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Effects of shade on milk production in Swedish dairy cows on pasture

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Content

Abstract

Heat stress negatively influences the performance of dairy cattle such as lactation and reproduction. Heat stress can cause production losses as well as welfare problems. Years of research have shown that heat stress is a huge problem for dairy cattle in both the tropics and temperate zones but no such research have so far been done in northern European countries. It seems like shade is an important tool when improving pasture conditions and therefore deserves more attention. The aim with this study was to investigate whether there is a need of providing shade for grazing dairy cows during the summer in Sweden.

Two groups of lactating Swedish Red dairy cows (n=15 per group) were kept on pasture. To evaluate the effects of shade, one of the groups had access to shade (group 1) and the other had not access to shade (group 2). Metrological data such as ambient air temperature (°C), relative humidity (%) and black globe temperature (°C) were measured both on the inside and outside of the tent and temperature-humidity indexes (THI) were calculated. Other measured parameters were daily milk yield and occasional fur temperature, rectal temperature and respiration rate. During days with warm and sunny weather also milk composition were analyzed for each cow. The trial did also include behaviour studies of the cows. These data are however not analyzed in this thesis which instead focus on milk production and physiological parameters of the cows.

The ambient temperature varied between 7.3°C and 33.1°C during the trial period with a daily mean temperature of 18.5°C. THI values calculated for the outside of the tent, varied from 45.5 to 79.6. Both mean and max temperature and THI was lower inside the tent compared to outside the tent. On 13 of the days associated with milk samples THI-values ≥72 were observed. Also THI-values over 78 (which are considered to cause extreme heat stress) occurred occasionally.

The cows with access to shade chose to use it but the results from the trial showed no significant effects of the weather variables on the milk production. However, THI and ambient air temperature had a significant effect on respiration rate and fur temperature for the cows in both treatment groups. But temperature and THI did not affect rectal temperature and no difference in rectal temperature between the two groups of cows could be seen.

In conclusion, access to shade did not affect the milk production but it seemed as the shade had a cooling effect on the cows which was demonstrated by the results of lower fur temperature and respiration rate for the cows with access to shade. Even though the study did not verify the importance of shade for grazing dairy cows from an economic perspective, the fact that the cows with access to shade also used the opportunity to be in shade, indicates that shade on pasture is important for the cow from a well-being perspective.

Sammanfattning

Värmestress har en negativ inverkan på produktionen hos mjölkkor som till exempel laktation och reproduktion. Värmestress kan orsaka produktionsförluster likväl som djurvälfärdsproblem. År av forskning har visat att värmestress är ett stort problem för mjölkkor både i tropikerna och i tempererade zoner, men ingen forskning i ämnet har hittills gjorts i Nordeuropeiska länder. Det verkar som att skugga är ett viktigt verktyg för att förbättra betesförhållanden och därför förtjänar det mer uppmärksamhet. Syftet med den här studien var att undersöka om det finns ett behov av att förse skugga till betande mjölkkor i Sverige under sommaren.

Två grupper med lakterande mjölkkor av rasen Svensk röd och vit boskap (n=15 per grupp) hölls på bete. För att utvärdera effekterna av skugga hade den ena gruppen tillgång till skugga (grupp 1) medan den andra gruppen inte hade tillgång till skugga (grupp 2). De meteorologiska data som mättes, både utanför och under tältet, var lufttemperatur (°C), relativ luftfuktighet (%) och black globe-temperature (°C) vilka användes till att beräkna temperature-humidity index (THI). Andra parametrar som mättes var daglig mjölkmängd, den ytliga kroppstemperaturen, rektaltemperatur och andningsfrekvens. Under dagar med varmt och soligt väder togs även mjölkprover från varje ko för att analysera dess beståndsdelar. Studien inkluderade även beteendestudier av korna. Dessa data analyseras dock inte i denna uppsats som istället fokuserar på kornas mjölkproduktion och fysiologiska parametarar.

Lufttemperaturen varierade mellan 7.3°C och 33.1°C under försökstiden med en genomsnittlig temperatur dagtid på 18.5°C. THI-värden beräknade för tältets utsida, varierade från 45.5 till 79.6. Både medel- och maxtemperaturen samt THI var lägre under tältet jämfört med utanför tältet. Av de dagar då mjölkprover togs, observerades THI-värden ≥72 upprepade gånger under 13 av dessa dagar. Även THI-värden över 78 (vilka anses orsaka extrem värmestress) inträffade då och då.

Korna som hade tillgång till skugga valde att använda den, men resultaten från studien visade inga signifikanta effekter av vädervariablerna på mjölkproduktionen. Hur som helst, THI och lufttemperatur hade signifikant effekt på andningsfrekvens och ytlig kroppstemperatur för korna i båda grupperna. Lufttemperatur och THI hade dock ingen påverkan på rektaltemperatur och inte heller kunde någon skillnad i rektaltemperatur påvisas mellan grupperna.

Sammanfattningsvis, tillgång till skugga påverkade inte mjölkproduktionen men det verkade som att skugga hade en svalkande effekt på korna vilket påvisades av resultaten av uppmätt ytlig kroppstemperatur och andningsfrekvens. Även fast studien inte verifierade att skugga är viktigt för betande mjölkkor utifrån ett ekonomiskt perspektiv, så indikerar ändå faktumet att korna med tillgång till skugga också använde den, att skugga på bete är viktigt för korna sett från ett välfärdsperspektiv.

Introduction

A warm climate can lead to a restricted welfare for dairy cows with lowered production as a secondary result. Temperatures higher than the cow's comfort zone have a negative effect on the cow's well-being. Heat stress negatively influences cattle's performance such as lactation, reproduction and growth. Years of research have shown that heat stress is a huge problem for dairy cattle in the tropics as well as in temperate zones, especially for breeds not genetically adapted to live and produce in a warm climate. With insufficient thermoregulation in warm and humid weather, the cow will be heat stressed (e.g. Kadzere *et al.*, 2001; West, 2003; Kendall *et al.*, 2006).

No previous research has focused on the heat stress situation for dairy cattle in northern Europe. However, in New Zealand where the climate is of a mild temperate character similar to Swedish summers, research has shown that dairy cattle avoid the sun by the use of shade if it is accessible (Kendall *et al.*, 2006). Sweden has one of the world's most restricted animal welfare legislation. The legislation requires farmers to give heifers older than six months and cows access to pasture for a certain period of two to four months (length depending on country region) during the summer months (SFS1988:539, SJVFS 2010:15, SJVFS 2012:13). In addition, the legislation says that if cattle are kept outside during the winter, the animals must have access to a shelter providing protection against harsh weather and wind. But no legislation exists on shelter provision at pasture during the summer. In case of extraordinary environmental conditions during the summer it can however be acceptable to keep the cattle indoors for a restricted period.

Silanikove (2000) writes that provision of shade shelter is essential to the welfare of farm animals in areas where ambient temperatures and temperature-humidity-index (THI) exceeds 24°C and 70 respectively. This means that dairy cattle in Swedish summer conditions also might appreciate shade if getting access to it and with that achieve a better well-being and also avoid heat stress with all the negative effects it has. It seems like shade is an important tool when improving pasture conditions and therefore deserves more attention. Heat stress can cause production losses as well as welfare problems. It would be a good way to avoid such problems by providing protection from heat stress to grazing dairy cows and maybe shade would be enough. Knowledge about dairy cows behaviour when having access to shade and what behavioural and physiological signs a heat stressed dairy cow shows, are important when developing good summer pasture conditions. Besides, if providing shade would show that the dairy cow also performs better than she would without shade, it would be relevant for both animals and farmers to discuss an addition to the Swedish law concerning summer pasture conditions with provision of shade shelter.

Aim and expectations

The aim with this study was to investigate whether there is a physiological need of providing shade for dairy cows on pasture during the summer in Sweden. This study was part of a study where we studied how heat stress affected physiology, production and behaviour of dairy cows and if access to shade could counteract the level of heat stress.

The expectation was to see an increased use of shade by the cows when the temperature and solar radiation were high. Milk yield was expected to decrease in both groups but with a greater reduction seen among the cows with no access to shade.

Literature survey

Heat stress

Dairy cows produce large quantities of metabolic heat and absorb additional heat from the surrounding, essentially from radiant energy. The body heat must continuously be dissipated or else the body temperature might rise above normal level, which could be fatal for warm-blooded animals. Briefly, if the cow gains more energy than she loses, she will get warmer, overheated and die. At the same time, if the cow loses more energy than she gains, she will not be able to survive because of a decreasing body temperature. A cow may be too warm or too cold for a limited period of time, but in the long run, she must be in an energy balance with the environment (Gebremedhin, 1985; Kadzere *et al.*, 2001).

Normally there is a balance between heat production and heat loss, thus the body temperature of the cow is relatively constant. This balance regulates through metabolic heat production and sensible heat loss and latent heat loss (Ehrlemark, 1988; Kadzere *et al.*, 2001). It is the environment in which the cow lives, including both the abiotic and biotic factors, which settles the thermal condition. Most responsible for heat stress are the abiotic factors: air temperature, humidity, solar radiation, and wind (Yousef, 1985a). These four independent variables are acting simultaneously and constitute the microclimate around the cow (Gebremedhin, 1985). The combined effect of high relative humidity with high temperature makes it even more difficult for the cow to dissipate heat (West, 2003). Furthermore, animal properties which affect the exchange of energy are metabolic rate, moisture loss rate, and geometric structural properties of the coat such as colour, hair density, length, diameter, pelt thickness, hair transmissivity, and absorbtivity (Gebremedhin, 1985). A light fur colour reflects more solar radiation than a darker fur colour which instead absorbs the radiation which is transferred to the skin and raise body temperature (Finch and Western, 1977; da Silva *et al.*, 2003; West, 2003).

To sum up, heat stress means the animal gains more heat than she dissipates and the stored body heat results in raised body temperature. Therefore, the cow has different strategies to avoid being overheated.

Thermoregulation

The body temperature is controlled by the energy exchange between the cow and its environment. Temporary changes of the body temperature can occur due to muscle work, metabolic processes, physiological changes and environmental stress. Besides, animals can have a natural diurnal temperature rhythm with maximum temperature values according to activity and feed intake daytime, and rest during night-time, respectively. This temperature rhythm refers to deep body temperature and the changes under constant temperature conditions are less than 1°C (Kadzere *et al.*, 2001). On the other hand, the peripheral body temperature (e.g. fur and skin temperature) varies considerably with environmental temperature and the changes in fur and skin temperature can be very large (Gebremedhin, 1985; Robertshaw, 1985). Gebremedhin (1985) describes metabolic heat, body temperature, and water loss as independent variables which all in part are determined by environmental conditions and in part by the animal's physiology. What connects the environmental factors, with the animal response, is energy.

