in particular, the break down of body protein and a significant depression in production (Vercoe, 1990). Therefore, the maintenance of a constant body temperature or being in a state of thermal equilibrium is a prime requirement for productive dairy cattle.

However, animals are dynamic and adaptable and are able to maintain life and productive performance in a relatively broad range of environments. Coping with environmental stressors involves behavioural, physiological and immunological functions, which are mobilized at different stressor levels to minimize adverse consequences (Hahn, 1999). Performance, health and well-being can be compromised when adverse environmental stressors exceed threshold limits for coping and compensatory mechanisms. Genetic diversity within a population can also influence the level of response and degree of adaptability so that what is stressful to some may not be stressful to others. Although Zimbabwe is situated in a sub-tropical region which poses a lot of climatic limitations to dairy productivity, the *Bos taurus* dairy breeds which have been introduced in the country have managed to adapt over years. Milk yields in commercial dairy farms have been improved to average of 15 litres per day per dairy cow (Topps, 1999).

2.2 Meteorological Factors Affecting Dairy Cattle Performance

Knowledge of the influence of meteorological factors on animal production is of value in the manipulation of the environment and the cow for optimum production (Svotwa, 2001). Livestock managers need information about how and why their animals respond to environmental challenges to make improved decisions on strategies and tactics to reduce losses during hot weather (Hahn, 1999). The understanding of meteorological factors which can contribute to a decline in production is therefore of prime importance. According to Piggins *et al.*, (1992), heat stress is the major constraint on animal production in hot climates. Farmers and farm managers, especially in the dairy industry need to understand the main meteorological factors which have direct contributions to heat stress. The primary sources of heat gain from the environment are solar radiation and elevated ambient temperatures (Bray *et al.*, 1994). These are complicated by high relative humidity and a lack of air movement.

2.2.1 Ambient temperature

Temperature is the condition which determines the direction of the net flow of heat between two bodies (W.M.O., 1996). In such a system, the body which overally loses heat to the other is said to be at the higher temperature. The thermodynamic temperature (T), with units of Kelvin (K), is the basic temperature. The Kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. The temperature (t) in degrees Celsius defined by equation below is used for most meteorological purposes.

$$t=T-273.16 \tag{2.1}$$

Ambient temperature is measured by a dry bulb thermometer which gives the dry bulb temperature (ambient temperature). According to Paggot (1992), the dry bulb thermometer of the mercury or alcohol type gives the ambient temperature. A wet bulb thermometer can be used at the same time with the dry bulb thermometer to give the wet bulb temperature (dew point temperature).

Ambient temperature is probably the most important environmental parameter that affects cattle (Svotwa, 2001). It determines the degree of comfort in animals by influencing heat loss and heat gain, which in turn affects the behaviour and performance of animals. As ambient temperature increases, the difference in temperature between the body of a cow and the surrounding environment is reduced, thus reducing the amount of body heat that can be lost by conduction, radiation and convection. Further increase of temperature makes the cow rely more on evaporative cooling (sweating and panting) to loose body heat (W.M.O., 1989). If these do not lower the heat load then the body temperature of the cow will rise and, according to Stokes (1998), this results in a higher maintenance requirement in an attempt to dissipate the heat.

According to Schmidt *et al*. (1988), a decrease in feed consumption, and increases in water intake, body temperature and respiration rate take place as a result of high ambient temperatures. Amongst the dairy breeds, the smaller breeds, particularly the Jersey, are more tolerant to high temperatures than are the larger breeds like the Holsteins. The smaller breeds have a larger surface area per unit of body weight and apparently can dissipate heat more rapidly than do larger cows. Other factors may modify the effect of temperature on cattle performance. High relative humidity accentuates the problem due to high ambient temperature while air movement at high temperature helps to cool the animals. Solar radiation increases the stress of the animal as a result of higher temperature caused by the increase in solar radiation.

2.2.2 Relative Humidity

Relative humidity is the ratio, in per cent, of the observed vapour pressure to the saturation vapour pressure with respect to water at the same temperature and pressure (W.M.O., 1996). Humidity is measured by a hygrometer. According to Paggot (1992), derivation of air humidity is achieved by measuring the difference between the temperature recorded on two identical thermometers, one of which is cooled by the evaporation of a thin film of water in contact with the bulb of the thermometer (wet thermometer) and which therefore registers a lower temperature than the second thermometer (dry thermometer) whose bulb is dry and uncovered. The lowering of temperature depends upon the rate of evaporation which is itself a function of the hygrometric state of the air, that is, how much water vapour it holds.

Humidity in the air has a direct effect on the rate of evaporation of water from the body surfaces of animals. Moisture in the air influences the rate of evaporative heat loss from animals through both the skin and the respiratory tract (Kurihara *et al.*, 2003). According to West (1995), the effectiveness of evaporative cooling is reduced by high relative humidity during such hot humid conditions. The higher the ambient vapour pressure, the lower the humidity gradient from the skin or the respiratory tract to the air National Research Council (NRC), 1981). This effectively lowers the rate of latent heat loss and dissipation of heat is impaired causing an increase in body temperature (rectal temperature).

2.2.3 Radiation

Radiation quantities are classified into two groups according to origin: solar radiation and terrestrial radiation (W.M.O., 1996). Solar radiation is the energy emitted by the sun and terrestrial radiation is the long-wave electromagnetic energy emitted by the Earth's surface and by the gases, aerosols and clouds of the atmosphere. It is measured in units of watts per square metre (Wm^{-2}) using radiometers.

Radiant heat from both the sun and the animal's surroundings affect the rate of heat loss from radiation, convection and conduction (Kurihara *et al.*, 2003). According to Clark (1981), the sources of radiation that impinge on an animal standing in the sun include direct solar radiation and solar radiation scattered by aerosols (Sd), long-wave radiation from the atmosphere (Ld), solar radiation reflected from the ground (Su) and long-wave radiation emitted from the ground (Lu). Exposure to solar radiation can add considerably to the heat load on an animal (Mount, 1979). Yamamoto *et al*. (1996) indicated in an equation that solar radiation as measured by black globe temperature contributes substantially more to the heat load on animals than does dry bulb temperature.

Coat colour is important for the absorption of solar radiation; in the visual region of the spectrum, white coats have a low absorbance and a correspondingly high reflectance, and black coats have a high absorbance, with correspondingly smaller and greater radiant heat loads respectively (Mount, 1979). The smooth and light coated *Bos indicus* cattle have higher reflectance and lower skin surface temperature than *Bos taurus* cattle. The contribution of solar radiation to the heat load of a cow is accentuated by high ambient temperatures. The level of radiant heat load on livestock in the tropics is very high in summer and its effect on milk production is very important. Radiation incident on an animal's skin raises the skin surface temperature and this increases the temperature gradient between the skin surface tissues and the inner body core. A widening in the difference between the rectal temperature (body core temperature) and the skin surface temperature with the skin temperature higher than the rectal temperature results in thermal flow towards the body core tissues and a rise in body core temperature is created. The skin surface temperatures, body temperatures and respiration rates of cows exposed to radiant heat are usually significantly higher than in those not exposed (Kurihara *et al.*, 2003). The thermoregulatory and physiological processes which accompany a rise in the heat load of an animal will result in a decline in production. So the reason why animals exposed to direct solar radiation seek shade is to avoid a net heat gain which effectively increases body temperature.

2.2.4 Air Movement

Wind velocity is a three-dimensional vector quantity with small-scale random fluctuations in space and time superimposed upon a larger-scale organized flow (W.M.O., 1996). Wind speed is given in metres per second and measured using anemometers. Wind affects the heat loss from the body surface of an animal by the processes of convection and evaporation

(Shioya *et al.*, 1997). Wind reduces the insulation of animal coats (Turnpenny *et al.*, 1999). Campbell *et al.* (1980), cited in Turnpenny *et al* (1999), showed that the coat conductance, which is the reciprocal of resistance increases linearly with wind speed. Wind gives a continuous supply of fresh and unsaturated air, hence accelerating convective heat loss from the animal's body to the surrounding air in contact with it. Johnson (1976) observed that at 10^{o}C ambient temperature, the effect of wind on milk production of Holstein cows was not significant but at 27^{o}C, the effect of wind moving only at 2 m s^{-1} was beneficial.

2.2.5 Precipitation

Precipitation is defined as the liquid or solid products of the condensation of water vapour falling from clouds or deposited from air on the ground (W.M.O., 1996). It includes rain, hail, snow, dew, rime, hoar frost and fog precipitation. The total amount of precipitation which reaches the ground in a stated period is expressed in terms of the vertical depth (or water equivalent in the case of solid forms) to which it would cover a horizontal projection of the Earth's surface. The unit of precipitation is linear depth usually in millimeters for liquid precipitation and precipitation gauges or rain gauges are the most common instruments used to measure precipitation.

With regard to heat gain and dissipation in cows, precipitation plays an insignificant direct role. Several studies show that precipitation can increase considerably the heat loss from animals, although the effect is difficult to quantify accurately (Turnpenny *et al.*, 1999). Precipitation affects the heat load of the animals when it accumulates in the animal pelage. The presence of moisture on the animal skin surfaces enhances latent heat loss as the water evaporates from the skin and, from this fact, sprinkling of water has been used as one effective method of cooling heat stressed cows. Precipitation plays a more indirect but important role in dairy livestock through its influence on the quantity and quality of forages.

2.3 Temperature-Humidity Interaction

Researchers at the University of Arizona developed the Temperature Humidity Index (THI) which is a combination of temperature and humidity measurements (Wagner, 2001). The THI is a combination of temperature and humidity that is a measure of the degree of discomfort experienced by an individual animal in warm weather; it was originally called the discomfort index (Encyclopaedia Britannica, 2005). According to Smith *et al.* (1998), the THI is used to quantify the severity of heat stress. The THI is calculated through three different formulas which use measured values of dry bulb temperature, wet bulb temperature and relative humidity. All the formulas below can be used to calculate the THI:

$$THI = 0.72 * [T_d + T_w] + 40.6 \text{ (WMO., 1996)} \qquad (2.2)$$

Where T_d and T_w are dry and wet bulb temperature readings (^oC), respectively, from a hygrometer:

$$THI = T_d + [0.36T_{dew}] + 41.2^o C \quad \text{(Johnson, 1990)} \qquad (2.3)$$

Where T_d is dry bulb temperature and T_{dew} is dew point temperature in degrees celcius and

$$THI = T_d - [0.55 - 0.55 * RH/100] * [T_d - 58] \quad \text{(Spencer,1995)} \qquad (2.4)$$

Where T_d is dry bulb temperature in degrees Fahreinheit and RH is relative himidity (%). Smith *et al.* (1998) came up with five stress categories which can be used by dairy farmers to determine the level of stress in their dairy herds. The table below shows stress categories which were postulated with THI calculated the formula $THI=0.72x(T_d+T_w)+40.6$.

Table 2.1: Temperature-Humidity Index ranges and their corresponding stress categories (Pennington *et al.*, 2004)

Stress Category	THI range (inclusive)
No stress	72
Mild stress	72-79
Heat stress	80-89
Severe stress	90-98
Dead cows	99

THI above 72 is usually considered the point at which heat stress occurs (Pennington *et al.*, 2004).

Bianca (1962) cited in Clark (1981) used a similar parameter called the Heat Stress Index (HSI) to assess stressful environments and this was calculated using equation below:

$$HSI = 0.35T_d + 0.65T_w \qquad (2.6)$$

Where T_d and T_w are dry bulb temperature and wet bulb temperatures respectively. Both THI and HSI make it possible to compare temperature and humidity data and accompanying animal responses from different climatic environments (Clark, 1981).

2.4 Thermal balance of livestock

The interaction between the atmosphere and animals represents one of the highest levels of complexity in the boundary layer (Oke, 1987). The heat balance of any animal can be written in the general form:

$M + R_n = C + \lambda E + G$, where each term refers to the gain or loss of heat per unit of body surface area (Monteith *et al.*, 1990): M is the rate of heat production from metabolism, R_n is net radiation, C is convective heat flux, λE is the sum of latent heat transfer components representing losses from the respiratory system λE_r and from the skin when sweat evaporates λE_s and G is conductive heat loss. Oke (2003) cited that the energy balance of an animal may alternatively be written as:

$Q^* + Q_M = Q_H + Q_E + Q_G + \Delta Q_S$ where,

Q^* = the net all-wave radiation flux density,

Q_M = rate of heat production by metabolic processes,

Q_H = turbulent sensible heat flux density,

Q_E = turbulent latent heat flux density,

Q_G = sub-surface heat flux density and

ΔQ_S = net change of body heat storage.

In this balance Q_M is always a heat source, and Q_H and Q_G can become heat sources if the air surrounding the animal or the ground it is in contact with is warmer than the body temperature of the animal. Otherwise Q^*, Q_H, Q_E and Q_G all represent channels of heat loss to dissipate the animal's metabolic heat output. Net heat storage can be an energy gain of loss, but in many homeothermic animals it must remain close to zero because the range of tolerable body temperatures is small. Heat balance models for animals outdoors have been developed to assess their food and shelter requirements in relation to weather. The body surface is usually considered to be warmer than the surrounding air, so that heat is always lost by convection (McArthur, 1991). When the temperature of the air is above that of the body core, the body surface can gain heat by convection. However when the air is cooler than the body core, as is usually the case, surface temperature can fall below air temperature when the net radiation loss is large.

The basic concept of heat exchange between an animal and the thermal environment as illustrated by Robertshaw (1981) relies on the premise of a zone of thermoneutrality where, by definition, an animal's metabolic heat production is constant and independent of the ambient temperature. The zone of thermal comfort is the range of ambient temperature and humidity at which energy losses needed to ensure constant body temperature are minimal (Paggot, 1992). In this scheme there are zones above and below thermoneutrality where the animal's heat production is dependent upon the environmental temperature (Young *et al.*, 1981). The lower border of the zone of thermoneutrality is called the lower critical temperature (LCT) and is defined as temperature below which an animal must increase its rate of metabolic heat production to maintain homeothermy. Below the lower critical temperature, metabolic heat production becomes increasingly dependent upon the ambient temperature. The animal usually adopts a more compact position in order to reduce the surface area exposed to the environment (Mount, 1979). Pilo-erection is employed to increase the boundary layer resistance to heat loss (Monteith and Unsworth, 1990).

The upper limit of the thermoneutral zone is called the upper critical temperature (UCT). If the environmental heat load causes a rise in ambient temperature above the UCT, dry heat loss falls because of the reduction in temperature gradient between the body core temperature of the animal and its surroundings (National Research Council (NRC), 1981; Otengi, 1988; Hill, 1990). This results in an animal having a reduced capacity for sensible heat loss from its body (Svotwa, 2001). A surrounding that is warmer than the body temperature of an animal shifts the needs of the animal from heat production to heat dissipation (Mount, 1979). The animal restricts an increase in body temperature by adopting an extended posture, thus increasing the surface area that loses sensible heat by conduction, convection and radiation. A rise in skin surface temperature is due to peripheral vasodilation and increased skin blood flow to transport excess heat to the periphery (Mount, 1979; Paggot, 1992). These physiological responses can be easily monitored to track the levels of heat stress on the animal (Mount, 1979; Gates, 1980). Further increases in body temperature induce panting and sweating as passive evaporation from the external skin surface would no longer be adequate to shed off excess heat (NRC, 1981; Hill, 1990). The animal will have high breathing rate which according to Hahn (1999) can be monitored by counting flank movements per minute and express them as breaths per minute (bpm).

A homeothermic animal attempting to maintain body core temperature at a relatively steady value despite changes in its thermal environment must balance the rates at which heat is gained and dissipated its body (McArthur, 1981). When an animal is in thermal equilibrium with its environment, the total rate of heat loss less respiratory losses, must be transferred by conduction and convection from the body core through the tissue to the skin surface (Turnpenny *et al.,* 1999). The heat gained by an animal originates primarily from metabolic conversion of the chemical energy stored in food. The rate of metabolic heat production in a thermoneutral environment ranges from about 50 to 200 Wm^{-2}, depending on species and level of production (Webster, 1981). In strong sunshine outdoors, the heat gained by absorption of solar radiation can exceed metabolic heat production by a factor of 3 or 4 and is a major component in an animal’s heat balance, but indoors this gain is usually negligible (McArthur, 1981).

Heat loss to the environment occurs by two routes; sensible (conduction, convection and radiation) and latent heat (evaporation) transfer. There are two avenues through which evaporative cooling is effected: sweating and respiration. Cattle have well developed sweat glands in the skin but the density and depth of these glands, and consequently their effectiveness as a dissipatory mechanism, varies within an animal (the neck, shoulder and escutcheon regions are better endowed than the flanks and backline) and between animals and breeds (Vercoe, 1990). In contrast to human sweating mechanisms which are under cholinergic control, sweat glands in cattle are adrenergically controlled. As heat load increases and body temperature begins to rise, sweat glands throughout the body surface are synchronously activated, and the overall sweating rate is regulated to maintain body temperature. As outlined by Robertshaw (1981), at low environmental temperatures the loss of heat is mainly through sensible heat transfer and if the rate of heat loss exceeds metabolic heat production then the rate of metabolic heat production must be raised to prevent a drop in body temperature. Metabolic rate can reach 500 Wm^{-2} (summit metabolism) in response to cold, but this level can not be maintained for more than a few hours. As heat production is maintained by oxidation of food intake or body reserves, an increase in metabolic rate above metabolic heat production results in lowered productivity because a higher proportion of the food eaten is employed in thermoregulation (McArthur, 1981).

