EFFECT OF ENVIRONMENTAL HEAT STRESS ON PERFORMANCE OF CROSSBRED DAIRY CATTLE

by

M. THIAGARAJAN

Thesis submitted

in partial fulfilment of the requirements for the degree of

Doctor of Philosophy

Faculty of Veterinary and Animal Sciences
Kerala Agricultural University
Department of Livestock Production Management
College of Veterinary and Animal Sciences
Mannuthy, Trichur

1989

EFFECT OF ENVIRONMENTAL HEAT STRESS ON PERFORMANCE OF CROSSBRED DAIRY CATTLE

By

L.THIAGARAJAN

Department of Livestock Production Management
College of Veterinary and Animal Sciences
Mannuthy, Trichur

1 9 8 9

EFFECT OF ENVIRONMENTAL HEAT STRESS ON PERFORMANCE OF CROSSBRED DAIRY CATTLE

By

M.THIAGARAJAN

THESIS

submitted in partial fulfilment of the requirement for the degree

DOCTOR OF PHILOSOPHY

Faculty of Veterinary and Animal Sciences
Kerala Agricultural University
Department of Livestock Production Management
College of Veterinary and Animal Sciences
Mannuthy, Trichur

1 9 8 9

DECLARATION

I hereby declare that this thesis entitled, "Effect of environmental heat stress on performance of crossbred dairy cattle" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

20.11.89

Place: Mannuthy

Date : 20.11.89

Signature of the Candidate

M. THIAGARAJAN

Name of the Candidate

CERTIFICATE

Certified that this thesis, entitled, "Effect of environmental heat stress on performance of crossbred dairy cattle", is a record of research work done independently by Sri M.THIAGARAJAN under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

Place: Mannuthy

Date : 21-XI-1989

Dr.C.K.THOMAS, B.V.Sc.,
M.Sc., Ph.D.,
(Chairman, Advisory Board)
Professor, Department of
Livestock Production Management,
College of Veterinary and
Animal Sciences, Mannuthy,
Trichur.

C O N T E N T S

Page No.

LIST OF TABLES

LIST OF ILLUSTRATIONS

ACKNOWLEDGEMENT

I wish to place on record my deep sense of gratitude and indebtedness to Dr.C.K.Thomas, the Major Advisor and Professor, Department of Livestock Production Management, College of Veterinary and Animal Sciences, Mannuthy for suggesting the problem, his valuable guidance, keen interest, constructive criticism and ideas and for shaping-up the manuscript amidst his busy schedule of work.

I am very greatly indebted to Dr.T.G.Rajagopalan, Professor and Head of the Department of Livestock Production Management and the Director, Students Welfare, Kerala Agricultural University for kindly providing me the inspiration and the opportunity to do my doctorate degree and for all the encouragement and guidance given by him as member of the advisory committee.

I am thankful to the members of the advisory committee, Dr.K.Pavithran, Professor and Head, Department of Dairy Science, Dr.K.C.George, Professor and Head, Department of Statistics and Dr.C.T.Thomas, Professor, Department of Animal Nutrition for their help and valuable suggestions rendered to complete the research programme.

I gratefully acknowledge the valuable help extended to me by Dr.P.Kurian Thomas, Professor, Dr.[illegible].Sebastian and Dr.Francis Xavier, Associate Professors and

Dr.T.Sreekumar, Assistant Professor and all other staff members of the department of Livestock Production Management, College of Veterinary and Animal Sciences, Mannuthy.

I am grateful to the Vice-Chancellor, Kerala Agricultural University, the Director of Veterinary Research and Education and to the Dean, College of Veterinary and Animal Sciences for the facilities provided to me to undergo this course. I am thankful to the members of staff of the University Livestock Farm, the Fodder Research Station, Department of Surgery and the Department of Dairy Science for kindly permitting me to carry on the research work in their field and laboratories. Thanks are due to the Department of Statistics for helping in the analysis of the data.

I express my gratitude to the Vice-Chancellor, Tamil Nadu Agricultural University and to the Dean, Madras Veterinary College for kindly granting me deputation facilities to undergo this course.

I also wish to place on record my heartfelt gratitude to Dr.R.Prabaharan, Head of the Department of Animal Husbandry Economics, Madras Veterinary College with whose encouragement only, I ventured this assignment.

INTRODUCTION

It is widely accepted that the average performance of livestock of the warm climatic areas, remain much lower by northern latitude standards. Still, there are numerous factors that go to favour sustained efforts to be taken for development of livestock production in these areas (McDowell, 1972).

There are so many livestock enterprises already established in the tropical regions of the world, which function efficiently. With fast expanding human population, there will always be an increasing demand for livestock products and the indigenous people's traditional taste for animal products ever remains high. Animals are needed to provide power for agriculture and their importance in soil and water conservation are well established. The domestic animals have the admirable flexibility in their capacity for transforming feeds and agricultural wastes into products necessary for the most efficient total agricultural productivity of these regions. McDowell (1972) has aptly stated, that what has been achieved in Israel with dairy cows, in Australia with sheep and in Jordan and Tanzania with poultry shows that it is not impossible to have a large number of productive animal enterprises in the other warm climatic regions of the world. However, it is not the question of increasing the total number of animals but it is to obtain the optimum yield from the total soil-crop-animal environment complex (Williamson and Payne, 1978).

The genetic aspects of animal production have already been extensively studied in the cooler regions of the world and there may not be much use in repeating this work in the warm climates since characteristics that depend exclusively on the genotype of animals will be the same in any environment. On the contrary, management practices adopted, like housing and feeding have to be quite different in cooler and in warmer regions to obtain anywhere near the same level of performance, in as much as the expression of the full genetic potential of the animals is highly dependent upon environmental conditions (Sainsbury, 1965; Fuquay, 1981; Gangwar, 1988).

On the basis of reviews written over the last 25 years (Bianca, 1965; Thatcher, 1974; Yousri, 1976; Horz and Steinhaur, 1978; Fuquay, 1981; Hahn, 1981, Dantzer and Mormede, 1983; Beede and Collier, 1986; Gangwar, 1988), the conclusion that high environmental temperature reduces productive and reproductive efficiency of livestock is well justified. Also, through studies in controlled environmental chambers, upper critical temperatures have been established for a number of production traits and these temperatures fall between 24 and 27°C for most traits and most species (Fuquay, 1981). Studies in controlled environment chambers have been valuable in establishing the basic parameters of stress (Dantzer and Mormede, 1983). However, application of such information to field situation is often difficult. With diurnal variations in ambient temperature and relative humidity, with difficulty in controlling other aspects of animal environment and with possible intrinsic compensatory mechanisms involved, apparent inconsistent responses to summer stress are not uncommon (Fuquay, 1981). The most useful information relating to animals in natural environments has been gained by the application of simple modifications that reduce heat gain and/or facilitate heat loss (Hahn, 1981; Clark, 1981; Beede and Collier, 1986; Gangwar, 1988). More research information is needed to aid in the management of livestock under adverse conditions (Ansell, 1981). Practical methods to achieve the desired levels of production performance are to be developed (Gangwar, 1988).

In a large country like India where climatic conditions vary considerably from place to place, defining animal housing needs becomes extremely difficult. Investigations on animal housing have also been limited, mainly due to the high expenditure involved. Many types of traditional animal housing systems have been evolved in course of time. They need to be evaluated in the light of changing genetic structure of cattle population due to cross-breeding.

Some of the previous studies (Wiersma and Stott, 1965; Starr, 1981; Hahn, 1981) indicate that certain types of animal houses instead of giving them comfort may add to their thermal stress and may lower productivity. Some have even indicated that cattle remain more comfortable under a tree in the open than inside cattle houses (Smith, 1981; Gangwar, 1983). In the present study an attempt has been made to evaluate the effect of a common type of cattle shed on the performance of crossbred cows and calves *vis-a-vis* open conditions without any housing.

There had been also conflicting reports with respect to the quality of the ration and the proportion of concentrates in the diet on the thermal comfort and productivity of cattle. One hypothesis mainly based on the Israeli experience is that to treat the dairy cow more or less as a monogastric animal with a very high proportion of concentrates in the ration. This is expected to reduce heat production by the animals, thereby reducing the heat load and to result in higher levels of production. How far this hypothesis holds good in the case of growth in crossbred heifers has been investigated in this study.

Among climatic factors, the solar radiation and the wind speed have been rarely quantified in field studies carried out in tropical regions. The present study also aims at doing so and relating the results to animal performance.

REVIEW OF LITERATURE

Environmental heat stress increases animal's maintenance requirements of energy (Kauheimer-Thomeick *et al.*, 1983b) and reduces their growth rate, production and reproductive performance. This leads to sizable economic losses to producers of intensively managed livestock (Beede and Collier, 1986). In the warm climatic regions, the environmental temperatures exceed the upper critical temperature of animals during major portions of the day. Prevalence of chronic warm weather for seven to nine months or more in a year is common in the tropical regions. Under such conditions, by understanding the principles of the physiological and other reactions of domestic animals, the housing, feeding and management conditions can be altered in order to be able to keep animals under economically feasible production conditions (McDowell, 1972).

