THE EFFECTS OF HIGH TEMPERATURE AND HOUSING MODIFICATION ON THE PRODUCTIVE AND REPRODUCTIVE PERFORMANCE OF DAIRY COWS

INTRODUCTION

Extended periods of high ambient temperature coupled with high relative humidity compromise the ability of the lactating dairy cow to dissipate excess body heat. Cows with elevated body temperature exhibit lower DMI and milk yield and produce milk with less efficiency, reducing profitability for dairy farms in hot, humid climates. Although adequate cooling systems exist, their efficiency in humid climates is less than in arid climates and these systems often lack the ability to assist dairy cows in maintaining normal body temperature.

Heat stress is caused by environmental factors such as air temperature, radiation, humidity, and wind velocity, which tend to displace physiological variables from their equilibrium values. There have been many attempts to develop an index that relates specific environmental characteristics to the physiological variables of heart rate, respiratory rate and volume, sweating rate, and body temperature. Such an index might allow the prediction of heat stress levels that are capable of causing severe distress or even death. One potential solution is to increase the efficiency of cattle production systems, with the objective of reducing the number of animals and area of land utilized by cattle thereby resulting in fewer resources being required for the same output; increased economic efficiency should also lead to the conservation of resources.

With the overall aim of improving dairy cow reproductive performance under tropical conditions, the present study was designed to investigate the effects of heat stress on the reproductive performance of Holstein Friesian cows in Thailand and avenues to ameliorate low reproductive performance associated with heat stress. Four experiments were conducted with the following objectives:

OBJECTIVES

1. To investigate the production and reproductive performance of dairy cows in Northeast of Thailand.
2. To identify and investigate the most economic method, under tropical conditions, for increasing the reproductive performance of dairy cows.
3. To define the thermal environment under modified housing conditions in Summer.
4. To evaluate the physiological response of dairy cows to the environment in hot – humid conditions of Thailand.

LITERATURE REVIEW

Most of the earth's surface between 23 ^{o} north or south of the Equator is hot and humid with low wind runs. Such tropical environments also lack photoperiodic seasonality, and unchanging day length can impact on the hormone secretion patterns of temperate breeds whose coat changes, reproductive cycles and metabolism are linked to seasonal light changes.

High Summer temperatures challenge agricultural animals in many regions of the world, and as a consequence heat stress is usually associated with Summer conditions. The result is reduced performance, and in some cases, death from extreme heat events (e.g., heat waves).The impact of heat stress can be reduced by recognizing the adaptive ability of animals and by the proactive application of appropriate counter-measures such as sunshades and/or evaporative cooling either by direct wetting alone or in conjunction with mechanical ventilation (Hahn *et al.,* 1992).

Heat stress is caused by an inappropriate combination of environmental factors including air temperature, radiation, humidity, and wind velocity. There have been many attempts to develop an index that relates these specific environmental characteristics to an animal's physiological variables such as its heart rate, respiration rate and volume, sweating rate, and body temperature. The aim has been to develop an index that might allow the prediction of heat stress status and particularly stress causing severe distress or even death (Blackshaw and Blackshaw, 1994).

Thermal stress in dairy cattle results in major decreases in milk production each summer. These decreases have been documented in many studies and reviews (Armstrong, 1994; Collier *et al.,* 1982; Ravagnolo *et al.,* 2000; Ray *et al*., 1992). Igono *et al*. (1992) proposed that the Temperature Humidity Index (THI) could be used to evaluate the level of thermal stress imposed by the environment. This index combines relative humidity and temperature parameters into a single value that provides an estimate of the potential environmental heat load. An environment is generally considered stressful for cattle when the THI exceeds 72 and when THI is at or above this level, adverse affects are expected (Johnson, 1987).

1. The impact of high environmental temperature on the general physiology of dairy cows

The stress of high environmental temperatures may be severe enough that unless physiological changes are initiated, decreased productivity or death can occur. While animals do acclimatize by gradually adapting to such stressors within their natural environment (Willmer *et al*., 2000), the level of adaptation is not well documented in most situations. Heat stressed cattle tend to have increased body temperatures (core and rectal) and as a result stressed cattle will decrease dry matter intake (DMI) and increase water intake.

During thermal stress, several physiological rearrangements occur in cows as they attempt to facilitate heat dissipation and/or reduce metabolic heat production. The major physiological changes involved in this acclimation and acclimatization are discussed below.

1.1 Rectal temperature

The effects of heat stress on animal production are well known and have been investigated and documented for a number of years. In pioneering research at the Climatology Laboratory in Missouri, the relationships between high ambient temperature and increased rectal temperature of dairy cows (Johnson, 1987) and the subsequent impact on milk yield, feed and energy intake (Tyrrell *et al*., 1988; Kirchgessner *et al*., 1991) were established. Elevated body temperature was due largely to a reduction in the temperature gradient between skin surface and the environment. Hence the interaction of environmental and body temperature and its effects on cattle performance form a complex interrelationship that affects the dissipation of body heat.

The ability of an animal to withstand the rigor of climatic stress under warm conditions has been assessed physiologically by changes in body temperature (BT) and respiration rates (RR; Bianca, 1965; Amakiri and Funsho, 1979; Legates *et al.*, 1991). A combination of rectal temperature (RT) and RR is suggested as a useful indication of heat tolerance when measured in the shade as compared to that measured in the sun (McDowell, 1958; Bianca, 1965; Herz and Steinhauf, 1978). RR is a mode of thermoregulation while RT is the result of thermal equilibrium (Kabunga, 1992).

Temperature measurement has been reviewed by Bianca (1965) in terms of skin and hair temperatures, deep BT and the temperature in the rumen. A considerable emphasis has been placed on the measurement of deep BT. RT is generally considered to be a useful measure of BT and changes in RT indicate changes of a similar magnitude in deep BT (Herz and Steinhauf, 1978; Rosenberger, 1979; Robertshaw, 1985).

The normal range in RT is very narrow in most domestic animals; not more than about 2.5°C (Herz and Steinhauf, 1978). The normal body temperature range for adult dairy cattle lies between 38.0°C and 39.3°C with an average of 38.6° C (Frandson, 1986). Daily variations are known to exist with the maximum temperature occurring in the early afternoon and the minimum in the early hours of the morning (Amakiri and Funsho, 1979). A rise in RT generally occurs above an ambient temperature of 21-26°C in *Bos taurus* cattle and above 32°C in *Bos indicus* cattle; younger cattle are affected at lower ambient temperatures than old ones (Dobinson, 1951; Bianca, 1965; Johnson, 1972). Death may occur when RT of a *Bos taurus* reaches 41.7°C (Vajrabukka, 1978).

1.2 Respiration rate

An increase in RR is one of the first visible reactions when ruminants are exposed to ambient temperature above the thermoneutral zone (TNZ; Riek and Lee, 1948). The responses to ambient temperature of dairy heifers and dairy cows were similar such that there was a rapid increase in respiration rate in the first hour of exposure to high ambient temperature and would maintain a high respiration rate there after while rectal temperature would be increased gradually to a certain level (Allen *et al.,* 1974).

An evaporative heat loss from the respiratory tract is regarded as one of the primary mechanisms for maintenance of heat balance (McDowell, 1958). This respiratory response arises from direct heat stimulation of peripheral receptors which transmit nervous impulses to the heat centre in the hypothalamus. The cardio-respiratory centre is then stimulated to send impulses to the diaphragm and inter-costal muscles for further respiratory activity (Findlay and Ingram, 1961). A high RR in most cases does not necessarily indicate the animal is successful in keeping its temperature balance, but rather that it is already overheated and trying to restore normal heat balance (McDowell, 1958).

Normal respiration rate is approximately 10 – 30 breaths/min (Hafez, 1968) and the respiration rate increases when environmental temperature increases (McDowell, 1958; Bond and McDowell, 1972; Singh and Bhattacharya, 1991). The critical respiration rate before the onset of panting for cattle is around 80 breaths/min (Robertshaw, 1985, Kabunga, 1992). Panting occurs when cattle breath with mouth wide opened and salivate heavily (Figure 1). The breathing can be described as shallow rapid breaths and 200 - 400 breaths/min can be reached (Kabunga, 1992). Heat exchange, therefore, takes place at the mucosa of the upper respiratory tract in the region of the turbinate bones. Heat is provided by the blood supply to the nasal mucosa and the cool blood drains into the venous sinuses at the base of the skull, where it joins blood draining the ears and horns. There, they encircle the rete mirabile, the network of small arteries that makes up the blood supply to the base of the brain. It has been suggested that the function of the rete mirabile is as a countercurrent heat exchanger; the blood supplying the brain being cooled by blood draining the nasal mucosa, the ears and the horns (Hales, 1967; Robertshaw, 1985).

Figure 1 A pure blood Holstein Friesian panting under severe heat stress.

The significance of an increase in RR under heat stress is that it enables the animals to dissipate excess body heat by vapourising more moisture in the expired air, which accounts for about 30% of total heat dissipation (McLean, 1963). However, excessive respiratory activity may cause respiratory alkalosis and in severe heat rapid shallow breathing (panting or polypnea) followed by open-mouthed breathing seems to be associated with a shift in respiration from first phase rapid shallow breathing to a second phase deep open-mouthed breathing (Bianca, 1963). This transitional breathing is indicative of reduced efficiency of nasal cooling (Young *et al.,* 1998). A respiratory alkalosis has been shown to develop in cows and calves experiencing 'second phase' breathing, and is characterized by a low carbon dioxide content of the blood plasma with a high blood pH and a rise in urine pH (Bianca, 1965). However, panting is not the main factor in the control of body temperature in cattle (Herz and Steinhauf, 1978).

With increasing environmental temperature, the RR continues to rise linearly and reaches its peak at about 150- 170 breaths/min for Jerseys and Holsteins, after which it is likely to decline (McDowell, 1958; Bianca, 1963). This level is considered the ceiling response or the limit of the physical capacity of the respiratory system due to muscular fatigue. The RR of European breeds of cattle rarely exceeds 50 breaths/min at temperatures under 26ºC (Johnson, 1987).

1.3 Pulse rate

Pulse rate of heat stressed cows are inconsistent (Herz and Steinhauf, 1978). The normal pulse rate of cows is 60-70 breaths/min (Hafez, 1968), a rate which reflects primarily the homeostasis of circulation along with the general metabolic level (Bianca, 1965; Habeeb *et al.,* 1992). It increases on exposure to high ambient temperature at 32-38° C (Mullick and Kehar, 1959; Bianca, 1965), and associated changes in capillary flow cause an increase in blood flow from core to surface and thus allow more heat to be lost by sensible (conduction, convection and radiation) and insensible (evaporative) ways. However, some studies show that pulse rate does not always change appreciably under high environmental temperature (Yousef and Johnson, 1966) due to a decrease in thyroid hormone levels which affect a decrease in the basal metabolic rate of the animals under heat stress. It appears, therefore, to be questionable whether pulse rate can be regarded as a good indicator of heat stress in cattle (Herz and Steinhauf, 1978).

1.4 Haematocrits and Haemoglobin

Changes in blood constituents have also been suggested as measures of adaptability (McDowell, 1958). The haematocrit values, erythrocyte count and the haemoglobin concentration in the blood seem to fall during heat stress (Bianca, 1965). The lower haematological values in the heat stressed cows may be due to haemodilution, by which more water is transported in the circulatory system for evaporative cooling (Shebaita and Kamal, 1973; Marai *et al*., 1999)

Zebu cattle in general have higher values for the concentration of Hb than do temperate cattle (Evans, 1963). High haemoglobin values are associated with high adaptability to extreme conditions of temperature and it has been suggested that this character might be an index of their superior heat tolerance (Bianca, 1965; Johnson, 1987). It would appear, however, that such a relationship, if established at all, would be incidental rather than causative.

Chronic exposure to heat results in decreases in the packed cell volume (haematocrits percentage) (Weldy *et al.,* 1964; Rowlands *et al.,* 1974; Bond *et al.,* 1984) due to red cell destruction and/or to haematodilution (Hafez, 1968) and to reduction in cellular oxygen requirements to minimize the metabolic heat load (Lee *et al.,* 1976). On the other hand, Bianca (1965) has reviewed the increases in haemoglobin concentration and in haematocrits value during acute exposure of European calves to heat, and the minimal effects on Zebu crossbred heifers, and concluded that the latter was possibly because the heat load was not sufficiently high to stress the Zebu cross heifers.

The erythrocyte (Red Blood Cell) count is also found to decrease significantly (by 12-20%) in cattle under heat stress conditions (Habeeb *et al.,* 1992) due both to the destruction of erythrocytes and to the haemodilution effect (Schaffer *et al.,* 1981). In contrast, leucocyte (White Blood Cell) count values have been mostly found to increase by 21-26% in Friesian cattle under heat stress due to thyromolymphatic involution (Habeeb *et al.,* 1992).

2. The impact of high ambient humidity on the general physiology of dairy cows

In dairy cattle, evaporative heat loss, especially from sweating, increases in importance as environmental temperature increases (Figure 2). This is associated with diminished evaporative heat loss capacity as either ambient temperature or humidity rise. In hot climates, the potential for non-evaporative heat loss is reduced and animals rely on the evaporation of water to dissipate any excess heat generated by metabolism (McArthur and Clark, 1988). When the thermal load exceeds the evaporative heat loss capacity, body temperature rises and, if unchecked, the animal dies from hyperthermia.

High relative humidity reduces evaporation which means that body heat dissipation is more difficult to attain, and this is particularly so when the environmental temperature is close to an animal's body temperature. Further, vaporization from the respiratory tract and the outer body surface is directly affected by the temperature and relative humidity of the air (McDowell, 1972). Furthermore, relative humidity influence body temperature although Quczi and Shrode (1954) found that under field conditions the air moisture content had minimum effects on body temperature. On the other hand, under climatic chamber the air moisture content has been shown to have some impact on body temperature, high moisture content conditions leading to increased body temperature (Vajrabukka, 1978; Allen *et al.,* 1974). The latter authors found that at 35 °C environmental temperature, if relative humidity was increased heat production and heat dissipation from the body were obstructed and body temperature and respiration rate increased.

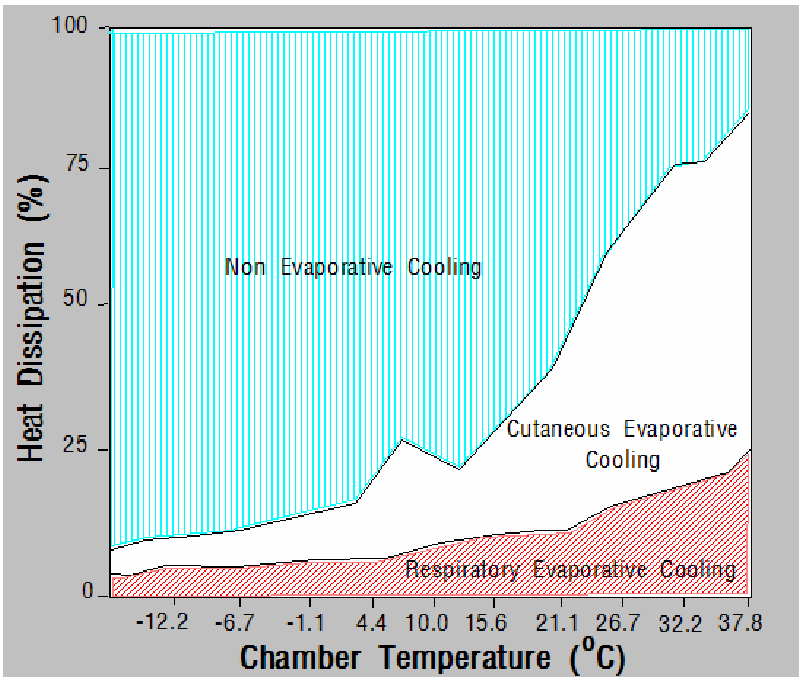

Figure 2 The partition of heat losses from Bos taurus cows

Source: (modified from Kibler and Brody, 1950; Esmay, 1977).

2.1 Temperature Humidity Index (THI) and heat stress in dairy cows

Since both ambient temperature and ambient humidity (Relative Humidity, RH) contribute to heat stress in dairy cattle. The temperature-humidity index (THI, Thom (1959) incorporates the effects of both ambient temperature and relative humidity in an index. This index is widely used in hot areas worldwide to assess the impact of heat stress on dairy cows (Hahn, 1969; Fuquay, 1981).

The environmental temperature, radiant energy, relative humidity, and wind speed all contribute to the degree of heat stress (De Rensis and Scaramuzzi, 2003). Heat stress may be defined as any combination of environmental variables that give rise to conditions that are higher than those of the temperature range of the animal's thermal neutral zone (Garcı´a-Ispierto *et al*., 2007). Dairy cows respond to heat stress in several ways: reduced feed intake and increased water intake, changed metabolic rate and maintenance requirements, increased evaporated water loss, increased respiration rate, changed blood hormone concentration, and increased body temperature (Knížková and Kunc, 2002; Koubková *et al*., 2002). All dairy cows, especially higher producing and multiparous cows are more susceptible to heat stress (Brouček *et al*. 1990; Bucklin *et al*., 1991). However, consideration of temperature alone is not sufficient; it is important to consider also relative humidity. There is a difference in the effects of high temperatures in humid or dry environment (Blackshaw and Blackshaw, 1994). Johnson *et al*. (1962) noted that milk production in dairy cows decreased with an increase in THI and later (Johnson *et al*., 1987) showed that milk production and dry matter intake declined when THI reached the value of 72.

From Johnson *et al*. (1962), THI values (Table 1) were developed and used by Nienaber and Hahn (2004) for measuring and estimating heat stress conditions in beef cattle confinement as well as in dairy cows and swine production. The normal values were considered ≤ 74, alert values were those from 75 to 78, danger values are those from 79 to 83, and emergency values were ≥ 84.

Table 1 Temperature Humidity Index in various countries.

	Climate Zone	A. Ave. months above 72	B. No. months above 72	C. Time index: A x B	D. Average Annually
1	U.S.A. (Missouri)	74.5	2	149	54.6
2	Japan (Kyoto)	74.7	3	224	61.6
3	U.S.A. (Phoenix)	77.0	4	308	66.6
4	Egypt (So. Delta)	76.5	4	306	68.8
5	Costa Rica (Atenia. low-land-dry)	71.9	2	144	69.5
6	Costa Rica (CATIE, mid-alt.- humid)	71.4	2	144	70.7
7	Saudi Arabia (Hufuf)	80.5	7	563	71.9
9	Mexico (Cardenas, Tabasco)	76.0	8	608	74.0
10	Costa Rica (Guapiles) (low-humid)	73.2	11	805	73.2
11	Bangladesh (Dhaka)	75.8	10	758	73.9
12	Costa Rica (Limon)(low-humid)	74.2	11	816	73.0
13	Puerto Rico (San Juan)	75.0	12	900	75.0
14	Thailand (Bangkok)	75.7	12	908	75.8
15	Dominican Republic (Santiago)	76.2	12	915	76.2
16	South America (Guyana)	77.2	12	926	77.3
17	Malaysia (Kuala Lumpar)	78.7	12	944	78.7

Source: (Johnson, 1989).