At high environmental temperatures, the rate of sensible heat loss may be lower than metabolic heat production and an animal relies on the evaporation of water to dissipate its excess heat, either from the skin surface as a result of sweating or from the respiratory system by panting. This is necessary to prevent a rise in its body temperature due to storage of thermal energy (Clark, 1981). Although heat dissipation by evaporation may prevent an increase in body core temperature, elevated skin temperatures, high respiratory rates and the associated thermal discomfort reduce an animal's appetite and therefore lower its productivity because of the reduced food intake (McArthur, 1981). High respiratory rates can also result in an increase in metabolic rate above metabolic heat production, because of the increased muscular activity associated with panting. The range of environmental temperatures outside which thermal strain causes a loss of productivity depends on the metabolic rate and on the thermal resistances to heat and mass transfer between the body core and the surroundings.

Dairy cattle generate heat from two sources: the environmental temperature and humidity, and their internal body metabolism and digestion (Lee, 2003). Within the thermoneutral zone (-4 to 18.5^{o}C), the production and loss of heat from a cow's body is about equal. Within this zone cows are able to maintain a normal body temperature of 38.5 to 39.3^{o}C relatively easily. In a thermal environment in which the animal's heat production exceeds heat loss, an increasing amount of heat is stored in the animal's body, resulting in increased body temperature (Johnson, 1990). When the body temperature is significantly elevated, a myriad of homeothermic events are initiated. These events include increases in evaporative heat loss by respiration and from the skin by sweating. However, when high temperatures and radiation lessen the ability of the animal to radiate heat from the body, feed intake, metabolism, body weight and milk yields decrease to help alleviate the heat imbalance.

2.5 What is Heat Stress?

Heat stress occurs when the sum of the cow's own physical heat production and the environmental heat become greater than her ability to lose heat (Spencer, 1995). Wagner (2001) also reported that heat stress occurs when the cow's heat load is greater than her capacity to lose heat. Heat stress itself is a function of time, temperature and humidity, because cows rely on water evaporation via sweating and panting to dissipate an excess of heat they have generated metabolically or absorbed from the environment (Cruz *et al.*, 2004). It is important to note that heat stress is a combination of the cow's own physical heat production as well as environmental heat that overloads the cow's ability to maintain normal metabolism. Heat load is made up of the cow's body heat production plus environmental heat which includes, air temperature, relative humidity, air movement and solar radiation. The primary factors that cause heat stress in dairy cows are high environmental temperatures and high relative humidity (West, 1995). In addition, radiant energy from the sun contributes to stress if cows are not properly shaded. As the environmental temperature increases, the difference between the temperature of the cow's surroundings and her body decreases and her reliance on evaporative cooling (sweating and panting) to dissipate body heat increases. However, high relative humidity reduces the effectiveness of evaporative cooling and during hot, humid summer weather, the cow can not eliminate sufficient body heat and her body temperature rises. The tremendous amount of body heat that the high yielding dairy cow produces is helpful in cold climates but is a severe liability during hot weather.

A cow's own physical heat production is a combination of internal factors as well as external factors (Spencer, 1995). Internal heat load comes from basic functions such as respiration, digestion, as well as other daily maintenance requirements. These factors will be influenced by stage of lactation, production levels, as well as quantity, quality and type of feed consumed. External physical heat loads are management factors that affect physical activity and performance. Cow comfort, layout of facilities, stocking densities and fly control can all impact on the cow's external physical heat load (Spencer, 1995). Environmental heat, as mentioned before, is a combination of the direct effects of temperature and solar radiation increasing the heat load, and the indirect effects of humidity and air movement reducing the cow's ability to dissipate its heat load. Heat load will increase as temperature, humidity and solar radiation increase and air movement decreases. All four of these factors must be controlled if a cow is to be maintained in its thermal neutral zone.

2.6 Production, Physiological and Behavioural Responses to Heat Stress

Heat stress can cause reduced productivity in beef and dairy cattle herds. Heat stress affects two of the most economically important segments of the dairy farm business, milk production and reproduction (Kabuga, 1990; Wagner, 2001). Milk yield can be reduced by 3% to 20% or more. Conception rate can go as low as 0% in extreme cases. Feed intake can be reduced by 8% to 12% or more. This all translates into many lost dollars to the dairy business (Wagner, 2001). The effects of severe heat stress are often seen in the form of reduced reproductive performance, reduced daily weight gain of growing cattle and reduced milk production. Dairy producers are very aware of the decreased milk production and dry matter intake; however, often it seems that the milk production drops more than would be expected (Dunham *et al.*, 1996). Heat stress induces a number of physiological responses by the cow in an attempt to keep body temperature within normal limits (Linn, 1997). Cattle are more sensitive to heat stress than humans although cattle do seem to have a wide range of heat tolerance. From an environmental perspective, heat stress is a combination of temperature, relative humidity and wind speed. However, animal factors such as age, hair coat length, hair coat colour and nutritional status interact with these environmental factors to determine the severity of heat stress. In cattle of the same genotype, it is the highest producers that show signs of heat stress and reduced production under hot conditions (Vercoe, 1990).

Cows react to heat stress behaviourally as well as physiologically (Spencer, 1995). Behavioural changes will occur well before physiological ones such as panting and sweating. A cow's first response to heat stress is to stand which is a way of increasing the surface area exposed to heat dissipation. The cow will seek shade or move to wind exposed areas to increase boundary layer turbulence which enhances heat dissipation by convection (Gaughan *et al*., 1996). The next behavioural change will be to decrease dry matter intake to lower internal heat production as well as increase water intake to meet an increase in maintenance requirements and cool the body core (Epperson, 2002).

Temperature sensitive neurons provide information to the hypothalamus that controls the physiological as well as the behavioural responses. The hypothalamus integrates signals from the skin, body core and brain sensors relating to body temperature and orchestrates the animal's physiological responses (Vercoe, 1990). During heat stress, the cow will increase its respiratory rate and this reduces core temperatures through evaporation in the lungs. Together with an increase in respiration rate, rectal temperatures and sweating also increase. Some responses of cattle to heat stress such as panting may actually increase heat production in their bodies (Epperson, 2002). This is due to the mascular activity and energy requirements that are associated with the physiological process.

Along with reduced feed intake, heat stressed cows have a lower rate of feed and gut motility (Wagner, 2001). Rumen fermentation characteristics change. Total volatile fatty acids (VFAs) production is decreased and according to Linn (1997), this is associated with an increase in the molar percent of acetate. The impact of heat stress on performance is in part due to specific behavioural responses leading to reduction in dry matter intake, as well as physiological responses leading to decreased blood flow to the internal organs that leads to decreased nutrient uptake as well as an increase in maintenance requirements. Physiologically, the cow's most important way of dissipating heat is by evaporative means (Spencer, 1995).

Heat stress has a negative effect on reproduction. For dairy cows, heat stress reduces conception rates, decreases duration and intensity of estrus and has been reported to alter circulating concentrations of estradiol and follicular dynamics (Trout *et al*., 1998). Since the main factors regulating ovarian activity are gonadotriphin releasing hormone (GnRH) from the hypothalamus and the gonadotropins; lutenising hormone (LH) and follicle stimulating hormone (FSH) from the anterior pituitary gland, several authors have studied the effect of heat stress on the secretion of these hormones (Rensis *et al*., 2000). However, the mechanisms by which heat stress alters the concentrations of circulating hormones are not well known (Gilad *et al*., 1993).

2.7 Managing Heat Stress in Lactating Cows

Alleviating heat stress is critical to milk production (Epperson, 2002). There are basically three interventions management can consider to reduce heat stress. These are genetic changes, nutritional strategies and environmental modifications. Genetically there are breed, colour and individual differences in susceptibility to heat stress (Spencer, 1995). However, to base a genetic program around a cow's susceptibility to heat stress is a tremendous step backward. Dairy cows are more prone to heat stress than other animals due to the genetic selection for high milk production having produced an animal with a high internal heat load. Therefore, the profitability of using genetics to decrease production to manage heat stress is highly questionable.

Using nutritional strategies as a method of heat stress abatement will result in a rise in the production costs of a dairy enterprise and diet has a far less impact than cooling the cows using shade, or cooling systems such as misters, water sprinklers or fans but dietary modification will help cows cope with heat stress. This implies that environmental modification remains the only cheaper and probably most reliable method that can be employed as a way of reducing the impacts of heat stress during hot weather conditions and it comes in two main forms which are shading and cooling. The management of heat stress and its effects through environmental modification involves reducing heat gain via solar and thermal radiation and high ambient temperatures. This may reasonably be accomplished with shade and evaporative air cooling (Shearer *et al*., 2002). According to West (1995), provision of shade has been observed to be the easiest and most obvious way to help heat-stressed cows. Because air temperature and humidity are costly to modify, evaporative cooling systems have their limitation in humid regions. Consequently, when interventions on dairies to alleviate heat stress are made, there is need to deal with the non-evaporative means of cooling which primarily involve the provision of shade. Shade provision to livestock has become an issue of debate although little work has been carried out to quantify its effects on livestock productivity. The appropriate investment in environmental modification to alleviate heat stress will depend on the climate as well as current facilities. The more extensive the environmental modifications, the greater the potential for reduction of the detrimental effect of heat stress.

2.7.1 Shade

Technology to avoid solar heat loads or increase heat losses from the animal to maintain heat balance is especially important for exotic temperate cows introduced into the humid tropics and during temperate zone summers (Johnson, 1990). Solar radiation is a major factor in heat stress and increases heat gain by direct as well as indirect means (Shearer *et al.*, 2002). Direct sunlight together with heat energy that is reflected from areas exposed to the sun such as the ground, walls and other exposed surfaces add a tremendous amount of heat load (West, 1995). Pennington *et al.* (2004) revealed that shading from direct sunlight allows cows to rest in a more comfortable environment. Shade will reduce heat loads in cattle and if cattle can be moved to shaded pens, the severity of the heat stress will be reduced (Epperson, 2003).

Shade reduces the black globe environmental temperature (measure of temperature and radiant energy) and lowers the rectal temperature and respiration rate of cows, increasing feed intake and milk yield (West, 1995). Results from studies in Florida and Arizona indicate that when compared to high producing cows exposed to direct sunlight and a THI above 80 during daylight hours, shaded cows will produce approximately 2 to 3 kgs more milk per day (Smith *et al.*, 1998). Florida researchers (Roman-Ponce *et al.*, 1977) found that cows housed with shade had high milk yields and conception rates than non-shaded cows (Smith *et al.*, 1998). Therefore, shading is of benefit to the alleviation of heat stress in dairy cows during hot weather.

To reduce stress in feedlot cattle, researchers have suggested low cost light weight structures to provide shade. Access to shade has shown an increase in growth and milk production in warm regions (Brown *et al.,* 2004). According to a study by Brown *et al*. (2004) designed to quantify the reduction in stress level of feedlot cattle given access to shade, animals given access to shade had lower body temperature than unshaded animals at hotter hours of the warmest days. Respiration rates of shaded cattle were lower at hotter hours of all days. Shade covering over the holding pen area is an economical method of altering the effects of summer environmental conditions (Atkeson and Bickert, 1997). Blocking the effects of the sun with properly constructed shade structures alone increased milk production by 10 to 19% in studies conducted in Florida.

With management concerns for cow comfort and the effects of heat stress in the holding pen, the use of shade cloth can be an economic benefit for cow comfort and milk response. Therefore, in times of heat stress conditions, the addition of shade to the holding pen area can improve cow comfort and performance and be economically feasible. Some Michigan dairy producers have seen benefits in cow comfort and performance with the addition of fan and sprinklers in the holding pen area. However the payback generally will be longer than by simply providing shade cloth over the holding area. Simple shade is the basic method in summer of protecting animals from direct solar radiation during the day and it has a beneficial effect on the physiological response of dairy cattle to heat (Kurihara *et al.,* 2003). The body temperature, heart rate and respiration rate all decreased when shade was provided during the summer in the Kyushu area of Japan.

In a research conducted in Queensland, Australia over 88 days in summer, shade-type preferences by Holstein-Friesian cows were investigated under natural climatic conditions. Forty two cows were placed in a feedlot provided with different shade types. Shade types provided were a 3 m high galvanized iron roof, *Sechium edule* (choke) vines on a 3 m high trellis, 70% shade cloth on a 3 m high frame and natural shade trees. An unshaded area was also provided. Number of cows using a particular shade type and their respiration rates were recorded daily at 1300. Ambient temperature, relative humidity, solar radiation and wind speed were also measured. Cows selected the galvanized iron roof most frequently when temperatures rose above 30^{o}C with no significant differences between the other shade types. At temperatures below 30^{o}C animals did not seek shade. As ambient temperature, solar radiation and relative humidity rose, respiration rate rose.

Two options are available for providing artificial shade to dairy cows during the summer and these are permanent or portable shade structures (Shearer *et al*., 2002). Regardless of the type chosen, there are a number of factors to consider with respect to design, maintenance and initial cost. Different materials are used in the provision of shade during warm weather and these range from solid material like iron and asbestos sheets to shade cloths which cut solar radiation at different levels. Shade cloth patterns come in various weaves providing 30 to 90% shade and are fabricated from a variety of material (Jones *et al*., 1999). According to Atkeson and Bickert (1997), the most common material used for animal shades is the woven polypropylene fabric providing 80% shade. Shade cloth is considerably less expensive than solid roofing material but does not provide as much protection from solar radiation as a solid shade. While longevity is less than a permanent structure, shade cloth can last 5 or more years when maintained correctly and kept tight (Atkeson and Bickert, 1997). Thermal radiation from the roof of shade structures especially solid shading materials like iron sheets can add significant heat load to cattle particularly in low structures without a ridge opening (Shearer *et al*., 2002). To achieve the most benefit from shade structures, feed and water must be available to the cows under the shade.

Shading can be done as an integral programme together with cooling. Cooling has been used as another way of modifying the micro-climate of animals to alleviate the effects of heat stress. Cooling the cow basically comes in two main ways. The first method involves the use of fans which increase air movement and this in turn increases the rate of heat loss from a cow's body surface by convection, as long as the air temperature is lower than the animal's skin temperature. The second method of cooling involves the use of water sprinklers and fans. Sprinklers are used to wet the hair coat of the animal to the skin; fans are then used to dissipate the heat from the cow by evaporative cooling of the water on the animal skin (Pennington *et al*., 2004). Research showed an 11% increase in milk yield when cows were cooled with fans and sprinklers compared with shading alone (West, 1995).

Protecting the cow from solar radiation with shades and reducing ambient air temperatures through the process of water vaporization and controlled ventilation are important considerations in cooling dairy cattle. Therefore, environmental modification to protect the cow from excessive heat load and supporting her natural cooling ability are keys to optimizing milk production, reproduction and cow health during periods of heat stress (Spencer, 1995).

2.7.2 Feeding and Nutritional Management

Besides the provision of shade as a heat stress management programme in the hot tropics, feeding and nutritional management can also be used as a relatively effective method of helping heat stressed cows. Decreased feed intake and a resultant decline in metabolizable energy (ME) intake is a major problem for the exotic (*Bos taurus*) breeds of cattle imported into the tropics (Johnson, 1990) especially during the hot summer months which are characterized with intense solar radiation and high ambient temperatures. The composition of the diet is believed to be important in alleviating heat stress. However, diet has far less impact than cooling the cows using shade. There are no reliable scientific guidelines for feeding cows in hot climates (Linn *et al*., 2004). Major nutritional components which are of importance to heat stressed cows are water, fibre and non-fibre carbohydrates, fats, proteins, minerals and feed additives. These and some alterations in the feeding programme can help entice cows to eat during heat stress periods (Linn, 1997) and reduce their heat loads.

Water is the most important nutrient for lactating cows especially heat stressed cows (Linn, 1997). The cow's water requirement increase significantly as the environmental temperature increase and cows drink up to 50% more water when the THI is above 80 units (Pennington *et al*., 2004; Linn, 2004). This increase in water intake under heat stress helps dissipate heat through the lungs and by sweating (Lee, 2003). Water is the most important nutrient in minimizing heat stress because it acts as a heat sink; therefore, heat is transferred from the cow's body to the ingested water. Therefore, drinking water has an immediate cooling effect on cows with body temperature cooling down as it heats consumed water (Linn, 2004). Heat stressed cows should have an unlimited quantity of clean water in an easily accessible area.

High quality forages should be available to animals during periods of hot weather. Fibre digestion results in a higher heat increment than digestion of fat or non-fiber carbohydrates (Linn, 1997). Diets high in grain and low in fibre cause less heat stress for lactating cows because of lower heat of digestion (Pennington *et al*., 2004). Therefore, feeding a minimum but adequate amount of total and effective fibre should be the objective during summer months. Added dietary fat also plays an important role as an excellent way to increase energy content of the diet especially during summer when feed intake is depressed (West, 1995). As compared to other feeds, fats have a low heat increment. In a study conducted by the University of Illinois, cows fed the high fat diet during hot summer produced milk much more efficiently and had a significantly lower early morning respiration rate than cows fed a high grain and fibre diet. Fats should be supplemented during heat stress at 2 to 3% of the diet (Linn, 2004).