Heat gain

The cow's body heat origin from metabolic processes within the body and the cow does also gain heat from surrounding energy sources through radiation, conduction and convection. High producing dairy cows have a higher metabolic heat increment, due to a higher energy intake, and heat increment during milk synthesis, and may be more susceptible to heat stress than a lower-producing dairy cow (Kadzere *et al.,* 2001; West, 2003). The metabolic heat increment of feeding accounts for about 30% of the ingested metabolizable energy in mammals (Smith *et al.,* 1978; West, 2003). In a cold climate, high nutrient intake contributes to a maintained body temperature. In contrast, in a warm climate this metabolic heat must be dissipated to sustain thermal neutrality (Kadzere *et al.,* 2001).

Heat production over the basal metabolic rate is increased by factors such as exercise or shivering, imperceptible tensing of muscles, chemical increase of metabolic rate, heat increment and disease causing fever (Kadzere *et al.,* 2001).

Heat loss

The total heat energy loss from the cow is the sum of sensible and latent heat loss. Through nonevaporative heat transference (conduction, radiation and convection) the cow can both absorb and lose heat energy. In addition, the cow can also lose body heat through evaporative cooling which means by sweating and breathing (Gebremedhin, 1985; West, 2003). Evaporative cooling, especially sweating, is an extremely important thermoregulatory mechanism for the cow (Kadzere *et al.,* 2001). Sweating and breathing becomes more important with rising ambient temperatures while the nonevaporative cooling is less effective. But evaporative cooling impedes by high relative humidity, and wind speed influences heat transfer by convection and evaporation between the animal and the environment (Kadzere *et al.,* 2001; West, 2003; Yousef, 1985a).

Figure 1 illustrates the sensible and latent flow of energy both to and from the cow: direct sunlight, scattered skylight, and reflected heat, or infrared thermal radiation, emitted by the natural environment and from the atmosphere. If the wind has an air temperature cooler than the surface temperature of the cow, heat energy will be transferred from the animal to the air by convection. The opposite will be that, if the air is warmer than the animal surface temperature, convection will add heat to the animal. In addition to convection, heat energy may be exchanged by direct conduction if the animal is in contact with a substrate at a different temperature. Heat is also dissipated by evaporation within the respiratory tract and from the skin surface of the cow. The evaporative heat loss increases by both panting and sweating, but sweating is superior to panting in cows (Robertshaw, 1985). Moreover, heat is also lost by defecation and urination, but this loss is usually very small compared to the total heat energy loss (Gebremedhin, 1985).

The cow loses heat energy through radiation by the radiation law. Normally in a warm climate with sunny days, the ambient temperature decreases at night time and stored heat within the cow may dissipate and the body temperature falls. Research shows that a cool period of less than 21°C for 3-6 hours can minimize the production loss due to heat stress, despite high temperatures at daytime (Igono *et al.,* 1992).

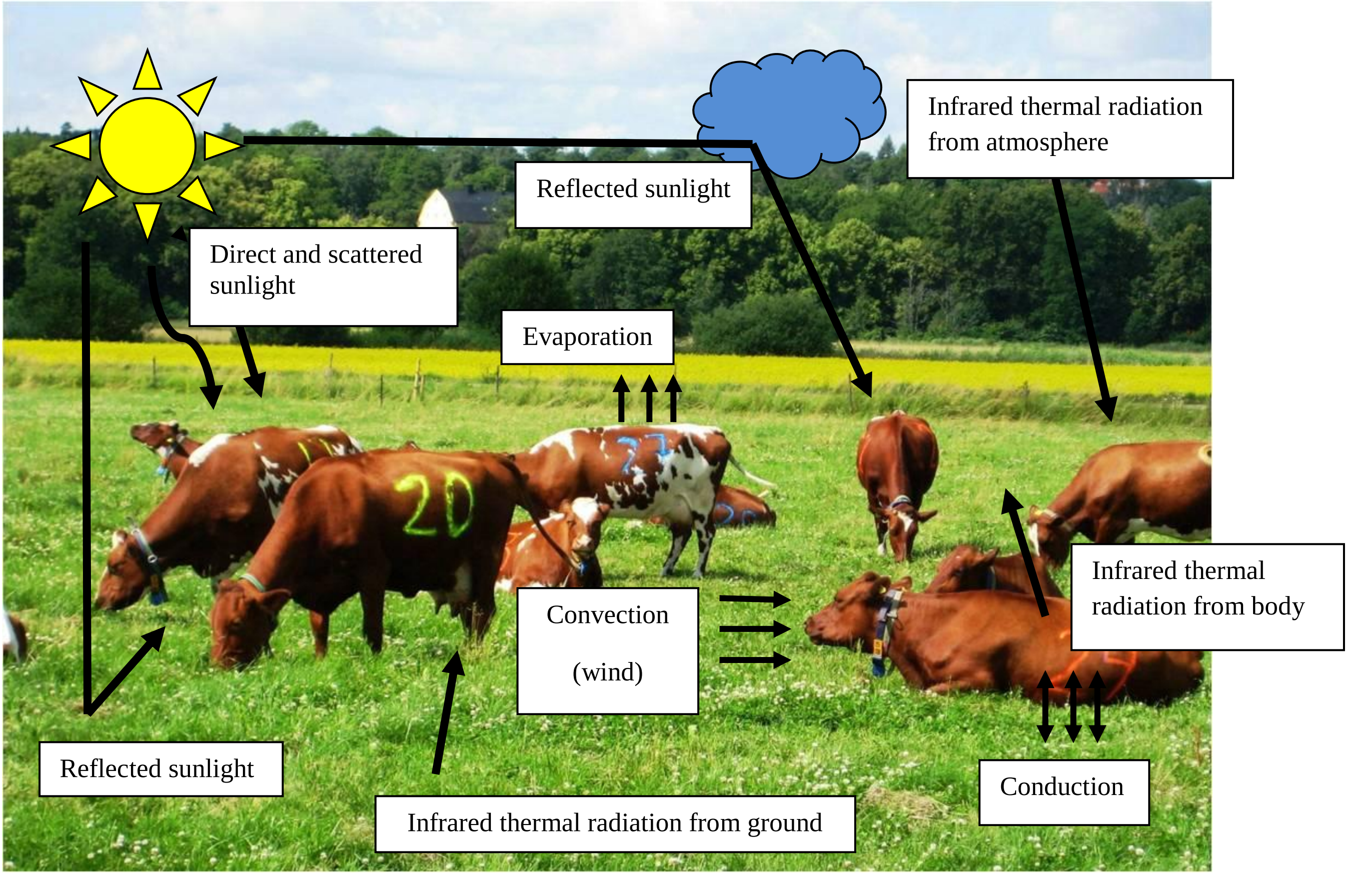

Figure 1. *Streams of energy between the cow and the environment (after Gebremedhin, 1985).*

Thermoneutral zone

The thermoneutral zone (TNZ) is a way of describing a specific temperature interval in which maximum productivity normally is achieved (Kadzere *et al.*, 2001). The TNZ (*Figure 2*) has also been called the "comfort zone" which may give a more direct description of what it is all about. The internationally recognized definition of the TNZ as defined by environmental physiologists is: "the range of ambient temperature within which metabolic rate is at a minimum and within which temperature regulation is achieved by nonevaporative physical processes alone" (Bligh and Johnson, 1973). The heat production is by definition constant in the TNZ (Ehrlemark, 1988). This temperature interval is restricted by the upper critical temperature (UCT) and the lower critical temperature (LCT) respectively (Ehrlemark, 1988; Kadzere *et al.*, 2001; Yousef, 1985b). It is only the LCT that theoretically can be calculated on the basis that the cow's total heat production is the same as dissipated heat to keep a constant body temperature. At LCT the evaporative heat losses are minimal thus the respiration rate is as low as possible and there is minimal perspiration (Yousef, 1985b).

At the UCT the animal's body temperature rises as a result of inadequate heat loss. Far above the UCT the environmental heat load exceeds the animal's capacity of heat loss and death occurs. Berman *et al.* (1985) stated the UCT for dairy cows to 25-26°C, independent of milk yield or acclimatization. On the other hand, other researchers describe LCT and UCT for a specific cow to vary depending on: age, breed, feed intake, diet composition, pregnancy status, previous state of temperature acclimation or acclimatization, level of production, specific housing and pen conditions, tissue insulation, external insulation, and behaviour (Martello *et al.*, 2010; Yousef, 1985b). Igono *et al.* (1992) reported highest daily milk production when ambient dry bulb temperatures of less than 21°C occurred for 24 hours per day in a desert climate indicating a threshold level.

Heat stress is produced by any combination of environmental conditions that cause the effective temperature of the environment to be higher than the thermoneutral zone of the animal (Bucklin *et al.,* 1991). The farther away from the preferred body temperature of the cow, the more damaging temperature becomes to productive processes, e.g. endocrine function which, in turn, can reduce lactation and fertility etc. (Kadzere *et al.,* 2001; Roman-Ponce *et al.,* 1976).