The failure of homeostasis at high temperatures may lead to reduced productivity or even death (Blackshaw and Blackshaw, 1994). Heat stress results from the combined effects of relative humidity and ambient temperature. Therefore, THI is commonly used to indicate the degree of stress in dairy cattle. THI values suggest that within the normal range up to 70, cattle show optimal performance.

In the warning range of THI values 70–72, dairy cow performance is inhibited and the cooling of animals becomes desirable. Critical THI values are 72–78, when milk production is seriously affected and the dangerous category where survival is threatened is at THI values 78–82 (Du Prezz *et al*., 1990).

Table 2 Temperature Humidity Index at different level of heat stress for dairy cows.

°C	RELATIVE HUMIDITY													Stress level
	40	45	50	55	60	65	70	75	80	85	90	95	100	
23.9	No Stress					72	72	73	73	74	74	75	75	Mild
26.7	73	73	74	74	75	76	76	77	78	78	79	79	80	
29.4	76	77	78	78	79	80	81	81	82	83	84	84	85	Medium
35.0	79	80	81	82	83	84	85	86	86	87	88	89	90	
95.0	83	84	85	86	87	88	89	90	91	92	93	94	95	Severe
37.8	86	87	88	90	91	92	93	94	95	97	98	99		
40.6	89	91	92	93	95	96	97							

Source: (modified from Wiersma, 1990).

Wiersma (1990) has tabulated the THI index (Table 2) into different level of heat stress for dairy cows and recently, Chase (2008, Table 3) has identified symptoms at the various levels of heat stress based on the THI table of Wiersma (1990).

The influence of environmental heat and THI is especially critical to conception rates of temperate zone lactating cattle during summer heat (Rabie, 1983) and in the subtropics (Ingraham *et al*., 1976). Most evidence suggests that most reproductive failure associated with hyperthermia in cattle is due to embryonic death (Thatcher and Roman-Ponce, 1980; Putney *et al.,* 1988) rather than insufficient LH, high prolactin or low progesterone, which are responsible for ovulation and fertilization actions. Embryonic death may be due to thermal or uterine environmental changes (including hormonal or immunological changes; Spencer, 1988).

Table 3 The Effect of heat stress on dairy cows.

THI	Stress level	Comments
72	None	
72-79	Mild	Dairy cows will adjust by seeking shade, increasing respiration rate and dilation of the blood vessels. The effect on milk production will be minimal.
80-89	Moderate	Both saliva production and respiration rate will increase. Feed intake may be depressed and water consumption will increase. There will be an increase in body temperature. Milk production and reproduction will be decreased.
90-98	Severe	Cows will become very uncomfortable due to high body temperature, rapid respiration (panting) and excessive saliva production. Milk production and reproduction will be markedly decreased
>98	Danger	Potential cow deaths can occur

Source: (Chase, 2008).

3. High environmental temperature and endocrinology of dairy cows

The detrimental effects of a hot climate on a cow's reproductive performance are a result of the drastic changes induced by the animal's own temperature regulation mechanisms. Heat stress is known to be responsible for a delay in functional luteolysis and a decrease in circulating estradiol (Hansen, 1994; Wilson *et al.,* 1998) and key metabolic hormones are also thought to be influenced by heat stress including T3, T4, leptin and insulin.

3.1 Thyroid hormones

Thyroid hormones are important in an animal's adaptation to a hot environment. Both triiodothyronine (T_3) and thyroxine (T_4) are associated with metabolic homeostasis and are susceptible to climatic changes (Perera *et al.,* 1985). Shade or cooling can therefore alter thyroid activity when cattle are exposed to heat stress (Collier *et al*., 1982a; Gomila *et al*. 1977). Likewise the decrease in the level of triiodothyronine (T_3) and thyroxine (T_4) hormones from the thyroid gland is also thought to play a role in decreasing reproductive activity (Farghaly, 1984). In a healthy cow living at a thermoneutral temperature in the luteal phase, a corpus luteum is formed under the influence of pituitary LH. The function of the corpus luteum is to secrete progesterone, which provides a negative feedback to reduces the amount of oestrogen produced. As long as the corpus luteum is functional, follicle development is suppressed (Figure 3). T_3 is also an important factor in maintaining normal lactation (Van Jonack and Johnson 1975) and high milk production (Swanson and Miller 1973). Lower concentrations of T_3 in milk were found by Magdub *et al.* (1982) in heat-stressed Holstein cows compared to cows at a thermoneutral temperature and Deresz (1987) reported that during the hot Summer in Arizona, Holstein cows subjected to evaporative cooling showed higher levels (+0.17 ng/ml) of T_3 in serum than did shaded cows although differences were not significant. Yousef and Johnson (1966) reported that dairy cows exposed to chronic high environmental temperatures had depressed thyroid activity and milk production.

The thyroid hormones, T_4 and T_3, provide a major mechanism important for acclimation (Johnson and Van Jonack, 1976; Horowitz, 2001) and are known indicators of heat stress (Pusta *et al*., 2003). As a general observation, it is well known that heat acclimation decreases endogenous levels of thyroid hormones and that mammals that have adapted to warmer climates follow this pattern (Johnson and Van Jonack, 1976; Horowitz, 2001).

3.2 Leptin

During the transition into lactation, dairy cows undergo large metabolic adaptations in glucose, fatty acid, and mineral metabolism to support lactation and avoid metabolic dysfunction (Overton and Waldron, 2004) but the level of feeding in grazing dairy cows during the last month before calving has only small effects on the cows' metabolic and hormonal status (Doepel *et al.,* 2002; Roche *et al.,* 2005). However, since leptin is thought to play a critical role in regulating energy metabolism throughout mammalian life (Block *et al.,* 2003a) and nutritional change induced by heat stress may be a factor influencing leptin changes. Heat stressed dairy cows reduce dry matter intake (Drew, 1999; Hansen, 1997; Fuquay, 1981; Ronchi *et al*., 2001) and this reduced DMI, coupled with the higher energy requirement, especially in lactating cows, result in a deficit in Net Energy Balance (NB) and subsequently a loss in production.

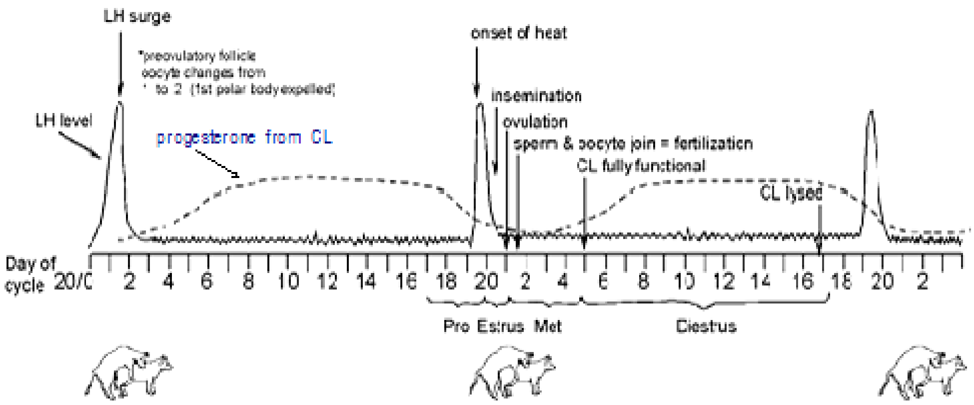

Figure 3 Schematic of stages of the estrous cycle, serum progesterone concentrations, and serum luteinizing hormone (LH) concentrations.

Source: (modified from Larson and Randle, 2008).

Leptin may be a metabolic signal to the neuroendocrine reproductive system and under conditions of inadequate energy reserves it is hypothesized that, low leptin levels act as a metabolic "gate" to inhibit the activity of the neuroendocrine reproductive axis in both males and females (Cunningham *et al.,* 1999). The direct influence of leptin at the pituitary level in other species is supported by the presence of leptin receptors in the pituitary of ewes (Iqbal *et al*., 2000) and studies demonstrating increased release of LH from pituitary explants in rats (Yu *et al*., 1997).

fasted sheep (Nagatani *et al*., 2000) and cows (Zieba *et al*., 2003). One reported exception to these associations is that leptin does not appear to consistently influence the secretion of GH in well-fed sheep (Henry *et al*., 1999; Henry *et al*., 2001; Morrison *et al*., 2002) or the anterior pituitary responses of well-fed cows (Zieba *et al*., 2003). It seems that in prepubertal, intact heifers, exogenous leptin has the ability to prevent fasting-mediated reductions in LH pulse frequency, to enhance responsiveness of the anterior pituitary to GnRH, and to increase basal GH secretion (Maciel *et al.,* 2004a).

Hence, leptin is positively correlated with net energy balance (NB) of ruminants (Minton *et al*., 1998; Blache *et al*., 2000a; Tokuda and Yano, 2001) and dairy cows. As such the level of leptin represents an animal's metabolic status and may also be an indicator of the impact of other environmental effects such as environmental temperature (Accorsi *et al*., 2005)**.**

3.3 Insulin

Nutrition plays a major role in controlling reproductive processes. However, the physiological mechanisms through which nutrition mediates its effects are not well understood. Clearly, changes in the availability of nutrients are perceived by the hypothalamus and influence gonadotropin secretion via effects on hypothalamic GnRH release (Foster *et al*., 1989; Ebling *et al*., 1990). Insulin and leptin are hypothesized to be the adiposity signal for the brain to regulate body weight.

Johnsson *et al,* (1997) suggested that the reduction in dry matter intake by heat stressed animals resulted in a negative energy balance, which prolonged the postpartum period and decreased fertility in dairy cows. Negative energy balance leads to decreased plasma concentrations of insulin and glucose, which are essential for normal follicle development. Lower plasma concentrations of insulin and glucose lead to impaired follicular development and delayed ovulation.

Insulin appears to play a role in regulating synthesis and secretion of leptin. Adipose tissue fragments cultured in the presence of insulin increased both synthesis and secretion of leptin into the medium (Barr *et al*., 1997). Furthermore, a positive correlation between insulin and leptin levels has already been demonstrated in dairy cows (Block *et al*., 2001, 2003b; Holtenius *et al*., 2003).

The depression of many hormones in heat stressed cattle, especially insulin (Habeeb, 1987), thyroxine (El – Masry and Habeeb, 1989), and cortisol (Kamal *et al.*, 1989) may contribute to a decrease in milk production as well as changes in milk composition. The upper critical environmental temperatures of European cattle are in the range of 21-27 °C and 24-30 °C for milk production and growth rate respectively. The adverse effects of hot weather on reproduction will vary from farm to farm depending upon how effectively heat stress is minimized, on feeding management, on cow comfort and on the accuracy of heat detection.

3.4 IGF-I

The concentration of IGF-I has been found to decrease in the summer months compared to winter (Ingraham *et al.*, 1982; Butler and Smith, 1989; Whitaker *et al.*, 1993; Jolly *et al.*, 1995; Richards *et al.*, 1995; Johnsson *et al.*, 1997; Hamilton *et al.*, 1999). and since plasma levels of IGF-1 are directly related to energy status and IGF-I is critical to ovarian follicular development (Beam and Butler, 1999) it is possible that IGF-1 is associated with poor reproductive performance in Summer. This effect may be mediated through reduced feed intake as undernourished cows in a phase of negative energy balance have lower IGF-1 levels (Webb *et al.*, 1999; Bousquet *et al.*, 2004) and an increase in dietary intake improves LH pulse frequency (Spicer *et al.*, 1990) and the diameter of the dominant follicle in heifers (Diskin *et al.*, 1999).

4. High environmental temperature and reproductive efficiency of dairy cows

High environmental temperatures have been shown to suppress oestrus, resulting in periods of anoestrus and also interruptions to early pregnancy causing death of embryos and abortion (Van Heerden, 1963). Age at puberty, oestrous cycle length, duration and incidence of oestrus, incidence of abnormalities of the ova, embryonic mortality, fetal death rates, gestation length and fetal size (Hafez, 1968), percentage of silent heat, ovulation failure, interval from parturition to conception and number of services per conception may increase as a result of heat stress (Mohamed, 1974) while the frequency of ovulatory oestrus, fertilization rate and neonatal survival may decrease (Hafez, 1980). Heat stress has also been reported to cause loss of libido, ovarian activity and conception rate (Mohamed, 1974).

A comparison between the seasons of the year shows that in hot summers ovarian activity decreases, while it increases during winter and spring when ambient temperatures are lower. In buffalo (El – Fouly *et al*., 1976) and Holstein cows ovarian activity was found to decrease under heat stress (Mirzaei *et al*., 2007). The proportion of cows with clear symptoms of oestrus is also lower in the summer (25%) than in the winter (48%) and heat stress has been shown to decrease the intensity and duration of oestrus (Fuquay, 1981; Shearer *et al.,* 1991) and increase the incidence of anoestrus and silent ovulation. In dairy cows the consequence of these changes are an increase in the total number of inseminations and a reduction in the proportion of inseminations resulting in pregnancy (Cavestany *et al*., 1985). Oestrus in thermally stressed dairy cows may be reduced from 18 to about 10 hours (Thatcher and Collier, 1986; Fuquay, 1981; Shearer *et al.,* 1991) and cows generally show most activity during the cooler parts of day (Bearden and Fuquay, 1992). Cows bred during the summer season generally exhibit more average days open, apparently because of irregular or missed oestrus periods (Hansen, 1994).

5. Amelioration of the effects of high environmental temperature on reproductive efficiency

A number of strategies have been used successfully to reduce the heat stress experienced by cows and to consequently increase feed intake, milk production and reproductive efficiency during the summer. One modification of particular significance is the modification of housing facilities but also nutrition and hormonal modulation has been attempted.

5.1 Housing modification

Solar radiation and humidity have been identified as major factors contributing to heat stress in mature lactating dairy cows (Badinga *et al*., 1985; Collier *et al*., 1982; Thatcher *et al*., 1978; Ulberg and Burfening, 1967). Although several elaborate methods for reducing heat stress in cows have been reported (Flamenbaum *et al*., 1986; Roman-Ponce *et al*., 1977; Thatcher, 1974; Thatcher *et al*., 1978; Wise *et al*., 1988), simple shade appears to be the most cost-effective method that is currently available. Shade has been shown to reduce ambient and rectal temperatures and respiration rate and to increase milk production and conception rate (Roman-Ponce *et al*., 1977; Thatcher *et al*., 1978) in lactating cows. Polypropylene fabric or shade cloth has become popular as an alternative shade source for animals, particularly fabric which provides 80% shade (Bucklin *et al.,*1993).

Fans cool by moving air over the body of animals at a faster speed than normal air movement but when fans are not sufficient to elevate cooling levels, additional cooling can be achieved by using evaporative cooling. Research at the University of Florida has shown a 10 percent increase in milk production in cows that are cooled by fans and sprinklers compared with animals in free stalls (Brouk *et al*., 2005). Smith *et al.* (2006) found that cooling cows with evaporative tunnel ventilation reduced respiration rates by 15.5 ± 0.56 breaths/min and rectal temperatures by 0.6 ± 0.02°C compared with shade and fans alone in 2003 in the southeastern USA.

In areas of high radiation load modern dairy housing systems have been designed to reduce the impact of heat stress and to improve the performance of cows (Roman-Ponce *et al.,* 1977). Metal roof structures, shades, sprinklers, and fans have also all been used to reduce the thermal load on cattle during periods of elevated ambient temperatures (Givens, 1965; Singh and Newton, 1978; Stott *et al.,* 1976**;** Turner *et al.,* 1992).

The response of cattle to shade in areas of high humidity are generally less predictable than those of cattle in arid regions (Fuquay, 1981). Trees serve as very effective shade, but may die when cow density is high (Hansen, 1994) and therefore trees need to be protected in such situations (Bucklin *et al.,* 1992). Improved efficiency of shading with metal roofing has been noted where rooftops are painted white and the underside black; by placing about 2.5 cm. of insulation directly beneath the underside, and by sprinkling the roof with water (Hansen, 1994; Bucklin *et al.,* 1992; Fuquay, 1981). The first and fundamental objective of shading is to block solar radiation and both portable shade cloth or permanent shade structures can achieve this objective.

For cattle it has been calculated that shade should be at least 4m high, and preferably 5-6 m. high, to minimize radiation reflection from the shade roof back to the cow, and to maximize air velocity flowing over the roof, subsequently reducing roof temperature (Berman and Wolfenson, 1992). However the literature on this topic is limited and further experimentation to optimize designs is needed. Ridge vents on sheds used in warm climates should be at least 0.3 m. wide with an additional 4 cm. for each 3m of structure width over 6m (Bucklin *et al.,* 1992). It has been suggested that roof slopes should be at least at 33% (Jacobsen, 1996) although experimental evidence appears to be sparse.

Hansen (1994) has reported that temporary shade structures should be oriented with the long axis North and South to maximize use of the sun in drying the ground under the shade during the morning and afternoon. This methodology is widely used in yarded cattle exposed to high temperatures such as is the case with feedlots in tropical areas.

5.2 Heat stress and nutritional manipulation

Two sources of heat, ambient temperature and the nutrient metabolic heat, impact the cow. As milk production and feed intake increase, more heat from nutrient metabolism is produced aggravating any heat stress being incurred from environmental sources. Therefore, higher milk production cows will begin experiencing heat stress before lower producing or dry cows (Linn, 1997).

A reduction in DMI is the primary reason milk production declines during heat stress periods (West, 2003). At the same time as DMI decreases, maintenance cost of the cow increases in an attempt to maintain body temperature and thus, the overall availability of nutrients and energy for milk production is decreased. There is possibility that added fat alleviates heat stress by providing non-fermentative energy (McDowell *et al*., 1969; Tyrrell *et al*., 1979) to cows. This can be done by protecting the fat globules thus enable them to go through the rumen without being attacked by the microbes after which they will be digested in the small intestine similar to the digestive process of a monogastric.

It has been found that using by-pass fat can enable a dairy cow to receive sufficient energy for production. Wrenn *et al*. (1978) reported substitution of the energy fraction at 25 % level with by-pass fat in the diet of Holstein cows after parturition 1 - 3 months and with milk yield at more than 20 kg/d. The digestible energy was increased from 220.08 to 249.37 MJ/hd. Andrew *et al.* (1991) supplemented by-pass fat in the form of Ca-LCFA (Calcium salt of long chain fatty acid : Megalac®) in a cow diet at 2.95 %. and found that cows received less gross energy but more digestible, metabolizable and net energy.