Cattle suffering from heat stress often have a negative nitrogen (N) balance because of reduced feed intake (Lee, 2003). Both the quantity and form of protein in the diet need to be considered when feeding heat stressed cows (Linn, 1997). According to research conducted in Arizona, it was suggested that during heat stress, the level of crude protein (CP) in the diet should not exceed 18% while the level of rumen-degradable protein should not exceed 61% of crude protein. Since cows reduce their voluntary feed intake during hot season weather in the tropics (Collier *et al*., 1982), their mineral intake may also be less than optimal in hot weather adding an additional limiting factor in hot, humid environment (Johnson, 1990). Therefore, balancing for dietary cations (sodium (Na) and potassium (K)) and anions (chlorine (Cl) and sulphure (S)) is very important during heat stress periods. Mineral balance is evidently an important dietary component that can be modified to lessen the effects of heat stress in lactating cows during hot weather.

Digestion aids such as buffers, yeast cultures and others like niacin can be beneficial during heat stress periods. Arizona researchers have shown that feeding *Aspergillus oryzae* reduced heat stress in cows through lowering rectal temperatures. Milk yield increased in some studies and this was attributed to improved fibre digestion in the rumen. Due to changes in the feeding behaviour of heat stressed cows, feeding management intergrated with nutritional modification can help alleviate the impacts of heat stress in lactating dairy cows during periods of hot weather.

2.8 Conclusion

Although some researchers have indicated that there are positive benefits in providing shade to lactating cows during hot weather, little is known about the physiological responses of cows provided with shade and the effectiveness of different materials that can be used for providing shade. In as much as dairy farmers in Zimbabwe generally agree that there is a notable decline in milk yield during the hot months of September to November, it has not been confirmed whether the decline in yields is due to heat stress or nutritional factors. Little research in Zimbabwe has yet been carried out to try and quantify the general decline in milk yield during the hot summer season and try to explain it in terms of environmental heat stress after factoring out other factors like nutrition and disease incidences. Such a study would properly quantify in terms of production, the positive impacts of providing shade during hot weather.

CHAPTER 3

RESPONSES OF LACTATING HOLSTEIN COWS TO DIFFERENT LEVELS OF SHADING

3.1 Experiment 1: Comparison of physiological and production responses of Holstein cows under corrugated iron sheets and under Hessian 30% shade cloth shading.

3.1.1 Introduction

Typically, summers in Zimbabwe can be both hot and humid, which combines to make a very uncomfortable environment for lactating dairy cows. Physical modification of the environment is the most effective way to reduce heat stress (Linn, 1997). According to Shearer *et al.* (2002), provision of shade has proved to be the best and less costly way to decrease the effects of solar radiation particularly in the hot tropics and sub-tropics.

Careful management which can alleviate heat stress is the best way to maintain high production levels in lactating cows in a hot environment (Kurihara *et al.*, 2003). Heat abatement programmes for any dairy individual must take into account the environmental challenges of the area, the type of facility, as well as the management levels and economic benefits. A clear understanding of when heat stress occurs and what contributes to it, how a cow responses to this heat stress as well as how a cow dissipates her body heat are necessary to design an effective heat abatement programme (Spencer, 1995).

On this background, it was decided to study the benefits of providing shade to lactating Holstein cows during the summer and observe the general production, physiological and behavioural responses of the cow to heat stress under different levels of shading.

Characteristics of Holsteins

Holstein-Friesian is the official name of the breed although they are commonly referred to as Holsteins in the United States (Schmidt *et al.*, 1988). The Holstein cow (Fig 3.1) originated in Europe. The major historical development of this breed occurred in what is now the Netherlands and more specifically in the two northern provinces of North Holland and Friesland which lay on either side of the Zuider Zee (Atkinson, 2000). Holsteins are large and usually have clearly defined black and white or red and white coat colours but can also throw light brown coat colours in rare cases. In Zimbabwe, Holstein cows produce the largest volume of milk with the lowest milk fat percentage amongst the exotic dairy breeds. The lowest milk fat percentage is also accompanied by the lowest non-fat solids percentage. In general, if the non-fat solids percentage of a breed is low, the milk fat percentage will be low and vice. The Holsteins are the most susceptible *Bos taurus* dairy breed to heat stress and are less tolerant to heat stress than the light coat coloured breeds like the Jersey (Schmidt *et al*., 1988).

Figure 3.1: Photograph of a Holstein dairy cow at the University of Zimbabwe Dairy Unit

3.1.2 Materials and Methods

3.1.2.1 Site Description and Experimental Design

The University of Zimbabwe (UZ) Farm was selected as the site for studying the general responses of lactating Holstein cows to different levels of shading and then evaluate the benefits of shade to cows during periods of intense solar radiation and high ambient temperatures. The farm's dairy unit is located in Agro-ecological Region 2a and situated about 6 km north of Harare along the Harare to Mazowe road. It lies at an altitude of about 1492 m on latitude 17.42^{o} and longitude 31.07^{o}. The area receives a mean annual rainfall of between 750 to 1000 mm or an average of 18 rainy pentads and generally enjoys reliable weather conditions (Surveyor General, 1998). It rarely experiences dry spells in summer. Maximum ambient temperatures during the summer can go above 27^{o}C with relative humidity averaging around 65%.

The experiment was conducted from 13 to 20 November 2004 in a feedlot (Fig 3.2) which is sited in one of the grazing paddocks on the farm. Ten lactating Holstein cows of parities ranging from 1 to 8 and at different stages of lactation, comprising nine black and white and one light coat coloured were used in the experiment. The ten cows were randomly allocated to ten feeding pens. The pens were in turn randomly allocated to two treatments: 100% and 30% shade. 100% shade was provided using galvanized iron sheets and 30% shade was provided using Hessian 30% shade cloth which was purchased from Farm and City; an agricultural inputs supplier in Zimbabwe. The suppliers had prescribed that the shade cloth provides 50% shade but after running a programme to measure the transmission of solar radiation through the material it was observed that it only provides 30% shade and thus the treatment was referred to as 30% shade.

Figure 3.2: Feedlot at the University of Zimbabwe farm

There were inbuilt feeding troughs in the feedlot and water troughs made from calibrated half cut 200 litre drums were placed at the back of each feeding pen. Clean water was piped using a hose pipe from a tap that was approximately 100 metres from the feedlot. An aspirated pyschrometer (wet and dry bulb thermometer) was placed at the centre of the feedlot.

Cows in the experiment were milked twice per day; in the morning and evening. The ten cows were driven into the feedlot at 0900 h after the morning milking session and were released at 1600 h for the evening milking session. Measurements of solar radiation, dry and wet bulb temperature, relative humidity, skin surface temperatures, respiration rates and rectal temperatures were taken from 1000 to 1600 h every day during the course of the day. This time band was chosen because of basically two reasons which are: the time band 1000 to 1600 h is the period when cows normally experience heat stress due to high solar radiation fluxes and elevated ambient temperatures and also that the milking schedule for the UZ dairy unit only allowed the experiment to be conducted within this time band. Figure 3.3 shows part of the feedlot under 100% shade.

An Automatic Weather Station (AWS) where some of the meteorological data was collected is sited in the Agricultural Meteorological Research Site approximately 500 metres from the feedlot.

The main objective of this experiment was to investigate the benefits of providing shade and to determine and observe production, physiological and behavioural responses of the Holstein cows subjected to different levels of shading.

Figure 3.3: Holstein cows in part of the feedlot (under iron sheets) at the University of Zimbabwe Farm

3.1.2.2 Management of the cows

Cows were fed with concentrate (crushed maize mixed with soya) at 1 kg per 2 kg of milk produced after the morning milking session at 0800 h. They were also given hay treated with 2 litres of molasses and mixed with 2 kg poultry manure. After finishing the after milking ration, the cows were driven to the feedlot at 0900 h where they were each given 5 kg concentrate dairy meal with 14.4% crude protein, 4.0% fat and 18.0% crude fibre at 1100 h. At 1200 h, the cows were given equal amounts of hay treated with molasses. Water was available in the water troughs. Each calibrated water trough was filled with 80 litres of fresh water everyday before the start of the experiment. At 1600 h the cows were released for the evening milking. Again after the evening milking, they were fed a concentrate (crushed maize mixed with soya) at 1 kg per 2 kg of milk produced together with hay treated with 2 litres molasses and mixed with 2 kgs poultry manure. The cows were not kept in the feedlot over the night.

3.1.2.3 Data Collection

Skin surface temperatures were taken from the cows using an infrared radiation thermometer which records the temperature in degrees Celsius. The measurements were taken from the lumbar region of the animal's exposed back area. Readings were taken at hourly intervals from 1000 to 1600 h everyday during the course of the experiment from 13 to 20 November 2004. Breathing rates per minute were measured with the aid of a stop watch by visual observation of flank movements of the animal (Hahn, 1990; Gaughan *et al.*, 1999). Observations of breathing rates were taken hourly from 1000 to 1600h each day of the experimental period. Rectal temperatures were recorded by putting a clinical thermometer in the rectum for one minute (Sarkar *et al.*, 1995). The animals were restrained before inserting the thermometer in the rectum. After taking the reading the instrument was shaken in order to reset it before the next measurement was taken. Rectal temperatures were taken at 2 hourly intervals from 1000 to 1600 h for only four days of the course of the experiment. This was due to the problems in the availability of manpower and difficulties which were associated with restraining the cows.

The total amount of water consumed by each animal per day was recorded at 1600 h. This was obtained through taking the volume of water which was left in the calibrated water troughs and subtracting it from 80 litres which was the initial amount in the trough. The feeding behaviour and the quantity consumed from 0900 to 1600 h were monitored and observed. Changes in frequency of feeding as ambient conditions change were also monitored. Times when the cows stopped and when they resumed feeding were noted. Milk yields were recorded during milking in the morning and evening and the total daily milk yield was obtained by adding the morning and evening milk yields. Calibrated milk collecting tanks which are part of the milking machine were used to record the yields. Milk yield was recorded everyday during the course of the experiment. In addition, records of milk yields of the ten cows for the five days before the start of the experiment were also obtained from the milk record book and were used as covariates in the analysis of milk yields.

Dry and wet bulb temperatures were recorded using an aspirated psychrometer positioned at the centre of the feedlot. Measurements were taken hourly from 0900 to 1600 h everyday during the course of the experiment. The values were used to calculate the Temperature-Humidity Index (THI) using the formula: $THI = 0.72 * [T_d + T_w] + 40.6$ where T_d and T_w are dry and wet bulb temperatures from the aspirated psychrometer, respectively (WMO., 1989; Jones and Stalling, 1999). Measurements of relative humidity and temperature were obtained from the Automatic Weather Station sited in the nearby Agricultural Meteorology Research Unit where the readings are saved in a datalogger and downloaded to a computer. Readings of relative humidity averaged over the previous 30 minutes were taken from 0900 to 1600 h everyday during the course of the experiment. Measurements of direct solar radiation were obtained from the Automatic Weather Station sited in the Agricultural Meteorology Research Unit where a Kipp and Zonen Solarimeter was mounted and it recorded solar radiation fluxes automatically and saved the readings in the datalogger connected where the data can be downloaded to a computer. Readings of solar radiation were taken at hourly intervals from 0900 to 1700 h everyday during the course of the experiment.

3.1.2.4 Statistical Analysis

The regression analysis with PROC REG and correlation analysis with PRO CORR in SAS was used. The following model was used in the analysis.

Y= Mean + S + THI + Covariate + Error

where:

Y = milk yield (kgs)/ skin surface temperature (^{o}C)/ respiration rate (breaths/minute)/ rectal temperature (^{o}C)/ water intake (litres/day) or feed intake (kgs/day),

S = effect of shade/ level of shade (%),

THI = temperature humidity index (THI units)

Covariate = mean values before treatments,

Error = measurement error

Correlations of skin surface temperature, respiration rate, rectal temperature and water intake with solar radiation, THI or ambient temperature were computed using the PROC CORR procedure of SAS (SAS, 1990). Mean skin surface temperature, respiration rate, rectal temperature, water intake and milk yield of cows under the 100% and 30% shade treatments was compared using ANOVA using the PROC GLM procedure of SAS.

3.1.3 Results

3.1.3.1 Meteorological Data

The highest solar radiation flux of 1194.1 W m^{-2} was recorded on 18 November 2004, highest day time relative humidity of 57.7% on 20 November 2004, highest dry bulb temperature (ambient temperature) of 31.5^{o}C on 12 November 2004 and the highest THI of 82.4 on 14 November 2004. Daily trends of solar radiation and dry bulb temperature showed that they both reached their maxima during midday but the peak of dry bulb temperature lagged behind the peak of solar radiation by an average of 2 h (Figure 3.4). Solar radiation reached its peak at 1200 h while the maximum ambient temperature was recorded 2 hours letter at 1400 h. Hourly averages for a whole day showed that THI increased from 0900 h reaching maximum levels in the middle of the day at 1400 h after which the index declined to get to low levels at 1700 h (Figure 3.5). Day time relative humidity declined from a maximum at 0900 h to a minimum level at 1300 h and later rose again towards sunset (Figure 3.4).

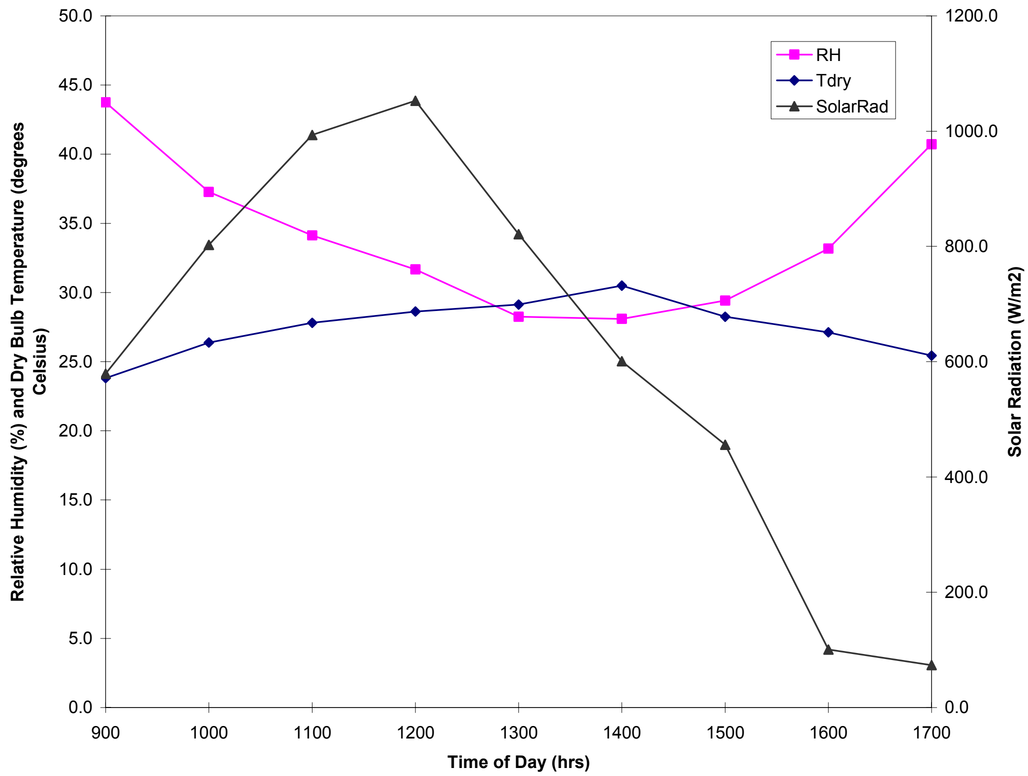

Figure 3.4: Average hourly solar radiation fluxes (SolarRad), dry bulb temperatures (Tdry) and day time relative humidity from 0900 to 1700 h for the period 13 to 20 November 2004 at the University of Zimbabwe Farm.

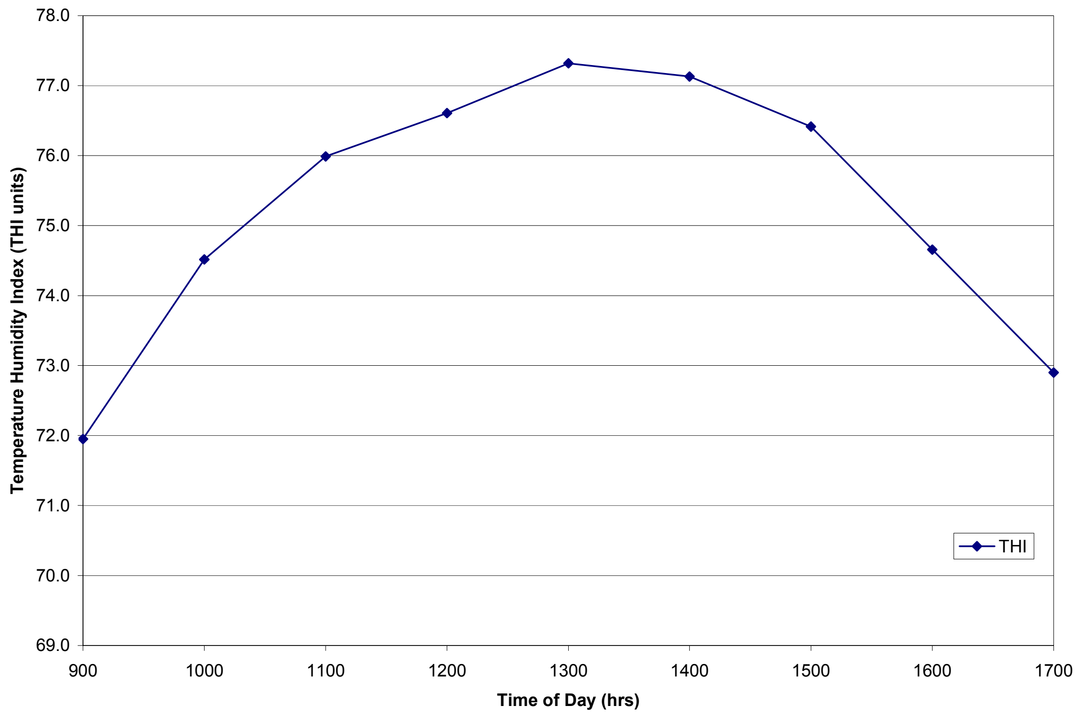

Figure 3.5: Hourly average temperature-humidity index (THI) for the period 13 to 20 November 2004 at the University of Zimbabwe Farm.