It is stated that investigations into the effect of a warm climate on domestic animals are carried out either in the form of field studies or under simulated conditions in controlled environment chambers. The most frequently measured parameters are energy exchange (body and surface temperature, basal metabolism), water balance (intake, evaporation, distribution, excretion and secretions), cardio respiratory reactions (pulse rate, rate of breathing, vasodilatation, blood pressure and volume), biochemical paramoters (blood components, harmones, enzymes) and fertility, productivity and behaviour patterns (Herz and Steinhauf, 1978). Investigations carried out on this aspect in India and elsewhere are reviewed in the following chapters:

I. ENVIRONMENTAL HEAT STRESS FACTORS:

The principal climatic factors causing heat stress are air temperature, humidity and solar radiation. Wind acts as a partial heat stress factor when environmental temperature exceeds body temperature.

a) Air temperature and humidity:

Under tropical and subtropical conditions, ambient temperature has the most decisive effect of all climatic factors on the animal organism. The direct effect of other factors such as air humidity and air movement, is relatively insignificant. They tend, rather to have an indirect effect by increasing or lessening the temperature effect (Herz and Steinhauf, 1978).

The effect of air temperature and its relationship with air humidity has been studied, amongst other things, in a series of tests on cattle and other animals (McDowell *et al.*, 1961; Bianca, 1962; Hahn *et al.*, 1965; Nardan *et al.*, 1968; Ghosal and Guha, 1974; Renner, 1976; Bayer *et al.*, 1980; Ansell, 1981; Berman *et al.*, 1985; Wolfensen *et al.*, 1983; Sharma *et al.*, 1988). The results showed that in general, below 24°C air temperature, humidity had no effects on those parameters which were generally measured in connection with heat stress. The reason for this may be that direct heat output mechanisms were adequate at these temperatures and evaporation played only an insignificant part (Bianca, 1965).

Above 24°C, the body functions of various cattle breeds are significantly affected by air humidity because evaporation is inhibited by the reduction in water vapour pressure gradients between skin, lungs and the air. This effect is purely a physical one. The relationship established for the rate of heat loss from the bovine respiratory tract indicated that at 29°C and 60 per cent RH, a cow was able to loose 3.4 J m^2 of heat while at 90 per cent RH, this was reduced by 25 per cent (McDowell, 1972). Respiratory volume and evaporative heat loss through the pulmonary tract under cool conditions (18.5°C) were appreciably lower than under either hot humid (33.5°C) or hot dry conditions (42.5°C). Under hot humid conditions, the respiratory volume was more than double that of a hot dry environment but the evaporative heat loss was lower under hot humid conditions (Ghosal and Guha, 1974).

According to Sainsbury (1965) and Hilliger (1969), a relative humidity of 20 to 90 per cent did not affect domestic animals if they were kept within their optimum temperature range. Starr (1981) had stated that heat balance could become a problem at 20°C and above when RH was in excess of 60 per cent. Neuworth et al.(1979), in their experiment, found that 3 to 4 weeks old male calves responded to acute heat stress only above 32.2°C at RH of 60 per cent. Razdan et al.(1968), while reporting a positive correlation of rectal temperature and respiratory rates with ambient air temperature and humidity, found that the zone of thermoneutrality for Tharparkar animals was high and varied widely between 15 and 38°C. Christensen and others (1975) in Mexico showed that milk production in Holstein cows significantly dropped at temperature outside the range of 3 to 21°C and RH above 60 per cent. Voigtlander et al.(1973), Renner (1976), Beslin and Anojcic (1979), Bayer et al.(1980), Igono et al. (1985) and Rodriguez et al.(1985) have all worked on the relationship of temperature and RH on milk production traits in cows.

High air humidity at a high environmental temperature acts as a powerful heat stress factor. Bianca (1962) determined weighting factors for dry and wet bulb temperature and his findings indicated that the effect of wet bulb temperature was approximately twice as large as that of dry bulb temperature. As heat stress is a combined temperature/humidity effect, numerous indices have been developed which include both factors - Discomfort Index (Thom, 1958), Temperature-Humidity Index (US Weather Bureau), Black-Globe Humidity Index (Buffington *et al.*, 1981) and Temperature-Humidity-Sunshine Index (Thomas and Acharya, 1981).

b) Solar Radiation:

Under outdoor conditions, solar radiation is a powerful heat stress factor. In the hotter countries of the world, the radiant heat exchanges comprise a very significant part of the heat balance of animals. Besides the direct solar beams which the animal body intercepts, some solar radiation is diffusely scattered downwards on to the animal by atmosphere (Monteith, 1973). Furthermore, water vapour, carbondioxide and ozone which absorbs solar radiation, emit long wave radiation towards the earth's surface and on to the animal. Shortwave radiation is reflected on the animal from the ground while solar radiation absorbed by the ground is emitted towards the animal as long wave radiation (Robertshaw, 1981).

To emphasise the significance of solar radiation, the table below shows the results of calculations of heat balance of a Zebu cow in an equatorial noon sun (fluxes in Wm^{-2}) at an air temperature of 27°C and relative humidity of 32 per cent. The figures in parenthesis are the percentages of total heat dissipated by various avenues of heat loss. The most striking feature of this computation is the magnitude of the radiant heat absorbed being greater than 12 times the resting metabolism (Robertshaw and Finch, 1976).

Metabolic heat	Radiant heat	Reradiated heat	Convective heat loss	Cutaneous heat loss	Respiratory heat loss	Heat storage	Gain	Loss
50.7	638.0	397.3 (57.7)	63.6 (9.2)	146.2 (21.2)	36.1 (5.2)	7.6 (1.1)	688.7	650.9

Starr (1981) stated that measurements of mean monthly radiation levels aided in establishing and refining assessment of housing needs of cattle in the tropics.

In a 20 year study with milk producing 12,212 Holstein and Jersey cows at the University of Florida, Sharma et al.(1983) obtained results that were unique to the specific climate involved and the characteristics of the climate prevailed were as follows:

Month	Mean maximum tempera-ture (oC)	Mean minimum tempera-ture (oC)	Mean RH (per cent)	Solar radiation (Langleys)		
				High	Low	Mean
January	20.0	6.7	46	425	72	262
February	23.9	10.0	44	567	66	431
March	26.1	10.6	36	647	242	493
April	27.8	12.8	42	756	204	554
May	30.6	17.2	41	752	301	543
June	32.8	20.6	46	740	193	584
July	33.3	22.2	46	700	244	537
August	32.2	21.1	53	706	138	507
September	31.1	20.6	53	579	190	426
October	28.9	16.1	43	565	240	426
November	25.0	11.1	43	495	189	354
December	21.1	6.7	52	464	93	269

The authors concluded that the intense solar radiation restricted mobility and feed intake of the animals and resulted in declines in production. The air temperature and RH had remained within tolerable limits and solar radiation alone had brought about the decline in production.

Yassen (1977) studied in detail the respiratory responses of N'Dama and Boran cattle to the climatic conditions of Nigeria. The five year monthly averages of agrometeriological data at University of Nigeria (Nsukka Station, latitude 6° 52'N; longitude 7° 24'E; altitude 400 m.) presented were:

Month	Rainfall (mm)	Solar radiation (cal/cm²/day)	Temperature °C		Relative humidity (percent)
			Maximum	Minimum	
January	6	269	31	20	[illegible]
February	15	289	33	22	69
March	37	286	32	23	73
April	121	273	31	22	76
May	217	273	30	21	79
June	242	244	28	21	83
July	148	214	27	21	87
August	198	209	27	21	83
September	373	233	27	20	86
October	205	251	28	21	82
November	8	300	31	20	69
December	18	283	31	20	[illegible]

He concluded that Zebu differed in their response to direct solar radiation and this was the only factor to be considered in selecting Zebu breeds for tropical climate than all other climatic variables.

On a comprehensive screening of the available literature of past 30 years, it is found that only very few researchers have worked on the effect of direct solar radiation on animal's performance. They are Harris et al. (1960), Shrode et al.(1960), Williams et al.(1960), Thompson et al.(1964), Guthrie et al.(1967), Shafie and El-sheikaly (1970), Kahoun (1971), Roman-Ponce et al.(1977), Eley et al.(1978), Ingraham et al.(1979) and Colliar et al. (1982). In India, such work on Zebu and crossbred cattle are by Razdan et al.(1968), Thomas et al.(1969), Thomas and Razdan (1973a, b), Thomas et al.(1975) and Thomas and Acharya (1981) and on buffalos by Pandey and Roy (1969), Tripathi et al.(1972) and Sastry et al.(1973). Satyapal and others (1973) have worked on the influence of unsheltered conditions in north India on the water consumption in buffalos. None of these authors had quantified the solar radiation in their experiments. Thomas and Acharya (1981) have stated that measurement of solar radiation posed problems and required sophisticated equipments. McDowell (1972) suggested that methodical assessment and recording of each of the climatic variables prevalent in a location could be of aid in defining the shelter needs of livestock in that particular locality.

c) Air movement:

An increase in air velocity will increase heat loss if the body temperature is higher than the ambient temperature. In tropical zones, the advection of hot air over the animal may increase heat stress and in cold locations, air motion enhances cold stress. In climatic zones between these two extremes, air movement generally mitigates climatic stress (Starr, 1981). Sparsely haired pigs and buffalos lose heat more easily by convection. Buffalos sweat but pigs do not and so in hot environments buffalos benefit more from air movement (Macfarlane, 1981). Schmidt-Nielsen (1972) stated that a major difference between panting and sweating is that the panting animal provides its own air flow over the cooling surfaces and the sweating animal depends on free or external forced convection.

Siegel and Drury (1968) demonstrated that velocities upto 2.5 m per sec diminish the physiological responses to high dry bulb temperatures upto a level of 40°C; above 40°C where the temperature is equal to or greater than body temperature, increasing air velocity exacerbates the physiological responses. However, if the animals are exposed to the sun outdoors, radiation can raise their skin temperature well above the ambient temperature with the result that the wind has a cooling effect. A wind speed of 2.25 m per sec is quoted by McDowell (1972) as ideal in hot dry day time environments and after sunset, the restoration of heat balance is encouraged by wind speeds of the order 2.25 to 4.50 m per sec.