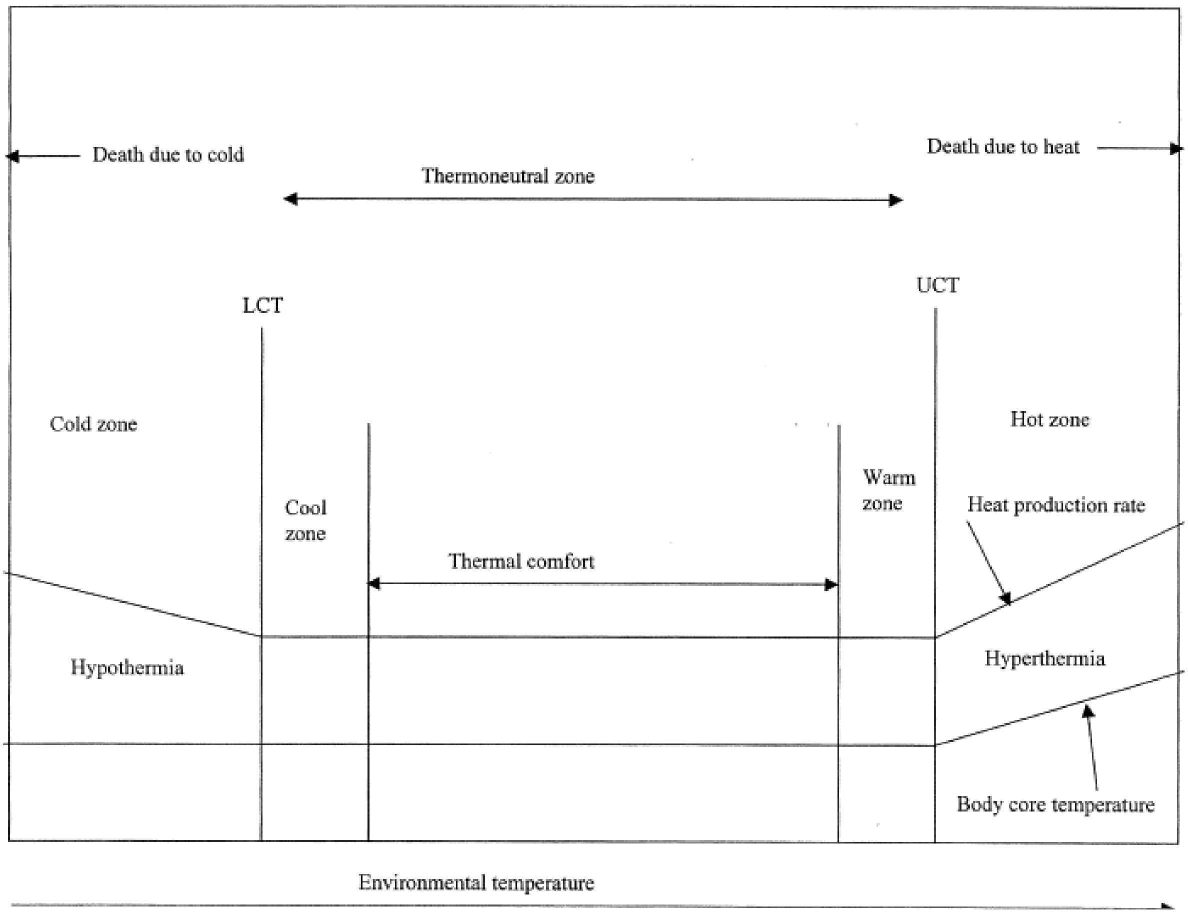

Figure 2. *Illustration of TNZ and the relationship between the cow's body core temperature, heat production and environmental temperature (Kadzere et al., 2001).*

Temperature-humidity index

The risk for cows to be heat stressed exists when air temperature rises above the TNZ and especially in combination with high humidity (Bucklin *et al.,* 1991; Martello *et al.,* 2010; Schütz *et al.,* 2009; West, 2003). Temperature humidity index (THI) is a measurement of thermal climatic conditions based on the current air temperature and relative humidity. Values <70 are considered comfortable, 75-78 stressful and values >78 cause extreme distress (Igono *et al.,* 1992; Kadzere *et al.,* 2001). A THI-value of ≥72 might cause mild heat stress with a decline in milk production and this value is often considered to be a threshold value (West *et al.,* 2003). The threshold value of 72 has nevertheless recently been questioned by Zimbelman *et al.* (2009) who suggests a new THI threshold of 68 for high producing dairy cows (cows producing >35 kg/day). Zimbelman *et al.* (2009) reported a significant milk yield loss after 17 hours of exposure to an average THI of 68. When THI increases, the mean body temperature rises (Schütz *et al.,* 2009) and as a result of peak THI, peak vaginal temperature will be observed a couple of hours later (Kendall *et al.,* 2006). This delay in the response was also seen in a study made of West *et al.* (2003) which showed that THI and the mean air temperature during hot periods had impact on both milk yield and dry matter intake (DMI) 2 days later.

The THI is calculated from the following formula which in turn is based on relations between wet and dry bulb air temperatures:

$$THI = (1.8 \times T + 32) - ((0.55 - 0.0055 \times RH) \times (1.8 \times T - 26))$$

Where T is the air temperature (°C), and RH the relative humidity (%) (Tucker *et al.,* 2008).

Physiological responses to heat stress

To be able to keep the body temperature within the interval needed to get the body functions to work properly (e.g. the brain can be damage by temperatures higher than 45°C), the cow exhibit physiological responses to the environmental factors (Schütz *et al.,* 2009; Tucker *et al.,* 2008; West, 2003; Yousef, 1985c). There are two types of physiological responses to heat stress. One is controlled by the autonomic nervous system, e.g. sweating and panting. The other is behavioural, e.g. lying in a shaded area (Ingram and Dauncey, 1985). Behavioural processes of thermoregulation involve movement of the whole body, which affects changes in the heat flow to and/or from the body. It can also be changes in posture which influence the effective surface area through which heat can be exchanged with the environment (Bligh, 1985). The first reaction of heat stress is usually behavioural changes as an attempt to cool down, e.g. seeking shade, and extension of the limbs. If that is not enough, the autonomic nervous system will increase or decrease blood flow to the skin (vasodilatation and vasoconstriction respectively) to alter skin temperature (Robertshaw, 1985).

The heat production in the cow is controlled by the nervous and endocrine system. By modifying appetite and food digestive processes, and by alteration in the activity of respiratory enzymes in the respiratory chain and synthesis of proteins, the heat production can be regulated (Yousef, 1985d). The autonomic physiological and behavioural thermoregulatory mechanisms of the cow are for example increased respiration rate, reduced activity and reduced feed intake (Schütz *et al.,* 2009; Tucker *et al.,* 2008). Yousef (1985d) describes that a high feeding level for a cow decreases both the *lower* and the *upper* level of critical temperatures. Therefore, a heat stressed cow will reduce the feed intake and thus decrease the metabolic heat production (Yousef, 1985d). The cow does also actively seek shade and wind (Blackshaw and Blackshaw, 1994). If an animal have more than one alternative of behavioural thermoregulation it can alternates between them (Ingram and Dauncey, 1985).

When describing behaviour of a gregarious animal, the ranking order is of importance. The location of a cow, and thus also the thermal load it is exposed to, is determined largely by its ranking order. A subordinate cow will change its position with respect to the more dominant cows and therefore she runs the risk of being expelled from the shaded area (Berman *et al.,* 1985).

Production responses to heat stress

The cow adapt to the circumstances for its survival and probably not for maintaining a high production. Adaptations to heat stress are associated with decreased milk production and fertility, and high producing cows are generally the most susceptible (Bucklin *et al.,* 1991). Also increased somatic cell scores have been associated with heat stress (Lambertz *et al.,* 2013). Moreover, energy requirements for maintenance increase with higher ambient temperatures thus thermoregulation costs energy (Beede and Collier, 1986).

The rate of milk secretion is optimal over a certain temperature interval, but heat stress (and cold stress as well) reduces milk yield and might change the composition (Kadzere *et al.*, 2001). The physiological mechanisms responsible for the production changes are very complex. Some are direct responses with neural or endocrine origin, whereas others are secondary responses, for example reduced feed intake because of heat stress (Baumgard and Rhoads, 2012; Igono *et al.*, 1992; Thompson, 1985). Reduced appetite could be seen as an adaptive depression of metabolic rate (Beede and Collier, 1986; Silanikove, 2000). Heat stress also impairs the mammary gland development during the dry period which will result in a negative effect on the milk production in the subsequent lactation (Tao *et al.*, 2011).

Milk yield

As already established, heat stress has a negative effect on milk production. Milk yield is lower through periods with heat stress compared to thermoneutral conditions (Igono *et al.*, 1992; Silanikove *et al.*, 2009). A heat stressed cow eats less, drinks more and produces less milk (e.g. Kadzere *et al.*, 2001; Murphy *et al.*, 1983; West, 2003; West *et al.*, 2003). Heat stress inhibits appetite, and consequently feed consumption, digestion and absorption of nutrients (Beede and Collier 1986). High ambient temperatures lead to peripheral vasodilation to facilitate heat dissipation through the skin. This circulation change results in reduced blood flow to internal organs such as ruminant forestomachs and reproductive tract. The combination of fewer nutrients available and less blood flow to the gastrointestinal tract impede nutrient absorption and thus inhibit milk production (Beede and Collier, 1986).

Milk yield is known to decline with increased rectal temperature but a more important factor to predict production losses has shown to be THI (Ravagnolo *et al.*, 2000). High ambient temperature itself has a negative effect on milk yield but milk yield decreases more when the high temperature is combined with high humidity, and THI can be used to account for the effect of heat stress on production (Igono *et al.*, 1992; Ravagnolo *et al.*, 2000; West *et al.*, 2003). When THI increases, both milk yield and DMI decline. High milk production is positively correlated to feed intake and thus also metabolic heat production and increased body temperature. This in turn requires effective thermoregulatory mechanisms to maintain a stable body temperature within the thermoneutral zone. But thermoregulatory mechanisms maintain thermal balance in the cow at the expense of milk production as well as reproductive efficiency (Berman *et al.*, 1985; Kadzere *et al.*, 2001; West, 2003). Cows in early lactation (first 60 days) have an even lower ability to cope with heat stress, and heat stress in early lactation will result in lowered production constantly for the whole lactation (Kadzere *et al.*, 2001). It is also found that later parity cows usually are more susceptible to heat stress compared to first parity heifers (Aguilar *et al.*, 2009; Aguilar *et al.*, 2010).

There may be a lag of time between environmental events and the full effects on the production (Collier *et al.*, 1981; Spiers *et al.*, 2004; West *et al.*, 2003). Spiers *et al*. (2004) found a decreased DMI within 24 hours of heat stress and a decline in milk yield after 48 hours of heat stress. Moreover, Collier *et al.* (1981) reported that ambient temperature 24 and 48 hours prior to milking were associated with decreased milk yield. However, the most obvious parameter for decreased milk yield is the total time with high THI under previous days (West *et al.*, 2003). Studies have shown that mean air temperature and THI two days earlier have the greatest impact on DMI and milk yield and they both declined linearly with increases in air temperature or THI (West *et al.*, 2003). The decline in daily milk yield during a hot period compared to cooler periods has by Igono *et al.* (1992) shown to be up to about

17% or 5 kg/day. Silanikove *et al.* (2009) reported a 55.1% decrease in milk yield for heat stressed cows with no access to shade or other cooling whereas the reduction in milk yield for heat stressed cows but which had access to both shade and cooling by fans and sprinklers were 7.9%. Other results verifying the impact of heat on milk production are reported by Valtorta and Gallardo (2004) who found that cooling before milking (by sprinklers and fan) resulted in higher milk yield and Roman-Ponce *et al.* (1976) reported 10.7% higher daily milk yield from shaded cows compared to non-shaded cows.