The most effective management strategy to minimize production losses during heat stress periods is to provide a cool, comfortable environment by shading, sprinkling and/or forced air flow. Modifying the environment will result in bigger gains, or fewer losses, during heat stress periods than any dietary manipulations. Diet changes will have only a small effect on productivity and should be considered supportive of an enhancement to environmental conditions (Linn, 1997).

5.3 Somatotropin (bST)

Somatotropin is a protein hormone produced in the pituitary gland of all vertebrates including cattle. Bovine somatotropin (bST or BST) or more commonly bovine growth hormone can be produced synthetically, using recombinant DNA technology and the "recombinant bovine somatotropin" rBST (Anon, 2008) has been evaluated in heat stressed cows as a means to reducing heat effects on milk production.

Treatment of heat stressed lactating cows with bST can increase milk yield (West *et al*., 1990; Elvinger *et al*., 1992). Johnson *et al*. (1988), using the rBST, increased milk yields under summer farm conditions by 18% and subsequently showed larger increases in controlled laboratory experiments. The increase in milk, feed intake and metabolism did not increase body temperature more than controls due possibly to increased heat loss and/or efficiency of energy utilization (Johnson *et al*., 1987). However, other groups of scientists (Elvinger *et al*., 1992 ; Cole and Hansen, 1993) have found that treating cows with bST during heat stress conditions can increase body temperature. They suggested that some of this increase in body temperature may be independent of the effects of bST on lactation. Given the fact that elevated body temperature compromises fertility in lactating cows (e.g., a 0.5° C increase in uterine temperature on the day of insemination resulted in a 12.8% decrease in fertility; Gwazdauskas *et al*., 1973), it is possible that bST treatment during heat stress could compromise fertility. However, bST may overcome adverse effects of increased hyperthermia on fertility. Indeed, treatment of dairy cows with bST increased fertility (Moreira *et al*., 2000, 2001; Santos *et al*., 2004).

6. Conclusion

Optimal milk production requires facilities that will prevent excessive environmental heat load, while assisting cattle to dissipate surplus body heat. Feeding and management practices that help minimize internal heat production are also important (Shearer *et al.,* 1991) and can be combined with the use of shade, sprinklers, and fans to alleviate much heat stress (Hansen, 1994). The impact of well designed systems to reduce heat load and optimise milk production and reproductive performance of dairy cows have still not been widely assessed in tropical environments. Therefore a series of experiments were designed to investigate methodologies to ameliorate heat effects and increase reproductive performance of heat stressed dairy cows maintained in hot-humid conditions in Thailand. Four experiments were used to do this:

Experiment 1 - A survey of calving seasons on dairy reproductive performance and milk production under tropical conditions.

Experiment 2 - Effect of double shades on milk yield and reproductive performance of heat stress dairy cows under hot-humid conditions.

Experiment 3 - Part I and Part II

Part I - Effects of evaporative cooling on reproductive performance and milk of dairy cows in hot wet conditions.

Part II - Effects of evaporative cooling on the profile of triiodothyronine, thyroxine, insulin and leptin of dairy cows in hot wet conditions.

Experiment 4 - Effect of Double Shade on Milk Yield Performance of early postpartum dairy cows during rainy season in Northeast Thailand.

Figure 4 Holstein cows in Central Thailand utilizing natural shade.

Figure 5 Holstein cows in Western Thailand avoiding solar radiation.

Figure 6 Holstein cows preferred shaded house than shade from the trees.

MATERIALS AND METHODS

Experiment 1

A survey of calving seasons on dairy reproductive performance
and milk production under tropical conditions.

Materials

Data from the DHI (Dairy Herd Improvement) program of Sakol Nakhon Research and Breeding Centre, Department of Livestock Production, Ministry of Agriculture and Cooperatives, was used in conjunction with meteorological data from Sakol Nakhon Weather Station, Department of Meteorology, Ministry of Transport and Communications, to determine the effects of climatic conditions on milking and reproductive performance of dairy cows in the Northeastern region of Thailand.

Animals

All the dairy cows were raised at the Sakol Nakhon Breeding and Training Center (Latitude 17^0 $09^,$ N. Longitude 104^0 $08^,$ E and at 171 meters above sea level), which is situated approximately 641 km. Northeast of Bangkok. A total of 355 records from dairy crossbred cows (87.5 % Holstein × 12.5% *Bos indicus*), that calved during the period from 2000 – 2002, were selected from 537 records. Cows with history of dystocia, metritis and mastitis were excluded from analyses. The selected cows were divided according to season when they calved.

Dairy husbandry

On a typical day, at 5:30 am all milking cows were moved to the milking shed to be milked via a bucket-type milking machine and fed with a half day ration of concentrate (Table 4). The daily concentrate offered to each cow was calculated to provide for the individual cow requirements based on individual milk production levels (NRC, 1989). After milking, the animals were allowed to graze at pasture. During the dry season they were kept in an open shed and silage of Guinea grass (*Panicum maximum*; Table 4) was offered *ad libitum* as an alternative to pasture (*P. maximum*). Mineral block (Table 4) and water are provided at all time.

At 15:00 hrs, the cows were moved to the milking shed where they were fed with the remaining half day ration of concentrate and to be milked, after which they were allowed to return to the open shed to be fed with either green feed or silage.

All cows were vaccinated against FMD (Foot and Mouth Disease), injected with vitamins A, D_3 and E. The usual postpartum reproductive management at the station was such that the cows were visually checked for signs of oestrus by an experienced stockman. Once the 2nd oestrus had been detected they were artificially inseminated at 2nd heat and conception was confirmed at 60 days thereafter, if the animal did not return to service.

Dairy cow performance data

The data utilized included calving date, days open (d), number service (time), lactation period (d) and milk yield (kg/d). These data were collected and compared according to the season of calving.

Meteorological and Chronological data

The months in each calendar year in monsoonal Thailand were categorized into seasons (Anon, 2007). The seasons are Winter season (November to February), Summer season (March to May) and Rainy season (June to October).

The meteorological data collected from Sakol Nakhon weather station pertained to the years 2000 – 2002. Only Sakol Nakhon meteorological data was used in analyses of the influence of climatic conditions on the performance of dairy cows. Sakol Nakhon weather station is 6.0 km. from Sakol Nakhon Research and Breeding Centre where the herd of dairy cows is raised. The meteorological data was collected at 3-hourly intervals, and values for each parameter in a given 24 hour period were averaged to represent a daily value. The meteorological data collected were maximum and minimum air temperature, maximum and minimum relative humidity. From the above meteorological parameters, dew points were computed (Thai Department of Meteorology, 2003). The THI was derived from the equation (Armstrong, 1994) below.

$$THI = T_{db} + 0.36(T_{dp}) + 41.2$$

Where: T_{db} = The dry bulb temperature (°C)

T_{dp} = The dew point temperature (°C)

Analysis

Data from the DHI program (DLD, 2003) were extracted and analyzed using GLM procedures of SAS (SAS, 1999). The model included 4 treatments comprised of summer, rainy and winter. The effects of year and season*year interaction were also included in the model for unbiased adjustment. The statistical model was shown as follow:

$$Y_{ijk} = m + S_i + Y_j + S_i{*}Y_j + e_{ijk}$$

where Y_{ijk} = the record of the k^{th} cow of the i^{th} season, the j^{th} year and the i^{th} season*the j^{th} year interactions,

m = the overall mean,

S_i = effect of the i^{th} season (i = summer, rainy, winter),

Y_j = effect of the j^{th} year (j = 2000, …, 2002),

$S_i{*}Y_j$ = effect of the i^{th} season* j^{th} year interactions, and

e_{ijk} = the vector of residuals, which was assumed; e_{ijk} ~NID $(0, \sigma_e^2)$.

Experiment 2

Effect of Double shade on Milk Yield and Reproductive Performance of Heat Stressed Dairy Cows under Hot-Humid Conditions**.**

Materials

The experiment was carried out at the Sakol Nakhon Livestock Research and Testing Station (Latitude 17^{o} $09^{'}$ N,. Longitude 104^{o} $08^{'}$ E and at 171 meters above sea level) approximately 641 km. Northeast of Bangkok (Appendix 1.).

Animals

Sixteen crossbred cows (87.5 % Holstein Friesian × 12.5% *B. indicus*), in their 2^{nd} or 3^{rd} lactation, at 60-70 days postpartum who had non-returned to service and who had similar body condition were selected from a large herd of cows that were maintained at the Research Station. They were then randomly assigned to two shade treatments. The animals were provided with roughage *ad libitum* plus with a commercial meal concentrate. Mineral supplement and clean water were also freely accessed. Internal and external parasites were controlled in all cows. They were also vaccinated against FMD.

Housing facilities

The animal house was divided into two halves of equal area (total area 5 x 20 m^2.). One half was an open shed while the other half was fitted with a green woven polypropylene sheet ("green slant 70") which was stretched at 100 cm. above the entire roof casting shade over the roof area.

There were 2 treatments with 8 cows per treatment.

Treatment 1 - Single Shade (SS) treatment: consisted of 8 crossbred cows maintained under an opened house with grey corrugated iron roof.

Treatment 2 - Double Shade (DS) treatment: consisted of 8 crossbred cows maintained under an opened house with the iron roof shaded by green woven polypropylene sheet ("green slant 70") which was stretched at 100 cm. above the entire roof. It was a 210 days experimental period (March to September 2003),

A single diet was used throughout the study with all animals being fed half of the ration (5.05 to 5.88 kg) at 6:30 a.m. and the remainder at 15:30 p.m.. Concentrate represented 30% of total dry matter intake (DMI). The amount of the concentrate ration provided was calculated to provide for the individual cow requirements based on individual milk production levels (NRC, 2001). The roughage (silage of Guinea grass {*Panicum maximum*}) was provided *ad libitum* (group fed) after the cows had finished their concentrate feeding at the milking station. Water was available throughout the experiment.

Meteorological data

Meteorological data was collected using data loggers and sensors set at 160 cm. above ground in both sheds. The data collected consisted of daily maximum and minimum air temperatures, wet - dry bulb temperatures, black globe temperature (BG) and relative humidity (RH). From these data a Temperature Humidity Index (THI) was calculated (Armstrong, 1994):

$$THI = T_{db} + 0.36(T_{dp}) + 41.2$$

Where: T_{db} = Dry bulb temperature (°C)

T_{dp} = Dew point temperature (°C)

Methods

At weekly interval, morning milk and afternoon milk of each cow were mixed thoroughly and sampled to be sent for determination of milk protein, fat, solid not fat and specific gravity.

Performance parameters of the cows were measured including: days open (day), conception rate (%), milk yield (kg/hd/d), butter fat %, solid not fat (SNF) %, milk protein % and milk specific gravity. The 4% Fat Corrected Milk [4% FCM (kg/hd/d)] was calculated using the formula below:

$$
\begin{aligned}
4\%\ \text{FCM} &= (0.4 \times \text{kg. milk}) + (15 \times \text{kg. milk fat}) \quad \text{(NRC, 1989)} \\
&= \{0.4 \times (\text{kg. milk})\} + \{(\text{kg. milk}) \times (\text{butter fat }\%) \times (15/100)\} \\
&= (\text{kg. milk}) \times [0.4 + \{(\text{butter fat}\%) \times 0.15\}]
\end{aligned}
$$

Days Open: days between pregnancies; days from calving until successful breeding date if pregnant; also know as “days not pregnant” (DHI, 2005).

Conception of a cow was confirmed at 60 days post last AI.

Water intake (l/hd/d), concentrate and silage intake (kg DM/hd/d). Rectal temperature (RT) and respiration rate (RR) were measured at weekly intervals at 14:00 pm on the relevant day. This was done by inserting a clinical thermometer into the rectum to a depth of 7 cm for the RT measurement and also counting flank movement for a one minute period for the RR measurement.

Analysis

Completely Randomized Design (CRD) was used for statistical verification, with group (SS and DS) as effective factors. Each group consists of 8 replications, respectively (Steel and Torrie, 1980) using the model:

Y_{ij}	=	$\mu + A_i + \varepsilon_{ij}$
When Y_{ij}	=	The observational scores of the cattle No. j which was group at i.
μ	=	Population mean.
A_i	=	Effect of the group No. i (i = 1, 2).
ε_{ij}	=	Experimental error from random; ε_{ij} ~NID $(0, \sigma^2)$.

A t-test using PROC TTEST of SAS for Windows V. 8.1 (SAS, 1999) was applied to test if treatment differences were significant for meteorological data, physiological data, milk yield and reproductive performance. Values are presented as means±SEM. Conception rate was presented as percentage (%) and comparison on group using Chi-square test (SAS, 1999).

Experiment 3

Effects of evaporative cooling on reproductive performance and
milk production of dairy cows in hot wet conditions.

Part I

Materials

The experiment was carried out for a total of 210 days (March to September 2004) at the Sakol Nakhon Breeding and Training Center (Latitude 17^{o} 09$'$ N, Longitude 104^{o} 08$'$ E and at 171 meters above sea level) approximately 641 km. Northeast of Bangkok (Appendix 1.).

Animals

Fourteen crossbred cows (87.5 % Friesian X 12.5% *B. indicus*), in 2nd and 3rd lactation and with a 60-70 days post partum non-return period and of similar body condition were selected from a large herd of cows that were raised at the Research Station. Once selected they were randomly assigned to two treatments.

Housing facilities

The animal house was divided into two halves of equal area (total area 5 x 20 m^{2}.). One half of the animal house was an open shed while the other half was fitted with an evaporative cooling system (an evaporative wind tunnel consisting of 1.83×1.2×0.15 m^{3} cooling pad (Kasetpan Industry Ltd Bangkok, Thailand) and a 0.9m diameter fan driven by a 0.5 horsepower 3 phase electric motor). The evaporative cooler was set to operate when the ambient temperature reached 28 ^{o}C or more.

Methods

There were 2 treatments with 7 cows per treatment.

Treatment 1 - No Evaporative Cooling (NEVAP) was the control treatment, with the cows maintained in an open house with a grey corrugated iron roof.

Treatment 2 - Evaporative Cooling Treatment, (EVAP) consisted of cows raised under identical housing conditions to the control treatment except that the

house was fitted with the evaporative cooling system The two halves of the animal house were of equal area (total area 5 x 20 m^2.).

The experiment was carried out for a total of 210 days (March to September, 2004).

A single diet was used in the experiment and all animals were fed half of the concentrate ration (3.5 to 4.5 kg) at 6:30 a.m. and the remainder at 15:30 p.m.. Concentrate represented 30% of total DM intake and the amount provided was calculated to provide for the individual cow requirements based on individual milk production levels (NRC, 2001). Roughage (silage or dried grass) was provided *ad libitum* (group fed) after the cows had finished their concentrate feeding at the milking station. Water was available at all times throughout the experiment.

Meteorological data

Meteorological data was collected using data loggers with sensors set at 160 cm. above the ground in both sheds. The data collected consisted of daily maximum and minimum air temperatures, wet - dry bulb temperatures and relative humidity. From the meteorological data a Temperature - Humidity Index (THI) was calculated using the equation of Armstrong (1994):

$$THI = T_{db} + 0.36(T_{dp}) + 41.2$$

Where: T_{db} = Dry bulb temperature (°C)

T_{dp} = Dew point temperature (°C)

Performance parameters of the cows were measured as: days open (day), milk yield (kg/hd/d), water intake (l/hd/d), silage intake (kg/hd/d) and pregnancy rate (%). Rectal temperature and respiration rate were measured at weekly intervals at 14:00 pm on the relevant day. A clinical thermometer was inserted rectally to a depth of 7 cm to measure temperature and respiration rate was recorded by counting flank movement of the cows over one minute.

Analysis

Completely Randomized Design (CRD) was used for statistical verification, with group (EVAP and NEVAP) as effective factors. Each group consists of 7 replications, respectively (Steel and Torrie, 1980) using the model:

Y_{ij} = $\mu + A_i + \varepsilon_{ij}$

When Y_{ij} = The observational scores of the cattle No. j which was group at i.

μ = Population mean.

A_i = Effect of the group No. i (i = 1, 2).

ε_{ij} = Experimental error from random; ε_{ij} ~NID $(0, \sigma^2)$.

A t-test using PROC TTEST of SAS for Windows V. 8.1 (SAS, 1999) was applied to test if treatment differences were significant for meteorological data, physiological data, milk yield and reproductive performance. Values are presented as means±SEM. Conception rate was presented as percentage (%) and comparison on group using Chi-square test (SAS, 1999).

Experiment 3

Effects of evaporative cooling on the profile of triiodothyronine, thyroxine, insulinand leptin of dairy cows in hot wet conditions.

Part II

Methods

The same cows that were used in Experiment 3 Part I were also used in Part II of Experiment 3.

Blood samples were taken from all animals at 13:00 pm. on days 0, 30, 60 and 90 days postpartum. The sample were drawn from the coccygeal vein into heparinised vials. The serum was separated by centrification (3000 rev/min). Two ml of the serum for each animal placed into a plastic vial and these were frozen to -20 ^{o}C and then freeze dried. They were then transported to the Unversity of Western Australian to be analyzed for thyroxine (T_4), triiodothyronine (T_3), insulin and leptin.

Radioimmunoassay techniques described by Blache *et al*., (2000a) were used to measure the level of T_3, T_4, insulin and leptin hormones.

Performance parameters of the cows were measured as: days open (day), milk yield (kg/hd/d), water intake (l/hd/d), silage intake (kg/hd/d) and pregnancy rate (%). Rectal temperature and respiration rate were measured at monthly intervals at 14:00 pm on the relevant day. A clinical thermometer was inserted rectally to a depth of 7 cm to measure temperature and respiration rate was recorded by counting flank movement of the cows over one minute.

Analysis

Statistical analyses where conducted using a t-test in PROC TTEST of SAS for Windows V. 8.1 (SAS, 1999) to test if treatment differences were significant for meteorological data, milk yield and reproductive performance. For conception rate a Chi Square test was used (SAS, 1999).

Experiment 4

Effect of Double shade on Milk Yield Performance of early postpartum dairy cows during rainy season in Northeast of Thailand

Materials

The experiment was carried out at the Sakol Nakhon Livestock Research and Testing Station (Latitude 17^{o} 09′ N, Longitude 104^{o} 08′ E and at 171 meters above sea level) approximately 641 km. Northeast of Bangkok.