It is stated (Smith, 1981) that in the humid tropics, the use of high air velocity to cool the stock may be the only possible way of improving performance, if climate modifications by the various housing and landscaping techniques have been exhausted. Where it is possible to use both evaporative cooling and an increased air velocity to cool the stock, evaporative cooling could be used until the indoor RH reached 70 to 75 per cent. Following this, an increased air velocity would be the last means available for cooling on large scale. Air velocity inside animal houses is affected by the ventilation rate, and the position, shape and size of inlets (Bruce, 1981). The various factors in a ventilation system that affect the air flow patterns have been summarised by Carpenter (1974). Stolpe (1977) recommended that a rate of air movement of 0.6 m per sec was affective as a means of offsetting the deleterious effects of very high temperature in modern animal housing.

The effect of relieving heat stress by providing ventilation and air flow arrangements on thermal and productive responses of dairy cows has been examined in recent studies by Berman <u>et al</u>.(1985) and Lolman and others (1979). In Mississippi, natural cross ventilation in a free stall shelter as compared to no cross ventilation, resulted in significantly lower rectal temperatures and respiration rates with a nonsignificant trend towards higher milk production (Fuquay *et al.*, 1979). In India, Ludri (1979) studied the effect of air movement in a hot and humid climate (air temperature 26.6 to 32.6°C; RH 88 to 90 per cent) on DM consumption, physiological reactions and milk yield in crossbred cows. Increased air movement by fans decreased the rectal temperature, respiration and pulse rates. The drop in milk yield at the end of the experiment was much lower in the fan group compared to the controls and the average milk yield was higher by 1.22 kg per cow per day.

II. EFFECT OF ENVIRONMENTAL HEAT STRESS FACTORS ON:

A) Physiological Reactions:

1) Body and skin temperature:

The zone of thermal comfort is the range where there is minimal thermoregulatory effort and is the thermal environment that an animal will choose for itself (Webster, 1974; Ingram and Mount, 1975). Outside this range, ambient air temperature is found to influence the body temperature of animals to a larger extent (Razdan *et al.*, 1968; Pandey and Roy, 1969; Thomas, 1969; Bayer *et al.*, 1980; Collier *et al.*, 1982; Syamasunder and Choudhuri, 1988; Her *et al.*, 1988; Nauheimer-Thoneick *et al.*, 1988a). Thompson *et al.* (1964) demonstrated that when dairy animals were exposed to direct solar radiation, the skin temperature and respiratory rate were significantly higher in the sun

($P < 0.01$), yet thermal balance was not altered as indicated by normal rectal temperature. Their conclusion was that animals attempted preventing rise in body temperature by effectively increasing heat loss by accelerating breathing and raising the body surface temperature.

Warm blooded animals keep their body temperature within a narrow range even when the ambient temperature fluctuates widely. The normal fluctuation range in body temperature is around 2.5°C in most domestic livestock and it is between 38.0 and 39.3°C in adult dairy cows (Merz and Steinhauf, 1978).

Diurnal variations in body temperatures are reported (Holmes, 1970; Shafie and El-sheikaly, 1970; Sastry et al., 1973; Amakiri and Funsho, 1979; Flamenbaum et al., 1986) with the maximum occuring in the early afternoon and minimum in the early hours of the morning. However the diurnal differences measured were only 0.5°C between these two extremes (Wolfenson et al., 1988).

Battacharya and Singh (1931), in their trials with crossbred heifers found a significant variation in rectal temperature only when there was an undulating temperature - humidity complex. The rectal temperatures remained constant without variations when the same calves were subjected to a constant temperature - humidity complex or similar magnitude. Pandey and Roy (1969) concluded that buffalos were more susceptible to heat stress than Zebu but studies by Hassan et al.(1979) indicated that crossbred cows had a higher rectal temperature and respiration rate than buffalos under stressful environment. Lactating cows recorded a higher rectal temperature than non-lactating cows (Wolf and Monty, 1974) and rectal temperatures were higher in early lactation than in late lactation (Nauheimer-Thoneick et al., 1988a). Age differences (Aziz et al., 1979), breed differences (Shebaita, 1984) and variation in body temperature reactions due to differences in composition of diet (Beede and Collier, 1986) were reported. Under Egyptian climatic conditions, the rectal temperature values of Friesian cattle recorded were 38.8, 38.7 and 38.5°C respectively for summer, autumn and winter seasons. In summer when these cows were exposed to direct sun light, the rectal temperature increased to 39.8°C against 38.9°C of the cows kept in shade (Shafie and El-sheikaly, 1970).

Contrary to the above reports, some researchers did not find any difference in body temperature responses to variation in climatic and other factors. Amakiri and Funsho (1979) failed to find any breed difference as well as differences between heifers, milking cows, bulls and calves in their body temperature responses. Studies carried out at the Kerala Agricultural University also

(Somanathan and Rajagopalan, 1983) revealed that the rectal temperature of crossbred calves remained constant throughout the year inspite of wide variation in the ambient temperature and humidity levels between various seasons of the year. Fuquay et al.(1979) in their experiment, with dairy cows, found inconsistent responses in rectal temperatures and respiration rates under various treatments and concluded that the time of monitoring (Stott and Wiersma, 1974) or animal activity (Hutson et al., 1971) accounted for some of these inconsistencies.

The temperature of the body surface has been measured under a variety of hot conditions by many workers (Bianca, 1964; Wurster and McCook, 1969; Shafie and El-sheikaly, 1970; Bhupal singh and Sadhu, 1970; Sastry et al., 1973; Singh and Newton, 1978a; Thiagarajan et al., 1978; Koilpillai et al., 1979; Neuworth et al., 1979; Aziz et al., 1979; Bunger et al., 1982). Wurster and McCook (1969) studied the influence of rate of change in skin temperature on sweating. In 10 male subjects, step changes in ambient temperature (60 to 37°C) produced rapid decrease in skin temperature and inhibition of sweating. As rate of decline of skin temperature approached zero, sweating increased despite lowered skin temperature and declining central temperatures (tympanic membrane and oral temperature). It is stated that a decrease in tissue resistance on the trunk, would be of thermal advantage to a sweating animal in hot environment. Berman (1971) reported that the local tissue resistance on the trunk of Holstein dairy cows fell from about 0.28 to 0.12 Scm^{-1} when the corresponding skin temperature rose from about 36.0 to 39.0°C. The accompanying rise in body core temperature to about 39.7°C indicated that heat could be dissipated through the body tissue on the trunk at the rate of about 73 Wm^{-2} when mean skin temperature on the trunk reached 39°C. Few published measurements allow similar analysis and more information would be needed on the local changes in the tissue resistance of cattle in hot environment and on the role of the different body regions as avenues for heat dissipation (McArthur, 1981).

It is shown that in cattle, the thermoregulatory mechanisms come into operation in a certain order. Under conditions of moderate heat, vasodilation enables direct heat output (Thatcher and Collier, 1982). At hotter temperature, perspiration comes into effect which is later on accompanied to an increasing extent by greater respiratory activity. Only when all these mechanisms no longer suffice, does the body temperature rise (Herz and Steinhauf, 1978). This affects appetite and thyroid gland activity which leads to a drop in heat production. There is, however, a limit beyond which these reactions are no longer adequate and the body temperature rises to such an extent that the animal dies, the lethal increase being 4.4°C. above normal body temperature in the case of cattle (Terui *et al.*, 1979). This order of reactions also applies to the energy needed, as vasodilatation requires only small amounts of energy, sweating higher amounts and panting, the maximum energy (McDowell, 1972).

During heat stress, there is a delay of about two hours before the rectal temperature rises in reaction to ambient temperature. Rectal temperature has become widely used as an indicator of heat tolerance or heat stress in cattle (Bianca, 1969). In an attempt to identify the effects of thermal stress in terms of systemic response, Kauworth *et al.* (1979) subjected eight Holstein calves successively to five temperature levels, ranging from 15.5 to 37.7°C at 60 per cent RH and measured the rectal and skin temperatures. They found that the calves responded to acute heat stress only above 32°C and did not attempt to acclimatize until at least four to five hours of exposure at 37.7°C. Rectal temperatures of 42.2°C were recorded in Holstein cows which had been exposed for several hours to a temperature of 41°C (Johnson *et al.*, 1967). Ansell (1974) found that cows were able to tolerate high rectal temperature for long periods with little effect on performance but sustained rectal temperature of 40°C was approaching the limit of tolerance. West African Shorthorn cattle were exposed for 10 days to direct sunlight with an air temperature of over 29.5°C in the shade (Kahoun, 1971). The rises in body temperature evident in the first five days gradually declined over the second five days. Singh and Newton (1978b) subjected four, three month old calves to 18.3°C and 50 per cent RH for a week and later exposed to 40.5°C and 50 per cent RH in a climatic chamber for two weeks for acclimatization. Skin and rectal temperatures increased sharply on the first day of exposure and then gradually declined with continued exposure. The lower values were still higher than the original values. A gradual increase in sweating rate was seen after the second day of exposure. Most of the acclimatization in the physiological measurements was completed in the first nine to 10 days of exposure. Herz and Steinhauf (1978) stated, that such a reaction could be described as acclimatization, if by acclimatization is meant the reaching of a stable physiological state. It is known that the rectal temperature of a camel can fluctuate to a wide range of 34° and over 40°C. If it is exposed to thermal stress better use is made of its heat storage for thermolysis with minimum water loss (Yousri, 1976). The higher body temperature during the day stores heat which is dissipated directly by physical means when the environment cools down, during the night.