Of course a lowered DMI itself will result in a lower milk production but it is not only the decreased feed intake that is responsible for the loss in milk yield of a heat stressed cow. Heat stress also affects different endocrine functions important for milk secretion (Kadzere *et al.*, 2001; Rhoads *et al.*, 2009; Roman-Ponce *et al.*, 1976). Studies where DMI of cows exposed to a normal air temperature was adjusted to be equal to that of cows exposed to higher temperatures, have shown that the milk production of the heat stressed cows decline most (Bandaranayaka and Holmes, 1976; Rhoads *et al.*, 2009). Rhoads *et al.* (2009) found that reduced DMI as a result of heat stress only accounted for about 35% of the decline in milk yield and Wheelock *et al.* (2010) reported the same cause to be responsible for about 50% of the decline in milk yield in heat stressed cows. Furthermore, it has been shown that cows with access to shade have a higher milk production compared to cows without shade, even though the total time grazing for the two groups of cows was the same (Kendall *et al.*, 2006). These results indicate that heat stress itself changes the metabolism of cows. Physiological changes due to heat stress occur in the digestive system, acid-base chemistry and blood hormones. Some of these physiological changes are a direct response to reduced nutrient intake, but other changes occur as a result of strain in the cow. For example, evaporative cooling in the form of panting, affect blood acid base chemistry and can result in respiratory alkalosis (Beede and Collier, 1986; West, 2003). Lowered appetite could be explained by the associated effects of reduced gut motility and rumination which together with increased water intake creates some kind of negative feed-back to the hypothalamus of gastrointestinal filling (Beede and Collier, 1986).

Hormonal changes as a result of heat stress either have a role in nutrient distribution within the body and a process called *homeorhesis,* which means a coordinate redirection of metabolic resources, or a role in homeostatic regulation (Beede and Collier, 1986). In heat stressed cows, energy metabolism decreases whereas water and electrolyte metabolism increases. Thompson (1985) wrote that it is changes in substrate and hormone supply as a result of heat stress which leads to decreased milk yield. When a cow is exposed to high temperatures for a longer time, thyroid activity decreases (Beede and Collier, 1986; Thompson, 1985). This is partly known as a secondary response to reduced feed intake, but when refused food is put directly into the rumen (through a fistula), the depression of thyroid activity still persists in a hot environment. Thyroid hormones are known to influence different cellular processes and mainly the process of heat production (Beede and Collier, 1986; Silanikove, 2000). Physical stress factors, such as heat stress, inhibit the secretion of thyroid hormones. Consequently, the change in thyroid activity under heat stress are related to a decreased metabolic rate, feed intake and reduced growth and milk production (Silanikove, 2000).

Concentration and turnover rate of cortisol in blood plasma increases during the first few hours spent in high temperatures. But if the high temperatures continue for a few weeks, plasma cortisol concentration and turnover rate reduces below normal values (Thompson, 1985). Silanikove (2000) explains the secretion of cortisol as a stimulation of physiological adjustments that makes it possible for an animal to cope with the stress caused by hot environment. Cortisol is also required to maintain the secretory activity of mammary epithelial cells (Sjaastad *et al.*, 2003).

Growth hormone secretion is initially increased but after days or weeks with high temperatures, the concentration of growth hormone falls below normal (Thompson, 1985). Also the concentration of prolactin in plasma increases which is associated with stress. Both prolactin and growth hormone have the role to supply substrates to the mammary cells. They are involved in nutrient partitioning and homeorhesis (Beede and Collier, 1986). Bauman and Rhoads (2012) hypothesized that reduced growth hormone, IGF-1, is a mechanism by which the liver and mammary tissues coordinate reduced milk synthesis to make the nutrients available to maintain homeothermia instead.

Silanikove *et al.* (2009) have shown that the reduced milk synthesis in heat stressed cows are regulated by identified metabolites (found in the milk serum) which constitute a regulatory negative feedback system involving potassium channels in the mammary gland epithelial cells. Furthermore, Wheelock *et al.* (2010) wrote that the additional reduction in milk yield, not explained by decreased DMI, could be due to shifts in post absorptive glucose and lipid homeostasis. Increased plasma concentration of non-esterified fatty acids (NEFA) is a classic glucose-sparing mechanism to maximise milk synthesis in cows which are in a negative energy balance. But Wheelock *et al.* (2010) did not find any increase in plasma NEFA concentration in cows which were both heat stressed and in a negative energy balance. The authors speculated that this is an physiological act by the cow to survive a heat load since the oxidation of NEFA may produce more metabolic heat than that of carbohydrates (glucose) and consequently, a heat stressed cow will instead of utilize lipids from the adipose tissue as an energy source, use more glucose. This will lead to less glucose available for the mammary gland to synthesize milk lactose which in turn will result in lower milk yield since lactose is the primary osmoregulator (Baumgard *et al.*, 2006).

Milk composition

Research about how heat stress affects milk composition is contradictory. On one hand, results show significantly decrease in fat yield and a lowered, but not a significantly decrease, in protein yield in milk from heat stressed cows (Bandaranayaka and Holmes, 1976). Lactose percentage stayed constant and was not affected by high temperatures. A possible explanation for the decline in milk fat, according to Bandaranayaka and Holmes (1976), is the decreased rumen pH which they also found. Decreased rumen pH proves changes in the activity of rumen microflora which could be a result of decreased saliva production as a result of reduced forage intake (and maybe due to an increase in intake of high energy feed). This leads to an increased risk for rumen acidosis. Therefore, increased buffering of the rumen during heat stress could be justified (Collier *et al.*, 2006). Furthermore, Bandaranayaka and Holmes (1976) reported that the proportions of milk fat fatty acids were changed in the milk; heat stressed cows had a lower proportion of short chain fatty acids. They also mentioned that endocrine effects could be part of the explanation of the changes in milk fat. Less protein could be due to changes in the protein metabolism (Bandaranayaka and Holmes, 1976). On the other hand, Rhoads *et al.* (2009) found that milk lactose decreased during heat stress conditions but no other changes in milk composition occurred.

When comparing milk composition of shaded cows with non-shaded cows, the results of different studies diverge. Collier *et al.* (1981) and Kendall *et al.* (2006) reported that no differences could be pointed out whereas Roman-Ponce *et al.* (1976) reported higher solids-not-fat in milk from shaded cows compared to milk from cows with no access to shade. However, fat content remained the same.

Reproduction

Reproductive cows are obviously essential in the dairy industry. Heat stress affects reproduction negatively and results in a higher number of days open for the cow (Collier *et al.,* 2006; Kadzere *et al.,* 2001; West, 2003; Wilson *et al.,* 1998). The main reason is likely to be the decreased expression of estrus which is typical for heat stressed cows and could be due to anestrus or silent ovulation, but also fertility is likely reduced (Collier *et al.,* 2006; Wilson *et al.,* 1998). Furthermore, bull performance is reduced in a hot environment which could be of considerable importance if natural insemination is used (Collier *et al.,* 2006). Wilson *et al.* (1998) reported an abnormal ovarian function through inhibited follicular growth in heat stressed cows compared to cows in thermoneutral conditions. Serum estradiol was lower in heat stressed dairy cows during proestrus compared to thermoneutral cows. This probably led to the result of smaller size of second wave dominant follicles which did not ovulate and also a greater numbers of follicular waves. Heat stressed cows also had longer luteal phase which indicate problems with luteolytic mechanisms in heat stressed cows (Wilson *et al.,* 1998). Altered follicular development and reduced oocyte quality has been detected in cows for times even after heat stress is removed (Collier *et al.,* 2006).

Synchronized ovulation and timed insemination are management methods described to conquer problems with estrus detection. Also embryo transfer has reported to improve pregnancy rates for cows in hot environment (Collier *et al.,* 2006). But the best effect would be to manipulate the microclimate around the cow to overcome heat stress and improve her well-being and optimise the production. Roman-Ponce (1976) reported a higher conception rate, based on total services, for shaded cows compared to cows with no shade.

Measurement of heat stress

To measure if an animal is affected by environmental heat load, e.g. high ambient temperature, humidity or sunshine radiation, knowledge about its physiological responses to heat stress is useful. Behavioural observations and measurement of body temperature and respiration rate can give an idea about how the environmental heat load affects an individual cow.

Body temperature

Mammals try to maintain a body core temperature higher than the ambient temperature to be able to dissipate heat from the core to the surrounding (Collier *et al.,* 2006). If the cow does not manage to dissipate enough heat, there is an increase of rectal temperature above the normal upper limit which is 39.3°C (Martello *et al.*, 2010). Body temperature increases with increasing THI (Kendall *et al.,* 2007). Body core temperature can be measured at several locations, e.g. rectum, vagina, ear or arterial blood. The most commonly used site is the rectum. This measure point works satisfactory for steady-state conditions but for a transient measure, arterial blood is a better indication (Robertshaw, 1985). Spiers *et al.* (2004) investigated the use of physiological parameters to predict dairy cow performance in hot environment and they found an increase in rectal temperature within 24 hours of heat stress. Their results showed that rectal temperature is the best physiological indicator for prediction of milk yield and feed intake in heat stressed dairy cows. It was found that a 1.5°C rise of rectal temperature could be associated with reduction in performance.

It is suggested that body temperatures taken closer to external surface, e.g. on the skin surface, are more subjected to the influence of environmental temperatures and therefore are less stable than deeper body temperatures (Martello *et al.*, 2010; Spiers *et al.*, 2004). Martello *et al.* (2010) reported positive and high correlation between body temperatures measured in the ear, vulva and internal base of tail indicating a strong relation of temperatures measured in these anatomical sites.

Researchers in the tropics have found greater rectal temperature values at the end of the day when the daily ambient temperature already had passed its peak value and the environmental temperature decreased (Martello *et al.,* 2010). However, Martello *et al.* (2010) discussed other contradictory results which showed one peak of rectal temperature early in the morning and another in the middle of the day. They suggested that cows have differences in rectal temperature daily pattern due to great variation in environmental factors that both affect the animal as well as it is associated with physiological traits of the animal which are related to adaptation or acclimatization processes. The lag in rectal temperature, with respect to peak ambient temperature, was explained as the cows not having enough time to recover earlier from the heat load.

Tucker *et al.* (2008) found a positive relationship between increased ambient solar radiation and vaginal body temperature. Berman *et al.* (1985) reported little effect of ambient temperature on rectal temperature at ambient temperatures of less than 24°C but at higher air temperatures, a gradual rise of rectal temperature was evident. Cows exposed to an ambient temperature of 30°C had a rectal temperature of 38.42-39.11°C whereas the normal rectal temperature for a cow is 37.44-37.83°C (Bandaranayka and Holmes, 1976).