Animals and Housing facilities

Ten pregnant crossbred cows (87.5 % Holstein Friesian × 12.5% *B. indicus*), in their 1^{st} or 2^{nd} lactation, at 21 days prepartum who had similar body condition were selected from a large herd of cows that were maintained at the Research Station. They were then randomly assigned to two shade treatments, viz. Single or Normal Shade and Double shade. The animals were provided with *ad libitum* roughage (fresh panicum grass, *Brachiaria mutica*) with a commercial meal concentrate. Mineral supplement and clean water were also freely accessed. Internal and external parasites were controlled in all cows.

There were 2 treatments with 5 cows per treatment. Hence, the animal house was divided into two halves of equal area (total area = 5×20 m^2).

Treatment 1 - Single Shade treatment: consisted of 5 crossbred cows maintained under an opened house with grey corrugated iron roof.

Treatment 2 - Double shade treatment: consisted of 5 crossbred cows maintained under an opened house with the grey corrugated iron roof shaded by a black woven polypropylene sheet (“black slant 80”) which was stretched at 100 cm. above the entire roof of the second half of the animal house.

The experiment was carried out for a total of 91 days during August to November 2005.

A single diet was used throughout the study with all animals being fed half of the ration (5.00 to 6.00 kg) at 6:30 a.m. and the remainder at 16:30 p.m. Concentrate represented 30% of total DM intake. The amount of the concentrate ration provided was calculated to provide for individual cow requirements based on individual milk production levels (NRC, 2001). Roughage (fresh panicum grass) was provided *ad libitum* (group fed) after the cows had finished their concentrate feeding at the milking station. Water was available *ad libitum* throughout the experiment.

Methods

Meteorological data was collected using data loggers and sensors set at 160 cm. above ground in both sheds. The data collected consisted of daily maximum and minimum air temperatures, wet - dry bulb temperatures, relative humidity and the Sheds black globe temperatures. From these data a Temperature - Humidity Index (THI, Armstrong, 1994) was calculated:

$$THI = T_{db} + 0.36(T_{dp}) + 41.2$$

Where: T_{db} = Dry bulb temperature (°C)

T_{dp} = Dew point temperature (°C)

At day 7 postpartum and 3 days (Monday, Wednesday and Friday) a week, every week there after all cows were taken to a nearby building at 13:00 noon and remained there until 14:00 p.m. when they were taken back to their respective animal house. At the building, blood samples were taken from all animals. The samples were drawn from the coccygeal vein into heparin vials and the serum was separated by centrifugation (3000 rev/min) within an hour. Two milliliters of the serum from each sample was placed in a plastic vial and the samples were frozen to -20 ^{o}C and then freeze dried. The samples where then shipped to The University of Western Australian where they were analyzed for thyroxine (T_4), triiodothyronine (T_3), cortisol, IGF-1 and leptin hormones. Radioimmunoassay techniques as described by Blache *et al*., (2000b) were used to measure levels of the above hormones.

Performance parameters of the cows were measured including: milk yield (kg/hd/d), water intake (l/hd/d), roughage and concentrate intake (kg/hd/d). Rectal temperature and respiration rate were measured at fortnightly intervals at 14:00 pm on the relevant day. This was done by inserting a clinical thermometer into the rectum to a depth of 7 cm and also counting flank movement for a one minute period.

An animal would be taken off from the experiment when it was on heat at the second cycle there onwards.

Analysis

Completely Randomized Design (CRD) was used for statistical verification, with group (SS and DS) as effective factors. Each group consists of 5 replications, respectively (Steel and Torrie, 1980) using the model:

Y_{ij}	=	$\mu + A_i + \varepsilon_{ij}$
When Y_{ij}	=	The observational scores of the cattle No. j which was group at i.
μ	=	Population mean.
A_i	=	Effect of the group No. i (i = 1, 2).
ε_{ij}	=	Experimental error from random; ε_{ij} ~NID (0, σ^2).

A t-test using PROC TTEST of SAS for Windows V. 8.1 (SAS, 1999) was applied to test if treatment differences were significant for meteorological data, physiological data, milk yield and reproductive performance. Values are presented as means±SEM. Conception rate was presented as percentage (%) and comparison on group using Chi-square test (SAS, 1999).

RESULTS

Results of Experiments 1, 2, 3 and 4 are shown as following:-

Experiment 1 – Results

The results of chemical composition of the commercial concentrate and the silage of Guinea grass (*P. maximum*) are shown in Table 4.

Table 4 Percentage chemical composition of the feedstuffs.

Feedstuff	MC	DM	CP	CF	EE	NFE	Ash	Ca	P
Concentrate	8.2	91.8	18.2	20.1	3.8	46.6	9.1	1.20	0.62
Silage	77.7	22.3	6.4	32.7	2.7	33.7	16.6	0.57	0.27

MC = moisture content, DM = dry matter, CP = crude protein, CF = Cudet fiber, EE =ether extract, NFE = nitrogen free extract.

Mineral block: Calcium = 15.86%, Phosphorus = 1.60 %, Magnesium = 0.24 %, Sulfur = 0.27 %, Manganese = 271.39 mg/100g, Copper = 8.01 mg/100g, Zinc = 46.90 mg/100g, Iron = 308.26 mg/100g and Ca:P = 10:1

Table 5 Mean meteorological values during 2000 – 2002 of Sakol Nakhon Research and Training Centre.

	Calving season		
Parameters	Winter	Summer	Rainy
Mean dry bulb temp. (^{o}C)	24.11±0.26^{b}	28.41±0.21^{a}	26.93±0.08^{a}
Mean R.H. (%)	63.45±0.34^{c}	73.83±0.24^{b}	94.60±0.10^{a}
Mean dew pt. temp. (^{o}C)	16.50±0.25^{b}	23.40±0.10^{a}	26.20±0.28^{a}
Mean THI	71.25±0.34^{b}	78.03±0.24^{a}	77.56±0.10^{a}

Means with different superscripts within a row are significantly different (P<0.01).

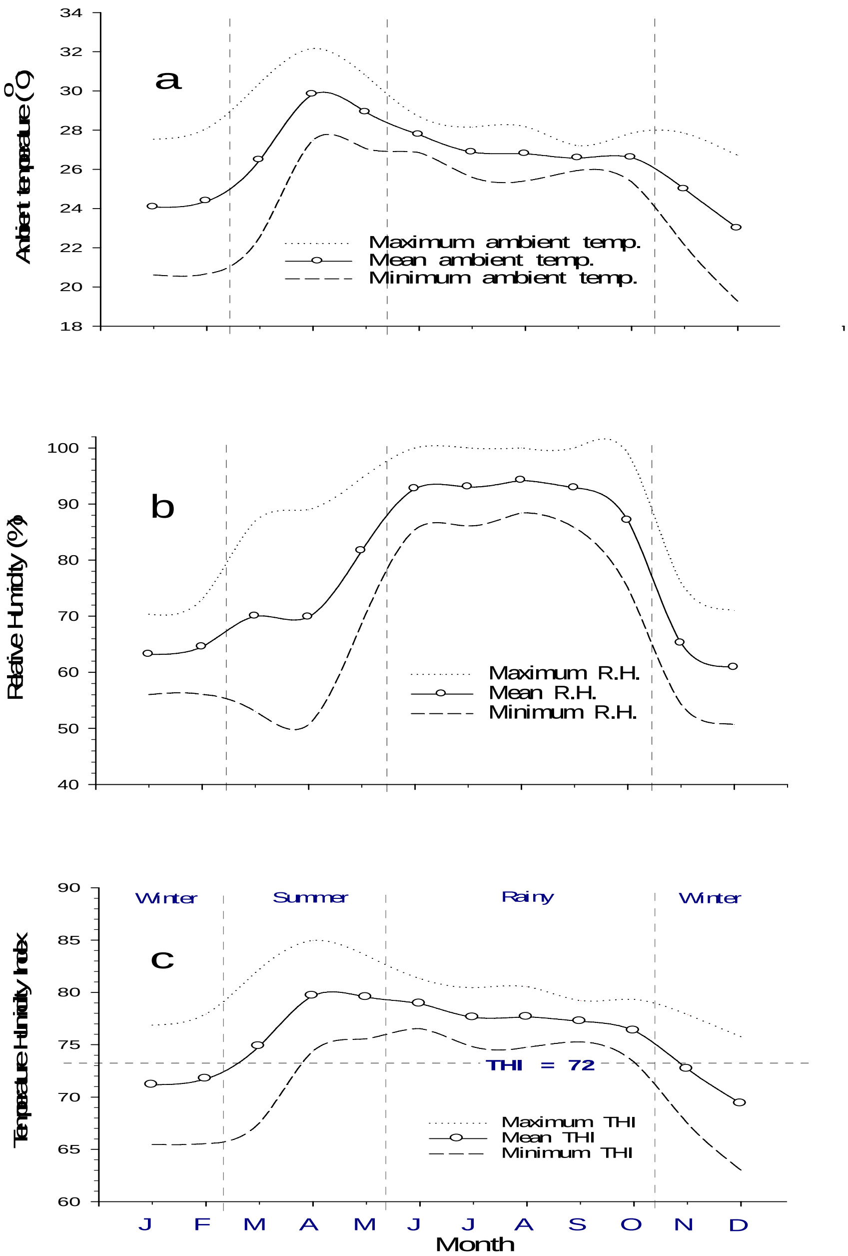

Figure 7 Mean monthly (a) Ambient temperature, (b) Relative Humidity and (c) Temperature-Humidity-Index values (2000 -2002) of the Sakol Nakhon Weather Station (Thai Department of Meteorology, 2003).

From Table 5 it has been found that Mean dry bulb temperature (MDBT) of Winter (24.11 ± 0.20 °C) was significantly ($P<0.05$) lower than that of both MDBT of Rainy season (26.93 ± 0.18 °C) and MDBT of Summer (28.41 ± 0.28.°C) season.

The results (Table 5.) also revealed that Mean Relative Humidity (MRH) of Rainy season (94.60±0.10 %) was highly significantly ($P<0.01$) higher than both MRH Summer (73.83 ± 0.24 %) and MRH Winter (63.45 ± 0.34 %). Furthermore, MRH Summer was also highly significantly ($P<0.01$) higher than MRH Winter.

Furthermore, it has been found that Mean Dew Point Temperature (MDPT) of Winter (16.50 ± 0.25 °C) was highly significantly ($P<0.01$) lower than that of both MDPT Summer (23.40 ± 0.10.°C) and MDPT Rainy season (26.20±0.28).

Furthermore, the results (Table 5) revealed that Mean Temperature Humidity Index (THI) of Winter (71.25 ± 0.34) was highly significantly ($P<0.01$) lower than both Summer MTHI (78.03 ± 0.24) and Rainy season MTHI (77.56 ± 0.10).

Meteorological data was collected during 2000-2002 at the Sakol Nakhon Weather Station and it was plotted by month as shown in Figure 7.

From Figure 7a it can be seen that the general weather pattern of Sakol Nakhon province has high maximum and minimum temperatures in both summer and rainy seasons and only a brief cool period in Winter when mean air temperature drops below 25^oC . Figure 7b and 7c shows the variation in relative humidity and THI, respectively. The combined effect of temperature and humidity on cow's comfort as measured by THI (Figure 7c) indicated that During both Summer and Rainy seasons the THI value was above the critical value of 72 (Johnson, 1987) and Winter THI at the station was well below the critical value 72.

Mean values of reproductive and milking performances of the dairy cows at Sakol Nakhon Research and Training Centre when using calving date as the commencement of observations are shown in Table 6.

The results (Table 6) shows that cows that calved in the summer season had significantly ($P<0.05$) higher days open (194.46±10.79 d) and number of services

(2.17±0.15 times) than those cows calving in Winter (156.43±7.98 d, 1.63±0.11 times, respectively) and Rainy seasons. (141.86±7.10 d, 1.78±0.10 times, respectively). However, the cows that calved in different seasons did not differ significantly in lactation period, MY, butter fat nor FCM 4%.

Table 6 Reproductive and production performances of the dairy cows under hot-humid conditions.

Parameters	Winter	Summer	Rainy
Number service (time)	1.63±0.11[b]	2.17±0.15[a]	1.78±0.10[b]
Days open length (d)	156.43±7.98[b]	194.46±10.79[a]	141.86±7.10[b]
Lactation period (d)	294.14±7.45	275.49±11.44	296.78±8.21
MY (kg/d)	10.41±0.36	9.58±0.42	9.56±0.32
Butter fat(%)	4.19±0.11	4.19±0.15	3.97±0.15
FCM 4% (kg/d)	10.70±0.37	9.80±0.44	9.51±0.33

a, b - Means with different superscripts within a row are significantly different ($P<0.05$).* Calving date assumed to be the commencement of observations.

*FCM = fat corrected milk, 4 % FCM = (kg. milk) × [0.4 + {(butter fat%) ×0.15}](*NRC, 1989).

Experiment 2 – Results

The results of chemical composition of the commercial concentrate and the silage of Guinea grass (*P. maximum*) are shown in Table 7.

From Figure 8 it can be seen that at 8:00 am. there was no significant (P>0.05) different between BGT of DS shed (25.41°C) and BGT of SS shed (25.90°C). However, the BGT of DS shed at 13:00, 14:00 and 16:00 pm. (32.43, 33.69 and 31.24 °C, respectively) were significantly (P<0.05) lower than the BGT of SS shed at13:00, 14:00 and 16:00 pm. (35.86, 37.45 and 34.27 °C, respectively).

Table 7 Percentage chemical composition of the feedstuffs.

	Feedstuff	
	Concentrate %	Silage %
MC	8.2	77.7
DM	91.8	22.3
CP	18.2	6.4
CF	20.1	32.7
EE	3.8	2.7
NFE	46.6	33.7
Ash	9.1	16.6
Ca	1.2	0.57
P	0.62	0.27

Figure 8 shows the result of average diurnal variation in BGT of the DS and SS animal houses.

The results of average daily variation in ambient temperature, Relative Humidity (RH) and Temperature Humidity Index (THI) of the Double Shade (DS) and single Shade (SS) sheds are shown in Figure 9a, 9b and 9c, respectively. From Figure 9a, it can be seen that the ambient temperature of the DS shed was significantly (P<0.05) lower than that of the SS shed for 5 hours (h) per day (10:00 am. – 15:00 pm.) while the THI (Figure 9c) of the DS shed was significantly (P<0.05) lower than that of the SS shed for 5 h 30 min. per day (10:00 am. – 15:30 pm.). There was very small variation in the RH values between the two sheds (Figure 9b).

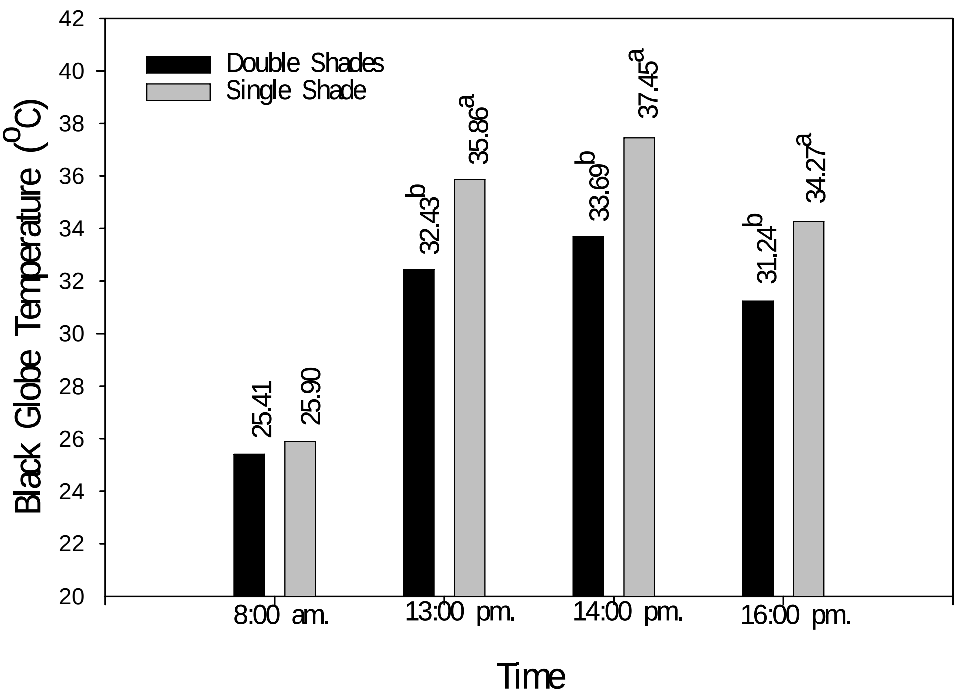

Figure 8 Diurnal variations in black globe temperatures of the DS and SS sheds.(Means values of adjacent histograms with different superscripts are significantly difference (P<0.01).