It is, therefore, to be presumed that a rise in rectal temperature is not necessarily a sign of failure on the part of the heat regulating mechanisms and tests are needed to find out whether the generally accepted interpretation of role of stable body temperature under heat stress is correct. As a result of tests carried out in Australia (Turner, 1972; Allen and Donegan, 1974), a combination of perspiration rate, food consumption, rectal temperature and respiration rate is suggested as a more useful indication of heat tolerance, the first two factors being set into equation with positive signs and the last two with negative signs (McDowell, 1972).

ii) Respiration and cardiac rate:

Heat is well known to augment the respiratory activity of cattle. Somanathan and Rajagopalan (1983) recorded onthly variations in the respiratory rates of 10 to 24 months old crossbred calves at Mannuthy. The respiratory rates were a maximum of 49.23 per min in April and a minimum of 30.97 in July when the ambient temperatures of 35.33 and 28.45°C were the maximum an the minimum respectively during the year of study. Fresian cows maintained under the climatic conditions in Egypt (Shafie and El-sheikaly, 1970) had exhibited seasonal differences in the respiration rates, the respective values for summer, autumn and winter being 45.2, 53.9 and

30.1 per min. Bhattacharya and Singh (1981) recorded significantly higher respiratory rates in crossbred calves that were subjected to a constantly high temperature condition than the calves that were subjected to undulating temperature conditions. In Hariana, Tharparkar and Sahiwal breeds, Ghosal and Guha (1974) found that the respiratory volume and evaporative heat loss through the pulmonary tract under cool conditions (18.5°C) were appreciably lower than under either hot humid (39.5°C) or hot dry conditions (42.5°C). Bunger and others (1982) have reported diurnal rythm in the respiratory rates of German Fresian cows. Significant breed differences are reported in Nigeria (Amakiri and Funsho, 1979). A higher respiration rate in crossbred cows than in buffalos is also reported (Hassan et al., 1979). A significant rise in respiration rate in response to hot weather was noticed by Wolff and Monty (1974) in Fresian cows in Arizona but the response was much more significant in lactating cows than in non-lactating ones. In the experiment by Colditz and Kellaway (1972) in Australia, the respiration rates of Fresian and Brahman x Fresian calves at 38°C air temperature were twice that at 17°. At both the temperatures, the respiratory rate of Brahmans was lower. When lactating cows were subjected to an ambient air temperature of 30°C (Lauheimer-Thoneick et al., 1983a), the respiratory rate increased by 130 per cent of the normal.

High air humidity greatly enhances the effect of high air temperature on respiration. Zia-ur-rehman *et al.*(1982) reported that respiration rates in crossbred cattle were the maximum in the month of August when the RH was highest.

Under the subtropical climate of Central Texas, Williams *et al.*(1960), working with European and Zebu breeds, found that the respiration rate which was more consistent among all the physiological responses studied, was affected more by direct solar radiation than by the other weather influences. Harris *et al.*(1960) concluded that air temperature variation was the predominant cause of variation in respiration rate while solar radiation was of considerable importance as a direct cause of increased respiration rate of dairy cattle when they were directly exposed to the sun. The variations in respiration rates as a consequence of exposure to direct solar radiation as reported by a few authors are tabulated below:

Sl. No.	Kind of animal	Respiration rate/min		Author
		Shelt-ered	Unshel-tered	
1.	Dairy animal in a subtropical environment:			
	a) Coated aluminium roof	64.0	94.0	Thompson *et al.* (1964)
	b) Corrugated galvanised iron roof	61.0	94.0	
	c) Corrugated aluminium roof	68.0	94.0	
	d) Natural shade under trees	66.0	94.0	
2.	Fresian cattle in Egypt	29.1	70.1	Shafie and El-sheikaly (1970)
3.	Murrah buffalo heifers in India (partially exposed)	32.7	41.1	Sastry *et al.* (1973)
4.	Sahiwal and Sahiwal x Brown Swiss bull calves in India	18.0	25.3	Thomas and Razdan (1973b)
5.	Lactating cows in a subtropical climate	54.0	82.0	Roman-Ponce *et al.* (1977)
6.	Fresian and Brown Swiss female calves in Egypt:			
	a) Brown Swiss	65.0	99.0	Shebaita (1984)
	b) Fresians	70.6	107.8	

It is stated (Herz and Steinhauf, 1978), that in cattle, whose heat output mechanisms are primarily vasodilatation and perspiration, panting may require a greater energy expenditure and is therefore less efficient. The change over from the first phase of respiratory activity to the second phase takes place in adult cattle at rectal temperature of 40.5°C (Bianca, 1965). During the second phase, there is a rise in cardiac rate which can be interpreted as a sign of increased body stress. In the experiment by Zia-ur-rehman et al.(1982), the highest cardiac rate in Sahiwal cattle was recorded when the RH was high along with high ambient temperature. Furukawa et al.(1979), in their attempt to study the effect of environmental temperature on physiological functions in cattle, adapted 14 six to 11 months old calves to 15°C for two weeks in a climatic room. At a constant RH of 70 per cent, the temperature was raised to 30 to 35°C at five or 10°C per h. The temperature 30 to 35°C was continued for three or six hours and then the temperature was reduced to 15° at the same rate of change on the increase. Increase in respiratory rate and rectal temperature occurred in all the animals but heart rate only increased greatly under severest conditions (35°C for six hours). With the elevation rates of five and 10° per h the body temperature began to rise at environmental temperature of 27.5 and

18.0°C respectively. Respiratory rate reached an equilibrium (about 160 per min) within one to three hours of exposure to the plateau temperature of 35°C; body temperature continued to rise for six hours after this. The heart rate began to increase greatly only when the respiration rate and body temperature reached their equilibria.

Horz and Steinhauf (1978) state that under hot dry conditions, where water supplies are at a minimum, it can happen that a periodic reduction in water evaporation through the respiratory passage is advantageous. At low ambient temperatures, skin evaporation corresponds roughly to that of respiratory passages. At high temperatures, evaporation through the skin is greater and amounts to about 70 to 80 per cent of total water loss through evaporation. Hence Zebu cattle rely less on respiratory cooling than B.taurus breeds, which breathe at a rate of upto 200 per min at air temperature of 38°C. Similarly, 12 per cent of water evaporates through the respiratory passages of Brahman cows compared with 24 per cent given off by Shorthorns under the same conditions.

Bianca (1965) stated that the effect of panting, which accounted for only about 20 to 30 per cent of total evaporation was somewhat uncertain. In cattle, panting was not the main factor in the control of body temperature and heat stress. The cooling effect of breathing was probably lessened by the fact that heat was produced in the respiratory muscles. In this way, cattle used about four times as much energy in their respiratory cooling system than in sweating.

Kazdan *et al.* (1968) opined that respiratory rhythm proved to be a more sensitive index under tropical conditions for assessing the animal response to environmental changes whereas Garcia and Rodriguez (1976) concluded that the respiration rate gave the poorest indication of heat tolerance.

Values of certain physiological functions of cattle in thermoneutral zone (TNZ) 13 to 18°C compared to a hot environment 40°C (Gangwar, 1988) are presented below:

Trait	TNZ	Hot	Percent change
Rectal temperature °C	38.6	39.9	+ 3.3
Skin temperature °C	33.3	37.9	+ 13.8
Pulse rate per min	64.1	57.8	- 9.8
Respiratory rate per min	32.0	94.0	+200.0
Blood pH	7.55	7.63	+ 10.6
Total evaporation (g per m^2 per h)		125.3	
Sweating rate	118.0	206.0	
Respiratory evaporation (g per m^2 per h)	7.3	25.2	+245.0
Water turnover ml per kg for 24 h		220.0	
Metabolic heat production (Kcal per h)	341.0	629.0	- 25.2

B. Growth:

One of the early and uniquely ingenious experiments on climatic effect on animal growth was by Hancock and Payne (1955). They had split up eight sets of identical twin calves between temperate New Zealand and tropical Fiji and provided similar conditions of feeding and management in both the places. Apart from an initial setback in the animals in Fiji due to transport and quarantine, an appreciable depression in growth rate occurred only when the temperature in Fiji was at its highest. At calving, the Fiji animals were 84 lb or 9.6 per cent lighter than the New Zealand animals. The retardment in growth of the Fiji animals was reasonably uniform in so far as all body measurements were affected except the belly girth, which was large in Fiji animals owing to their drinking twice as much water as New Zealand animals.

Later on, many more workers, in their experiments had shown that warm climate did affect the growth rate of cattle. Randel and Rusoff (1963) maintained two groups of Fresian calves either under controlled temperature, cycling from 75 to 90°F or under ambient winter climatic conditions (control). The average daily body weight gains by experimental and control groups respectively were 0.56 and 0.74 lb for 0 to 30 days age, 0.74 and 1.19 lb for 30 to

60 days and 0.56 and 1.50 lb for 60 to 90 days of age, the differences between treatment groups being highly significant ($P < 0.01$). Razdan and Ray (1968) subjected 12 Tharparkar heifers aged six to 12 months, to extremes of weather under field conditions and the control group was shielded from these extremes. Gains were less among the animals kept under stress.

Thomas (1969) observed that the feed intake and the relative growth rate of Sahiwal and Sahiwal x Brown Swiss bull-calves were depressed during the summer season in North west India. The bull-calves exposed to weather conditions lost their body weight significantly more than the sheltered ones in the hot-humid month of July.