Daily variation in maximum daily recorded THI and dry bulb temperature (ambient temperature) showed sharp changes in both maximum THI and maximum dry bulb temperature from one day to the other for the whole experimental period (Figure 3.6). Highest THI was recorded on 14 November 2004 while the highest dry bulb temperature was recorded on 17 November 2004. Daily variation in solar radiation and relative humidity revealed notable fluctuations in recorded maximum daily solar radiation and maximum recorded relative humidity from one day to the other (Figure 3.7).

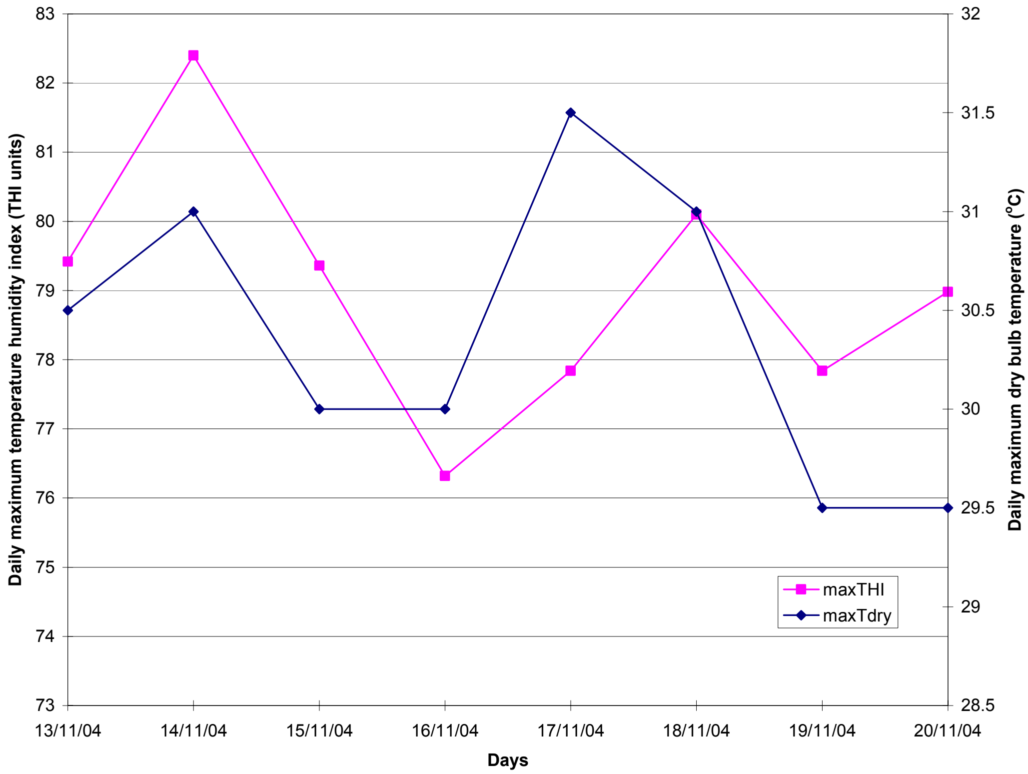

Figure 3.6: Daily maximum THI and maximum ambient temperature (Tdry) for the experimental period 13 to 20 November 2004

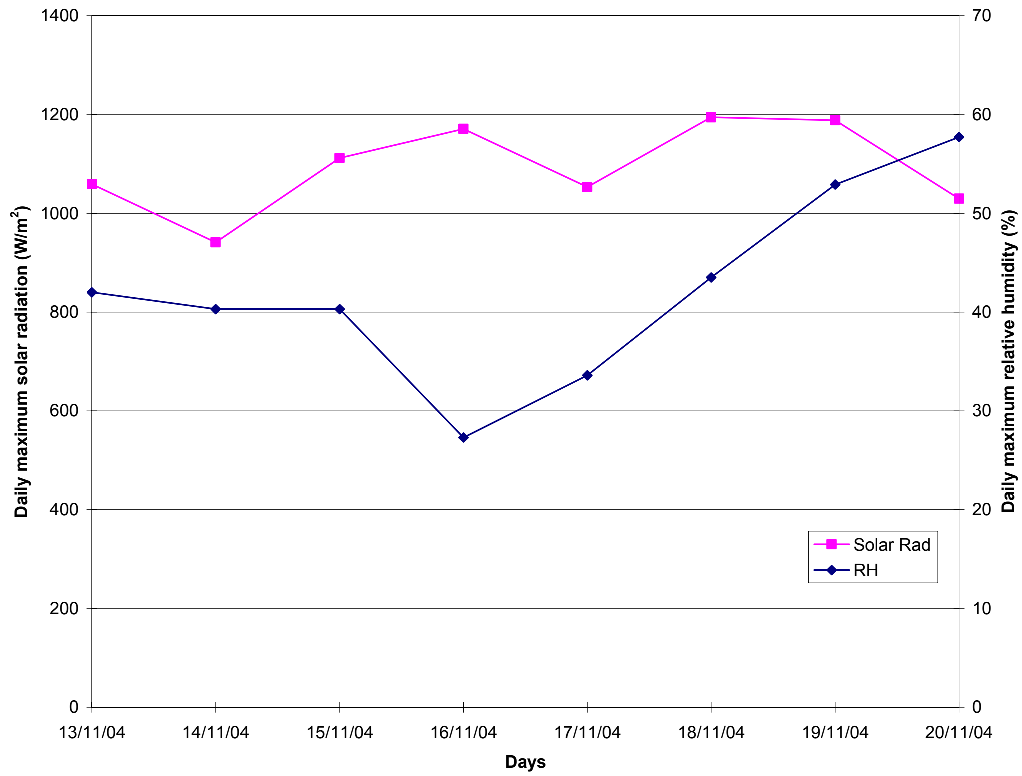

Figure 3.7: Daily maximum solar radiation fluxes and maximum day time relative humidity during the experimental period from 13 to 20 November 2004

3.1.3.2 Skin Surface Temperature

Measured skin surface temperatures under both shading treatments generally increased from a minimum at 1000 h, reaching maxima between 1200 h and 1400 h and then declining to low levels at 1600 h as both solar radiation and dry bulb temperatures decline to their minima. Skin surface temperatures under both shading materials fairly paralleled changes in THI (Figure 3.10). The highest skin surface temperature of 44°C for the cows under 30% shade was recorded at 1300 h on 20 November 2004 while the highest skin surface temperature (37.2°C) for cows under 100% shade was recorded at 1300 on 19 November 2004. Skin surface temperatures of cows under 100% shade never went above their rectal temperatures. Type and level of shading significantly ($P < 0.05$) affected skin surface temperatures. There were significant ($P < 0.05$) differences in average skin surface temperatures between cows under 100% shade and cows under 30% shade (Figure 3.8).

There was a low correlation (0.19) between skin surface temperatures of cows under 100% shade and solar radiation flux while a high correlation (0.94) was observed between skin surface temperatures of cows under 30% shade and solar radiation flux. High correlations between skin surface temperatures and dry bulb temperature of 0.81 and 0.75 were observed for 100% shade and 30% shade respectively. Correlations between skin surface temperatures and THI were 0.84 and 0.79 for 100% and 30% shade respectively. Changes in skin surface temperatures under both treatments generally followed changes in both THI and dry bulb temperature (Figures 3.9 and 3.10).

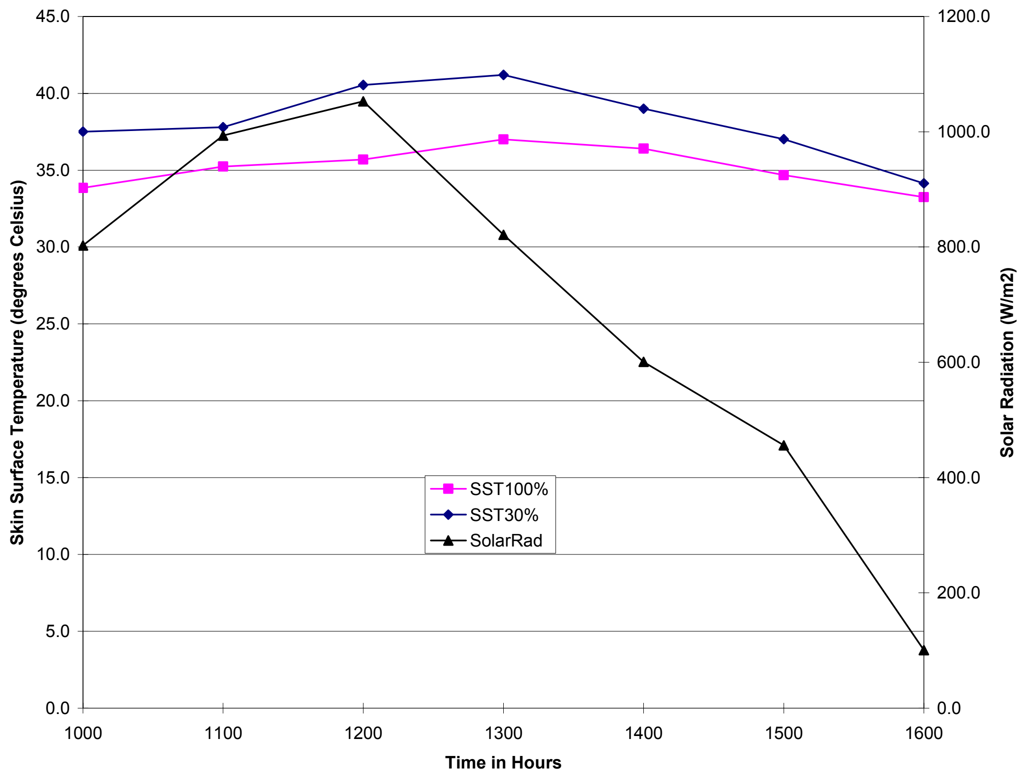

Figure 3.8: Average hourly solar radiation fluxes plotted with hourly average skin surface temperature for cows under 30% and 100% shade for the period 13 to 20 November 2004

[1]SST 100% - skin surface temperature under 100% shade

[2]SST30% - skin surface temperature under 30% shade

[3]SolarRad - solar radiation flux

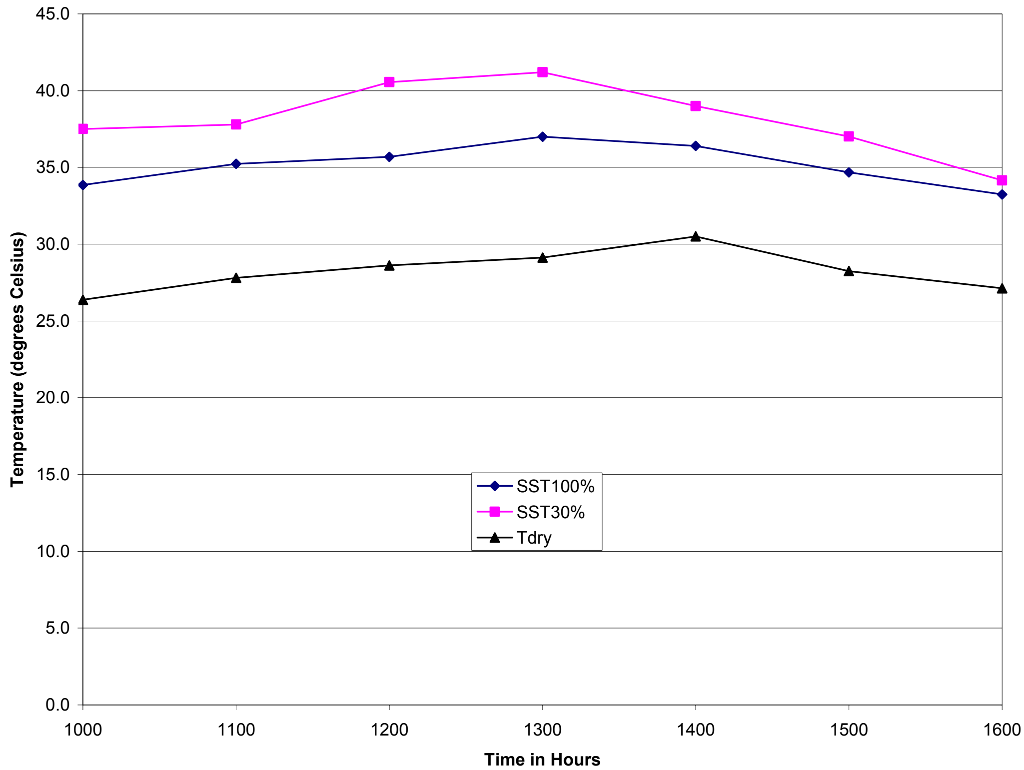

Figure 3.9: Average hourly skin surface temperatures (SST) for cows under 30% and 100% shade plotted with average hourly dry bulb temperatures (Tdry) for the period 13 to 20 November 2004

[1]SST 100% - skin surface temperature under 100% shade

[2]SST 30% - skin surface temperature under 30% shade

[3]Tdry - dry bulb temperature

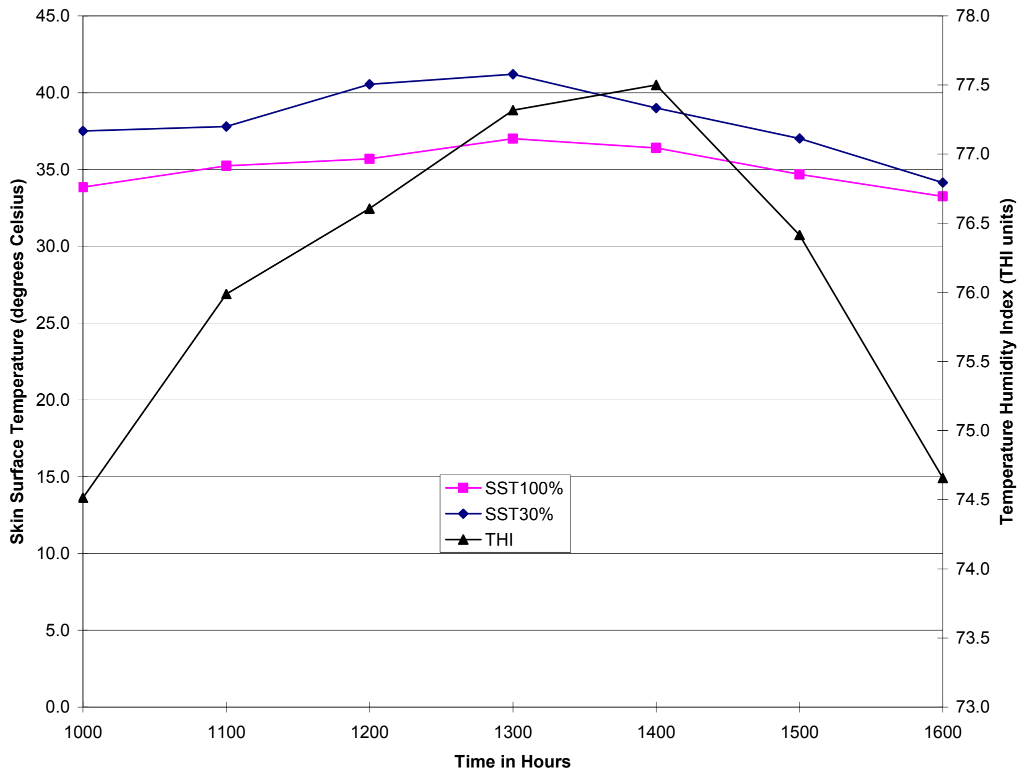

Figure 3.10: Average hourly skin surface temperature (SST) for cows under 30% and 100% shade plotted with temperature-humidity index (THI) for the period 13 to 20 November 2004

3.1.3.3 Respiration and Breathing Rate

Breathing rates for cows under both 100% and 30% shade tended to increase from low levels at 1000 h to maximum average values at 1400 h and declined to low levels again at 1600 h (Figure 3.11 and 3.12) following changes in both THI and solar radiation. The highest observed average breathing rate for cows under 100% shade was 43.2 breaths/minute while the highest observed average breathing rate for cows under 30% shade was 62.4 breaths/minute, both recorded at 1400 h. Average breathing rates between the two treatments were significantly different ($P < 0.01$).

Correlations of respiration rate with dry bulb temperature, THI, solar radiation and the difference between skin surface temperature and rectal temperature are summarized in table 3.2.