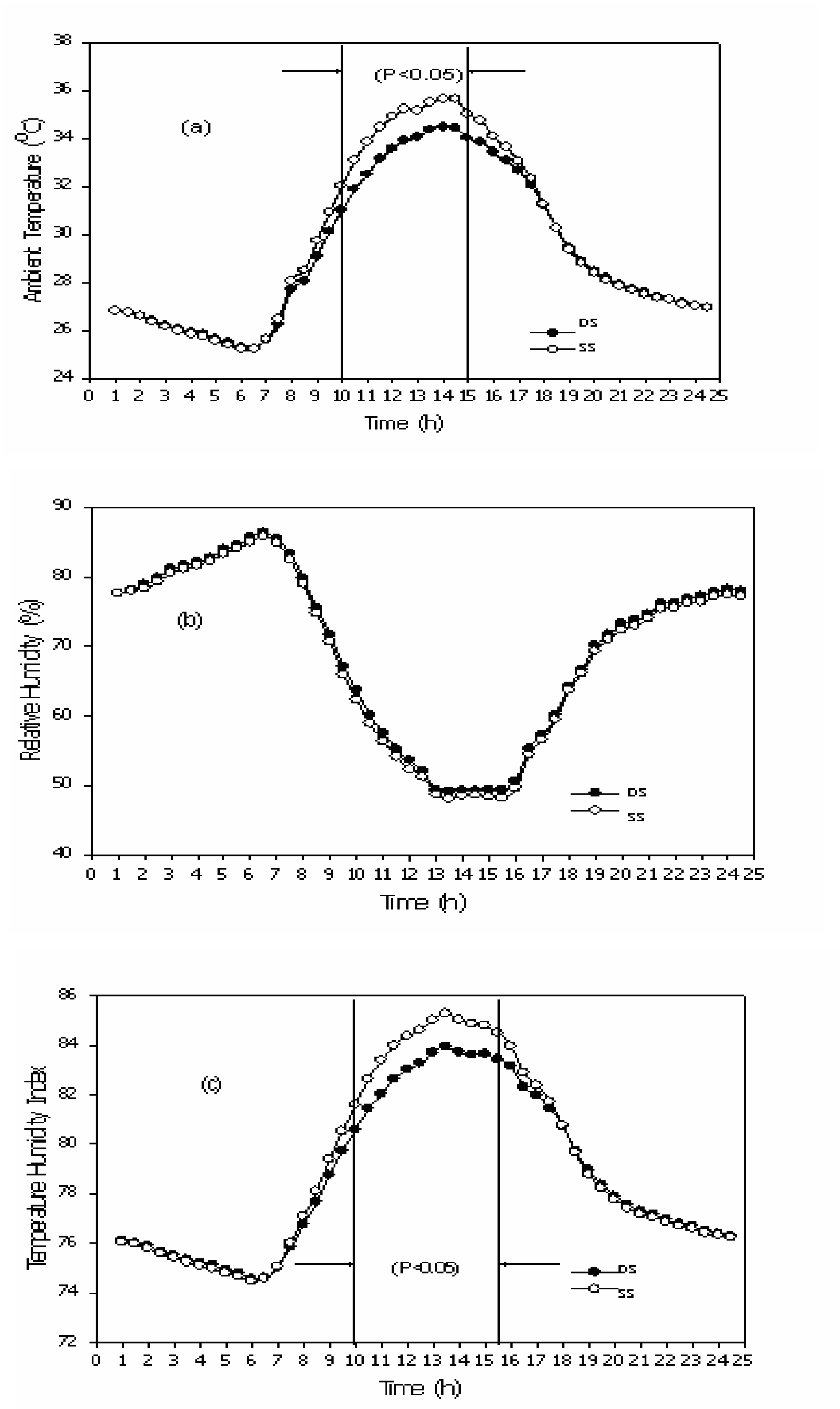

Figure 9 Ambient temperatures (a), Relative Humidity (b) and Temperature Humidity Index (c) in the DS and SS areas of the animal house.

Table 8 Mean values of production performances of the dairy cows under hot-humid conditions.

Parameter	Double Shade	Single Shade
Rectal Temp. (^{o}C)	38.56 ± 0.08^{b}	39.86 ± 0.09^{a}
Resp. Rate (breaths/min)	61.97 ± 0.16^{b}	85.16 ± 0.24^{a}
Water Intake ($l\ hd^{-1}\ d^{-1}$)*	43.58±0.96	48.32±0.80
Silage Intake (kg DM $hd^{-1}\ d^{-1}$)*	4.47±0.03	4.48±0.05
Concentrates Intake (kg DM $hd^{-1}\ d^{-1}$)	5.40 ± 0.13^{a}	4.64 ± 0.21^{b}

Means ± SE with different superscripts within a row are significantly different ($P<0.05$).

* Statistics analysis was not carried out due to group feeding.

The results in Table 8 show that the mean RT of the cows kept in DS (38.56±0.08 ^{o}C) was significantly ($P<0.05$) lower than the mean RT of the cows kept in SS (39.86±0.09 ^{o}C). Likewise the RR of the cows kept in DS (61.97±0.16 breaths/min) was significantly ($P<0.05$) lower than the mean RR of the cows kept in SS areas (85.16±0.24 breaths/min).

It was also found that the water intake of the cows kept in the SS (48.32±0.80 l $hd^{-1}d^{-1}$) was higher than that of the cows kept in DS (43.58±0.96 l $hd^{-1}d^{-1}$). The DMI of concentrates by the DS cows was significantly ($P<0.05$) higher than that of the SS cows.

The result (Table 9) shows that the days open of cows kept under DS was not significantly ($P>0.05$) shorter than the days open of cows kept in the SS shed. The conception rate of cows kept under DS was not significantly ($P>0.05$) higher than the conception rate of cows kept under the SS.

Table 9 shows that the average daily milk yield of the cows kept under the DS (10.12±0.05 kg $hd^{-1}d^{-1}$) was significantly ($P<0.05$) higher than that of the cows kept under SS (8.38±0.08 kg $hd^{-1}d^{-1}$) and that the average daily 4% FCM of the cows kept under the DS (8.96±0.07 kg $hd^{-1}d^{-1}$) was significantly ($P<0.05$) higher than that of the cows kept under SS (7.65±0.06 kg $hd^{-1}d^{-1}$). Figure 4 confirms this was the case at both morning (6.23 vs 5.23 kg $hd^{-1}d^{-1}$ $P<0.05$) and afternoon (3.90 vs 3.18 kg $hd^{-1}d^{-1}$, $P<0.05$) milking. Furthermore, there were no significant different between milk composition (SNF%, butter fat %, milk protein % and specific gravity) of the DS and SS cows.

Table 9 Mean values of production performances of the dairy cows under hot-humid conditions.

Parameter	Double Shade (Means ± S.E.M.)	Single Shade (Means ± S.E.M.)
Milk Yield (kg hd^{-1} d^{-1})	$10.12±0.05^{a}$	$8.38±0.08^{b}$
4% FCM (kg hd^{-1} d^{-1})	$8.96±0.07^{a}$	$7.65±0.06^{b}$
SNF(%)	7.60±0.07	7.56±0.06
Butter Fat Percentage (%)	3.17±0.17	3.25±0.11
Milk Protein Percentage (%)	2.94±0.08	3.10±0.08
Milk Specific Gravity	1.03±0.00	1.03±0.00
Days Open (d)	155.00±20.22	184.75±16.69
Conception Rate (%)	62.50	25.00

Means ± SE with different superscripts within a row are significantly different ($P<0.05$).

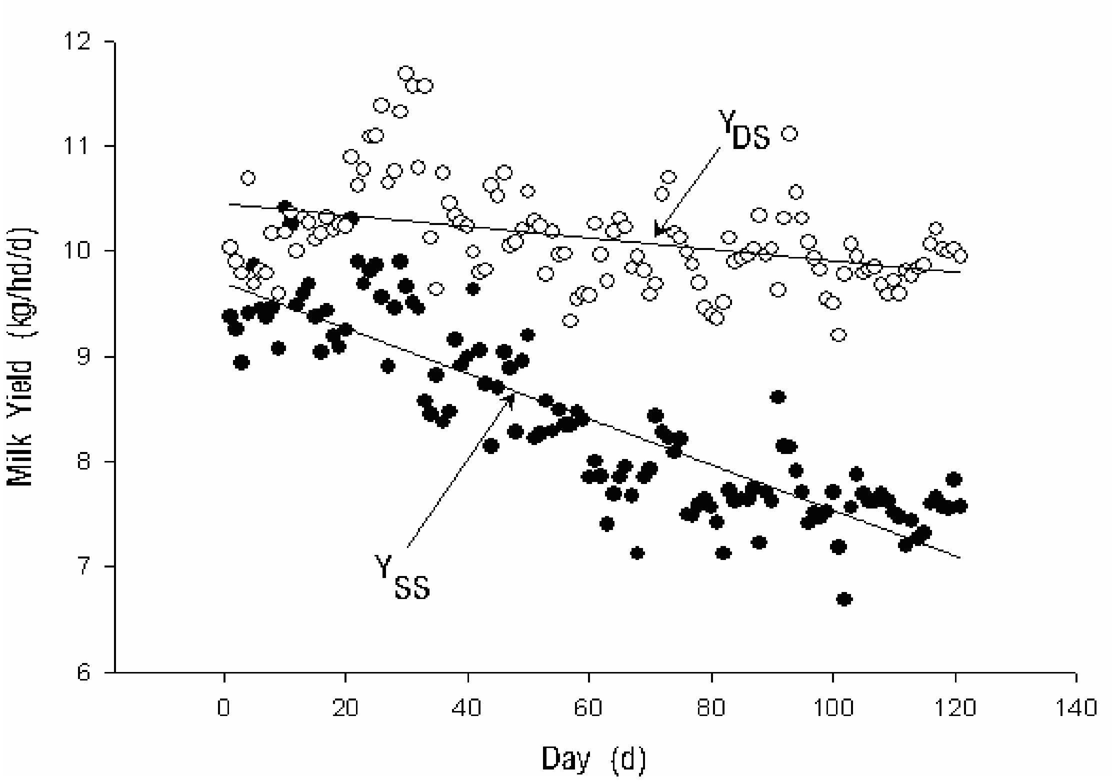

Figure 10 Average milk yield (kg hd-1 d-1) of the cows kept in the DS and SS areas of the animal house (Y_{SS} = 9.7006-0.0216X; R^2 = 0.7614; SE = 0.4254; Y_{DS} = 10.4532-0.0054X; R^2 = 0.1559; SE = 0.4445).

Figure 10 illustrates the average daily milk yield of cows kept under the DS was significantly higher than that of the cows kept under the SS throughout the experimental period.

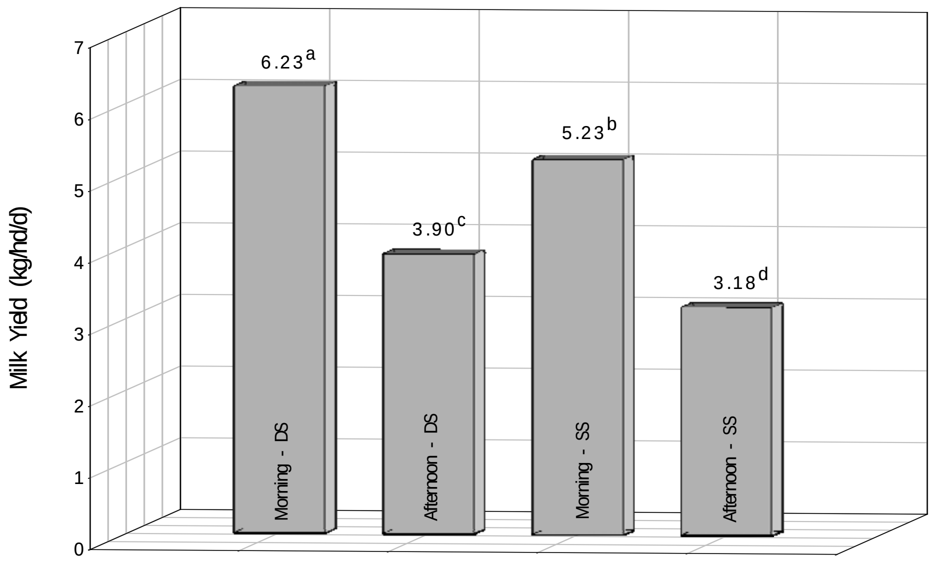

Figure 11 Average milk yield (kg $hd^{-1}d^{-1}$) in morning and afternoon milking sessions of the cows kept in the DS and SS areas of the animal house {values with different superscripts are significantly differ (P<0.05)}.

From Figure 11 it can be seen that the morning milk yield (MMY) of the DS shed (6.23 kg/hd/d) was significantly (P<0.05) higher than the MMY of the SS shed (5.23 kg/hd/d) which in turns was significantly (P<0.05) higher than the afternoon milk yield (AMY) of the DS shed (3.90 kg/hd/d). Furthermore, it can be seen that the AMY of the DS shed was significantly (P<0.05) higher than the AMY of the SS shed (3.18 kg/hd/d).

Experiment 3 – Results Part I

Ambient temperatures, relative humidity and THI in the Non-Evaporative Shed (NEVAP) and Evaporative Shed (EVAP) areas of the animal house are shown in Figure 12 (A), (B) and (C), respectively.

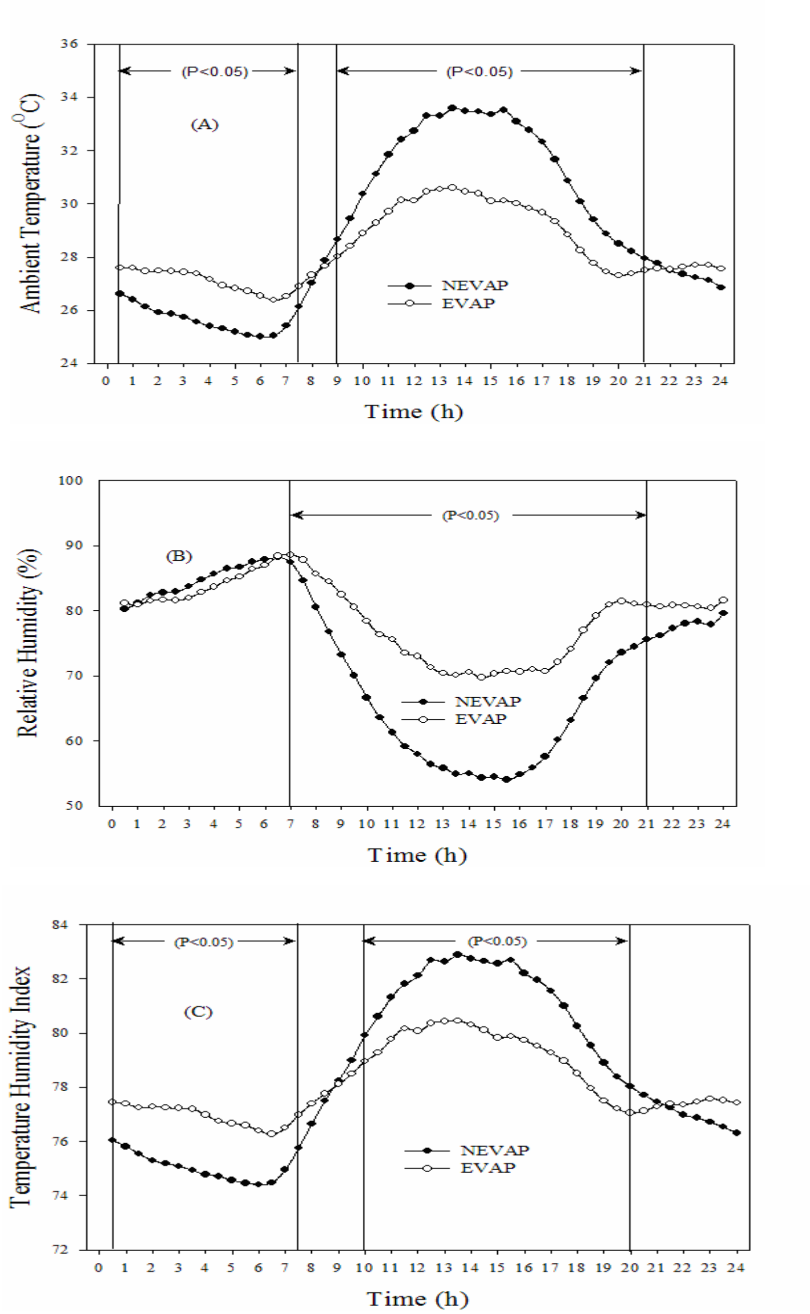

Figure 12 Ambient temperatures (A), Relative Humidity (B) and Temperature Humidity Index (C) in the Non-Evaporative Shed (NEVAP) and Evaporative Shed (EVAP) areas of the animal house.

The results revealed that although ambient temperature (Figure 12A) of EVAP was significantly ($P<0.05$) lower than that of NEVAP for 12 hours (from 9:00 to 21:00 pm.) however, it was found that the ambient temperature of the EVAP was significantly ($P<0.05$) higher than that of the NEVAP for 7 hours (from 0:30 am. to 7:30 am.). The THI (Figure 12C) of the EVAP was significantly ($P<0.05$) lower than that of NEVAP for 10 hours (from 10:00 am. to 20:00 pm.), however, the THI of the EVAP was significantly ($P<0.05$) higher than that of NEVAP for 7 hours (from 0:30 to 7:30 am.). Figure 12B showed that the RH of the EVAP was significantly ($P<0.05$) higher than the RH of NEVAP for 14 hours (from 7:00 am. to 23:00 pm.).

Table 10 shows the physiological differences between the two treatment groups. From Table 10 it can be seen that mean rectal temperature (RT) and respiration rate (RR) of the cows kept in the NEVAP (41.21 ± 0.28 ^{o}C; 86.87 ± 0.12 breaths/min, respectively) were both significantly ($P<0.05$) higher than the mean RT and RR of the cows kept in the EVAP (39.09 ± 0.07 ^{o}C, 61.39 ± 0.16 breaths/min, respectively) area of the animal house.

Table 10 Mean values of physiological and nutritional performances of the dairy cows raised in Non Evaporative (NEVAP) and Evaporative (EVAP) sheds in the hot-humid conditions.

Parameter	No Evaporative (Means ± S.E.M.)	Evaporative (Means ± S.E.M.)
Rectal Temp. (^{o}C)	41.21 ± 0.28^{a}	39.09 ± 0.07^{b}
Resp. Rate (breaths/min)	86.87 ± 0.12^{a}	61.39 ± 0.16^{b}
Water Intake* (l/hd/d)	45.39 ± 0.65	27.98 ± 0.55
Silage Intake* (kg DM/hd/d)	5.19 ± 0.07	5.18 ± 0.08
Concentrates Intake (kg DM/hd/d)	4.10 ± 0.34	4.46 ± 0.22

Means with different superscripts within a row are significantly differed ($P<0.05$).

* Statistics analysis was not carried out due to group offering.

Furthermore, it was found that the water intake of the cows kept in the NEVAP (45.39 ± 0.65 l/hd/d) was higher than water intake of the cows kept in the EVAP (27.98 ± 0.55 l/hd/d) area of the animal house.

Table 11 Mean values of reproductive and production performances of the dairy cows raised in No Evaporative (NEVAP) and Evaporative (EVAP) sheds in the hot-humid conditions.

Parameter	No Evaporative (Means ± S.E.M.)	Evaporative (Means ± S.E.M.)
Days Open (d)	203.43 ± 6.57^{a}	152.86 ± 16.88^{b}
Conception Rate (%)	14.29^{b}	71.43^{a}
Milk Yield (kg/hd/d)	8.28 ± 0.12^{b}	9.60 ± 0.11^{a}
4% Fat Corrected Milk Yield (kg/hd/d)	7.54 ± 0.12^{b}	8.17 ± 0.11^{a}

Means with different superscripts within a row are significantly differed (P<0.05).

It can be seen (Table 11) that the days open of cows kept under the NEVAP was significantly (P<0.05) longer than the days open of cows kept in the EVAP animal house. Likewise, the conception rate of the cows kept under the NEVAP was significantly (P<0.05) lower than the conception rate of cows kept under the EVAP (Table 11).