In New South Wales, five months old Fresian and Brahman x Fresian F1 heifers were kept in controlled environment rooms. Feed intake and growth were assessed during three periods of 21 days when the animals were maintained at 20, 30 or 38°C, with RH 68, 52 and 46 per cent respectively. The F1 animals were superior only under heat stress. Growth rates of Fresians and F1 animals were similar at 20°C. With each successive increase in temperature, live weight gains were significantly reduced (Kellaway and Colditz, 1975).

In an experiment with beef cattle in Canada (Al-Hassan *et al.*, 1975), daily live weight gains recorded were 1.06 and 0.82 kg respectively in groups exposed to 21.3°C and 24.6°C temperatures with constant RH of 74 per cent. However, in an experiment by Lucci *et al.* (1976) in Sau Paulo, no weight gain differences could be found in two groups of five months old Fresian calves that were either kept inside a closed stall heated to 30°C from 13.00 to 17.00 h or kept in a well ventilated stall. Rathi and Balaine (1986), in their attempt to study the seasonal effect on the growth rate of Hariana and Fresian, Brown Swiss and Jersey crossbred calves, did not find any significant difference between seasons in the growth rate except during the first month of age.

Young (1981) had summarised the results of various growth studies conducted in some of the universities in USA as below:

Sl. No.	Period of study	Average temperature °C	Average daily gain kg	Place of study
1.	Mar to Nov	12.5	1.54	Univ. of Saskatchewan
	Dec to Feb	- 9.8	1.20	
2.	May to Sep	14.6	1.46	Univ. of Alberta
	Nov to Mar	-13.6	1.15	
3.	Jul to Dec	11.7	1.49	Colorado State Univ.
	Oct to Mar	1.6	1.08	
4.	Apr to Dec	11.7	1.16	South Dakota State Univ.
	Jan to Jun	3.7	1.08	
5.	Annual	3.3 to 28.1	1.57	Oklahoma State Univ.
6.	Annual	10.4 to 29.1	1.38	Texas A. and M. Univ.

The annual temperature range of 3.3 to 28.1°C produced the best weight gains.

To alleviate the summer heat stress on buffalo calves by providing shelter and water sprinkling, thereby to improve their growth performance, two well planned experiments were conducted at Haryana Agricultural

University, Hissar. Tripathi et al.(1972) investigated the effect of shelter and water sprinkling on the weekly weight gains and six other body measurements of Murrah buffalo heifers between six to 18 months of age. Significant ($P < 0.05$) increases in weight gains by 15 per cent and body lengths by 30 per cent were obtained by the treatment given. In the other study by Thomas et al.(1975), between six to 12 months of age, thermal protection resulted in significant ($P < 0.05$) increases in heart-girth of the calves and improvement in weekly weight gains and abdominal girth measurements by 16 and 30 per cent respectively.

The effect of two types of housing and two concentrate feeds on growth of three months old crossbred calves was studied for five months at Kerala Agricultural University (Sasaendranath et al., 1983). The calves housed in conventional type of sheds and fed with calf starters gained 287 g per day which was much superior to the growth of calves reared in bamboo sheds and fed with pelleted feed.

Beede and Collier (1986) concluded that while assessing the factors that determine the growth of cattle in hot countries, it was difficult to dissociate direct from indirect effects and from effects that were not connected with climate. In the tropics, as in temperate climates, weight gain was affected by the quality of the grazing and by feeding and management.

C. Milk production and milk composition:

With rising environmental temperature there is a decrease in voluntary feed intake. As a result, a hot environment, apart from affecting milk production directly, will also cause changes in milkyield and milk composition that may be comparable to those caused by underfeeding or even by starvation (Bianca, 1965; Johnson, 1976). Hot weather acts through the hypothalamic and limbic control of both temperature and neurocrine mechanisms. Hahn and Osburn (1970) and Hahn (1976) have constructed maps predicting the likely reduction of milk output during summer. They tested animals in controlled and natural environments, then predicted the fall in production likely at each high temperature. The prediction agreed to five to 17 per cent in the field (Macfarlane, 1981). In USA, the depression of milk production due to heat ranged from 59 kg near latitude 40° N to 45 kg on latitude 32° (Hahn, 1969).

a) Production:

The reviews by Laben (1963) and Bianca (1965) and later the symposium of Thatcher (1974) discussed this aspect in great detail. Laben (1963) stated that optimum milk yield and efficiency usually were obtained within the comfort zone of 5 to 22°C. Below 5°C, often no appreciable declines in milk yield were noticed unless temperature dropped to about -15°C. But even moderate increases above 25°C resulted in measurable declines in milk production. Christensen et al.(1975) in Mexico, showed that milk yield started falling outside the range of 3 to 21°C and also at RH above 60 per cent. Renner (1976) suggested 0 to 16°C temperature and 70 to 85 per cent RH as optimal for milk production.

Some authors had used various heat tolerance indices to study the heat stress effect on milk productivity. Kundu and Bhatnagar (1980) applying Rhoad, Gaalaas, Benezra and Dairy Search Indices, did not find any specific trend of correlation between these indices and daily milk yield of crossbred cows. Earlier, Ingraham et al.(1979) found a definite relationship in that their estimated milk production decline per unit increase in THI was 0.32 kg. By providing shade, they could increase the daily average milk yield to 16.5 kg whereas it was only 14.5 kg in unshaded cows. Thomas and Acharya (1981) analysed the yearly averages of daily maximum temperature, vapour pressure, THI values, THSI values and milking averages of Friesian and Jersey halfbreds at six stations of All India Co-ordinated Research Project on cattle located at different regions in India. Their results indicated that THSI and the number of months with THSI exceeding 75 explained variations in milking averages to a greater extent than individual climatic factors concerned. Maximum temperature and vapour pressure considered together accounted for 36 and 14 per cent of variations in milk yields of Fresian and Jersey half breds respectively indicating an interaction between genotype and physical environment. Their analysis also confirmed that milk production generally tended to be lower in hot humid region than in hot arid or hot semi-arid regions inspite of a much higher temperature in the later regions.

Individual climatic factors' effect have been studied by many workers. Five thousand two hundred completed lactation records of German Black Pied cows, spread uniformly throughout the year were analysed with reference to atmospheric temperature, pressure, RH, hours of sunshine and rainfall (Voigtlander and others, 197.). Milk yield had a significant correlation with air temperature (0.26), RH (-0.26) and hours of sunshine (0.30). Beslin and Anojcic (1979) in their three year period study in Yugoslavia found that in Fresian cows, FCM yield ranged from 4007 kg at the lowest RH of

62 per cent and highest temperature of 23°C to 6403 kg R. at the highest RH of 83 per cent and a temperature of about 5°C. Dalal (1979) found significant correlation between 120 day milk yield with rectal temperature (-0.36), pulse rate (-0.18) and body surface area (0.36) in 296 halfbred and 3/4th bred cattle of Danish Red, Fresian, Jersey and Brown Swiss cows. Hassan et al.(1979) recorded daily milk yields of 7.70, 7.47, 6.57 and 7.71 kg respectively during winter, spring, summer and autumn seasons in Egyptian x Fresian crossbred cows and the variation in milk yield was 36 percent due to climatic factors. The same authors in Egypt, in a later study (Hasson et al., 1981) confirmed their earlier findings by obtaining similar results with daily average yields being 7.8, 7.6, 5.6 and 5.1 kg for the four seasons in that order with lowered yields in summer and autumn. Rodriguez et al.(1985) used 15 years data on 22,972 lactations of five dairy breeds maintained at Florida Agric. Expt. Station in their analysis. They found that RH and air temperature were associated with 1.6 to 5.6 per cent of variability in milk production. Milk yield was found to be affected only slightly by increasing temperature from 8 to 29°C but the yields declined rapidly when the temperature went beyond 29°C. Barman et al.(1985) found the upper critical temperature for milk productivity to be

25 to 26°C in Israeli Fresian cows. Sharma *et al.*(1988) found that optimum conditions for milk production were at maximum temperature below 19.4°C, increasing solar radiation and minimum RH between 33.4 and 78.2 per cent (Cool sunny days with moderate humidity). As long as temperature remained below 19.4°C, a rise in solar radiation or RH only increased milk yield under Florida climatic conditions. Her *et al.*(1988) studied the effect of cooling of cows by water sprinkling under Israel climatic conditions. Milk production of cooled cows was 2.6 kg per day (+8 per cent) above the control cows.

The fall of milk yield due to heat stress was more marked in early lactation than at later stages. In the experiment by Nauheimer-Thoneick *et al.*(1988a), switching over of lactating cows from an environment of 15°C and 70 per cent RH to 30°C and 50 per cent RH conditions reduced milk yield by 30.6 per cent in early lactation and only 25.9 per cent in late lactation.

Heat stress during gestation affects milk yield after calving. During the last trimester of pregnancy, 21 cows and 10 heifers were given no shade treatment, at parturition, they were removed to shade and were given normal management (Collier *et al.*, 1982). There was lowered calf birth weight and reduced lactation performance.

The authors concluded that heat stress had altered endocrine dynamics during pregnancy and affected subsequent milk yield. Wolfenson et al.(1988) reported that by cooling the high producing dairy cows during the dry period increased mean 150-day milk production by 3.6 kg per day. Their results suggested a possible increase in blood progesterone in late pregnancy by cooling during hot weather.

b) Composition:

The composition of cows' milk changed during heat stress. The inverse relationship known to exist between milk yield and milk fat percentage has also been shown to operate in reduction of milk yield due to heat stress. At elevated temperatures milk fat percentages increased side by side with a reduction in milk yield (Regan and Richardson, 1938; Ragsdale et al., 1950 and 1951). Nauheimer-Thoneick et al.(1988a) on the other hand did not observe any statistically significant difference in the fat percentage of German Holstein Fresian cows subjected to 30°C constant temperature in the climatic chamber eventhough their milk yield declined by 26 to 30 per cent.