Table 3.1: Correlations (r value) of respiration rate (RR) against dry bulb temperature (Tdry), temperature-humidity index (THI), solar radiation (SR) and the difference between skin surface temperature and rectal temperature (SST-RT)

Correlation	R^2 value	
	100% shade	30% shade
RR vs Tdry	0.97	0.97
RR vs SR	0.15	0.55
RR vs SST-RT	0.91	0.97
RR vs THI	0.99	0.87

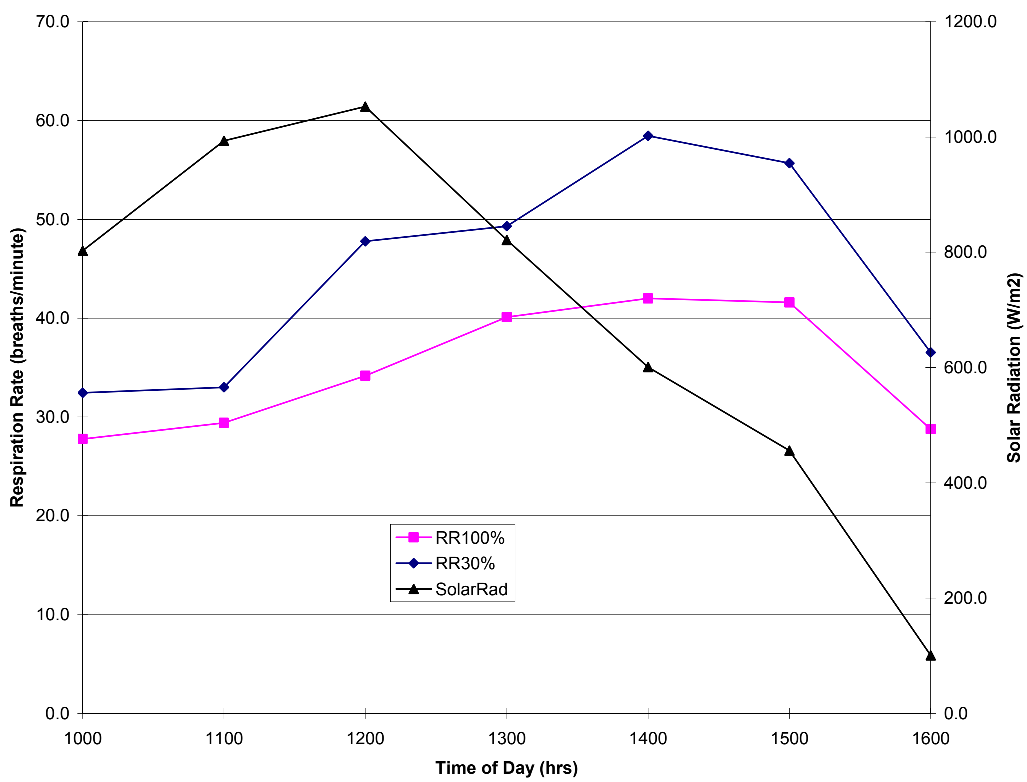

Figure 3.11: Average hourly solar radiation flux plotted with average hourly respiration rate for cows under 100% shade (RR100%) and cows under 30% shade (RR30%) for the period 13 to 20 November 2004

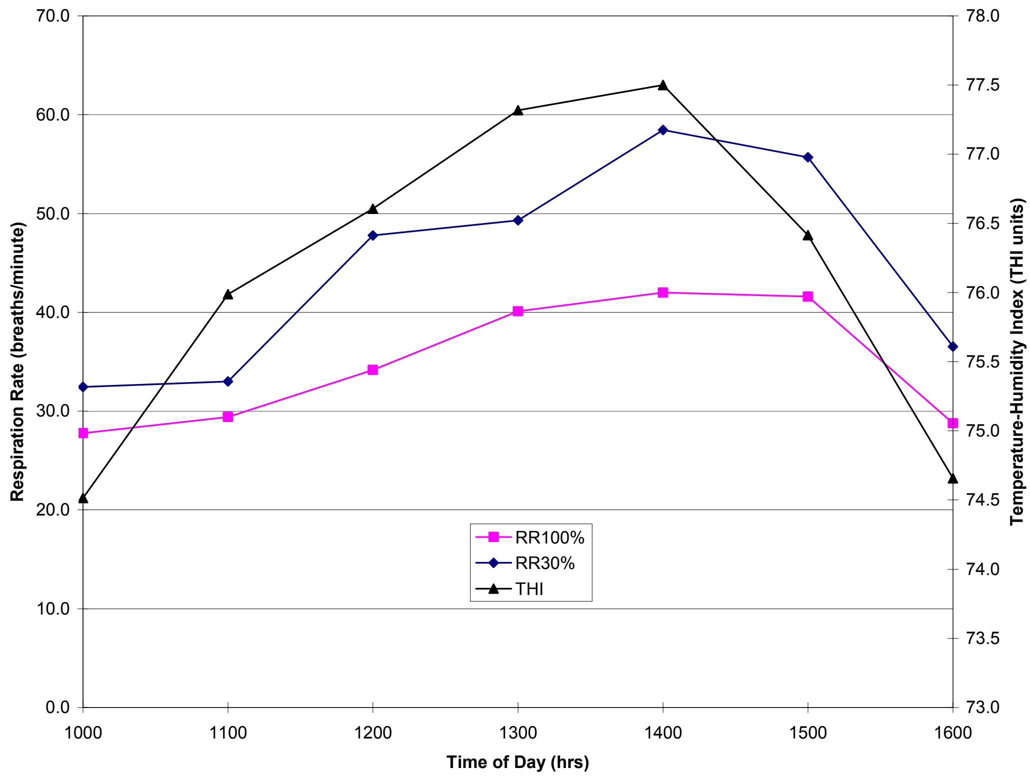

Figure 3.12: Temperature-humidity index (THI) plotted with average respiration rate for cows under 100% shade (RR100%) and under 30% shade (RR30%)

Respiration rates under both shade conditions increased as skin surface temperatures increased and as the difference between skin surface temperature and rectal temperature widened (Table 3.2). Highest breathing rates under both shade levels were recorded when the difference between skin surface temperature and rectal temperature was largest (Table 3.2). This is supported by the high correlations between respiration rate and the difference between skin surface temperature and rectal temperature (SST-RT) of 0.91 and 0.97 for 100% shade and 30% shade respectively. There was a high positive correlation (0.97) between respiration rate and dry bulb temperature under both shade levels (Table3.2). A high positive correlation (0.99) between respiration rate and THI was observed for cows under 100% shade while a positive correlation (0.87) was observed for cows under 30% shade. There was a low positive correlation (0.15) between respiration rate and solar radiation for cows under 100% shade while a fairly high correlation (0.55) was obtained for cows under 30% shade for the same regression. Table 3.3 gives a summary of diurnal changes in respiration rate as skin surface temperature change with a low variation in rectal temperature.

Table 3.2: Hourly changes in skin surface temperature (SST, ^oC), rectal temperature (RT, ^oC), respiration rate (RR, breaths/minute) and the difference between skin surface temperature and rectal temperature (SST-RT, ^oC) for cows under 100% shade on 18 November 2004

Time	SST	RT	SST-RT	BR/RR
1000	34.0	37.8	-3.8	27
1100	35.0	37.8	-2.8	30
1200	35.6	37.8	-2.2	37
1300	36.1	37.8	-1.7	39
1400	36.4	37.8	-1.4	43
1500	35.2	37.8	-2.6	33
1600	33.3	37.9	-4.6	28

Table 3.3: Hourly changes in skin surface temperature (SST, ^oC), rectal temperature (RT, ^oC), respiration rate (RR, breaths/minute) and the difference between skin surface temperature and rectal temperature (SST-RT, ^oC) for cows under 30% shade on 18 November 2004

Time	SST	RT	SST-RT	BR/RR
1000	36	37.8	-1.8	34
1100	37.2	37.8	-0.6	42
1200	38.9	37.8	1.1	57
1300	40	38	2	58
1400	40.5	38.1	2.4	62
1500	38.3	38	0.3	49
1600	35.4	38.5	-3.1	47

Diurnal trends in skin surface temperatures and rectal temperatures (Tables 3.3 and 3.4) for cows under both shading levels showed that the widest difference between the two was attained from mid-day to 1400 h and this is when the highest respiration rates were recorded.

3.1.3.4 Rectal Temperature (RT)

Changes in rectal temperatures showed a diurnal monophasic cycle with a minimum in the morning and a maximum in the late hours of the day (Figure 3.13).

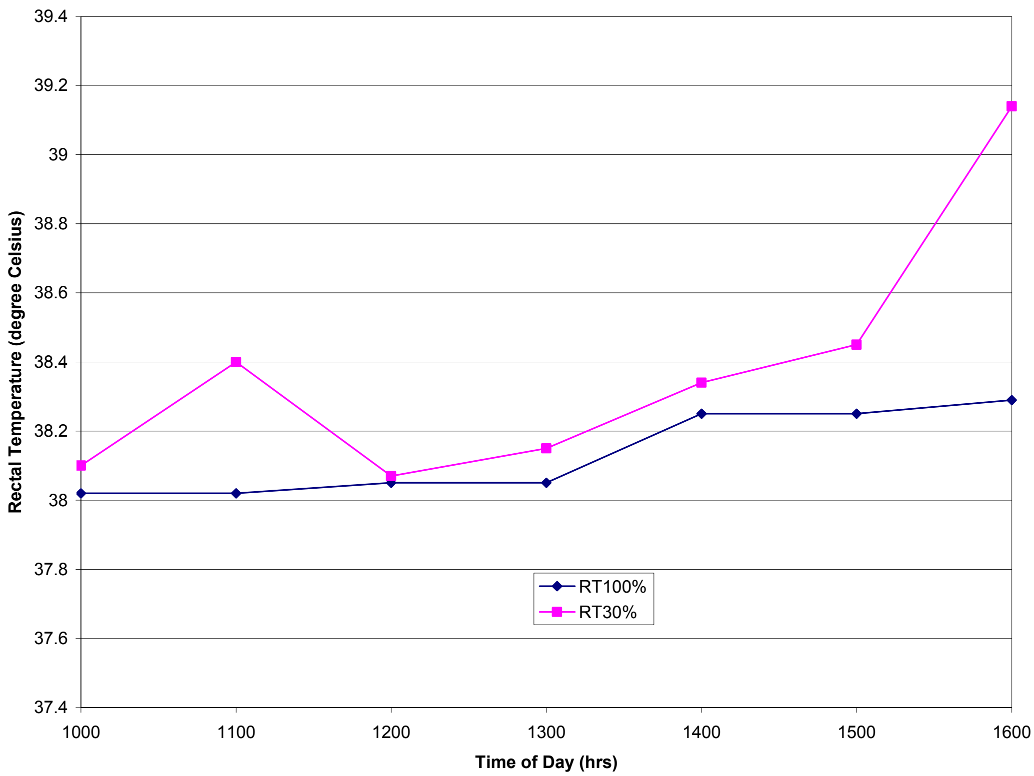

Figure 3.13: Hourly average rectal temperature for cows under 100% shade (RT100%) and cows under 30% shade (RT30%) for the period 13 to 20 November 2004

From Figure 3.13 it was observed that rectal temperatures of cows under 30% shading were always numerically higher than rectal temperatures of cows under 100% shading for the time interval 1000 to 1600 h. The highest recorded average rectal temperature for cows under 100% shade was 38.2^{o}C while the highest recorded average rectal temperature for cows under 30% shading was 38.7^{o}C and both were recorded at 1600 h. The average rectal temperatures recorded at 1600 h were significantly ($P < 0.05$) different between the shade treatments. The daily average rectal temperatures for cows under 100% and 30% shading were 38.1^{o}C and 38.4^{o}C, respectively. Rectal temperatures followed a different trend from that of solar radiation and THI (Table 3.5).

Table 3.4: Changes in rectal temperatures with changes in solar radiation, ambient temperature and THI for cows under 100% shade and 30% shade on 15 November 2004

Time	Solar Rad Wm^{-2}	Tdry ^{o}C	THI THIunits	Average Rectal Temperatures 100%shading	30%shading
1000 h	788.2	27.5	75.18	38.0	38.2
1200 h	1111.8	29.0	75.94	38.1	38.2
1400 h	217.6	30.0	79.36	38.2	38.6
1600 h	123.5	27.5	74.8	38.3	38.8

Results in Table 3.5 show that under both shading materials, maximum rectal temperatures lagged behind maximum solar radiation and maximum ambient temperatures by about 4 h and 2 h respectively. Maximum rectal temperature was recorded 2 h after the highest recorded THI. There were low correlations between rectal temperature and THI, solar radiation and dry bulb temperature. The average correlation coefficients between rectal temperature with THI and solar radiation for the whole research period were 0.46 and 0.14 respectively for cows under 100% shading and correlations for cows under 30% shading with the same factors were 0.51 and 0.58 respectively. Shading level differences did not have very significant ($P > 0.01$) effects on daily average rectal temperatures although cows under 30% shading recorded significantly ($P < 0.05$) higher average rectal temperatures during the late hours of the day (1600 h).

3.1.3.5 Water Intake

General drinking behaviour showed that cows under 30% shading started drinking water earlier than those under 100% shading. Three of the five cows under 30% shading would have their first drink of water at around 1100 h while four of the five cows under 100% shade would have their first drink of water at around 1300 h.

The average water intake for cows under 100% shade for the whole experimental period was 44.3litres while that for cows under 30% shade for the same period was 57.2 litres. Fig 4.13

shows daily changes in the average amount of water consumed under each treatment for the whole experimental period.

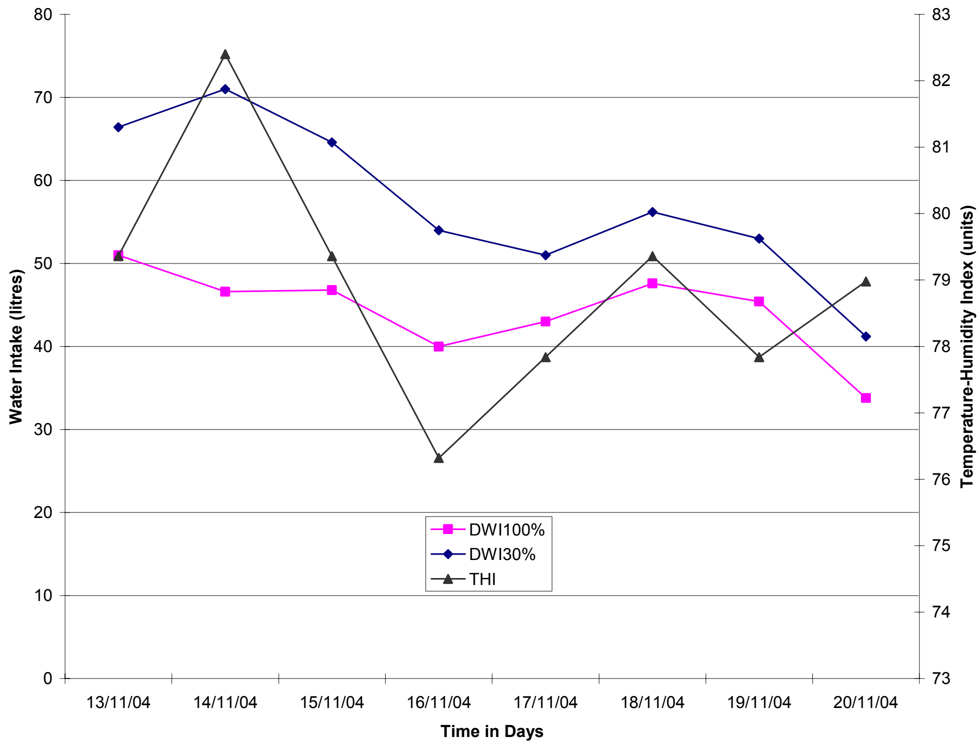

Figure 3.14: Daily average water intake for cows under 30% (DWI 30%) shade and 100% (DWI 100%) shade plotted with temperature-humidity index (THI)

3.1.3.6 Feed Intake

All the ten animals consumed the feed rations which were given to them but the general feeding behaviour varied between the two shading treatments. At 1100 h, all the animals consumed the 2 kg dairy meal concentrate which they were given. At 1200 h all the cows under 100% shade continued feeding while only 20% of cows under 30% shade were still feeding. Highest solar radiation fluxes were recorded between 1200 and 1300 and during this period, none of cows under 30% shade could be seen feeding (Table 3.6).All the cows under 30% shade stopped feeding at 1300 h. However, 60% of the cows under 100% shade continued feeding during this period. By 1600 h, all the cows in both treatments could be seen feeding.

Table 3.5: Feeding behaviour of cows under 100% shade and under 30% shade on 18 November 2004

Time (hrs)	Td (°C)	Solar Radiation (Wm^{-2})	Percentage of cows feeding 100% shade	30% shade
1100 h	27.5	958.8	100%	100%
1200 h	28	1194.1	100%	20%
1300 h	30.5	1183.4	60%	0%
1400 h	31	870.6	80%	0%
1500 h	30.5	752.9	100%	40%
1600 h	30	105.9	100%	100%

3.1.3.7 Milk Yield

There was a general improvement and decline in milk yield for cows under 100% and 30% shade respectively (Table 3.7). Average pre-treatment milk yields/cow/day were significantly ($P < 0.05$) different from average milk yield/cow/day after the experiment for cows under both shading levels. The average daily milk yield/cow/day for cows under 100% shade increased by an average of 6.9% while the average milk yield/cow/day for under 30% shade declined by an average of 16.3% from the pre-treatment averages.