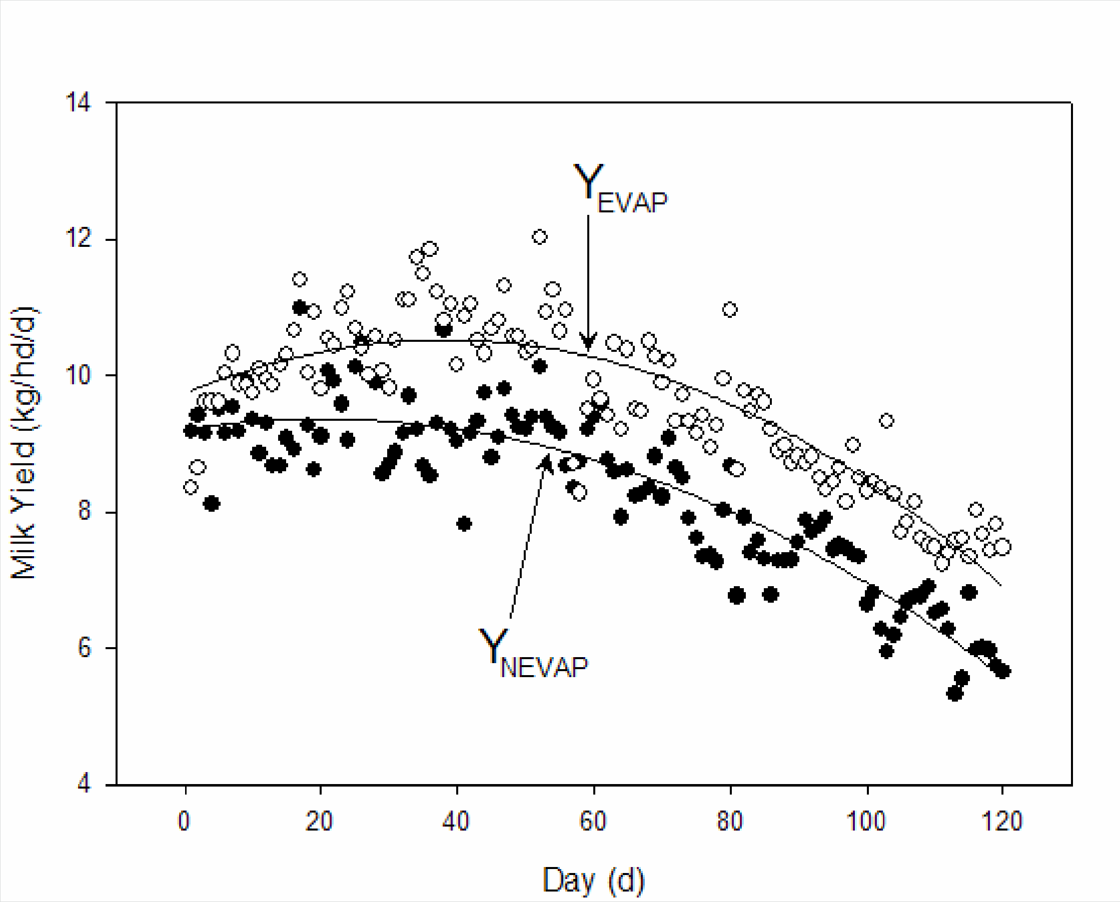

Figure 13 Average milk yield (kg/hd/d) of the cows kept in the Evaporative shed and Non Evaporative shed areas of the animal house.

The results in the present study show that cows kept under the NEVAP had significantly ($P<0.05$) lower milk yields than the cows kept under the EVAP treatment (Table 11, Figure 13).

From Figure 14 it can be seen that the morning milk yield (MMY) of the EVAP shed (6.22 kg/hd/d) was significantly ($P<0.05$) higher than the MMY of the NEVAP shed (5.17 kg/hd/d) which in turns was significantly ($P<0.05$) higher than the afternoon milk yield (AMY) of the EVAP shed (3.35 kg/hd/d). Furthermore, it can be seen that the AMY of the EVAP shed was significantly ($P<0.05$) higher than the AMY of the NEVAP shed (3.08 kg/hd/d).

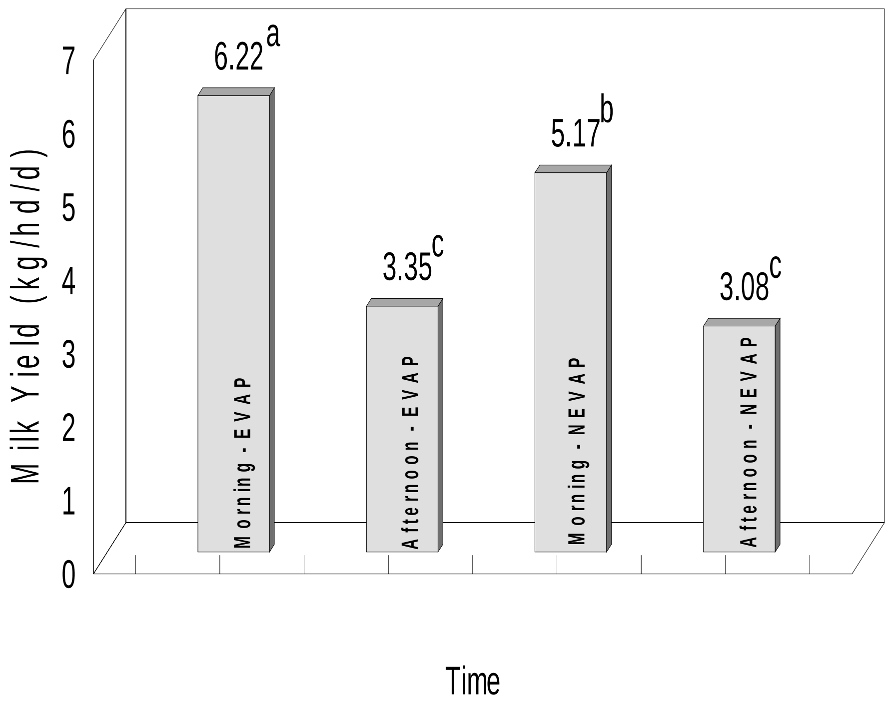

Figure 14 Average milk yield (kg/hd/d) in morning and afternoon milking sessions of the cows kept in the evaporative cooling shed and non evaporative cooling shed areas of the animal house {values with different superscripts are significantly different (P<0.05}.

Experiment 3 – Results Part II

The results of Experiment 3 are presented as following:-

The levels of serum T_3 of NEVAP and EVAP were not significantly (P>0.05) different at day 70 and day 100 (postpartum) of the experiment (Table 12; Figure 15); however they were significantly different at other times of the experiment such that at day 130 postpartum the level of T_3 of NEVAP (0.57 ± 0.09 ngm/ml) were significantly (P<0.05) higher than that of EVAP (0.33 ± 0.03 ngm/ml) and. at day 160 postpartum the level of T_3 of NEVAP (0.24 ± 0.05 ngm/ml) was also significantly (P<0.05) higher than that of EVAP (0.10 ± 0.02 ngm/ml).

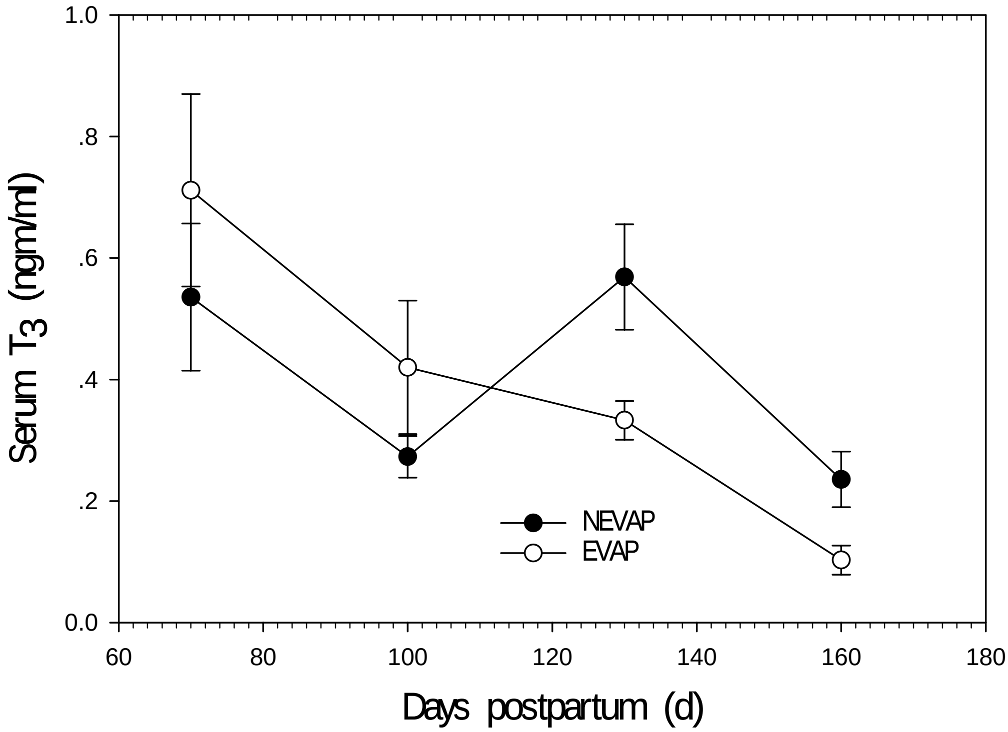

Figure 15 Serum T_3 concentration of the dairy cows kept in NEVAP and EVAP animal house in the hot-wet climatic conditions.

Table 12 Mean serum levels of triiodothyronine (T_3), thyroxine (T_4), insulin and leptin of the cows kept in normal open shed (NEVAP) and evaporative cooling shed (EVAP).

		Days Postpartum			
Hormone	Treatment	Day 70 Mean ± SE	Day 100 Mean ± SE	Day 130 Mean ± SE	Day 160 Mean ± SE
T_3	No Evap	0.54 ± 0.12	0.28 ± 0.03	0.57 ± 0.09^{a}	0.24 ± 0.05^{a}
(ngm/ml	Evap	0.71 ± 0.16	0.42 ± 0.11	0.33 ± 0.03^{b}	0.10 ± 0.02^{b}
T_4	No Evap	77.09 ± 6.90	82.74 ± 6.12	112.23 ± 16.48	94.40 ± 4.83^{a}
(M/L)	Evap	69.94 ± 10.96	111.36 ± 17.63	108.80 ± 8.92	59.43 ± 7.92^{b}
Insulin	No Evap	8.13 ± 1.40^{a}	6.57 ± 1.63	16.96 ± 2.81	16.81 ± 5.16
(lU/ml)	Evap	3.38 ± 0.25^{b}	4.01 ± 0.70	28.28 ± 5.85	10.25 ± 3.41
Leptin	No Evap	5.14 ± 0.33	4.57 ± 0.23	5.49 ± 0.42	6.10 ± 0.09^{a}
(ngm/ml)	Evap	4.61 ± 0.22	5.04 ± 0.42	6.31 ± 0.17	5.10 ± 0.36^{b}

Means within a column with different superscripts are significantly difference ($P<0.05$).

Furthermore, the results (Figure 16, Table 12) showed that at day 70, 100 and 130 postpartum the level of T_4 of NEVAP were not significantly (P>0.05) differ from that of EVAP, however, at day 160 postpartum the results revealed that the level of T_4 of NEVAP (94.40 ± 4.83 M/L) was significantly (P<0.05) higher than that of EVAP (59.43 ± 7.92 M/L).

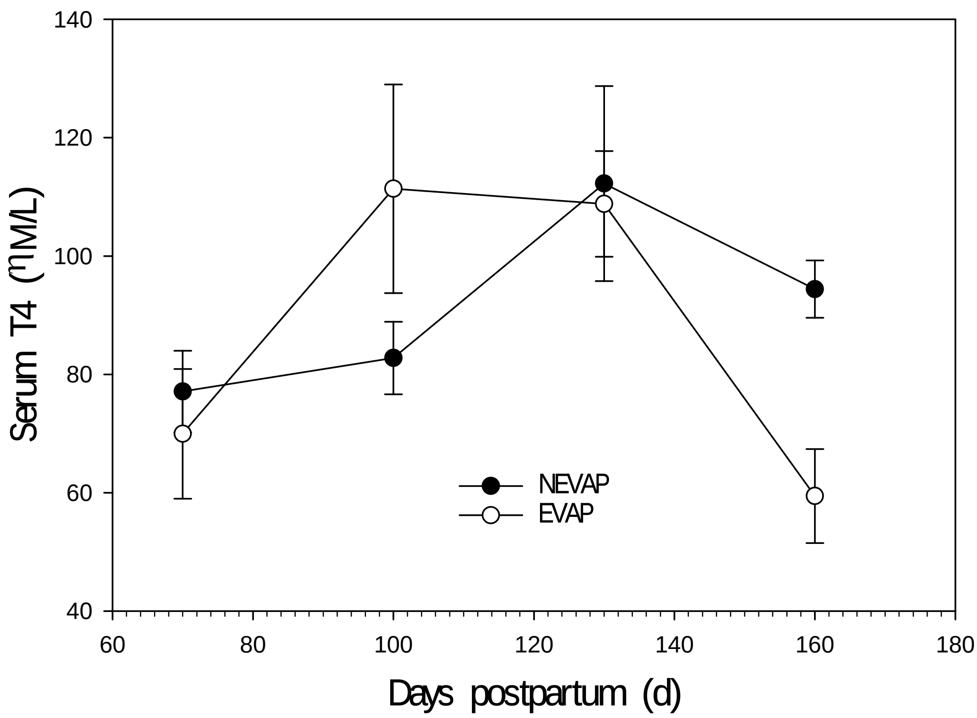

Figure 16 Plasma T_4 concentration of the dairy cows kept in NEVAP and EVAP animal houses in the hot-wet climatic conditions.

The insulin results (Figure 17, Table 12) showed that only at day 70 postpartum the level of insulin of NEVAP (8.13 ± 1.40 lU/ml) was significantly (P>0.05) significantly (P<0.05) higher than that of EVAP (3.38 ± 0.25 lU/ml), however, at day 100, 130 and 160 postpartum the results revealed that the level of insulin of NEVAP were not significantly (P<0.05) differ from that of EVAP.

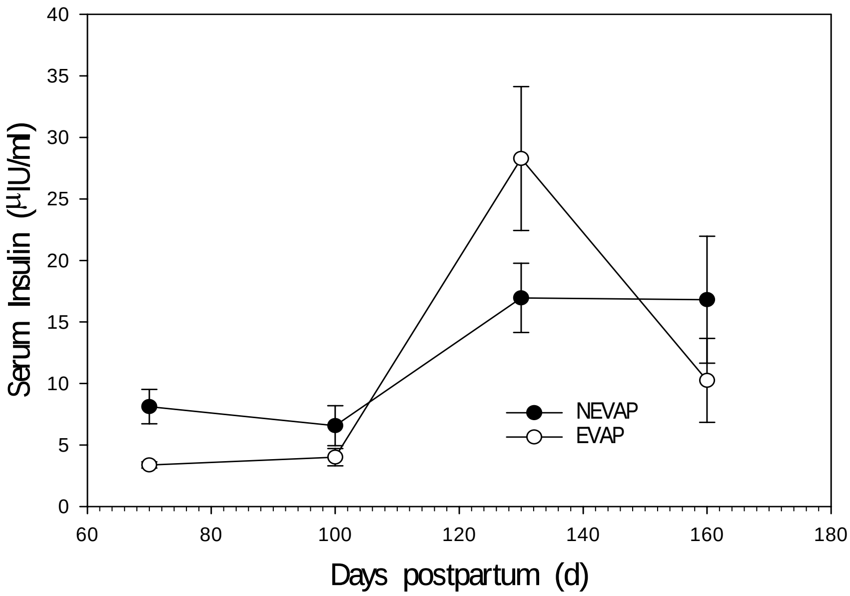

Figure 17 Serum insulin concentration of the dairy cows kept in NEVAP and EVAP animal houses in the hot-wet climatic conditions.

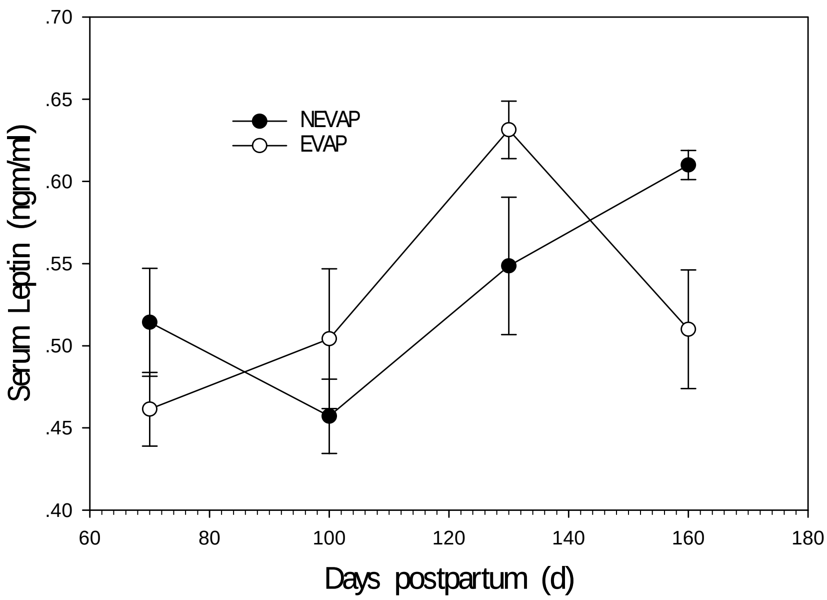

Figure 18 Serum leptin concentration of the dairy cows kept in NEVAP and EVAP animal house in the hot-wet climatic conditions.

Furthermore, the results of leptin (Table 12; Figure 18) at day 70, day 100 and day 130 postpartum, the serum concentration of NEVAP were not significantly ($P>0.05$) differ from that of EVAP treatments. Nevertheless, as time progressed the level of leptin of the NEVAP group increased while that of the EVAP decreased. Therefore by day 160 postpartum the serum leptin level of the NEVAP was significantly ($P<0.05$) higher than that of the EVAP treatment.

Experiment 4 – Results

Feed composition of Paragrass and commercial concentrates used in the present study are shown in Table 13.

Table 13 Feed composition of Paragrass (*Brachiaria mutica*) and commercial concentrates used in the present study.

Composition	Paragrass	Concentrates
Moisture content %	75.80	8.20
Dry Matter %	24.20	91.80
Protein %	7.60	18.16
Lipid %	2.60	3.80
ADF %	72.60	26.50
NDF %	41.40	20.10
Ash %	8.20	9.06
Calcium %	0.50	1.20
Phosphorus %	0.24	0.62
Gross Energy kcal/gDM	4.20	4.25

Ambient temperatures, BGT, RH and THI in the SS and DS areas of the animal house are shown in Table 14. From Table 14 it can be seen that the Maximum, Mean, BG and THI of the SS (31.69±0.14 ^{o}C, 27.29±0.08 ^{o}C, 31.93±0.20 ^{o}C and 81.84±0.23**,** respectively) were highly significantly ($P<0.01$) higher than that of the DS (29.55±0.14 ^{o}C, 26.12±0.10 ^{o}C, 29.80±0.18 ^{o}C and 80.03±0.20, respectively).