As might be expected, the yield of milk fat of cows exposed to heat declines with declining milk yield (Bianca, 1965). Similar results were reported by Shibaita and Mukai (1979) and Nauheimer-Thoneick et al. (1988a). Eley et al.(1978) did not find any difference in milk fat content between cows kept at 38.78 or 30.05°C black globe temperature, however they could find a depression in fat percentage in afternoon milk. Fuquay et al.(1980) subjected one set of cows to 22 to 31°C and another set to 17 to 26°C air temperature. Glucose, cholesterol, progesterone and cortisol were lower in the stressed group. Milk yields did not differ but milk fat percentage was lower in the hot stressed group of cows. They suggested that heat stress altered lipid metabolism but the animals' compensatory mechanism prevented reduction in milk production.

Sharma et al.(1983), based on their studies with Holstein and Jersey cows, predicted a maximum fat percentage of 3.5 in Holstein milk for maximum temperature below 30.8°C, minimum RH below 89 per cent and solar radiation below 109 langleys.

SNF and protein content of the milk were found to decrease in the heat stressed cow (Bianca, 1963). However, Nauheimer-Thoneick et al.(1988a) did not see any significant reduction in milk protein per cent of cows maintained at 30°C. Sahiwal x Jersey heifers showed decreases in milk protein yield, casein, betalactoglobulin and alpha lactalbumin when subjected to 40°C ambient temperature (Pan *et al.*, 1979). The optimum climatic condition for higher protein per cent in Jersey cows have been identified as maximum temperature of 10.6°C with solar radiation at 300 langleys and RH at 16 per cent (Cool sunny days, low humidity) (Sharma *et al.*, 1988).

In most experiments in which cows were heat-stressed, voluntary feed intake decreased, at the same time that milk production also decreased. In the experiment by Johnson (1977), when cows were changed over environments from 20°C temperature with 50 per cent RH to 30°C at 40 per cent RH, feed consumption decreased by 15 per cent and milk production by 18 per cent. Nauheimer-Thoneick *et al.* (1988a) found that reduction in DM intake under higher temperature was to the same extent as reduction in milk yield. This has raised the question whether heat stress had a direct effect on milk secretion or the effect was due to the indirect effect of lowered feed intake. Measurements of the energy exchanges of cows fed ad libitum at 32°C had shown that their output of energy in milk falls more than their digestible energy intake falls, which suggested that heat stress had an effect on milk secretion over and above lesser climate should prove no barrier to successful dairy farming. Many of the poor results obtained from 'exotic' stock in the tropics might be due to factors other than temperature stress *per se* and he suggested a more close scrutiny of management and nutritional factors.

D. Water consumption:

The amount of water drunk by normal cattle in a hot environment is governed by the severity of the heat and the amount of DM consumed (Bianca, 1965). Increase in water consumption with rising environmental temperature is well documented.

Mullick (1964) showed that water intake increased 38 to 40 per cent in buffaloes and 75 per cent in cattle from winter to summer. The water consumption was 25.9 and 49.6 l in winter and summer respectively for cattle whereas the corresponding values were 31.8 and 46.5 l in buffaloes. Sharma (1968) made a comparitive study on feed and water consumption of Hariana heifers imported to Egypt with Egyptian local cattle. Water intake was highest in summer in both the breeds. McDowell *et al.*(1968) studied the effect of heat stress on energy and water utilization of lactating Fresian cows. Body surface evaporation increased markedly at 32.2°C with the water coming mostly from a 28 per cent increase in consumption and a 33 per cent decrease in feacal water. Martz *et al.*(1971) examined temperature effect on water intake in Zebu and Scotch Highland heifers and found a significant breed x temperature interaction in water consumption. Water intakes of Fresians were much higher (Kellaway and Colditz, 1975) than those of Brahman x Fresians under heat stress but the calculated evaporative water losses were similar. In Murrah buffalo cows, Satyapal *et al.* (1973) found that voluntary and total water intake was more during summer compared to winter; lactating animals required one kg. extra water for every kg milk produced per 100 kg metabolic body size and the animals consumed 70 per cent of their voluntary water during the period from 0900 to 2100 h. Goel *et al.*(1979) did not find any correlation between three heat tolerance indices and water intake in crosses of Hariana with Fresian, Brown Swiss and Jersey cattle. Bunger *et al.*(1982) found in lactating cows that were kept at 30°C and 70 per cent RH during day and 23°C and 80 per cent RH during night that drinking frequency and water intake increased compared to temperate conditions. Drinking frequency showed a characteristic diurnal pattern independent of temperature.

Richards (1985) exposed Fresian cows to three sequential climatic treatments. T1 was a three week period at 14 to 21°C and 60 to 70 per cent RH; T2 was a similar period during which they were exposed to maximum temperature of 38°C and RH of 80 per cent for seven hours and the rest 17 h in the day to 14 to 21°C and 60 to 70 per cent RH and T3 was a three week period once again of thermoneutral conditions. Compared to free and feed water intakes at thermoneutral, cows under T2 significantly increased their mean intake by 12.2 per cent and in 75 per cent of the cows, this involved a shift, of more than 20 per cent in drinking habits from hot day time to cool night time. Water retention increased with accompanying significant increase in live weight despite a 9.1 per cent decrease in DM intake during T2. On return to thermoneutral T3, the cows exhibited a marked loss in weight and significant increase in urinary water excretion over T1 and T2 values signifying that the water retained was extracellular. Thomas and Razdan (1974) observed that the extracellular fluid volume per kg $W^{0.75}$ of Sahiwal and Sahiwal x Brown Swiss bull calves was significantly higher during hot and cold seasons compared to 'mild' season. A positive correlation was found between behavioural responses of individual cows and their retention of water. In the study by Nauheimer-Thoneick et al.(1988a), on exposure to heat stress, increase in water use by the cows (consumed water + water used by the cows for wetting their body) was higher during late lactation than in early lactation.

The rise in water consumption with rising temperatures does not manifest itself if the rising temperature depresses feed intake and with it, the milk secretion to such an extent that the decreased metabolic requirements for water outweigh the increased homeothermic requirements (Bianca, 1965). To allow for the effect of food intake, several workers have related the water consumption to the DM intake. Little and Shaw (1978) found that the individual water intakes of 16 (four groups of four) lactating dairy cows, measured on seven consecutive days were significantly correlated with DM intakes (range 4.6 to 14.4 kg per day) and milk yields (range 13.7 to 3.0 kg per day). There was no significant correlation with DM content of the feed (range 833 to 898 g per kg), body weight (range 400 to 620 kg) or mean air temperature (range 7.0 to 20.0°C). Applying multiple regression analysis of the data, the following relationship were obtained; water intake (kg per day) = 2.15 (± 0.415) x DM intake (kg per day) + 0.73 (± 0.197) x milk yield (kg per day) + 12.3 (± 5.57). After adjusting the data for variations in DM intake and milk yield, there was no significant difference between the mean daily water intakes of individual cows. There was however a significant day-to-day variation in the mean water intakes of the groups of four cows ($P < 0.01$) which was not explained by variation in DM intake, milk yield or mean daily temperature. Murphy *et al*.(1983) recorded the following results in 16 lactating cows maintained at 13.61°C ambeint air temperature (kg per day):

Water intake	:	89.24
DM intake	:	18.98
Milk production	:	33.09

Additional 0.90 kg of water was consumed for each kg of milk produced. Water intake increased by 50 ± 20 ml for each additional g of sodium fed.

It is obvious that the cooling effect on the animal of the water consumed depends on the way the water is being used in the body. If the water drunk is cool, the high water consumption may lead to an appreciable cooling of the body by conduction. Steers, which after a period of water restriction, drank 50 l of cold water (14°C) experienced a precipitous fall in rectal, skin and subcutaneous temperature of about 1.7°C (Bianca, 1964). Bayer *et al*.(1980) found the drinking frequency of German Fresian cows to increase when they were subjected to stress conditions at 30°C and 70 per cent RH and frequent drinking lead to local cooling of the head region. Anderson (1985) studied the effect of four drinking water temperatures, 3, 10, 17 and 24°C on water intake, feed consumption, milk yield and composition and rumination in tied up cows under barn temperature conditions of 10.2 to 23.7°C. She found the water intakes to be 75.6, 76.7, 76.9 and 71.5 l per day for the four respective water temperatures, the intake of the warmest water differing significantly ($P < 0.01$) from others. The corresponding figures for milk yield were 25.39, 25.93, 26.33 and 26.09 kg at 4.0 per cent FCM per day where a 't' test showed significance of $P < 0.05$ between 3 and 10°, $P < 0.01$ between 3 and 17°C and $P < 0.01$ between 3 and 24°C of water temperature. The feed consumption, milk composition, live weight and rumination were not affected by treatment.

The amount of water eliminated through the dung is important in relation to water economy. Tomer <u>et al.</u> (1969) studied the water balance in Sahiwal and Sahiwal x Brown Swiss F1 bull calves. It was found that water intake was significantly different in two breeds both during summer and winter and also under sheltered and exposed environments. Water output through the dung was significantly affected during the two seasons, the excretion being much less in summer. Insensible water loss was affected most, being more during summer. Sweating rate was maximum in Sahiwal exposed to direct solar radiation.