Respiration rate

As described earlier, panting is an evaporative process of thermoregulation used by the cow. Martello *et al.* (2010) reported a linear relation between body surface temperature and respiration rate, indicating that a higher body surface temperature increased the respiration rate as a thermoregulation mechanism to keep a stable body temperature. The highest respiration frequencies are registered during the hottest hours of the day and the respiration rate increases with increasing THI and ambient air temperature (Kendall *et al.,* 2007; Schütz *et al.,* 2008). A humid environment impedes evaporative heat loss. Increased respiration rate can prevent a rise in rectal temperature until THI reaches 80, over that the environmental influence becomes too stressful for the cow to maintain normal body temperature (Kadzere *et al.,* 2001).

Research has shown that at ambient temperatures over 25°C, cows have a respiration rate of 50-60 breaths per minute (Berman *et al.,* 1985). At ambient temperatures over 30°C, the respiration rate increase to 84-104 breaths per minute. The normal respiration rate for a dairy cow within the thermoneutral zone is 24-28 breaths per minute (Bandaranayka and Holmes, 1976). The increase in respiration rate occurs within 24 hours of heat stress (Spiers *et al.,* 2004).

Avoiding heat stress by management

To save dairy cows from heat stress, there are some possible arrangements. With the use of shade, sprinklers and ventilation, studies have shown that it is possible to alter the hot environment to make it easier for the cow to cope with it and at the same time maintain a high production level. Also by alter the feed ration it can be possible to lower the heat increment and in turn decrease the body temperature of the cow (West, 2003). It is known that grazing animals lower its feed intake already at a lower ambient temperature than cows fed with a concentrate dependent ration (Beede and Collier, 1986). This is explained by the fact that highly fibrous feed contribute to higher heat increment. Therefore, supplementation of ruminal escape protein and fat may reduce the heat increment of feed and increase dietary energy with a maintained milk production as a positive result (Beede and Collier, 1986; Silanikove, 2000). Ambient temperatures are also positively correlated with water consumption (Murphy *et al.,* 1983) whereupon it is extremely important with access to drinking water at high ambient temperatures. To serve chilled or cold water can reduce body temperature and respiration rate for a transient period of time (Lanham *et al.,* 1986a; Stermer *et al.,* 1986). Lanham *et al.* (1986b) did even report that 10°C drinking water increased DMI (compared to 28°C water) which resulted in higher milk yield.

Genetic selection for heat tolerance should be one important tool when trying to achieve high milk production in a hot and humid climate. The problem is that selection for heat tolerance probably automatically favours lower energy metabolism and consequently lowered milk production (Beede and Collier, 1986; West, 2003). But, there are research indicating that selection for both heat tolerance and production is possible (Ravagnolo and Misztal, 2000). However, Aguilar *et al.* (2010) reported that the most heat tolerant bulls transmitted lower production but higher fertility.

A significant condition for the dairy cow to perform well in a hot, humid environment is sufficient night cooling. Cows can tolerate relatively high daytime air temperatures if given possibility to cool during the night (Igono *et al.,* 1992; West, 2003). This implies that cooling for shorter periods would benefit heat tolerance of dairy cows during hot summers.

Shade

Shade is modifying the microenvironment of the cow by decreasing the black globe temperature (Roman-Ponce *et al.,* 1976). That means the heat accumulation from solar radiation is reduced but there is not necessarily an effect on air temperature or relative humidity which means additional cooling could be requisite for lactating dairy cows in a very hot and humid climate (West, 2003). However, THI has shown to be lower in shaded areas compared to areas with no shade (Kendall *et al.,* 2007). To provide shade is a relatively simple effort to make it easier for cows to perform in a hot and sunny weather.

Cows with protection from solar radiation have lower body temperature (Collier *et al.,* 1981; Kendall *et al.,* 2007; Roman-Ponce *et al.,* 1976; Silanikove *et al.,* 2009; Tucker *et al.,* 2008) and lower mean vaginal temperature (Kendall *et al.,* 2006) compared to non-shaded cows. Shade do also lower respiration rate (Collier *et al.,* 1981; Kendall *et al.,* 2007; Roman-Ponce *et al.,* 1976; Silanikove *et al.,* 2009). Dairy cows at pasture use shade when given access to it (Kendall *et al.,* 2006; Roman-Ponce *et al.,* 1976). The use of shade increases with increasing ambient air temperature and solar radiation (Schütz *et al.,* 2009; Schütz *et al.,* 2008; Tucker *et al.,* 2008) but according to Schütz *et al.* (2008) does not THI have any effect on shade use. It has been shown that cows are highly motivated to use shade during hot days. After 12 hours of lying deprivation, cows chose to stand in shade at high air temperatures rather than lying in the sun. The time spent standing in the shade increased with increasing ambient temperature (Schütz *et al.,* 2008). Cows spend more time in shade on days with higher ambient temperatures and higher solar radiation levels and they prefer shade that provide more protection from solar radiation (Schütz *et al.,* 2009; Tucker *et al.,* 2008) and black cows use the higher level of radiation blockage more compared to cows with lighter coat colours (Tucker *et al.,* 2008).

Economically interesting parameters are that shade improves milk yield and reproduction in both subtropical and temperate climate (Kendall *et al.,* 2006; Roman-Ponce *et al.,* 1976). Feed and water should be provided under the shade, otherwise cows must choose between the comfortable shaded area or drinking and eating (Bucklin *et al.,* 1991).

Other environmental modifications

The best effect, however, seems to be to combine shade with cooling of evaporative and convective character. For housed dairy cows, forced ventilation significantly reduces respiration rate in hot environment (Berman *et al.,* 1985). Ventilation with additional evaporative cooling, by the use of sprinklers, also results in reduced respiration rate in addition to a reduced rectal temperature (Bucklin *et al.,* 1991; Igono *et al.,* 1987; Kendall *et al.,* 2007; Valtorta and Gallardo, 2004) and milk temperature (Igono *et al.,* 1987). Igono *et al.* (1987) also found higher plasma growth hormone, lower plasma prolactin level and a higher milk production for cows treated with shade plus spray and fan cooling compared to shaded cows. Kendall *et al.* (2007) came to the conclusion that shade gives a faster cooling than sprinklers which on the other hand made the cows remain cool for a longer time. Therefore, the best effect is achieved with the combination of shade and sprinklers.

Bucklin *et al.* (1991) reported increased feed intake and milk production for cows in cooling systems built on sprinklers and fans in combination with shade. Furthermore, Valtorta and Gallardo (2004) reported that cooling grazing cows before milking, with sprinklers and fan, resulted in higher daily milk production as well as increased percentage of milk fat and protein. But research of production results is not unified. Kendall *et al.* (2007) did not see any positive effect of shade and/or sprinklers on milk production. They did mention though, that the ambient temperatures in their study were much lower compared to above mentioned studies (mean temperatures of 19.5°C and 23.5°C respectively), which might not depress the milk production to the same extent. This explanation seems relevant because they did not even see a correlation between daily milk yield and THI which usually is seen. However, their results of reduced respiration rate and body temperature for treated animals, tells us about the importance to provide cooling for dairy cows also in climates with the lack of the most extreme summer temperatures, for example in Sweden.

Material and method

The experiment was carried out at Kungsängen Research Centre in Uppsala, Sweden, from July 6 to August 16, 2009. The project also included behaviour studies of the cows but these data are not analyzed in this thesis which instead focuses on milk production and physiological parameters of the cows. Results from the behaviour studies can be found in Andersson (2009).

Animals and treatment

Thirty lactating dairy cows of the breed Swedish Red were used in this experiment. The cows were of mixed age (2-10 years) and with various lactation numbers (1-7). Days in milk for the cows varied from 3 to 449 on the first day of the study and the mean daily milk yield produced per cow during the trial period was 25.31 litres per day. Detailed facts about the two animal groups are presented in *Table 1*.

__Table 1.__ Mean milk yield, lactation number and days in milk per cow in each group, cow 1-15 were in group 1 and cow 16-30 were in group 2

Cow number	Mean milk yield (kg) during trial period	Lactation number	Days in milk day 1 of the trial
Mean for all cows group 1 (shade)	**27.7**	**2.8**	**109**
1	29.5	2	108
2	42.6	6	18
3	33.8	3	6
4	14.0	2	176
5	32.9	4	38
6	21.4	2	370
7	25.4	3	178
8	32.5	3	90
9	32.7	3	189
10	24.5	1	95
11	27.6	2	185
12	30.4	2	6
13	24.7	7	171
14	21.5	1	7
15	22.6	1	4
Cow number	**Mean milk yield (kg) during trial period**	**Lactation number**	**Days in milk day 1 of the trial**
Mean for all cows group 2 (no shade)	**22.9**	**2.4**	**208**
16	16.6	2	403
17	22.7	1	414
18	31.4	4	7
19	21.1	3	305
20	23.2	2	227
21	24.4	1	268
22	21.4	3	183
23	21.7	6	247
24	31.0	2	151
25	25.4	4	274
26	18.4	3	241
27	17.6	1	389
28	28.7	2	5
29	18.3	1	4
30	21.5	1	5

The cows were divided into 2 groups with 15 cows in each group and held in adjacent paddocks at pasture. In each paddock there were up to 18 cows because of animals that were not part of the study still had to use the same pasture. Group 1 had access to shade provided by a tent with a roof made of a plastic (PVC) cloth blocking 100% of solar radiation taut onto wooden poles. Group 2 did not have access to any shade. The cows were divided into the groups according to age for an equal distribution of young and older cows in the two groups and by how sun-sensitive the cow’s udder seemed to be. This distinction was performed through visually observations of the udders and the cows with sensitive udders (light coat colour of the udder and tanned teats) were placed in the group with access to shade.

Twice daily, the cows were brought indoors for milking in a tie-stall barn located about 500 m from the pasture. Every 3rd to 6th day, the cows altered paddocks, according to a scheme with rotation between 4 paddocks, for best pasture utilisation. Group 1 had access to the tent from a corner of all 4 paddocks (*Figure 3*). The paddocks were of equal design with an average size of 0.46 ha or 269 m^2 per cow if 17 cows were in the paddock. The tent had a total area of 78.5 m^2 which generated approximately 4.6 m^2 per cow if 17 cows were in the tent at the same time.