However, the results (Table 14) revealed that there were no significant difference ($P>0.05$) in both the Minimum temperature and the RH between the SS and DS animal houses.

Table 15 shows the physiological and production differences between the two treatment groups.

Table 14 Macro environment in the SS and DS areas of the animal house during the experimental period.

Parameter	SS (Means±SEM)	DS (Means±SEM)
Maximum Shed Temp. (^{o}C)	31.69±0.14^{a}	29.55±0.14^{b}
Mean Shed Temp. (^{o}C)	27.29±0.08^{a}	26.12± 0.10^{b}
Minimum Shed Temp. (^{o}C)	22.89±0.09	22.68±0.12
Black Globe Temp. (^{o}C)	31.93±0.20^{a}	29.80±0.18^{b}
Relative Humidity (%)	71.61±1.14	73.41±1.11
Temperature Humidity Index	81.84±0.23^{a}	80.03±0.20^{b}

Means with different superscripts within a row are significantly differed (P<0.01).

Table 15 Mean values of physiological responses of the dairy cows raised in SS and DS sheds under hot-humid conditions.

Parameter	SS (Means±SEM)	DS (Means±SEM)
Rectal Temp. (^{o}C)	39.43±0.19^{a}	38.72±0.13^{b}
Resp. Rate (breaths/min)	81.05±0.55^{a}	64.00±0.25^{b}
Ave. Daily Water Intake (l/hd/d)*	30.20±0.50	27.24±0.60
Ave. Daily Roug. Intake (kg DM/hd/d)*	8.24±0.17	8.40±0.16
Conc. Intake (kg DM/hd/d)	5.27±0.83	5.71±1.12

Means with different superscripts within a row are significantly differed (P<0.05).

* Statistics analysis was not carried out due to group feeding.

One cow (SK9745) in the SS treatment developed mastitis during the experiment, therefore, it's data were excluded from analyzes. The results (Table 15) revealed that the cows in the SS animal house had their RT and RR (39.43±0.19 ^{o}C and 81.05±0.55 breaths/min, respectively) significantly (P<0.05) higher than that of the cows in the DS (38.72±0.1 ^{o}C and 64.00±0.25 breaths/min, respectively) animal house. Nevertheless, there were no significant (P>0.05) differences in concentrate intakes between the cows maintained in the SS and DS animal houses.

Table 16 Mean values of production performances of the dairy cows raised in SS and DS sheds under hot-humid conditions.

Parameter	SS (Means±SEM)	DS (Means±SEM)
Body Conditions Score	2.53±0.05^{b}	2.78±0.07^{a}
Milk Yield (kg/hd/d)	10.35±1.60	11.56±2.31
4% FCM (kg hd^{-1} d^{-1})	8.22±1.98	10.22±2.50
Butter Fat Percentage (%)	2.65±0.32	3.06±0.51

Means with different superscripts within a row are significantly differed (P<0.05).
* Statistics analysis was not carried out due to group feeding.

More over, the results (Table 16) indicated that the body condition score (BCS) of the cows in the SS animal house (2.53±0.05) was significantly (P<0.05) lower than that of the cows in the DS (2.78±0.07) animal house. There were no significant (P>0.05) differences in milk yield, 4% FCM nor Butter Fat Percentage between the cows maintained in the SS and DS animal houses.

The results (Table 17) showed mean values of cortisol, T3, T4, IGF-1, and leptin hormones of the dairy cows raised in the SS and DS animal houses.

Table 17 Mean values of various hormones (Cortisol, T3, T4, IGF-1, leptin) of the dairy cows raised in the SS and DS animal houses in the hot-humid conditions.

Hormone	Treatment	
	SS (Means±SEM)	DS (Means±SEM)
Cortisol (ng/ml)	9.20±2.47	8.58±1.03
T3 (ng/ml)	0.61±0.10	0.74±0.24
T4 (nM/L)	79.42±7.37	93.83±5.87
IGF-1 (ng/ml)	20.10±3.57	22.77±3.02
Leptin (ng/ml)	0.64±0.09	0.64±0.02

Means with different superscripts within a row are significantly differed ($P<0.05$).

The results (Table 17) revealed that there were no significant ($P>0.05$) differences in the amount of plasma cortisol, T3, T4, IGF-1, insulin and leptin hormones concentrations of the dairy cows maintained in the SS and DS animal houses.

DISCUSSION

Experiment 1 - Discussion

The seasonal variation in THI (Table 5) illustrates that the only time that cows would not be stressed (THI< 72) was during Winter time, (Johnson, 1987). The THI values indicate that the dairy cows in the study area would be heat stressed significantly ($P<0.01$) particularly in summer and the rainy seasons. The difference between maximum and minimum THI during the rainy season was lower than during both Winter and Summer seasons suggesting that the dairy cows were exposed to heat stress conditions more consistently during the Rainy season.

Since night temperatures are often cooler this should help the animals to withstand the heat stress during in the hot part of the day (Mundia and Yamamoto, 1997). A typical day during the rainy season in a monsoon area can be described as hot and sunny from morning till mid afternoon, resulting in high humidity and heavy clouds building up to a thunderstorm in the evening. Therefore the condition of hot and humid would occur from mid afternoon until evening and the cows will become more heat stressed as air humidity increases (Vajrabukka, 1978), the higher humidity acting against cutaneous evaporation which is the major heat dissipation avenue for dairy cows.

Reproductive and milking performances

Reproduction data (Table 6) shows that the cows in this study had more days open than that reported for Holstein cows in temperate climates. Holstein cows subjected to heat stress usually have longer days open (Cavestany *et al*., 1985) and Washburn *et al*., (2002) showed that cows that calved in the summer season had significantly ($P<0.05$) more days open and a greater number of services per conception (2.17 times) than those cows calving in the Winter and Rainy seasons. Previous studies have shown that climatic extremes during pre- and post-partum often influence the reproductive efficiency of dairy cows (Collier *et al*., 1982; Jordan, 2003; Avendaño-Reyes *et al*., 2006).

The results of the present survey indicate that heat stress was severe enough to influence the reproductive status of the dairy cows with a higher number of services and longer days open in the Summer season compared with the Rainy and Winter seasons. . This effect is possibly mediated via an impairment of ovarian follicular development in responses to heat stress in Summer (Hansen and Aréchiga, 1999).

The cows in the present study that calved in various seasons did not differ significantly in the length of lactation or total milk yield. However, extending the number of days open also increases the calving interval which reduced the portion of the animals in any lactation cycle (Van Amburgh *et al.,* 1997) which in turn will reduce total milk yield. Earlier workers (De Bore *et al*., 1989; Barash *et al*., 2001) found a depression in milk production in dairy cows subjected to heat stress and suggested that part of energy cost for milk production is diverted to maintainbody temperature.

It is possible that nutritional status might interact with the effects of heat since there was no significant difference (P>0.05) in THI between the Summer and Rainy seasons (Table 5), and yet there was a significant difference (P<0.05) in the days open. There was more green feed available during the Rainy season and the increase in milk production per lactation in the Rainy season is most likely associated with an increase in the quality and quantity of grass available (Koonawootrittriron *et al*., 2001).

Experiment 2- Discussion

The green woven polypropylene sheet stretched above the grey corrugated iron roof was shown to reduce energy reaching the iron roof by casting shade over the iron roof. Since less solar energy fell onto the corrugated iron of the Double Shade (DS) roof, less heat energy would have been re-radiated from the roof. If the polypropylene sheet had been installed underneath the roof, there would have been no cooling advantage since the material's properties is to act as a light energy reducer and not as an insulator.

Solar radiation is the main route for heat gain by animals maintained in unshaded areas. The provision of shade will moderate heat stress to some extent, depending on the type of shade available (Valtorta *et al*., 1997). Although there are some concerns about re-radiation under corrugated iron roofs similar to that used in the present study, the amount of heat from re-radiation will be far less than if the animal were to have received it from a direct solar heat load. Furthermore, since both animal houses were of an open type there was a relatively small reflective re-radiation from the surroundings areas which was consistent for both. Hence, the shading of the iron roof was shown in this study to alter conditions within the shed significantly (Figure 8) suggesting that re-radiation load is significantly important under hot/humid conditions and the re-radiation heat load could be further reduced by the DS shed. The DS area had a significantly lower ambient temperature and THI ($P<0.05$) for 5 h and 5 h 30 min. respectively (Figure 9a, 9c), a difference most likely due to the reduction in re-radiated heat in the DS shed.

These results also indicate that, in both treatments, the animals were under heat stress at all times since the THI was greater than the 72 defined by (Johnson, 1987) as the threshold for stressful conditions (Fig. 9c). The threshold level of 72 (Johnson, 1987) was calculated for purebred low heat-tolerant (non-adapted) Holstein Friesian cattle, and therefore it might be expected that the THI threshold level for the crossbred animals of this study, especially as they were *Bos indicus* crossbreds, would be higher. However, there are no calculated THI threshold levels for such crossbred cows and the relatively extreme THI values confirm that the animals were probably severely stressed but with the cows in the DS group being stressed to a lesser degree than those in the SS group.

Even though the change in RT was 1 ^{o}C there was evidence that shade was successful in reducing heat stress of cows maintained in double shade. RR is often used as an indicator of thermal state in cattle; 20 breaths/min indicating cool conditions, and 80 breath/min indicating very warm conditions (Mount, 1979). Increased RR or panting by cows, although not as effective as sweating for evaporative cooling, it is needed to maintain homeothermy during exposure to increased heat load (Ingram and Mount, 1975).

A quadratic relationship between RR and air temperature was expected, given that lactating Holstein cows exhibited a 75% increase in RR from 21°C to 29°C but no additional increase from 29°C to 35°C (McLean, 1963; Goodger and Theodore, 1986). European cattle have been reported to exhibit maximum rates of respiratory vaporization at 27°C (Johnson, 1987). In the present study, treatment effect on RR rate was significant for the period ($P<0.05$). The DS treatment appeared to maintain RT of the crossbred cows close to that of non-heat stressed purebred lactating cows but the RR value was slightly higher than that found by Trout *et al*. (1998), suggesting that heat stress was not eliminated completely by application of DS. A rise in RR is normally preceded by a rise in RT on exposure to rising ambient temperature (Berman and Morag, 1971; Brown-Brandl *et al*., 2003).

The results of this study confirms the findings of other researchers that water intake is correlated to the level of heat stress (Armstrong and Wiersma, 1986; Beede, 1992; Bearden and Fuquay, 1992). The intake of concentrates by the DS cows was significantly ($P<0.05$) higher than that of the SS cows which also confirms the pattern previously reported of a decline in feed intake as the level of heat stress increases (Johnson, 1987).

Overall the results of this study show that the use of DS over the roof improves thermal status of the dairy cows.They also show that the days open and conception rate of the DS cows were not significantly improved when the air temperature and THI were decreased by the DS treatment . This was possibly due to the fact that the level of impact was insufficient to alter reproductive function although reproductive efficiency was shown to be improved significantly when an evaporative cooling system was used (Khongdee *et al.,* 2006) in similar circumstances. Hence, it is possible that reproductive efficiency might be improved given a longer period of experimentation and greater reductions in THI. It is known that heat stress can reduce reproductive efficiency of dairy cows (Marti and Funk 1994; Jordan, 2003; West, 2003) though a variety of mechanisms, usually resulting in a lengthening of days open.

Although the differences between morning and afternoon milk yield are primarily a function of milking intervals and the number of days in lactation (Shook *et al*., 1973), cows tend to have higher milk yield at the morning milking even when the interval between milking is equal (Palmer *et al*., 1994). As the difference ($P<0.05$) between the treatments occurred at the morning milking session it seems that alleviation of heat load during the night was not enough to remove any differential effects between the treatments induced during daylight hours. Since the average milk yield of the SS cows also declined at a faster rate than the cows kept under the DS as the experiment progressed it seems that the impact of heat stress was cumulative in terms of milk production (De Bore *et al*., 1989; Barash *et al*., 2001). The cumulative impact of DS would be a longer lactation period and higher lactation yield.

Experiment 3 – Discussion Part I

It can be seen from ambient temperatures, relative humidity and THI in the Non-Evaporative Shed (NEVAP) and Evaporative Shed (EVAP) areas of the animal house that the more stressful conditions occurred during the daylight although there were some afternoons of thunderstorm and rain where ambient temperatures dropped below 30 ^{o}C and the evaporative cooling system was turned off automatically.

The results reveal that although ambient temperature of EVAP was significantly lower than that of NEVAP for 12 hours, the THI of the EVAP was significantly lower than that of NEVAP for 10 hours only. This is most likely due to the influence of higher moisture levels, especially in the EVAP environment and implies that EVAP will be an effective form of temperature modulation even in more humid areas when the daytime humidity often is already low (Figure 12B) (Brown *et al*., 1974; Taylor *et al*., 1986).

The results also indicated that the animals in both groups of animals were under heat stress since the THI was greater than 72 (Johnson, 1987) at all times for both treatments. Thus, the cows in EVAP were heat stressed but to a lesser degree than those in the NEVAP.

The cows in the NEVAP were observed to be standing and panting, which would indicate that they may have received additional heat load from the re-radiation under the corrugated iron roof, particularly during sunny afternoons.

The water intake of the cows kept in the NEVAP was higher than water intake of the cows kept in the EVAP area of the animal house confirming previous observations that animals that are more highly heat stressed drink more (Bearden and Fuquay, 1992). Since the daily silage and concentrate intakes were not significantly different between the two groups of cows, then the lower water intake in the EVAP group in the present study cannot be attributed to feed intake differences and would appear to be directly related to a decreased demand for drinking water in the evaporative-cooled cows as a result of their less heat-stressed condition.

It is known that heat stress can reduce reproductive efficiency of dairy cows (Marti and Funk, 1994; Jordan, 2003; West, 2003) though a variety of mechanisms usually resulting in an increase in days open. Days open is a function of days to first breeding, number of services to conception, and intervals between services (Kuhn *et al*., 2004) and it can be seen from Table 11 that the days open of cows kept under the NEVAP was significantly longer than the days open of cows kept in the EVAP animal house. Likewise the conception rate of the cows kept under the NEVAP was lower than the conception rate of cows kept under the EVAP which indicates that reproductive efficiency of the EVAP cows was possibly ameliorated by the reduced stress effects on ovarian follicular growth.

Earlier workers (De Bore *et al*., 1989; Barash *et al*., 2001) reported depressions of milk production in dairy cows that were subjected to heat stress and the results in the present study show that cows kept under the NEVAP had significantly lower milk yields than the cows kept under the EVAP treatment. These findings confirm an amelioration of heat stress in the EVAP cows.

The EVAP treatment appeared to maintain RT of these crossbred cows close to that reported for non-heat stressed purebred lactating cows (Trout *et al*., 1998). However RR was slightly higher than that found by Trout *et al*. (1998) suggesting that heat stress was not eliminated completely by the evaporative cooling system as a RR rise precedes a rise in RT on exposure to rising ambient temperature (Berman and Morag, 1971; Brown-Brandl *et al*., 2003).

The days open of cows kept under EVAP was lower than the NEVAP. Hence, the cows kept under EVAP would become pregnant more easily than the cows kept under NEVAP. Conception rates were lower in Summer presumably as a result of greater severity of the thermal stress (Cavestany *et al*., 1985; Wolfenson *et al*., 2000). Such impacts are probably due to the fact that thermoregulatory mechanisms have priority for energy at the expense of milk production and reproductive efficiency (Shearer and Beede, 1990a, b). Nevertheless, both milk production and reproduction are under influence of various hormones

Experiment 3 – Discussion Part II

Thyroid hormones

The thyroid hormones, thyroxine (T_4) and triiodothyronine (T_3), may be a major mechanism involved in the acclimation process (Johnson and Van Jonack, 1976; Horowitz, 2001) andthese hormones are known to be good indicators of heat stress (Pusta *et al*., 2003) It is widely reported that as heat acclimation occurs endogenous levels of thyroid hormones decline and that mammals adapted to warmer climates follow this pattern (Johnson and Van Jonack, 1976; Horowitz, 2001).

The decreasing levels of T_3 of both NEVAP and EVAP and hence T_4 in the present experiment indicate that the cows in both groups were becoming less heat stressed and that the EVAP group was adapting more rapidly than the other group with differences most apparent at day 90 of the experiment. Presumably this was due to the EVAP cows being exposed to a significantly less stressful environment.

Insulin and Leptin hormones

It is also well known that a heat stressed dairy cows will reduced its dry matter intake (Johnson *et al.,* 1961) and that this reduced DMI, coupled with higher maintenance energy requirement results in a energy deficit, and lost of production. Insulin and leptin are hypothesized to be indicators of energy mobilization, leptin being the adiposity signal for the regulation of body condition (Baskin *et al*., 1999). It has been reported that plasma insulin is related to nutritional status in cattle (Gregory *et al*., 1982) with higher levels being associated with higher body fat (Sato *et al*., 1984; Matsuzaki *et al*., 1997). The changes in insulin throughout the present experiment could be related to nutritional status (Tokuda *et al*., 2002) with higher levels at 90 days reflecting higher feed intakes. A positive correlation between insulin and leptin levels has been demonstrated in dairy cows (Block *et al*., 2001, 2003b; Holtenius *et al*., 2003) and leptin has been reported to be positively correlated with net energy balance in ruminants (Minton *et al*., 1998; Blache *et al*., 2000a; Tokuda and Yano, 2001) and with environmental temperature (Accorsi *et al*., 2005).

The latter correlation may reflect the impact of heat in reducing food intake and the subsequent metabolic changes that this induces. In this experiment leptin differences between treatments (Figure 18.) were not evident until after 60 days postpartum and up to this time levels were increasing paralleling the rapid mobilization of body reserves that has been commonly reported for dairy cows in early lactation. Why there should be such a sharp decline in lepin for the EVAP cows between days 60-90 is unclear but would imply that energy balance has changed, and possibly that these animals have begun to restore body stores. Such a change in partitioning would also help explain the earlier return to oestrus and earlier conceptions.

Experiment 4 - Discussion

Environment and sheds conditions

It is known that heat stress can reduce reproductive efficiency and production performance of dairy cows (Marti and Funk, 1994; Jordan, 2003; West, 2003; Khongdee *et al*., 2006) though a variety of mechanisms. Effects of heat stress on reproduction and other physiological functions are a direct consequence of the increase in body temperature caused by heat stress and the physiological changes cows undergo to reduce the magnitude of hyperthermia. (Hansen and Are'chiga, 1999).