Table 3.6: Mean milk yields/cow for the treatment and the pre-treatment period

	Mean Milk Yields/Day/Cow									
	100% shade					30% shade				
Cow	0499	0485	0492	2912	37	0493	459	53	51	47
Pre treatment yields	12.6	10.3	12.0	10.9	9.9	13.9	11.9	15.2	15.5	8.9
Treatment yields	14.6	10.7	12.5	11.3	10.9	12.8	10.7	11.5	11.2	9.7
%change	13.7	3.7	4	3.5	9.6	-8.6	-11.2	-31.4	-38.4	8.2

3.1.4 Discussion

3.1.4.1 Meteorological Data

The weather conditions which were associated with Experiment 1 were typical of conditions experienced during the first trimester of the summer season in Zimbabwe. Temperature-humidity index which was used in Experiment 1 as an indicator of heat stress in dairy cows increased with time of the day from a minima at 0900 h, then peaked at 1400 h and declined at 1700 h. This was probably due to the general change in solar radiation flux and dry bulb temperature which followed the same trend. The general increase in radiation input to the earth's atmosphere system causes a corresponding increase in ambient temperature and hence THI increase. The period of maximum THI was around 1400 h, which is about two hour lag from 1200 h, the time of expected maximum solar radiation input. During the period of Experiment 1, the THI always exceeded 72 units which according to Wagner (2001) is usually the threshold point at which heat stress occurs. The average day-time THI at the University of Zimbabwe farm during the period when meteorological data measurements were taken was 74.8 units which was about 3 units above the stress threshold of 72 units. Therefore it can be said that the whole experimental period was characterized by heat stress conditions during the day and particularly the hottest hours of the day.

Relative Humidity was of little relevance as a parameter that was supposed to be considered as contributing to heat stress and this was evidenced by the low correlation with THI. Possibly it could have been more important if measurements of vapour pressure were taken. Vapour pressure gives an indication of the amount of moisture in the atmosphere which in turn determines the extent of heat loss from animals by latent heat through sweating and panting. For all the days when the research was conducted, relative humidity was lowest during the warmest hours of the day (1100 to 1400 h). According to Atkeson *et al*. (1997), the primary sources of heat gain by an animal from the environment are solar radiation by both direct and indirect radiation and elevated ambient temperature and these are significantly complicated by high relative humidity and lack of air movement.

3.1.4.2 Skin Surface Temperature

Average skin surface temperatures for cows under 30% shade were always significantly ($P < 0.05$) higher than temperatures of cows under 100% shade at each given time of the day. Highest skin surface temperatures for all the cows under the two different shading levels were recorded between 1200 h and 1400 h regardless of the type of shading material and this was roughly the period when maximum solar radiation and dry bulb temperatures were recorded. Skin surface temperatures of cows under both shading materials fairly paralleled changes in both THI and solar radiation. Skin surface temperatures for cows under 30% shading tended to respond more to changes in solar radiation than THI. Thus THI may need to be modified for indoor and outdoor animals.

According to Mount (1979), a rise in skin surface temperature is a thermoregulatory response that is adopted by animals as thermal needs of the animal shift from heat production or conservation to heat dissipation and a reduction on insulation. It was attributed that a raised skin surface temperature is a result of peripheral vasodilation and an increased skin blood flow. In Experiment 1, it was observed that skin surface temperatures rise as the surrounding ambient environment becomes warmer than before. Skin surface temperatures for cows under both shading materials were always higher than the ambient temperature. According to Gates (1980), in a warm environment, the body of an animal has to maintain a steep temperature gradient between the skin surface and the environment in order to achieve both sensible and radiative heat losses. This might be the reason why the skin temperatures became elevated as ambient temperatures rose. The notable differences in skin surface temperatures between cows under 30% and 100% shade could have been caused by differences in type and level of shading.

3.1.4.3 Respiration and Breathing Rate

There were drastic changes in respiration rates of cows under 30% shade as both solar radiation and THI changed. Respiration rates of cows under 30% Hessian shade cloth significantly ($P < 0.05$) paralleled changes in both solar radiation and THI. Cows under corrugated iron sheets had significantly ($P < 0.05$) lower respiration rates than those which were under the 30% Hessian shade cloth. This probably means that cows under 100% shade were less stressed than those under 30% shade and hence the comparatively different respiration rates between the two shade treatments.

Respiration rate has long been served as a gross indicator of heat load in animals during hot weather, increasing when animals need to maintain homeothermy by dissipating excess heat as benign avenues become inadequate (Hahn, 1999). According to Brown *et al*. (2004), it was found that respiration is a good indicator of stress and can be easily monitored without expensive equipment. Paggot (1993) revealed that respiration rate can change very rapidly and at the extreme, in a matter of minutes which is typical of what was observed in Experiment 1. Average respiration rates of 43 breaths/minute and 62 breaths/minute for cows under 100% and 30% shade respectively were far less than the threshold levels of 80 to 120 breaths/minute which were given by both Mount (1979) and Gaughan *et al.* (1999) as indicative of cattle under severe thermal stress. Hahn (1999) identified a threshold rate at an air temperature of 21.3^{o}C with respiration rate increasing by 4.3 breaths/minute/^{o}C above a baseline of 60 breaths/minute at the threshold temperature.

In a research conducted by the United States Department of Agriculture, Brown *et al*. (2004) observed that respiration rate of shaded cattle was lower at hotter hours of the day than of unshaded cattle. This probably supports what was observed in Experiment 1 where average respiration rate of cows under 100% shade was significantly ($P < 0.05$) lower than for those under 30% shade. According to Sarkar *et al*. (1995), respiration frequency has been reported to increase significantly around 20^{o}C in the European breeds of cattle and around 32^{o}C in Brahman cattle, although it starts rising around 16 to 18^{o}C and 28^{o}C respectively. In Hahn (1999), respiration rate lagged behind changes in dry bulb temperature during both thermoneutral and hot conditions with the highest correlation obtained for a lag of 2 h between respiration rate and dry bulb temperature and this agrees perfectly well with what was discovered by Brown *et al*. (2003) who observed that maximum breathing rates occur about 2 h after maximum ambient temperature. However both reports differ with what was observed in Experiment 1 where the highest respiration rate was recorded an hour after the maximum ambient temperature under both shading materials and this implies that there was a 1 h lag between highest respiration rate and maximum temperatures. Increased respiration rate can be described as a symptom which is considered to be an attempt by heat-stressed cows to maintain body temperature.

3.1.4. Rectal Temperature

Rectal temperature increased from a minima at 1000 h to reach a maxima at 1600 h when the last rectal temperature measurement was taken. The daily average rectal temperature for cows under 100% and 30% shade was $38.1^{o}C \pm 0.3$ and $38.4^{o}C \pm 0.4$ respectively. However, the normal rectal temperature of cattle has been found to be $38.5^{o}C$ (Seigmund, 1979 in Breinholt *et al*., 1981). The upper limit of rectal temperature is $38.6^{o}C$ (N.S.W, 2004) which is higher than the average rectal temperatures which were obtained for cows under both 100% and 30% shade. Rectal temperatures showed a mono-phasic diurnal rhythm with a minima in the morning and a maxima in the late hours of the day and this was in agreement with what was observed by Gaughan *et al*. (1999) and Hahn (1999). maximum rectal temperatures under both 100% and 30% shade lagged behind maximum air temperature by 2 h. Highest ambient temperatures were recorded at 1400 h while highest rectal temperatures were recorded at 1600 h. This agreed Kibler *et al*. (1956) cited by Breinholt *et al*. (1981) who reported that the rectal temperature rise lagged behind that in ambient temperature by 1 to 2 h and the fall to normal levels with falling ambient temperature required about 9 h. Research by Brown *et al*. (2003) on thermoregulatory responses of feeder cattle revealed that the maximum body temperature did not occur until about 4 h after maximum air temperature. Maximum rectal temperature in Experiment 1 lagged behind that in solar radiation by 4 h and the rectal temperatures rose significantly ($P < 0.05$) when the ambient temperature rose above $28^{o}C$ and this closely agrees with what Singh (1977) cited by Sarkar *et al*. (1995) reported, where a significant rise in rectal temperature in cattle at $27.3^{o}C$ ambient temperature.

Svotwa (2001) observed a low correlation between rectal temperature and THI and this is similar to what was observed in Experiment 1. A rise in rectal temperature results when heat load exceeds heat dissipation and according to Ansell (1981) the most convenient method of assessing the heat stress on animals is by monitoring rectal temperatures. Slightly higher average rectal temperatures for cows under 30% shade could have been a result of the higher radiation loads due to exposure to more direct solar radiation compared to cows under corrugated iron sheets which provided 100% shade.

3.1.4.5 Water Intake

The daily average water intake for cows under 100% shade was significantly ($P < 0.05$) lower than average water intakes for cows under 30% shade. Cows under 30% shade started drinking water a bit earlier that those which were under 100% shade. Nearly all cows under 30% shade would start drinking water at around 1200 h while those under 100% shade would start drinking water at around 1300 h. Water is the primary nutrient needed to make milk accounting for over 85% of the content of milk (Pennington *et al*., 2004) and this probably justifies why dairy cows generally drink more water compared to other breeds of cattle. On average, dairy cows consume 50 to 100 litres of water per day (Lee, 2003). The consumption of water increases sharply as the environmental conditions become stressful (Sarkar *et al*. 1995) and probably this explains why cows under 30% shade consumed more water than those under 100% shade. In Experiment 1, water consumption for cows under 100% and 30% shade increased by 10 and 25% respectively when the daily average THI rose above 80 units and this differs well with a 50% rise in water consumption that was reported by Pennington *et al*. (2004) when environmental temperature rise and THI rose by the same magnitude. Lee (2003) however reported that the water intake under heat stress could significantly increase by 120 to 200%. Lee attributed the increased water intake in heat stressed cows to increased water loss by heat dissipation through the lungs (respiration) and by sweating. Increased water intake is a thermoregulatory response by heat stressed cows which they use to maintain their body temperature by losing excess heat through evaporative means and this probably can also explain why cows which were exposed to more radiation (30% shade) consumed more water than those which were under 100% shade.

3.1.4.6 Feed Intake

In Experiment 1, cows under 30% shade stopped feeding at around 1200 h when the ambient environment was getting hotter as both solar radiation and THI rose to their maxima. THI rose above the threshold of 72 units between 1200 h and 1400 h. In contrast, nearly all the cows under 100% shade could continue feeding during this warm period of the day.

According to Linn (1997), voluntary dry matter intake can decrease by 50% of that in the thermoneutral zone during heat stress. The association between thermoregulation and voluntary feed intake is the basis for the concept of thermostatic regulation of feed intake, whereby control of body temperature is ultimately linked to the hypothalamic set point when energy density of the diet is not limiting (Hahn, 1999). Cows modify feeding behaviour during hot weather and this possibly explains why cows under 30% shade could not continue feeding during the hottest hours of the day. In a hot environment, feed or hay intake declines in relation to THI and this was clearly illustrated by Johnson (1990) who observed that the decline in feed intake during periods of heat stress was about 0.23 kg/day for each unit increase in THI above the threshold of 72 units. The related decline in milk yield with increasing THI was approximately 0.26 kg/day milk decline/unit increase in THI. Heat stressed cows decrease dry matter intake in an attempt to reduce heat production from the digestion and metabolism of nutrients.

3.1.4.7 Milk Yield

The average milk yield/cow/day increased in cows which were under 100% shade and dropped significantly ($P < 0.05$) in cows which were under 30% shade. Daily average milk yield/cow/day for cows under 100% shade increased by an average of 6.9% while those under 30% shading showed an average decline of 16.3%. The general decline in milk yield for cows under 30% shade agreed with what was reported by Wagner (2001) who revealed that under heat stress, milk yields can be reduced by 3 to 20% or more. Johnson (1982) observed that milk yield declined by 0.2 kg/day for each unit increase in THI. Possibly, the notable increase in milk yield for cows under corrugated iron sheets was due to the comfortable micro-environment provided by completely cutting off direct solar radiation. However much of the milk production observed for the heat stressed cows under 30% shade can be attributed to the decreased dry matter intake (Linn, 1997) and decreased feed efficiency (Wagner, 2001).

3.1.5 Conclusion

Cows under the Hessian 30% shade cloth had higher skin surface temperatures, respiration rate, rectal temperatures and water intake compared to those which were under corrugated iron sheets which were provided with 100% shade. Average percentage change in milk yield/cow/day between the pre-treatment and the treatment period was higher in cows under 30% shade compared to those under 1000% shade. The positive response of cows under 100% shade can therefore justify the benefits of providing shade to lactating cows during the hot summer season. Shading can be adopted as one of the effective measures to counteract the adverse effects of the hot summer weather at the University of Zimbabwe farm. From Experiment 1, it was observed, with regard to production and physiological responses of cows, that the Hessian shade cloth can not be used as an effective shading material and therefore there is need to test the effectiveness of other possible shading material like the commonly used Hessian 80% shade cloth although they do not necessarily cut off incident solar radiation completely like the corrugated iron sheets.

3.2 Experiment 2: Comparison of skin surface temperatures of Holstein cows under corrugated iron sheets (100% shade), under Hessian 80% and under Hessian 30% shade.

3.2.1 Introduction

From experiment 1, it was observed that the physiological responses of cows under 30% shade were typical of heat stressed cows. Compared to the galvanized iron sheets, it can be said that the 30% shade cloth was not an effective shading material. Besides the galvanized iron sheets and the Hessian 30% shade cloth, there are other materials which can be used for providing shade to dairy cows although their effectiveness has not been tested in a Zimbabwean situation. These materials include the commonly used 80% Hessian shade cloth which is normally used in carports and the locally produced mates made from rids. Although these do not cut out direct solar radiation completely, they can probably be as effective in providing comfort to dairy cows as the galvanized iron sheets or any other material that completely cuts out solar radiation like asbestos sheets. From this background, there was need to confirm the effectiveness of 80% Hessian shade cloth and compare it with the galvanized iron sheets and 30% Hessian shade cloth which were used in experiment 1. The main objective of this experiment was to compare the effectiveness of the three shading materials in reducing a rise in skin surface temperatures which is probably a direct response to high solar radiation loads on the skin of the cows.

3.2.2 Materials and Methods

3.2.2.1 Site Description and Experimental Design

The same site and feedlot which was used in experiment 1 was used in Experiment 11. The ten cows were randomly allocated to the feeding pens. The pens were in turn randomly allocated to three treatments: 100%, 80% and 30% shade. 100% shade was provided using galvanized iron sheets, 80% shade was provided using Hessian 80% shade cloth and 30% shade was provided using Hessian 30% shade cloth. Four pens were put under 100% shade, three under 80% shade and the other three pens under 30% shade. Feeding and watering facilities were arranged as in experiment 1. Figure 3.15 shows part of the feedlot under 80% shade.

Figure 3.15: Holstein cows in a feedlot under Hessian 80% shade cloth

3.2.2.2 Management of the Cows

Cows were fed with concentrate (crushed maize mixed with soya) at 1kg per 2kg of milk produced after the morning milking session at 0800 h. They were also given equal amounts of corn silage (5 kg). After finishing the ration, the cows were driven to the feedlot at 0900 h where they each received 5kgs concentrate dairy meal with 14.4% crude protein, 4.0% fat and 18.0% crude fibre at 1100 h. At 1200 h the cows were given equal amounts of corn silage. Water was made available in the water troughs. Each calibrated water trough was filled with 80 litres of clean fresh water. At 1600 h, the cows were released for the evening milking session and again after this milking session they were fed with concentrate (crushed maize mixed with soya) at 1kg per 2kg of milk produced and equal amounts of corn silage (3 kg). As in experiment 1, the cows were not kept in the feedlot over the night.

3.2.2.3 Data Collection

Only skin surface temperatures were recorded in this experiment and measurements were taken using the infrared radiation thermometer which records temperature in degrees Celsius. The measurements were taken from the lumber region of the back of the animals. The skin surface temperatures were taken at hourly intervals from 1000 to 1600 h everyday during the course of the experiment.

3.2.2.4 Statistical Analysis

The regression analysis with PROC REG and correlation analysis with PRO CORR in SAS (1996) were used. The model below was used in the analysis.

SST = Mean + S + Error

where:

SST – skin surface temperature (^{o}C)

S – level of shading (%)

Error – measurement error

Student's t-test for comparison of means of skin surface temperatures of cows under the three shading levels was carried out. PROC t-test procedure of SAS was used. Correlations of skin surface temperatures against solar radiation fluxes were computed using PROC CORR procedure of SAS (SAS, 1996).

3.2.3 Results

3.2.3.1 Skin Surface Temperature

Like in experiment 1, skin surface temperatures of cows under the three shading levels generally increased from a minima at 1100 h, reaching a maxima between 1200 h and 1400 h and then declining to low levels at 1600 h as both solar radiation and dry bulb temperature (ambient temperature) decline to their minima (Table 3.8).

Table 3.7: Hourly average solar radiation (Wm^{-2}), dry bulb temperature (Tdry, ^oC) and skin surface temperatures (^oC) of cows under 30%, 80% and 100% shading on 16 February 2005 at the University of Zimbabwe Farm

Time	Solar Radiation	Tdry	Skin Surface Temperatures		
			30% shade	80% shade	100% shade
1100	726.8	24.3	37.4	33.4	33.1
1200	566	25.2	40.3	35.4	33.9
1300	1129.6	25.3	45.6	36.7	35.2
1400	710.4	26.3	43.1	36.2	35.0
1500	557.2	25.6	34.3	33.1	33.4
1600	181.8	24.5	33.4	33.3	33.1

Average hourly skin surface temperatures of cows which were under 30% shading were significantly ($P < 0.05$) different from averages of cows under both 80% and 100% shading (Figure 3.16 and 3.17). There were no significant differences ($P > 0.05$) between average skin surface temperatures of cows under 80% shade and those of cows under 100% shade. Average skin surface temperatures paralleled changes in solar radiation fluxes especially for cows under 30% shading (Figure 3.16). Skin surface temperatures of cows under 80% and 100% shading did not go above average rectal temperature (38.5^{o}C) (Figures 3.16 and 3.17).