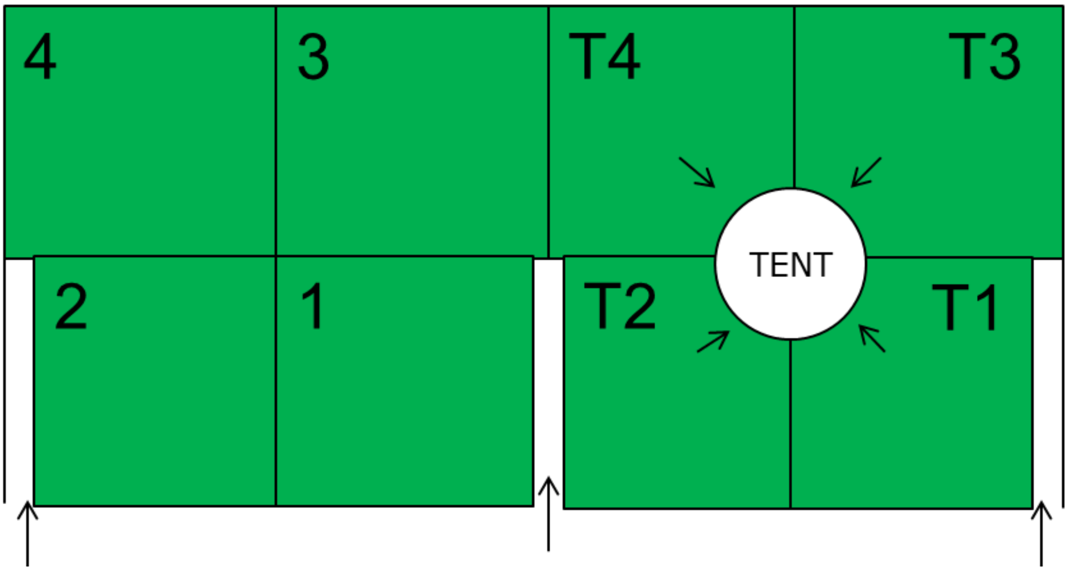

Figure 3. *Schematic illustration of the paddocks, not drawn in a proportionate scale. Cows with access to shade and cows with no shade alternated between paddocks T1-T4 and 1-4 respectively. Arrows show pathways and entrances to the paddocks and the tent. Shaded cows had always access to the whole tent area and one quarter adjacent to the current paddock in use, was open. Drinking water was located close to the tent for T1-T4 and close to the fenced cross that separates 1-4.*

Meteorological data

Ambient air temperature (°C), relative humidity (%) and black globe temperature (°C) were measured both on the in- and outside of the tent by a HOBO Pro Dataloggers (Onset Computer Corporation, Bourne, MA, USA). Black globe temperature is used to estimate the effect of solar radiation and was thus only measured on the outside of the tent. The data loggers measured all the weather variables every 10th minute throughout the trial with a few shorter interruptions when the data was transferred to a computer. The ambient temperature and the relative humidity were further used to calculate THI according to the formula:

$$THI = (1.8 \times T + 32) - ((0.55 - 0.0055 \times RH) \times (1.8 \times T - 26))$$

Where T is the air temperature (°C), and RH the relative humidity (%) (Tucker *et al.*, 2008).

Rations of the cows and feed samples

The pasture was of mixed grass and clover. Every time the cows were moved to another paddock, the forage in that paddock was analyzed to decide quantity, dry matter and energy content. Extra silage of 4-8 kg DM was fed to the cows during milking. The amount of silage that was fed depended on how much pasture there was available. Also an individual ration of concentrate was fed during milking according to milk yield and body condition. Fresh water was provided *ad libitum* with 4 water bowls per group at pasture and at each stall place in the tie-stall barn.

Milk samples

The cows were milked twice daily, approximately at 7:00 am and 3:30 pm. The milking equipment was provided by DeLaval and at each milking the individual milk yield was automatically measured by a milk meter and the records were transferred to the computerized herd management program DeLaval DelPro for stanchion barns. During periods with high ambient temperature and during the following days after a warm period, milk sample from each cow was collected from the milk meter containers to measure fat, protein and lactose content and the amount of somatic cells. The length of these periods varied between 3 and 6 days. The milk analyses were done with a mid-infrared spectroscopy method (MilkoScan FT120, FOSS Electric, Hillerød, Denmark). Somatic cells were measured by electronic fluorescence-based cell counting (Fossomatic 5000, FOSS Electric, Hillerød, Denmark). All analyses were performed at Kungsängen laboratory. On cooler days no milk samples were analyzed.

Physiological parameters

The rectal temperature of the cows was measured when the cows were tied up for milking, both in the morning and in the afternoon on the same days as the behavioural observations took place (in total at 13 days). At three occasions when the cows were at pasture, from 1:30 pm, the body surface temperature and respiration rate were measured. The body surface temperature of the cows (irrespective of if the cow was placed in the sun or shade) was measured with an IR-thermometer at three different spots on the cow’s body as described by Ehrlemark (1991). These three measurements were then used to calculate a mean value of the cow’s fur temperature. The respiration rate (breath per minute) was measured by observing number of flank movements in 15 seconds and expressed as flank movements per minute.

Statistical analyses

All data were analyzed by the PROC MIXED procedure in SAS (version 9.2, SAS Institute Inc., Cary, NC, USA). The statistical analyses are divided into four parts to analyse how the weather variables, measured on the outside of the tent, affected milk production, respiration rate, fur temperature and rectal temperature. A p-value of <0.05 was considered statistically significant.

Milk production

The two groups of cows (with or without access to shade) were compared concerning milk production. The statistical analysis aimed to investigate if different weather variables had effect on milk production and if there were any differences between the groups. The effect of each weather variable (*Table 2*) was analyzed individually for each of the milk production traits: yield, protein, fat, lactose and somatic cells. The following model was used:

$$Y_{ijklmn} = \mu + (\text{weather variable})_i + (\text{group})_j + (\text{cow})_k + (\text{lactation number})_l + (\text{days in milk})_m + (\text{start milk yield})_n + (\text{weather variable * group})_{ij} + \varepsilon_{ijklmn}$$

Where:

Y = change in milk yield or change in content of protein, fat, lactose or somatic cells
μ = mean of all observations
weather variable = effect of different weather variables, i = 1,2, …, 8
group = effect of having access to shade
cow = random effect of individual cows
lactation number = effect of lactation number for each cow
days in milk = effect of number of days after calving
start milk yield = effect of individual milk yield day 1 of the trial
weather variable * group = interaction between weather variable and access to shade
ε = random error

Table 2. *Weather variables used for statistical analysis of milk production*

Weather variable	**Description of weather variable**
Mean THI	Mean value of temperature-humidity index
Max THI	Max value of temperature-humidity index
Max THI 1	Max value of temperature-humidity index 1 day before the milk samples were taken
Max THI 2	Max value of temperature-humidity index 2 days before the milk samples were taken
Mean temp	Mean value of temperature
Max temp	Max value of temperature
Max temp 1	Max value of temperature 1 day before the milk samples were taken
Max temp 2	Max value of temperature 2 days before the milk samples were taken

Respiration rate

Each weather variable (*Table 3*) was analyzed individually to see if they had impact on respiration rate and to see if there was a difference in respiration rate between the two groups. This was the model:

$$Y_{ijklm} = \mu + (\text{weather variable})_i + (\text{group})_j + (\text{cow})_k + (\text{lactation number})_l + (\text{days in milk})_m + (\text{weather variable * group})_{ij} + \varepsilon_{ijklm}$$

Where:

Y = change in respiration rate
μ = mean of all observations
weather variable = effect of different weather variables, i = 1,2, …, 4
group = effect of having access to shade
cow = random effect of individual cows
lactation number = effect of lactation number for each cow
days in milk = effect of number of days after calving
weather variable * group = interaction between weather variable and access to shade
ε = random error

Table 3. *Weather variables used for statistical analysis of respiration rate*

Weather variable	Description of weather variable
Mean THI	Mean value of temperature-humidity index
Max THI	Max value of temperature-humidity index
Mean temp	Mean value of temperature
Max temp	Max value of temperature

Fur temperature

Different weather variables, including black globe temperature (*Table 4*), were analyzed individually to see if they had impact on fur temperature and to see if there was a difference in fur temperature between the two groups. The used model was:
$Y_{ijklm} = \mu$ + (weather variable)$_i$ + (group)$_j$ + (cow)$_k$ + (lactation number)$_l$ + (days in milk)$_m$ + (weather variable * group)$_{ij}$ + ε_{ijklm}

Where:

Y = change in fur temperature
μ = mean of all observations
weather variable = effect of different weather variables, i = 1,2, …, 6
group = effect of having access to shade
cow = random effect of individual cows
lactation number = effect of lactation number for each cow
days in milk = effect of number of days after calving
weather variable * group = interaction between weather variable and access to shade
ε = random error

Table 4. *Weather variables used for statistical analysis of fur temperature*

Weather variable	Description of weather variable
Mean THI	Mean value of temperature-humidity index
Max THI	Max value of temperature-humidity index
Mean temp	Mean value of temperature
Max temp	Max value of temperature
Mean black globe temp	Mean value of black globe temperature
Max black globe temp	Max value of black globe temperature

Rectal temperature

To analyse whether there was a difference in rectal temperature between the two groups of cows, and to see if THI or temperature (*Table 5*) had impact on rectal temperature, the following model was used:

$Y_{ijklmn} = \mu$ + (weather variable)$_i$ + (group)$_j$ + (cow)$_k$ + (lactation number)$_l$ + (days in milk)$_m$ + (morning rectal temperature)$_n$ + (weather variable * group)$_{ij}$ + ε_{ijklmn}

Where:

Y = change in rectal temperature
μ = mean of all observations
weather variable = effect of different weather variables, i = 1,2, …, 4
group = effect of having access to shade
cow = random effect of individual cow

lactation number = effect of lactation number for each cow
days in milk = effect of number of days after calving
morning rectal temperature = effect of rectal temperature measured in the morning in the stall before cows were taken to pasture
weather variable * group = interaction between weather variable and access to shade
ε = random error

Table 5. *Weather variables used for statistical analysis of rectal temperature*

Weather variable	Description of weather variable
Mean THI	Mean value of temperature-humidity index
Max THI	Max value of temperature-humidity index
Mean temp	Mean value of temperature
Max temp	Max value of temperature

Results

For results about behaviour, the reader is directed to the thesis by Andersson (2009). The forage feed samples have not been taken into account when analysing the results because they turned out to be irrelevant. Because of the feeding routines with additional feeding to "hungry cows" during milking, it turned out to be impossible to estimate the energy intake per cow. That is why energy intake not has been included in the statistical model.