The environmental conditions (Table 14) in the experimental animal houses indicate that the conditions in the SS was significantly more stressful than the conditions in the DS animal houses although there were no significant difference in either minimum temperature or RH between the two sheds. This inconsistency may reflect the fact that the minimum temperature occurs during night time when there is no solar radiation and differences between the houses would have been minimal.

The significantly lower heat stress conditions in the DS animal house are a result of the incoming solar radiation being reduced by the black woven polypropylene sheet which allows energy to be absorbed and re-radiated.

Although, the DS animal house was found to be less stressful than the SS animal house, the environmental conditions in both animal houses remain stressful for the crossbred Holstein cows to a certain extent as revealed by the THI values in both houses that exceeded the threshold value of 72 (Johnson, 1987). Thus, the cows in the DS animal house were heat stressed but to a lesser degree than those in the SS animal house. These effects were apparent even during rainy season when radiant load would have been expected to be lower. However for most of the study conditions were such that overcast sky and rain only occurred in the late afternoons. Therefore, if air movement was encouraged during the sunshine hours even in the rainy season, the heat stress of the DS cows would be further reduced via increasing cutaneous evaporative cooling (Vajrabukka and Thwaites, 1984).

Physiology and production

In response to significantly different levels of heat stress in the two animal houses, the cows in the DS were found to have lower RT, RR and average daily water intake than that of their counterparts cows in the adjacent SS animal house and is s consistent with the findings of other studies (Kibler *et al*., 1966; Yousef, 1985; Johnson, 1987; West, 2003; Khongdee *et al*., 2006). The cows in the SS were observed to be standing and panting, which would indicate that they may have received additional heat load from the re-radiation under the corrugated iron roof, particularly during sunny afternoons. While the cows in the DS were mostly observed to be lying; a position in which the cows were further away from the heated roof, and hence, less heat energy was being loaded to the cows (Muller and Botha, 1997).

The present results confirm earlier experiment (Experiment 3) that heat stressed dairy cows drink more.

De Bore *et al*., (1989) and Barash *et al*., (2001) have previously reported depressions of milk production in dairy cows that were subjected to heat stress but the results of this study reveal that milk yield and 4%FCM of the cows in the DS were not statistically different (although slightly higher) than the cows in the SS animal house. However BCS of the cows in the DS was significantly higher which could be due to the lower maintenance energy needed by the less stressed cows (Maia *et al*., 2005).

Hormones

Cortisol

Plasma cortisol concentration of the SS cows were higher than that of the DS cows but not significantly so which contrasts to some degree with other reports where comparsions have been made between cooled and heat stressed cows (Wise *et al*., 1988). This may indicate that the contrast between the two treatments in the present study were not large enough to induce clear differences in cortisol levels.

T_3 and T_4

T3 and T4 concentrations of the SS cows were lower than for the DS cows, but not significantly. Given that in many mammals including dairy cows plasma concentrations of both T_3 and T_4 decline when animals are heat stressed (Alvarez and Johnson, 1973; Bouraoui *et al*., 2002; Pusta *et al*., 2003) the differences between the treatment groups might have been expected to be significant. However given that both treatment groups were stressed this differences may have been reduced markedly. This may be further emphasized by the role that the thyroid hormones (T_3, T_4) play in the acclimation process (Johnson and Van Jonack, 1976; Horowitz, 2001).

IGF-1

The result of the IGF-I of the DS cows was slightly higher than the SS cows (22.8 vs 20.1 Ng/ml, respectively). IGF-1 has previously been found to increase in the winter months compared to summer (Ingraham *et al*., 1982; Johnsson *et al*., 1997; Hamilton *et al*., 1999). Milk yield of the DS cows was slightly higher than the SS cows indicating that IGF-1 stimulates milk production (Bauman *et al*., 1999). The BCS of the DS was significantly higher than that of the SS cows suggesting that nutrition, which is influenced by climate, influences the level of IGF-I of the cows that is when the cow is undernourished because of heat stress there is a decrease in IGF-1 levels (Webb *et al*., 1999; Bousquet *et al*., 2004).

Leptin

There was no significant difference between leptin levels of the DS and SS cows, even though lower DMI of stressed animals might have been expected to body fat which in turns will be reflected in plasma leptin concentration (Dagago-Jack *et al*., 1996; McGregor *et al*., 1996). Leptin level can be positively correlated to environmental temperature (Accorsi *et al*., 2005) which would support this argument but in the present study These differences were not seen again possibly due to the fact that both groups were heat stressed.

GENERAL DISCUSSION

The 4 experiments of the present study were designed to investigate climatic effects on dairy performance in North Eastern Thailand. The first experiment evaluated the effect seasonal variation on milking and reproductive performance of the dairy cows and highlighted that despite lower ambient temperatures during the rainy season the THI value still exceeded 72 suggesting an almost constant heat stress for livestock. However, the value is the threshold level of heat stress determined for purebred Holstein Friesian cows in temperate climatic conditions (Johnson, 1987) while the animals used in this study were *Bos indicus* crossbred cows with a long term opportunity to adapt to the tropical conditions. The fact that the cows in the present survey did not lower their performance significantly during the Rainy season as was anticipated from THI values suggests that the threshold level of heat stress of the crossbred (Holstein Friesian × *B. indicus*) cows should be greater than 72. Nevertheless, crossbred cow in hot – humid regions still have an overall lower production performance.

The dairy crossbred cows in this study in Sakol Nakhon province, had lowered production in the summer due to heat stress with significant reductions in both milking and reproductive performances. It is suggested that in monsoonal areas, in order to take advantages of low maximum air temperature and more availability of green feed, dairy cows should be joined to calve in the middle of the rainy season which should reduce the days open and increase milk production at the same time. Further research should examine ways to increase the performance of heat stressed cows in the small scale dairy farms both through genetic improvement in heat tolerance and also by lowering the ambient temperature of animal housing under tropical conditions.

The other experiments reported in this thesis assessed milk production and physiological responses of lactating cows under different housing systems and with cut and carry feeding conditions. Experiment II examined the effect of installing the Double Shade to the animal house. This was done through application of translucent materials as a double roof and resulted in cow production improvements presumably as a result of decreasing ambient temperature and THI and consequently reduced heat stress. The Double Shade roof did not significantly improve reproductive efficiency of the cows although trends suggest that with larger numbers of cows an advantage may have been apparant.

The double shade system is relatively cheap to install and requires minimum maintenance and therefore has advantages over more energy costly environmental modification systems. Polypropylene sheeting with higher solar energy reducing characteristics may further improved effects on cow performance.

The application of evaporative cooling to dairy cows under hot-humid conditions was also tested. Lower RR, RT and days open and increased milk yield per cow throughout the experimental period confirm that there are advantages of such environmental modification presumably gained by a lowering of THI particularly at night when a higher rate of air flow may increase cooling efficiency of the evaporative cooling system.

CONCLUSION AND RECOMMENDATION

Conclusion

Installation of the DS cooling system in an open shed helped to ameliorate heat stress effects on dairy cows in the rainy season of Thailand. The DS technique requires minimal maintenance with zero energy consumption (no moving parts installed). The cows housed in the double shaded cooled environment had reduced rectal temperature and respiration rate compared to cows in non modified housing. These differences were also reflected in improved milk production and reproductive efficiencies in the cows and this was true for both double shade and evaporative cooled animal housing. The differences in production were not reflected in measures of hormones associated with cow metabolism. Further studies incorporating air movement (fan) with Double shade during sunshine hours and/or the flat roof of animal houses should be redesigned to encourage hot air exhaust from underneath the roof are required to determine if further gains in production can be obtained. Additional studies on housing should also be used to determine thresholds of the effects of different treatments on milk production and reproductive function.

Recommendation

It is recommended, especially for small dairy farms, that in order to increase milking and reproductive efficiency of dairy cows in the hot humid climatic existing animal houses and sheds should be modified to lower ambient temperature inside using the Double Shade technique.

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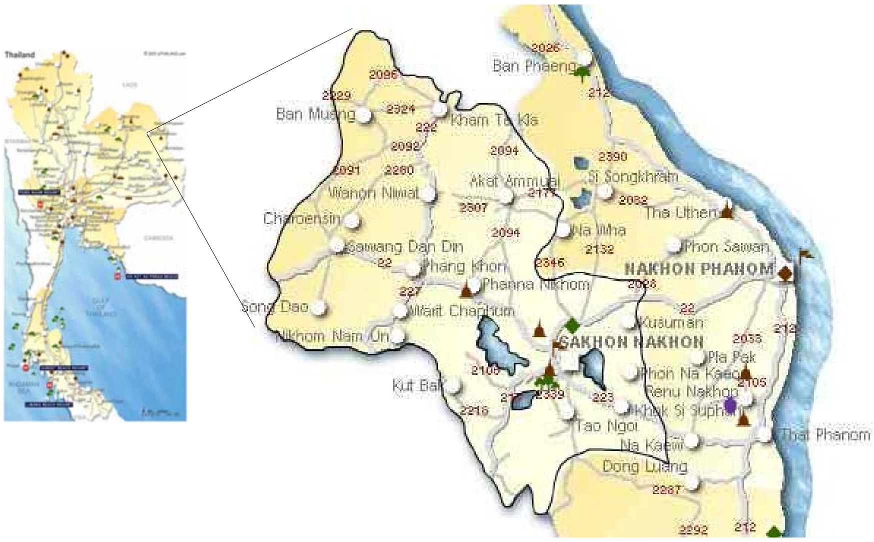
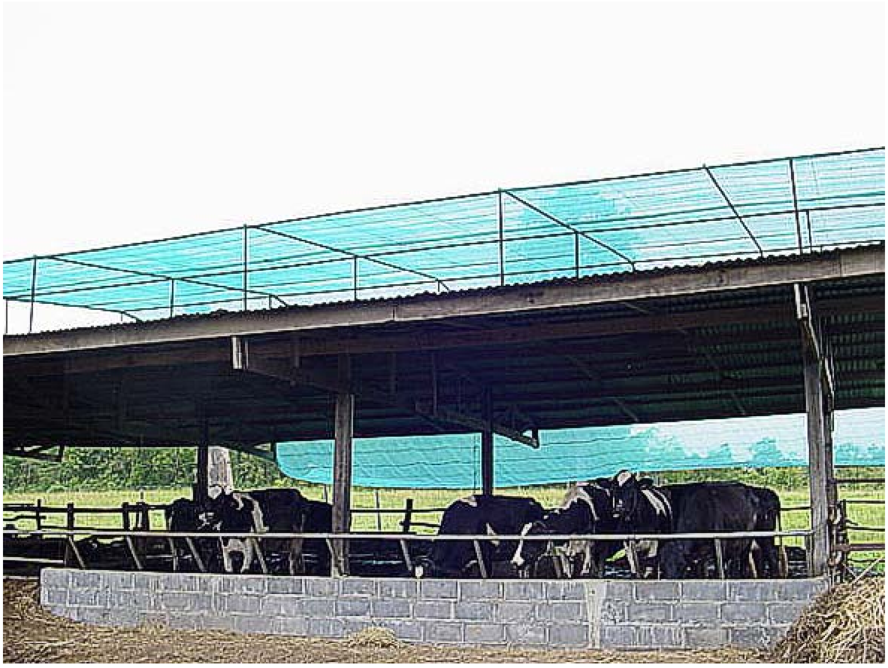
Appendix



Appendix Figure 1 A map of Sakol Nakhon Province.

Source: (modified from www.athailand.com/, 2003).

Appendix Figure 2 Cows in a single shade animal house.



Appendix Figure 3 A green woven polypropylene sheet (“green slant 70”)

Appendix Figure 4 Stephenson screen for recording on-farm meteorological data.

Appendix Figure 5 The Animal house used in Experiment 3.

Appendix Figure 6 Inside of the evaporative cooling animal house showing exhaust electric fan.

Appendix Figure 7 Inside of the evaporative cooling animal house showing watering trophs.

Appendix Figure 8 Inside of the evaporative cooling animal house showing the cows and the cooling pad.

Appendix Figure 9 Control units in evaporative cooling treatment**.**

Appendix Figure 10 Cows are waitng to have their blood samples taken.

Appendix Table 1 Temperature-humidity indexes (THI)[1] at varying temperatures and relative humidities for dairy cows.

Temp	- - - - - - - - Relative Humidity, % - - - - - - - -																				
(F)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
- THI - - - - - - - - - - - - - - - - - -																					
70	64	64	64	65	65	65	66	66	66	67	67	67	68	68	68	69	69	69	70	70	
71	64	65	65	65	66	66	66	67	67	67	68	68	68	69	69	70	70	70	71	71	**Heat Stress Begins**
72	65	65	65	66	66	67	67	67	68	68	69	69	69	70	70	70	71	71	72	72	
73	65	66	66	66	67	67	68	68	68	69	69	70	70	71	71	71	72	72	73	73	
74	66	66	67	67	67	68	68	69	69	70	70	70	71	71	72	72	73	73	74	74	
75	67	67	67	68	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75	
76	67	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75	76	76	**Sharp drops in production occur**
77	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75	76	76	77	
78	68	68	69	69	70	70	71	71	72	73	73	74	74	75	75	76	76	77	77	78	
79	68	69	69	70	70	71	71	72	73	73	74	74	75	76	76	77	77	78	78	79	
80	69	69	70	70	71	72	72	73	73	74	75	75	76	76	77	78	78	79	79	80	
81	69	70	70	71	72	72	73	73	74	75	75	76	77	77	78	78	79	80	80	81	
82	69	70	71	71	72	73	73	74	75	75	76	77	77	78	79	79	80	81	81	82	**Danger Zone**
83	70	71	71	72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	82	83	
84	70	71	72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	83	83	84	
85	71	72	72	73	74	75	75	76	77	78	78	79	80	81	81	82	83	84	84	85	
86	71	72	73	74	74	75	76	77	78	78	79	80	81	81	82	83	84	84	85	86	
87	72	73	73	74	75	76	77	77	78	79	80	81	81	82	83	84	85	85	86	87	
88	72	73	74	75	76	76	77	78	79	80	81	81	82	83	84	85	86	86	87	88	
89	73	74	75	75	76	77	78	79	80	80	81	82	83	84	85	86	86	87	88	89	
90	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88	89	90	
91	74	75	76	76	77	78	79	80	81	82	83	84	85	86	86	87	88	89	90	91	
92	74	75	76	77	78	79	80	81	82	83	84	85	85	86	87	88	89	90	91	92	

93	75	76	77	78	79	80	80	81	82	83	84	85	86	87	88	89	90	91	92	93	
94	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	
95	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	
96	76	77	78	79	80	81	82	83	85	86	87	88	89	90	91	92	93	94	95	96	
97	77	78	79	80	81	82	83	84	85	86	87	88	89	91	92	93	94	95	96	97	
98	77	78	79	80	82	83	84	85	86	87	88	89	90	91	93	94	95	96	97	98	
99	78	79	80	81	82	83	84	85	87	88	89	90	91	92	93	94	96	97	98	99	
100	78	79	80	82	83	84	85	86	87	88	90	91	92	93	94	95	97	98	99	100	

Source: [1]THI = t_d - (0.55 x RH)(t_d - 58), where ; t_d = dry bulb temperature (degrees F) and RH = relative humidity in decimals (Lucas et al., 2000).

Appendix Table 2 Mean monthly meteorological values (1995-2002) of the Sakol Nakhon Weather Station.

	MinDB	MaxDB	MeanDB	diffDB	MinDP	MaxDP	MeanDP	diffDP
J	18.46	27.38	22.89	8.91	10.63	20.96	15.83	10.33
F	18.01	28.36	23.78	10.35	10.71	21.38	16.09	10.66
M	21.04	32.08	27.58	11.04	11.92	23.19	19.15	11.27
A	24.30	32.79	28.84	8.49	17.94	24.08	21.91	6.14
M	24.70	31.56	28.20	6.86	20.89	25.20	23.75	4.31
J	25.44	30.05	27.75	4.61	23.32	25.58	24.45	2.26
J	24.93	29.80	27.76	4.88	22.88	25.60	24.38	2.73
A	24.85	29.60	27.39	4.75	23.14	25.57	24.43	2.43
S	25.28	28.73	26.89	5.95	20.51	25.13	23.60	4.62
O	23.61	28.66	26.87	5.05	17.08	24.55	21.98	7.47

	MinTHI	MaxTHI	MeanTHI	diffTHI	MinRH	MaxRH	MeanRH	diffRH
N	20.64	27.67	24.49	7.03	13.03	22.32	18.06	9.30
D	16.80	25.92	21.88	9.12	9.39	20.61	15.43	11.96
J	63.88	75.60	69.76	11.72	57.88	72.75	66.17	14.88
F	63.35	77.01	70.59	13.66	53.75	79.50	64.77	25.75
M	67.65	80.36	75.57	12.72	45.00	86.13	63.62	41.13
A	71.96	82.04	77.94	10.09	53.13	86.38	68.99	33.25
M	73.90	81.35	77.95	7.45	60.75	91.63	78.77	30.88
J	73.40	80.01	77.50	6.62	69.13	92.75	81.69	23.63
J	74.64	79.93	77.74	5.28	73.00	93.13	82.89	20.13
A	74.56	79.20	77.38	4.64	75.75	94.25	85.03	18.50
S	72.36	78.82	76.59	3.96	70.63	90.50	83.25	23.43
O	71.48	78.50	75.99	7.02	64.50	87.63	76.08	23.13
N	66.80	76.78	72.19	9.99	60.19	80.56	70.16	20.38
D	61.51	74.38	68.64	12.87	56.36	74.80	67.41	21.3

PUBLICATION

There are 3 papers that were submitted for publications, Two of which has already been published.

Khongdee, S., K. Makvichit , G. Hinch , N. Chaiyabutr, S. Tummabood and C. Vajrabukka. 2005. A survey of calving seasons on dairy reproductive performance and milk production under tropical conditions. Thai Journal of Agricultural Science (3-4): 95-100.

Khongdee, S., G. Hinch, N. Chaiyabutr, K. Markvichitr, S. Tummabood and C. Vajrabukka. 2008. Effect of double shades on milk yield and reproductive performance of heat stressed dairy cows under hot-humid conditions. Submitted AJAS.

Khongdee, S., N.Chaiyabutr, G. Hinch, K. Markvichitr and C.Vajrabukka. 2006. Effects of evaporative cooling on reproductive performance and milk production of dairy cows in hot wet conditions. Int. J. Biometeorol. 50:253–257.

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