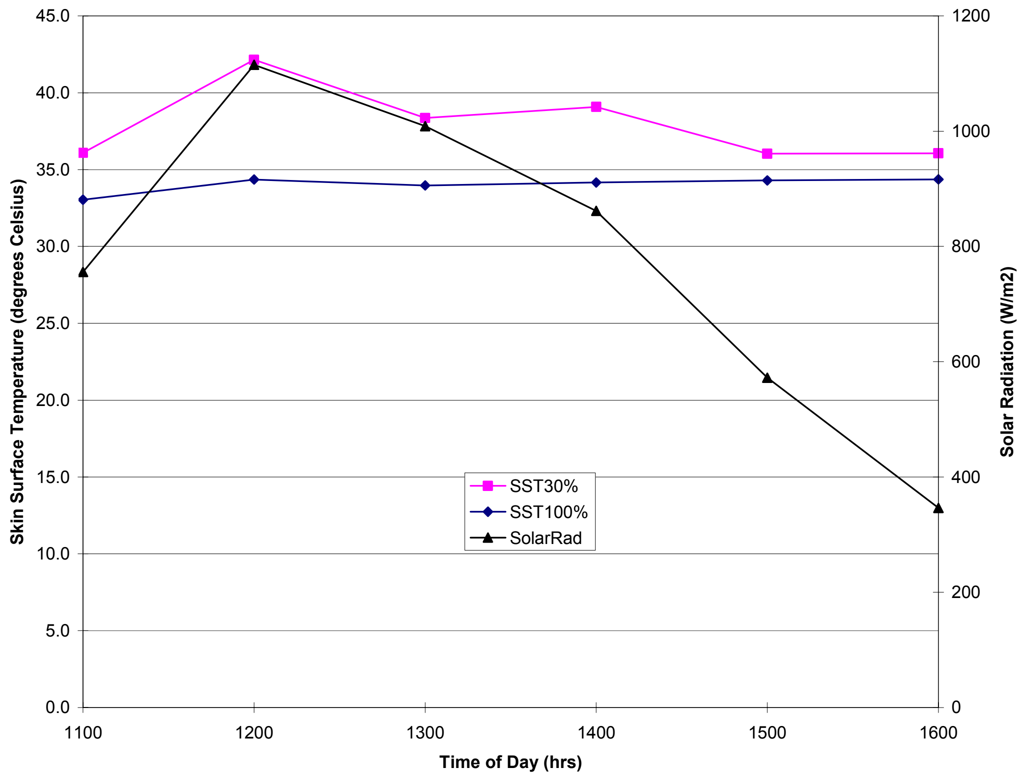

Figure 3.16: Average hourly solar radiation (SolarRad) and average skin surface temperature for cows under 30% shade (SST30%) and 100% shade (SST100%) for the period 15 to 18 February 2005

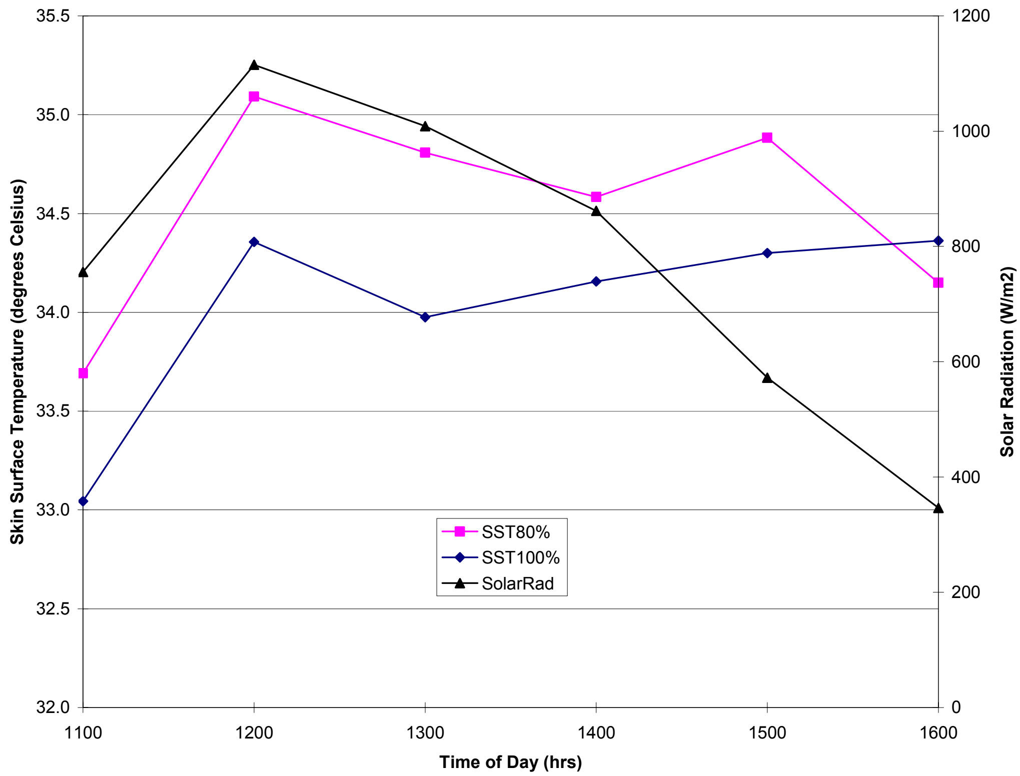

Figure 3.17: Average hourly solar radiation (SolarRad) and average skin surface temperature for cows under 80% shade (SST80%) and 100% shade (SST100%) for the period 15 to 18 February 2005

The highest average skin surface temperatures were recorded at 1200 h under the three shading levels although the skin temperatures for cows under 30% shade were significantly ($P < 0.05$) different from those of cows under both 80% and 100% shading.

3.2.4 Discussion

Skin surface temperatures of cows under Hessian 30% shade cloth were significantly ($P < 0.05$) higher than of those under Hessian 80% shade cloth and corrugated iron sheets. Like in Experiment 1, skin surface temperatures of cows under the three shading materials paralleled changes in both ambient temperature and solar radiation. There were no significant ($P < 0.05$) differences between skin surface temperatures of cows under Hessian 80% shade cloth and corrugated iron sheets. Hessian 80% shade cloth can be used as an alternative shading material and is the commonly used Hessian material for providing shade to lactating cows during the hot summer season.

3.2.5 Conclusion

Hessian 30% shade cloth can not be used as an effective shading material while Hessian 80% shade cloth can be used as an effective alternative shading material in place of those which completely cut off direct solar radiation. This can be supported by the physiological responses of cows which were under the Hessian 30% shade cloth which revealed signs typical of heat stressed animals.

CHAPTER 4

RADIATION BALANCES UNDER DIFFERENT SHADING MATERIALS

4.1 Experiment 3: Comparison of long wave and short wave radiation fluxes under corrugated iron sheets, Hessian 80% shade cloth and Hessian 30% shade cloth.

4.1.1 Introduction

There are many different materials that can be used for providing shade to dairy cows during the hot summer season and these include materials which were used in Experiment 2 and others like thatch, asbestos and locally produced mates made from rids. Little is known about the amount of solar radiation that passes through some of the materials which automatically has an effect on the animals that will be under the shade material. Little is also known about the thermal radiation that can be emitted by the different possible shading materials. This can be of major concern considering materials like iron sheets which can heat up to very high temperatures and in turn emit a significant amount of thermal radiation which will impinge on the animals under the shading material. So, there is need to quantify the amount of thermal radiation that can be emitted by different shading materials and amount of direct solar radiation that can pass through the different shading materials. The main objective of Experiment 3 therefore was to compare fluxes of the different components of radiation across the different shading materials which were used in Experiment 2 and then give recommendations as to which material is the best effective for providing a comfortable micro-environment to lactating cows during hot weather.

4.1.2 Materials and Methods

4.1.2.1 Site Description and Experimental Design

The same site, feedlot and shading materials which were used in Experiment 2 were also used in Experiment 3. Radiation and temperature sensors were mounted onto masts which were placed under the Hessian 30% shade cloth, Hessian 80% shade cloth, corrugated iron sheets and outside the shades. Table 4.1 lists the sensors which were used in Experiment 3.

Table 4.1: Radiation and temperature sensors used in Experiment 3

Sensor	Measurement	Units
CM Net Radiometer	Measured shortwave radiation from the atmosphere, long wave radiation from the shading material and sky, short wave radiation from the ground and long wave radiation from the ground and give net radiation	W/m^2
Kipp& Zonen Pygeometer	Measured long wave radiation from the atmosphere	W/m^2
Net Radiometer	Measured outside net radiation	W/m^2
Pyranometer	Measured outside short wave solar radiation	W/m^2
Infra-red thermometer	Measured soil surface temperature	^oC

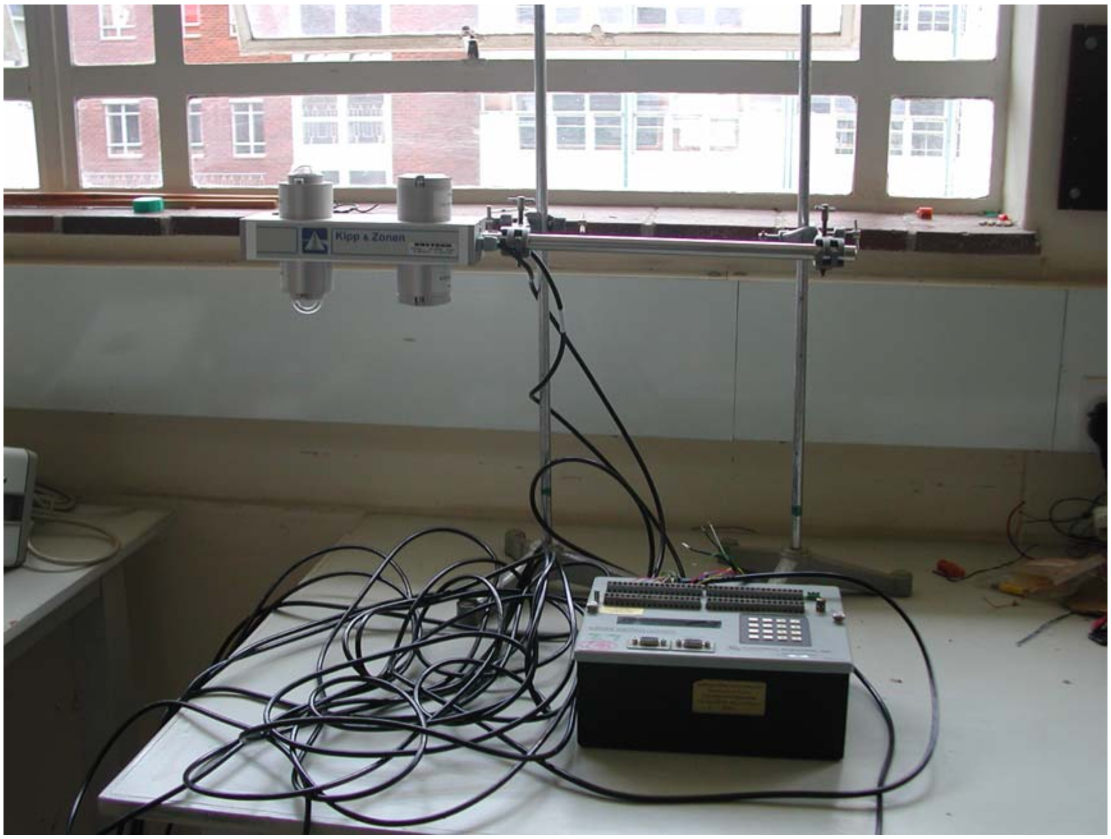

Figure 4.1: CM Net Radiometer

The CM Net Radiometer (Figure 4.1) was mounted onto a mast and moved from one shading material to the other measuring the four components of radiation under each shading material from 0600 to 1800 h. The Kipp& Zonen Pygeometer, Pyranometer, Net Radiometer and the Infra-red Radiation thermometer were mounted onto a single mast outside the shades as a control.

4.1.2.2 Data Collection

Data of radiation and ground temperature measurements under each shading material and outside the shade was collected automatically by a delta-T datalogger and then down loaded to a computer. Two sets of data were collected on each day of the experimental period. One set was for radiation measurements under each given shade material and the corresponding data was made of outside radiation measurements.

4.1.2.3 Statistical Analysis

The Student's t-test was used for comparison of mean direct and thermal radiation across the three shading materials. Line graphs showing changes in the different components of radiation from 0600 h to 1800 h under each respective shading material were plotted.

4.1.3 Results

4.1.3.1 Hessian 30% shade cloth

Downward short wave solar radiation under the Hessian 30% shade cloth closely followed changes in outside direct short wave solar radiation with outside solar radiation measurements being on average 30% above measurements under the shade (Figure 4.1). Highest solar radiation was recorded at around 1130 h. Downward long wave radiation (thermal radiation) was higher under the Hessian 30% shade cloth than outside the shade (Figure 4.2) but it did not go above 450 Wm^{-2}.

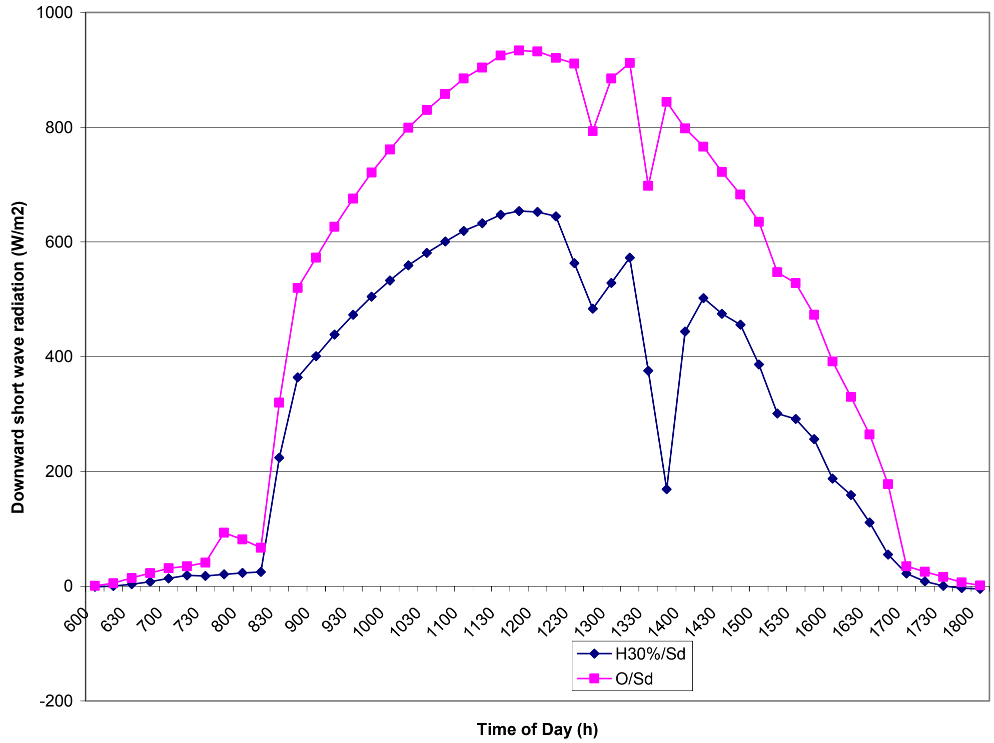

Figure 4.2: Downward short wave solar radiation under Hessian 30% shade cloth (H30%/Sd) and outside the shade (O/Sd) on 20 April 2005

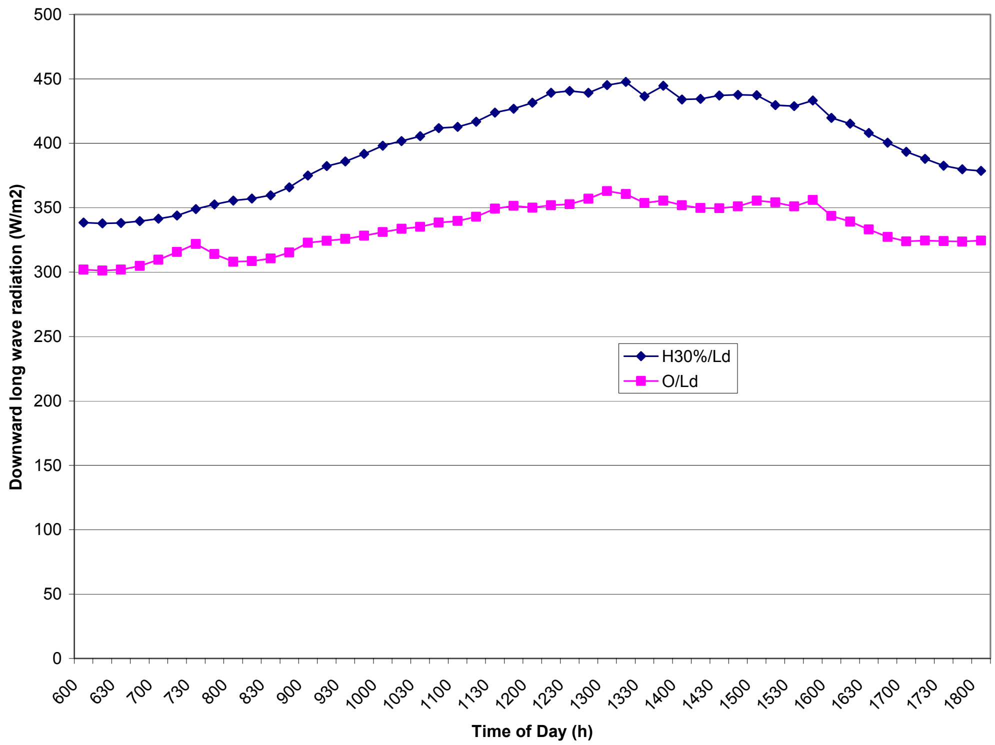

Figure 4.3: Downward long wave radiation under Hessian 30% shade cloth (H30%/Ld) and outside the shade (O/Ld) on 20 April 2005

4.1.3.2 Hessian 80% shade cloth

Downward short wave solar radiation under the Hessian 80% shade cloth followed changes in outside down ward solar radiation but it was significantly ($P < 0.05$) lower (Figure 4.3). Downward solar radiation under Hessian 80% shade cloth was on average 80% lower than outside downward solar radiation measurements. Downward thermal radiation under Hessian 80% shade cloth was higher than outside measurements (Figure 4.4) but did not exceed 500 Wm^{-2}.