Meteorological data

In *Table 6*, a summary is presented of the weather variables: temperature (°C), relative humidity (%), black globe temperature (°C) and THI measured on the outside and inside of the tent, for the total trial period. Black globe temperature was only measured on the outside of the tent.

Table 6. *Meteorological data from the total trial period*

Weather variable	Outside tent			Inside tent		
	Mean	**Min**	**Max**	**Mean**	**Min**	**Max**
Temp, °C	18.5	7.3	33.1	18.2	8.9	30.6
Relative humidity, %	75.7	33.6	97.8	76.1	37.2	96.9
Black globe temp, °C	20.8	6.5	45.3	-	-	-
THI	63.7	45.5	79.6	61.9	50.1	71.6

The weather during July and August 2009 varied with periods of both rain and thunderstorms, and sunny weather. The measured daily mean temperature during the period was 18.5°C which, according to the Swedish Meteorological and Hydrological Institute (SMHI), did not differ from the normal daily mean temperature in July and August. In July it rained twice as much as it normally does whereas in August the amount of rainfall was normal (SMHI, 2012). The lowest temperature (7.3°C) was measured nighttime on July 30th and the highest (33.1°C) at noon on August 6th. THI values varied from 45.5 to 79.6.

Meteorological data showing temperature (°C), relative humidity (%), and THI from the same days the milk samples were taken and from the previous 2 days, are summarized in *Table 7*. The highest measured air temperature (33.1°C) and THI (79.6) was measured during a milk sample period (on August 6). Number of hours per day with THI-values exceeding the threshold level 72 has been calculated for the days associated with milk samples. On 13 of these days THI-values ≥72 was observed. The result shows that the warmest period with the most hours of THI-values exceeding 72 occurred in August. During three days, 5th to 7th of August, THI-values over 78 (which are considered to cause extreme heat stress) occurred. On the 5th and 7th of August, these high THI-values only occurred as one single measured value, whereas on the 6th of August, THI-values of more than 78 was measured repeatedly for 1.5 hour in the middle of the day. Periods with THI-values ≥68 never came up in a cohesive time interval of ≥ 17 hours. The mean THI per day never reached beyond 67.2. Mean daily temperature never exceeded 25°C but during the same days as THI-values ≥72 was observed, also temperatures ≥25°C were observed for about the same hours.

Table 7. *Meteorological data from the same day, and 1 and 2 days before milk samples were taken*

		Temp, °C		**Relative humidity, %**		**THI**		**THI ≥ 72**
Milk sample	**Date**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**	**h/day**
	2009-07-07	No data because of technical problems						
	2009-07-08	18.1	15.3-21.3	70.0	53.4-92.2	65.2	59.5-68.2	0
x	2009-07-09	14.1	12.4-15.5	93.4	90.5-96.3	57.3	54.4-59.8	0
x	2009-07-10	15.7	12.5-21.2	81.4	53.7-96.9	59.5	54.6-67.6	0
	2009-07-11	16.9	9.7-21.8	74.9	51.9-95.7	61.3	49.7-68.0	0
	2009-07-12	17.3	11.9-23.6	80.1	56.2-97.3	62.2	53.5-70.7	0
x	2009-07-13	18.8	10.2-25.5	71.3	43.6-94.9	64.2	50.7-72.2	<1
x	2009-07-14	17.4	7.7-25.1	79.1	53.8-97.4	62.1	46.2-72.4	<1
x	2009-07-15	20.4	9.2-27.6	67.7	41.1-96.4	65.7	48.8-74.2	8
x	2009-07-16	20.3	12.3-25.3	71.8	48.4-96.4	66.3	54.3-72.3	<1
x	2009-07-17	21.2	14.7-28.7	66.6	39.0-93.4	67.2	58.4-75.3	6
	2009-08-03	19.2	10.1-28.6	71.1	38.1-97.8	64.0	50.6-75.0	5
	2009-08-04	19.4	8.4-28.4	72.3	47.7-96.1	64.4	47.5-76.7	9
x	2009-08-05	20.9	10.5-31.7	71.1	33.6-96.7	66.3	51.2-78.0	10
x	**2009-08-06**	**21.4**	11.3-**33.1**	70.6	34.5-96.7	67.2	52.5-**79.6**	11
x	2009-08-07	20.1	11.7-29.7	77.4	46.3-97.2	66.0	53.2-78.0	8
x	2009-08-08	20.3	10.5-29.6	69.3	38.7-96.9	65.5	51.0-76.8	9
x	2009-08-09	19.9	9.9-28.3	67.4	39.9-96.6	64.7	50.0-74.9	8
x	2009-08-10	19.0	11.4-26.5	72.2	44.2-96.9	64.1	52.6-73.8	6
x	2009-08-11	No data because of technical problems						

Milk production

No significant effects of the weather variables on the milk production or on the content of the milk were found.

Respiration rate

Table 8 shows the statistically analyzed effects of THI and air temperature on respiration rate for the two treatment groups respectively. Max THI (but not mean THI), mean temperature and max temperature had a significant effect on respiration rate for the cows in both treatment groups. The calculated effect shown in *Table 8* should be read as the average increase in respiration rate (breath per minute) in each group (plus/minus the standard error (SE)) for every one unit rise in THI or air temperature. The effect was greater for group 2 which means that the respiration rate for the cows with no access to shade (group 2) increased more compared to the shaded cows in group 1. This difference in increased respiration rate between the two groups was less than one breath per minute for every one unit increase in THI or air temperature.

Table 8. The effects of a one unit rise in THI and air temperature on the mean increase (± SE) in respiration rate (breaths/min) for cows with access to shade (group 1) and cows with no access to shade (group 2)

Weather variable	Effect group 1 (breaths/min)	SE	Effect group 2 (breaths/min)	SE	P-value	Significance
Mean THI	4.1049	0.95	4.2651	0.95	0.0633	ns
Max THI	3.8607	0.62	4.0190	0.62	0.0202	*
Mean temp	5.3986	1.13	6.0094	1.15	0.0260	*
Max temp	3.3395	0.55	3.8360	0.56	0.0059	**

ns = no significance *= 5% significance level **=1% significance level

In *Figure 4* the observed mean values of the respiration rates in each group from the three data collection occasions are plotted against the actual THI-values at each data collection occasion. The data shows a trend of increased respiration rate with increasing THI for both groups but with a greater increase in the group with no access to shade (group 2). For example, if THI increases from 72 to 76 the average increase in respiration rate for group 1 is 7 breaths per minute whereas the average increase for group 2 is 28 breaths per minute. The average respiration rate in group 1 at THI 76 is 48 breaths per minute and 73 breaths per minute in group 2 (*Figure 4)*.

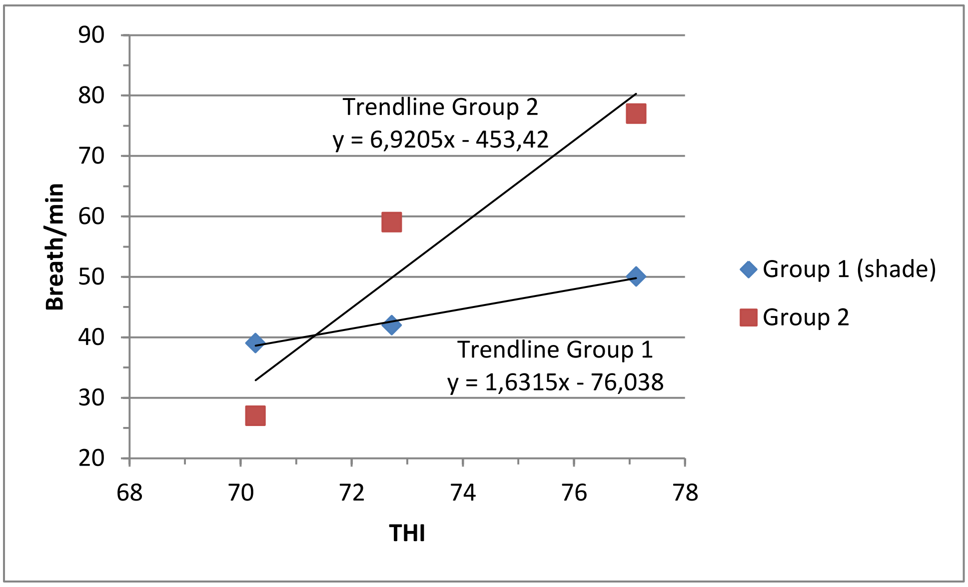

Figure 4. *Effect of increasing THI on respiration rate, based on the real data points observed at three occasions for shaded cows (group 1) and non-shaded cows (group 2).*

Fur temperature

In *Table 9* the statistically analyzed effects of THI, air temperature and black globe temperature on the fur temperature are shown for the two treatment groups respectively. The results show a significant effect of THI, air temperature and black globe temperature on fur temperature of cows in both treatment groups. The calculated effect shown in *Table 9* should be read as the average increase in fur temperature (°C) in each group (plus/minus the standard error (SE)) for every one unit rise in THI, air temperature or black globe temperature. Fur temperature increases with increasing THI, air temperature and black globe temperature. The effect was greater for group 2 which shows that fur temperature for cows with no access to shade (group 2) increased more compared to cows with access to shade (group 1). This difference in increased fur temperature between the two groups was less than 0.15°C for every one unit increase in THI, air temperature or black globe temperature.