Restricting cows on pasture, to drink water only twice daily had no effect on their performance. Payne (1963) working with identical twins in Tanganyika found that 4-days water deprivation reduced the output of water in urine and feaces and that this effect was more pronounced in Zebu than in B.taurus cattle. Effect of restricted access to water supply and shelter for a period of 20 days was investigated in Murrah buffalos (Satyapal et al., 1975). When water was restricted to twice-a-day and once-a-day availability, the voluntary water intake was reduced by 20 and 30 per cent respectively. Restricted water supply slightly increased milk yield in the sheltered group and decreased in unsheltered. Voluntary feed intake, DM digestability, body weight, urine pH, urine chloride content, rectal temperature, pulse rate, respiration rate and milk fat percentage were not significantly affected by the frequency of watering. The study indicated that restricting access to water for a short while (20 days) had no apparent ill effect on the physiology and production of buffaloes.

III. EFFECT OF HOUSING AND OTHER MANAGEMENTAL PRACTISES:

Reviews on this subject include those of Bianca (1965), Sainsbury (1965 and 1967), McDowell (1972), Johnson (1976), Clark (1981), Hahn (1981) and very recently in India, by Gangwar (1988). All these workers have discussed the design of livestock shelters in relation to meteorological variables. Starr (1981), while signifying the housing needs of livestock has questioned the wisdom of providing shelters in areas that are hot and humid. For humid tropics, it is suggested that the more suitable system would be to provide access to shade during the warmer part of the day and to leave the animals in the open after sunset to promote loss of heat accumulated in the animal body (Caro-costas et al., 1965; Wiersma and Stott, 1965).

Animals generally produce less under heat stress. Hahn (1981) has stated that, however, adequately fed animals can usually compensate for suppressed production through compensatory yields in subsequent favourable weather unless management restrictions do not permit the time flexibility needed for recovery. His contention therefore, is to limit the shelter requirements to shades or other means just adequate to insure survival of the animals.

In tropical regions, during summer, a simple sunroof could reduce the radiant heat load upto 30 per cent and hay or straw proved the coolest of several materials tested for sunroofs (Gangwar, 1988). The efficiency of metal roofs as radiation shields has been improved by painting the top side white (Roman-Ponce et al., 1977) and underside black (Fergusan, 1970; Williamson and Payne, 1978), by insulation (Daniel et al., 1973) and by sprinkling with water (Brown et al., 1973; Fuquay et al., 1979). The temperature and movement of the air were essentially the same in the sun and under a sun roof made of corrugated galvanised steel and painted white on top but the radiant temperature measured with a globe thermometer was much lower under the sun roof than in the sun, 45° compared with 82°C (Boren et al., 1961). Macfarlane (1981) stated that where solar radiation was a major source of heat, white walls and roofs aided the comfort of animals. A white wall heated only to 55 to 60°C in the sun whereas a dark wall or roof heated to 70 to 80°C according to its reflectivity. The ambient temperature recorded at animal level inside the house roofed with aluminium was 1.0°C lower than the house with galvanised iron roof during summer in Madras (Thiagarajan and Michael, 1978).

Smith (1981) suggested that the radiant heat load could further be reduced by shading the building with trees and shrubs. As soon as the ground surface was covered with vegetation, the heat absorbing surface, previously the soil, was transferred to the top of the plants. Solar radiation absorbed by the foliage was largely carried away by forced convection. For enclosing shelters, Bond (1967) recommended wood which had lowest thermal diffusivity, which substantially reduced short wave radiation and slightly of long wave radiation. For common construction materials, thermal diffusivities are in the order wood $<$ asbestos $<$ cement $<$ concrete $<$ steel $<$ aluminium (Hassell, 1973). Starr et al.(1978) reported that concrete floors acted as a thermal mass and helped in cooling if wet.

Thomas and Razdan (1973b) found that provision of shelter had a heat preserving effect during colder months and a heat preventing effect during summer. Crossbred calves housed in a tin-roofed well-ventilated shed gained higher body weights than the calves housed in thatched shed with woven bamboo sides and slotted floor in Kerala (Saseendranath et al., 1983). Shivprasad et al.(1986) did not find growth differences in crossbred calves allotted to three different housing management treatments. Provision of shade (Razdan and Ray, 1968; Razdan et al., 1968; Pandey and Roy, 1969; Eley et al., 1978; Ingraham et al., 1979; Beede et al., 1981; Collier et al., 1982), shade with insulation (Roman-Ponce et al., 1977) and shade with roof sprinkling (Fuquay et al., 1981) improved animal comfort, feed efficiency, growth and milk production.

There were no significant differences in performance in the experiments reported by Thomas *et al.* (1969), Thomas and Razdan (1973a) and Thomas and Razdan (1974) between shade and no shade treatments. Thus the results obtained by shading treatment appears to be inconsistent.

Sprinkling followed by shade was more effective than shade alone in promoting growth rate of calves (Tripathi *et al.*, 1972). Buffalo bull calves kept in shelter and sprinkled with water recorded faster gains in body weight (15 per cent) and length (30 per cent) than the controls. Sprinkling reduced various heat responses in Murrah heifers (Sastry *et al.*, 1973) and weekly live weight gains were 2.93 kg in sheltered + sprinkled group compared to 2.53 kg in unprotected group (Thomas *et al.*, 1973). The weekly increase in chest circumference was 0.79 versus 0.68 cm ($P < 0.05$) respectively. Mehta (1976) and Gulyani (1984) have worked with she-buffalos and found substantial increase in their reproductive efficiency when water spraying and wallowing facilities were provided. Lactating crossbred cows sprayed with water twice daily during the summer in Madras consumed significantly less amount of water ($P < 0.01$) and recorded lower values of body and skin temperatures ($P < 0.05$) compared to nonsprayed group (Thiagarajan *et al.*, 1978).

Observations made with Brown Swiss x Sahiwal cows in North India (Ludri, 1979) showed that body temperature and other physiological responses could be kept practically normal by fanning the dairy cows in the sheds, where the ambient temperature ranged from 26.6 to 32.6°C and RH 88 to 90 per cent. The average milk yield was higher in animals housed in sheds with fans than the control by 1.22 kg per animal per day and variable expenditure and income statement indicated that the animals kept under the ceiling fan returned an extra amount of Rs.1.42 per animal per day than the controls. In the experiment by Folman et al.(1979), cows provided with forced ventilation in summer yielded 4416 kg milk compared to 4183 kg in controls. Berman et al.(1985) examined the thermoregulatory function of 170 Israeli Fresian cows over a period of two years by providing forced ventilation. One set of cows were force-ventilated to produce an air velocity of 1.5 to 3.0 m per sec from 0500 to 2200 h and the control side had a poor air velocity of 0.5 m per sec. Within 10 to 24°C air temperature range, forced ventilation increased rectal temperature by 0.02°C per kg FCM in animals producing above 24 kg milk per day. Between 26 to 36°C air temperature, the rectal temperature increased with increasing air temperatures in both groups but rate of rise was halved by forced ventilation. In this range of air temperature, rectal temperature increased with rising milk yield as in the lower air temperature range in both high producing and low producing cows in forced ventilation group.

Gangwar (1988) has furnished the following considerations for providing shades in warm climates:

Factor	Hot dry environment	Hot humid environment
1. Shade desirable for animal comfort	Yes	Yes
2. Desirable type of shade	Shed	Trees
3. Construction:		
a) Height (m)	3.7 to 4.3	2.4 to 3.7
b) Orientation	North-South	North-South
c) Flooring	Earth	Concrete
d) Roof type	Sloping	'A' type with cap
e) Covering	Aluminium (or) straw	Snow fence
4. Shade with fogger or sprinkler	Yes	No
5. Shade with desert cooler	Yes	No

The effect of sprinkling could be enhanced by fanning (Araki *et al*., 1985; Igono *et al*., 1985; Flamenbaum *et al*., 1986; Wolfensen *et al*., 1988; Nor *et al*., 1988). Araki *et al*.(1985) studied the effect of sprinkler + fan cooling on vaginal temperature of dairy cows. Igono *et al.*(1985) used a Digital Dataloger with thermocouples attached to Boumatic flow meters to record the milk temperature as it came out of cows udder after spray cooling. The spray cooled cows gave 0.70 kg per day more milk than the controls. Flamenbaum *et al.*(1986) devised a method for cooling dairy cattle based on repeated wetting to attain maximal water trapping in the coat followed by its rapid evaporation by using forced ventilation. When cows were cooled five times a day for 30 min the rectal temperatures were maintained within 38.2 to 38.9°C which were significantly lower than those not cooled. Wolfensen *et al.*(1988) attempted cooling by a combination of wetting and forced ventilation from 0600 to 1800 h of dry cows until parturition. Cooling increased 150-d milk production by 3.6 kg per day. Hor *et al.*(1988) obtained an increased milk production of 2.6 kg per day (+8 per cent) by sprinkling of dairy cows for 30 sec followed by forced ventilation for 4.5 min.

The provision of cooled drinking water has improved milk production in dairy cows (Ingraham, 1968; Anderson, 1985). Cold water in the rumen had increased intake by 24 per cent and lowered both rectal and tymphanic membrane temperatures (Bhattacharya and Warner, 1968). Cooling of water by mechanical refrigeration may be too expensive and hence this method has not received much attention.

With the aid of evaporative coolers, air temperature in shelters could be reduced but the system had the drawback of increasing the air humidity (Thiagarajan et al., 1973). The use of evaporative cooler has improved production in lactating cows, and has been economically feasible in Arizona (Stott and Wiersma, 1974). Other responses to evaporative cooled studies have ranged from no response in Okalahoma (Nelson et al., 1961) to a variable response over three summers in Mississippi (Brown et al., 1974).