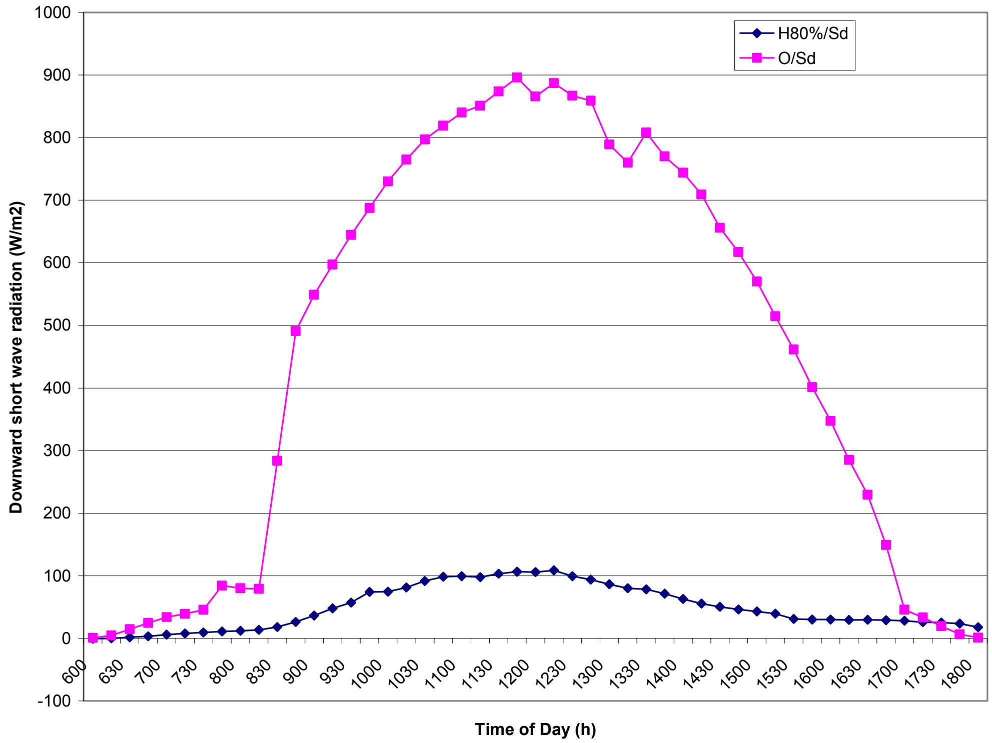

Figure 4.4: Downward short wave solar radiation under Hessian 80% shade cloth (H80%/Sd) and outside shade (O/Sd) on 22 April 2005

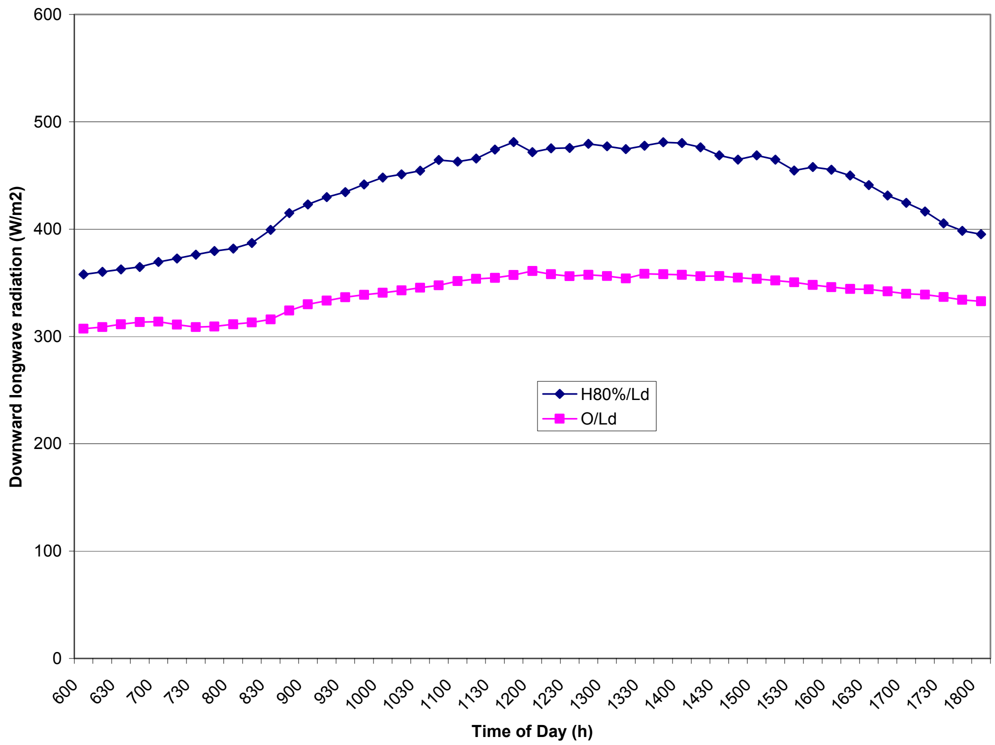

Figure 4.5: Downward long wave radiation under Hessian 80% shade cloth (H80%/Ld) and outside the shade (O/Ld) on 22 April 2005

4.1.3.3 Corrugated Iron Sheets

Downward short wave radiation under the corrugated iron sheets was significantly ($P < 0.05$) lower than downward solar radiation measured from outside the shade. Infect, down ward solar radiation under the corrugated iron sheets was apparently zero for whole day time period from 0600 to 1800 h (Figure 4.5). Downward thermal radiation under the corrugated iron sheets was significantly ($P < 0.05$) higher than radiation measured from outside the shade (Figure 4.6).

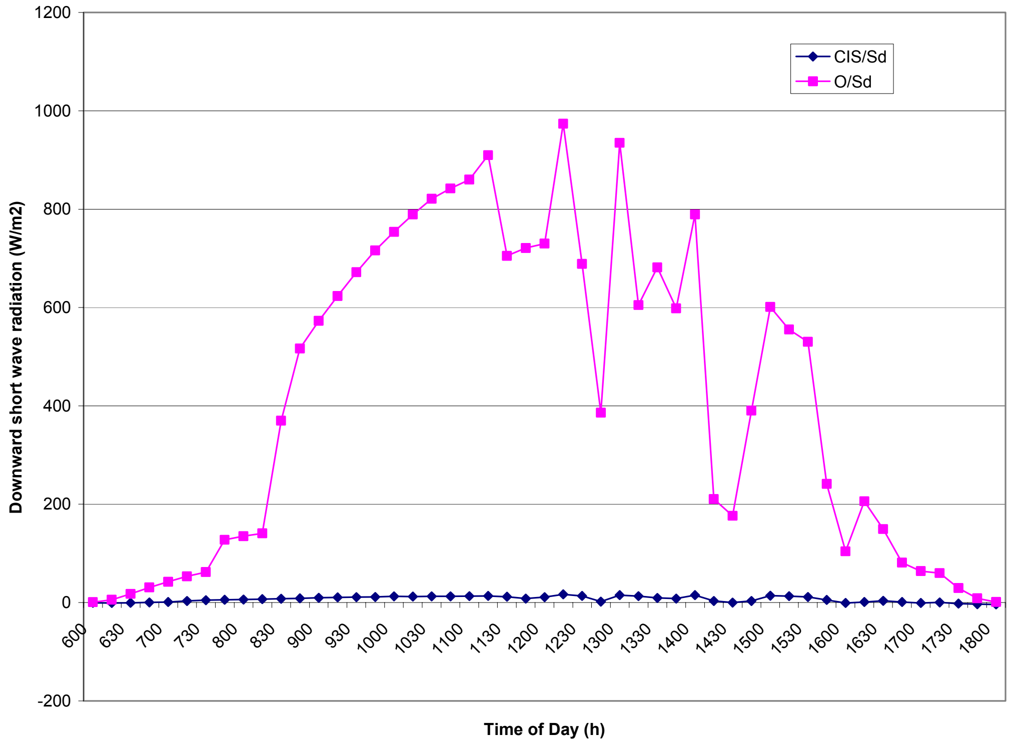

Figure 4.6: Downward solar radiation under corrugated iron sheets (CIS/Sd) and outside the shade (O/Sd) on 18 April 2005

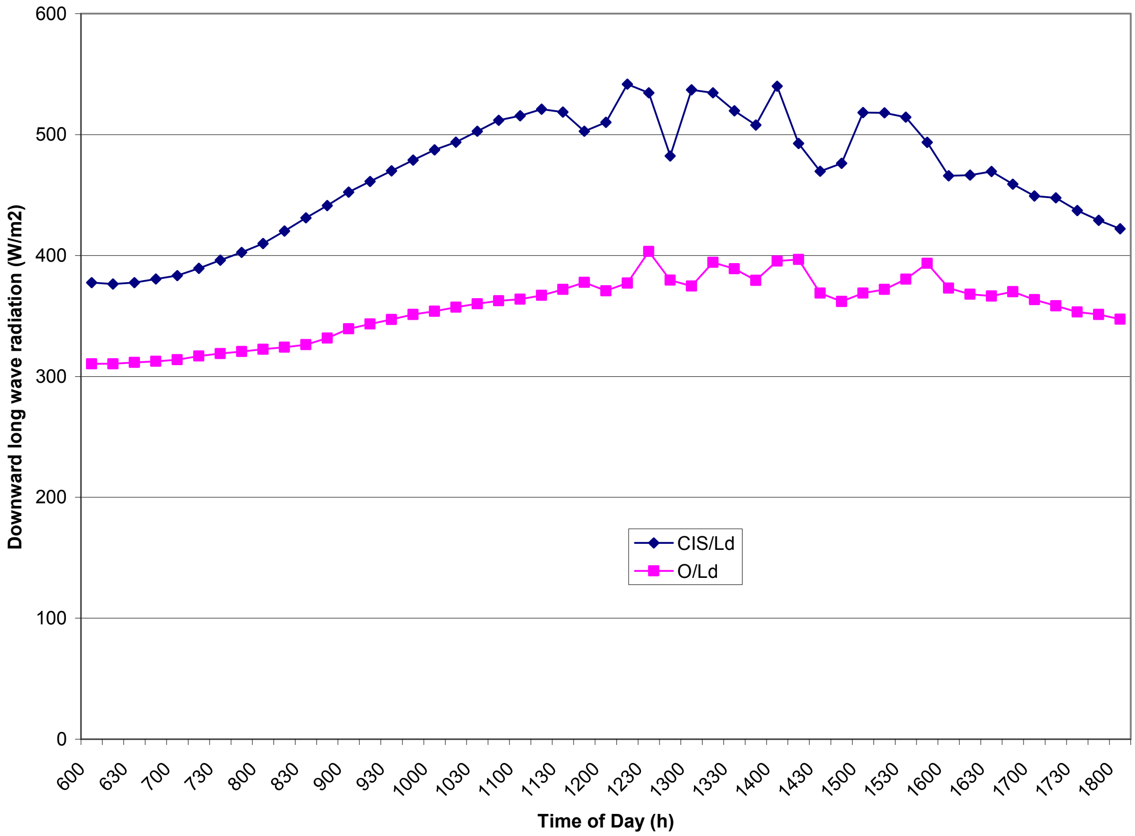

Figure 4.7: Downward long wave radiation under corrugated iron sheets (CIS/Ld) and outside the shade (O/Ld) on 18 April 2005

4.1.4 Discussion

The three shading materials: Hessian 30% shade cloth, Hessian 80% shade cloth and corrugated iron sheets which were tested in Experiment 3 all blocked direct solar radiation but at different levels. Corrugated iron sheets, provided 100% shade while the Hessian 80% and Hessian 30% shade cloth provided 80% and 30% shade respectively. Blocking of direct solar radiation is usually the main essence of providing shade to cows during periods of intense solar radiation so the corrugated iron sheets can be rated the best in providing shade among the materials which were used in Experiment 3.

The three shading materials emitted thermal radiation with a significant larger amount being emitted by corrugated iron sheets. Corrugated iron sheets emitted the highest amount of thermal radiation amongst the three shading materials higher than what was measured under both Hessian 80% shade cloth and Hessian 30% shade cloth. Infect, thermal radiation that was measured under all the three shading materials was higher than the down ward long wave radiation recorded from the pygeometer which was outside the shade. This generally implies that, although direct solar radiation is being cut off by providing shade using some of these materials, a significant amount of thermal radiation would be emitted by the materials as they heat up and this is especially true for the corrugated iron sheets which emitted the highest amount of thermal radiation. Thermal radiation from shading materials can substantially contribute to the radiation load of the animal that would be under a specific shading material.

Therefore, type of material should be considered when selecting materials that can be used for providing shade to cows during the summer season. Type of material determines the amount of direct solar radiation that passes through to the animal and the amount of thermal radiation that can be emitted by the shading materials.

4.1.5 Conclusion

Corrugated iron sheets blocked the highest amount of direct solar radiation but emitted the greatest amount of thermal radiation. Considering the significant amount of thermal radiation that was emitted by corrugated iron sheets, Hessian shade cloth can be used as an alternative effective shading material for heat stressed cows during the summer season. However, although the Hessian 30% shade cloth emitted the least amount of thermal radiation, the material can not be used as an effective shading material due to the significantly high amount of direct solar radiation that passes through and contributes immensely to the radiation load of the animal that would be underneath.

CHAPTER 5

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATION

The general picture emerging from this study is that if the University of Zimbabwe Farm is to be used as representative of the sub-tropical climate of Zimbabwe, it can be said that the country is characterized by conditions of heat stress during the first months (September to November) of the summer season due mainly to intense solar radiation and elevated ambient temperature. Basing on this fact, there is need to establish proactive environmental modification measures which can be applied to livestock especially high producing dairy cows during the summer season. Shade provision during periods of hot weather proved to be of benefit in Experiments 1 and 2 of this study. Cows which were provided with adequate shade had low skin surface temperature, respiration rate, rectal temperature and water intake with a remarkable improvement in milk yield. Cows under Hessian 30% shade cloth (30% shade) had significantly elevated skin surface temperature, respiration rate, rectal temperature and water intake compared to cows under corrugated iron sheets (100% shade) which indicated that cows under 30% shade were typical of animals under heat stress. This probably is explained by the fact that thermoregulation is a prime illustration of a dynamic process in a homeothermic animal as observed from short-time changes in body temperature, which reflect temporary imbalances in heat production and heat dissipation (Hahn, 1999). Part of the decline in milk yield during the beginning of the summer season at the University of Zimbabwe Farm can be attributed to thermally stressful conditions associated with this period. Therefore shade provision can be recommended as one of the measures that can be undertaken to maintain high levels of milk yield during the summer season.

Type of shade material should be one of the prime aspects to be considered when choosing possible materials for providing shade to dairy cows during the summer season. As noted in Experiment 3, the three different shading materials which were used in the study provided shade at different levels and had different thermal emissions. Livestock managers and dairy managers in particular will need to know the amount of direct solar radiation that can be blocked by a given type of shade material and the amount of thermal radiation that can be emitted when selecting a suitable material. This will establish the level of comfort that will be provided by a specific shading material.

Basing on results from the findings from this study, corrugated iron sheets and Hessian 80% shade cloth are two materials that can be used for providing shade to dairy cows during periods of hot weather. However, the significant amount of thermal radiation that was emitted by the corrugated iron sheets should be of major concern when considering them as an effective shading material.

Further studies are needed to evaluate the benefits of shade provision during the summer season with regard to conception rates and milk quality in dairy cows during periods of hot weather. Detailed studies are also needed to investigate the hormonal changes associated with heat stress and the positive response associated with shade provision. In terms of milk quality, emphasis should be placed on changes in somatic cell count during periods of hot weather and what positive responses can be realized by providing lactating cows with shade during these periods. Related studies, such as evaluating the benefits of shade provision to other breeds of cattle like beef breeds during the hot summer season can also be conducted. Such studies will look at the benefits of shade with emphasis placed on food conversion efficiency and weight gain particularly during pen fattening. There is also need to test the effectiveness of locally available and less costly materials such as mates made from rids and thatch in providing shade to dairy cows.

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