Table 9. *The effects of a one unit rise in THI, air temperature and black globe temperature on the mean increase (± SE) in fur temperature (°C) for cows with access to shade (group 1) and cows with no access to shade (group 2)*

Weather variable	Effect group 1 (°C)	SE	Effect group 2 (°C)	SE	P-value	Significance
Mean THI	0.4980	0.12	0.5369	0.12	0.0006	***
Max THI	0.4259	0.08	0.4616	0.08	0.0002	***
Mean temp	0.6201	0.14	0.7619	0.14	0.0001	***
Max temp	0.3534	0.07	0.4593	0.07	< 0.0001	***
Mean black globe temp	0.3805	0.08	0.5083	0.09	< 0.0001	***
Max black globe temp	0.1980	0.04	0.2788	0.04	< 0.0001	***

***=0,1% significance level

In *Figure 5* the observed mean values of the fur temperature in each group from the three data collection occasions are plotted against the actual THI-values at each data collection occasion. The data shows a trend of increased fur temperature with increasing THI for both groups but with a greater increase in the group with no access to shade (group 2). For example, if THI increases from 72 to 76 the average increase in fur temperature for group 1 is 0.3°C whereas it is 3.7°C for group 2. The average fur temperature in group 1 at THI 76 is 31.9°C and 37.3°C in group 2 (*Figure 5).*

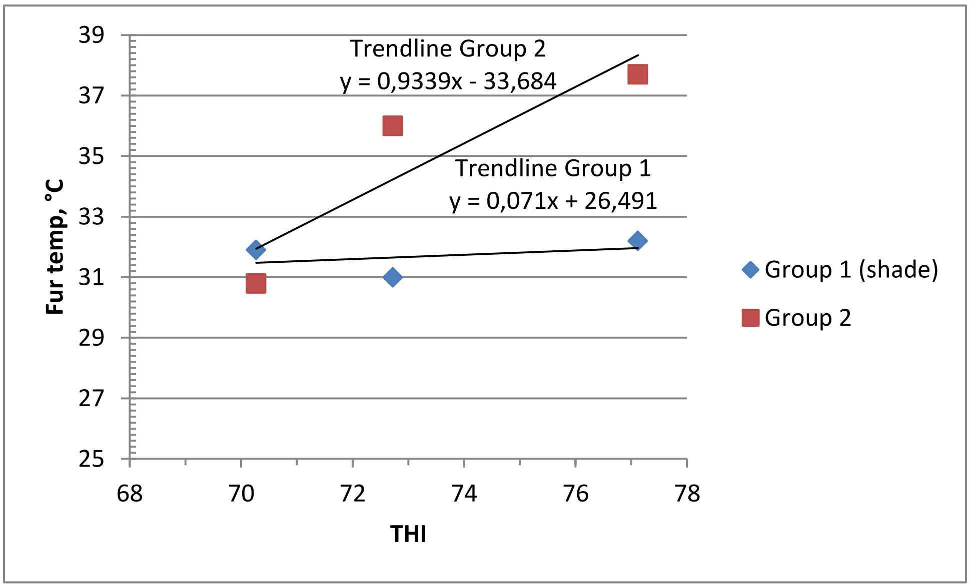

Figure 5. *Effect of increasing THI on fur temperature, based on the real data points observed at three occasions for shaded cows (group 1) and non-shaded cows (group 2).*

Rectal temperature

No significant effects of the weather variables on the rectal temperature were found.

Discussion

Milk production

Neither the weather nor the use of shade had a significant effect on milk yield or milk composition. These results are also confirmed by previous research (Collier *et al.,* 1981; Kendall *et al.,* 2006). Maybe the weather during the trial never was extreme enough to affect the cows to that extent so the production would be influenced, or maybe the periods of extreme weather (e.g. high temperature) were too short to affect the milk production. Both explanations are likely since periods with air temperatures of less than 21°C for 3-6 hours are believed to minimize production losses due to heat stress despite very high temperatures at daytime (Igono *et al.,* 1992). In fact, mean daily temperature during the trial never exceeded 25°C, which is considered to be the upper critical temperature (Berman *et al.,* 1985). Kendall *et al.* (2007) mentioned that the ambient temperatures in their study (mean temperatures of 19.5°C and 23.5°C, conditions very similar to the conditions in this study) might have been too low to depress the milk production.

THI-values over 78, which are considered to cause extreme heat stress (Igono *et al.,* 1992; Kadzere *et al.,* 2001), only occurred a few times during the trial; on two days when it was measured one time each day, and during one more day when it was measured repeatedly for 1.5 hour in the middle of the day. Furthermore, a THI-value over 72 is thought to cause mild heat stress with a decline in milk production (West *et al.,* 2003). This threshold was only achieved periodically during daytime for about one third of the trial period days and this might not been enough to cause a drop in the milk production due to heat stress. In addition, the milking facilities at Kungsängen Research Centre could be described as a holding pen with cooling (inside the barn with no solar radiation) where the cows are held twice daily for about 2-3 hours each time. This is, according to previous studies, a very effective way of cooling cows by management (Collier *et al.,* 2006) and could also have been a reason why the warm summer weather did not seem to affect the milk production. Furthermore, the somewhat cold nights with air temperatures around 10°C made it possible again for the cows to dissipate stored heat periodically. It has been suggested to lower the THI threshold from 72 to 68 for high producing dairy cows with a daily milk yield of 35 kg or more (Zimbelman *et al.,* 2009). This is probably useful since we breed for increased milk yield and it is the high producing dairy cows which are most susceptible to heat stress. Especially in a temperate climate with in general lower mean ambient temperatures during the year which do not enable the cows to acclimatize, to the same extent as cows in a tropical climate, to short periods of higher temperatures or THI during the summer months. However, the research behind the new suggested THI threshold value indicates a required time interval of 17 hours with an average THI of 68 before milk yield decreases (Zimbelman *et al.,* 2009). These particular conditions never occurred during this study.

The study period in this trial was only about 6 weeks and maybe we had got other results if data from the whole summer season, or even several summer seasons, had been collected and analyzed with complete milk sample analysis included.

Respiration rate and fur temperature

Respiration rate increased with increasing ambient air temperature and THI for cows in the both treatment groups but the effect was greater for non-shaded cows as has also been found in other studies (Bandaranayka and Holmes, 1976; Berman *et al.,* 1985; Silanikove *et al.,* 2009; Spiers *et al.,* 2004). Similar result was shown for fur temperature which increased with increasing THI, air temperature and black globe temperature in both groups but even more for the non-shaded cows. This probably means that the shade had some small cooling impact on the cows. The normal respiration rate for cows in the thermoneutral zone is 24-28 breath per minute (Bandaranayka and Holmes, 1976). In our observations the mean respiration rate varied between 39-50 breath per minute in group 1 and 27-77 breath per minute in group 2 at the three observation occasions (*Figure 4)* which indicates the cows were affected of the heat load. Only by establish that the cows with access to shade also used the shade voluntarily, you could say that the shade had some positive impact on the cows. Previous research has described that cows with dark fur colours absorb more heat than cows with a lighter fur colour (Finch and Western, 1977; da Silva *et al.,* 2003; West, 2003). The impact of fur colour was however not analyzed in this study where only cows of the breed Swedish red with fur colour of the variety from almost totally red to a mix of white and red fur was used. No black cows participated in the study and it would probably have been more interesting to compare a black cow with a red cow. Fur temperature is thus highly correlated with respiration rate which is a good measure of the microenvironment around the animal (Collier *et al.,* 2006). Earlier studies have shown that an increase in THI increases the respiration rate (Kendall *et al.,* 2007; Schütz *et al.,* 2008) with the function of preventing a rise in body temperature. This is a sufficient cooling strategy for the cow until THI reaches 80. Over that threshold the environmental influence becomes too stressful for the cow to maintain normal body temperature (Kadzere *et al.,* 2001). THI in our study never came up to that threshold. The highest measured THI was 79.6 but mean THI varied only between 57.3 and 67.2. The increased respiration rate found in this study might be a sufficient thermoregulatory mechanism for dairy cows in a climate similar to Swedish summer conditions.

Rectal temperature

Both respiration and dissipation of heat through the skin are evaporative cooling, and thus were our results of increased respiration rate and increased fur temperature with increasing ambient temperatures and THI expected. However, body temperatures taken closer to the external surface such as fur temperature, are less stable than deeper body temperatures due to influence from the environment (Martello *et al.,* 2010; Spiers *et al.,* 2004). Therefore, also rectal temperature was measured. Other studies have shown that cows in shade have lower deep body temperature compared to non-shaded cows (Collier *et al.,* 1981; Kendall *et al.,* 2007; Roman-Ponce *et al.,* 1976; Tucker *et al.,* 2008). The expectation was to see a higher rectal temperature in the afternoons for both groups but no such relation could be seen probably due to the fact that the rectal temperatures differed widely between the cows. Sometimes the rectal temperature for an individual cow was higher in the afternoon compared to in the mornings and sometimes the opposite. No differences concerning rectal temperature between the two groups were seen either. The heat load caused by ambient temperature and humidity might not have been as tough as in other heat stress studies and since the cows had to walk several hundred meters before the rectal temperature was measured, the eventual temperature difference probably was leveled out for cows in the both groups due to the walk as mentioned by Kendall *et al.* (2007). All cows were also under shade, inside the barn, when the rectal temperature was measured which probably affected the results of the measurements.

Recommendations

The study did not verify the importance of shade to dairy cows on pasture from an economic perspective meaning that shade on pasture would prevent a drop in milk production during the warm summer season. However, all cows in group 1, which had access to shade, used the shade from the tent to some extent during the trial period and the use of shade increased with increasing THI (Andersson, 2009). These results could be interpreted as the cows preferred to be in the shade instead of out in the direct solar radiation due to the cooling effect of shade.

If this trial should be run once again, some changes in the set-up would be recommended: The trial period should be longer and/or be followed up during upcoming summer seasons. For example in a cross-over design to get the tent tested on so many cows as possible to eliminate the effect of some individuals being more or less positive to use it than others. For example, in this trial there was one cow which never stayed in the tent presumably due to her low ranking order and not because she preferred to stay in the sun. The dividing of the cows in the two groups should be done in another way than in this trial. It would be desirable to use cows with parallel stage of lactation curves in both groups. It is also important to divide the cows equal in both groups according to parity since later parity cows usually are more susceptible to heat stress compared to first parity cows (Aguilar *et al.,* 2009; Aguilar *et al.,* 2010). Also, only cows included in the experiment should be in the paddocks to eliminate all influence from the other cows on the result. In this study we had a restricted budget which did not allow complete milk sample analysis for all trial days however, it could be something to consider since the more data you can analyze the higher will the accuracy probably be. When measuring rectal temperature, this should be done outdoors; in the shade or outside the shade respectively and preferably more often than in this study and as a suggestion with two decimals instead of only one. However, in this trial it was impossible to measure rectal temperature outdoors since the cows were untied and free. A solution to this is to use automatic temperature loggers rigged on the cows, for example inserted into the vaginal cavity, but this is of course costly. Respiration rate and fur temperature should also be measured more frequently than in this study and it is important that the people doing the observations are well synchronized. Finally, better control of the feed intake per cow would be desirable since this has a huge impact on milk production.

Conclusions

The cows with access to shade also chose to use it. Access to shade did not affect the milk production but it had a small cooling effect on the cows which was demonstrated by the results of measured fur temperature and respiration rate. For cows with no access to shade, fur temperature and respiration rate increased slightly more with increasing THI, air temperature and black globe temperature than it did for the cows with access to shade. Having access to shade did not affect the rectal temperature.

Even though the study did not verify the importance of shade to dairy cows on pasture from an economic perspective, the fact that the cows with access to shade also used it more with increasing THI, indicates that shade on pasture is important for the cow from a well-being perspective.

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