Summer air-conditioning has generally been beneficial to the lactating dairy cows (Stewart et al., 1966; Hahn, 1969; Hahn et al., 1969) but the cost makes it impractical. Thatcher (1974) claimed that either continuous or day time air-conditioning of cow houses increased average daily milk yield from 14.23 to 15.37 kg and reduced expected summer time decreases in fertility in the dairy herd maintained in Florida, USA.

The potential of inspired air-cooling systems has been demonstrated for lactating cows in pilot studies by Hahn et al.(1965), Roussel and Beatty (1970) and Canton et al.(1982). An evaporative cooling device for cows fitted with constantly wetting pads through which ventilation was forced by mancoolers which provided comfort conditions inside cow houses in summer was described by Koilpillai *et al.*(1979). A 2-cow inspired air cooling device for the allevaation of heat stress in lactating dairy cows in subtropical conditions is suggested and described by Canton *et al.*(1982). Marked responses to inspired air temperature of 10.0 and 15.5°C were obtained, including increased feed intake and milk production with accompanying decrease in rectal temperature and respiration rate. The design was to cool only the cows head and neck, thus cooling the inspired air. A shade structure was also provided so that analysis could include comparison of air cooling with shading and no shading treatments. It was confirmed that in hot weather conditions with no shade, effective reduction of rectal temperature and respiration rate was achieved with inspired air treatments. However reduction of the radiant temperature by a well designed shade structure was more beneficial economically in reducing heat stress than inspired air cooling. Hahn (1981) had stated that the present high energy costs had dulled interest in the development of improved field models for use with cattle.

IV. EFFECT OF TYPE OF FEEDING:

Thermal stress affects nurture of animals by directly altering the absolute requirements of specific nutrients, by affecting physiological processes and metabolism and by reducing total feed consumption

(Bayer *et al.*, 1980; NRC, 1981; Beede and Collier, 1986). Reduction in voluntary intake near or above the upper critical temperature of the animal is widely accepted as a major negative influence on productivity (Bianca, 1965; Thomas, 1969; McDowell, 1972; Johnson, 1977; Beede and Collier, 1986; Nauheimer-Thoneick *et al.*, 1988a). Other climatic factors such as wind velocity, humidity and radiation also directly affect homeothermy under natural conditions and thus are interrelated with ambient temperature in affecting feed consumption (Beede *et al.*, 1985; Gangwar, 1988).

Randel and Rusoff (1963) reported significant differences in daily grain and hay DM intake between Holstein calves maintained under ambient winter conditions and those that were subjected to cycling temperatures of 75 to 95°F. Thomas *et al.*(1969), conducting an experiment with Sahiwal and Sahiwal x Brown Swiss crossbred calves, reported that DM intake was significantly less in summer by 0.59 kg DM per day per 100 kg body weight compared to winter. The TDN intake was also lower by 486.5 g per day per 100 kg body weight during summer. Shibaita and Mukai (1979) reported lower DM and TDN intake in Holstein cows kept at 30°C with 60 per cent RH compared to 18°C temperature. The experiment by Holmes *et al.*(1980) also agreed with the above findings with a significant decrease in feed intake and growth rate of Fresian and Brahman x Fresian calves that were exposed to direct solar radiation at 32°C air temperature. Recently, Neuheimer-Thonwick *et al.*(1983a) reported that in lactating cows, at 30°C ambient temperature, the DM intake was reduced by 30.7 per cent in early and 24.6 per cent in late lactations, compared to 15°C. This was reflected uniformly in all feed components, namely hay, lucerne pellets and concentrate mixture pellets, all of which been available *ad libitum*.

With lactating dairy cows, NRC (1981) suggested that greater the proportion of roughage in the diet, the greater and more rapid was the reduction in DM consumption as environmental temperature increased. In an interesting experiment by Sharma and Talapatra (1963), keeping concentrate amount same, when wheatstraw feeding was restricted to buffalo yearlings, they ceased to grow whereas those fed *ad libitum* straw gained weight at the rate of 0.8 lb per day. There was 18 per cent utilization of absorbed nitrogen in restricted roughage feeding and 40 per cent in those on *ad libitum* roughage feeding. Amble (1965), based on application of linear programming, stated that the most economic way of meeting the feed short fall was to go in for growing and feeding nutritious green fodder to cattle in India. In a two year experiment with milking cows and buffalos, Singh *et al.*(1972) found that with *ad libitum* sorgum forage feeding, 250 g of concentrate supplementation per kg of milk was sufficient to maintain five to 10 l per day milk production. Gir heifers lost weight when they were fed wheat straw alone whereas concentrate supplementation at various levels supported gain in weight (Sharma and Jhanwar, 1973). Buffalo calves supplemented with concentrates recorded higher body weight gains by 41 per cent than those not supplemented with concentrates (Thomas *et al.*, 1975). Clover-grass silaga and concentrates were fed in the ratios of 100:0, 75:25, 50:50 and 25:75 to four groups of Black and White breed heifers (Sejrensen and Larsen, 1977). It was found that with increasing amount of concentrates daily gains also increased. Daily gains in Zebu cattle were significantly better on 30 per cent roughage diet than on 50 per cent one (O'Donovan, 1979). The feasibility of feeding reduced concentrates after providing unlimited supply of forages, was explored in an experiment with growing crossbred heifers at Mannuthy. The results of 12 months observations on body weight, height, length and girth indicated that reduction in concentrates by 50 per cent did not affect growth, provided forages were supplied *ad libitum* (Thomas and Nair, 1982). An investigation was aimed at finding the economically optimum level of concentrate supplementation in the ration of growing buffalo heifers, with basal ration of berseem and wheat straw. Gains in body weight and measurements were significantly ($P < 0.01$) enhanced by a minimum level, 0.2 per cent of body weight of concentrate supplementation and further increases in concentrates did not produce any further economic benefit (Sharma and Thomas, 1981). Three groups of lactating Murrah buffalos were fed roughage:concentrates in the ratios of 25:75, 50:50 and 75:25 and milk production among treatments did not vary (Mudgal and Mallikarjunappa, 1986). In another experiment (Nawab Singh et al., 1987), Murrah buffalos in milk were either fed green fodder ad libitum + concentrates, or 1/3 green fodder, 1/3 dry fodder + 1/3 concentrates or wheat straw ad libitum + concentrates. There were no significant differences in milk yield between treatments.

Bhosrekar et al. (1967) gave the conclusion that productive cattle could be maintained on roughage feeding with minimum concentrate mixture allowance provided good quality roughages were available throughout all seasons. Razdan and Ray (1968) stated that the depression in feed intake noticed during heat stress was associated with quality of fodder. Thomas and Razdan (1973a), in their studies on the feeding behaviour of crossbred calves and the effect of shelter on it in a subtropical environment, found that the animals made a day-to-night shift in feeding regimen during summer. In winter, they ate 8.5 per cent more of dry matter during day than during night. In summer, they ate 12.4 per cent more of feed during night and cooler hours of the day, thus maintaining normal growth. Dragovich (1979) stated that the reduction in digestibility and palatability of grasses during late summer appeared to be of greater importance in influencing production patterns than the direct effects of stressful temperature-humidity conditions. Beede and Collier (1986) suggested that intensively managed ruminants are less deleteriously affected by rising ambient temperatures than are grazing animals because reduction in feed intake was due mainly to reduced forage consumption resulting from reduced grazing activity and attempts to maintain heat balance.

Reducing dry matter intake and thereby heat generated during ruminal fermentation and body metabolism aid in maintaining heat balance. Additionally, elevated respiratory rates and water intake resulting from increased environmental temperature lead to concomitant reduction in dry matter consumption (Roman-Ponce et al., 1977; Mallonee et al., 1985). An associated effect is reduced gut motility and rumination which along with increased water intake lead to gutfill. Rates of ruminal contractions are reduced at high environmental temperatures (Attebery and Johnson, 1969). Also, reduced rates of passage of ingesta in steers fed forage diets during thermal stress, increased gutfill, depressing the appetite (Warren et al., 1974). A direct negative effect of elevated temperatures on the appetite centre of the hypothalamus is also reported (Baile and Forbes, 1974).

Thermal stress affects the dynamic characteristics of digestion and neuroendocrine factors influencing digestion. A number of studies assessing effects of increasing environmental temperature on digestibility have been summarised in NRC (1981). In general, in more temperate regions, as environmental temperatures rise, digestion of roughages by cattle increases (Colditz and Kellaway, 1972; McDowell, 1972; Lippke, 1975; Shibaita and Mukai, 1979). However, in sheep experiencing severe thermal stress, dry matter digestibility was depressed (Bhattacharya and Hussain, 1974). Lippke (1975) had reported significant increases in digestibilities of dry matter and fibre components of alfalfa pellets fed to steers housed at 32° compared to 2°C. This phenomenon appears to be dissimilar between cattle and sheep.

A variety of factors as rate of feed consumption, feed quality, nutrient composition, rates of passage and volumes of digestive organs affect digestibility (Ellis et al., 1984). All the above factors are influenced by ambient temperature. Feed consumption and forage quality are depressed by high environmental temperature and could alter digestibility, with reduced intake increasing and poorer forage quality decreasing digestiblity (NRC, 1981). However, increases in digestiblity are not solely due to lower rates of intake. When dry matter intakes were equal among heat stressed cattle and those at thermoneutral, digestiblities were higher among heat stressed cattle (Warren et al., 1974; Lippke, 1975). Some reports indicate that thermal stress may alter digestiblity by causing transient or longer lasting changes in rates of passage and digestive tract volume (Warren et al., 1974; Schneider et al., 1984a). In general, rates of passage of ingesta are slower and ruminal volumes are greater allowing for greater residence time to digest potentially digestible feed. These alterations in digestive function would be helpful particularly for animals consuming higher forage diets, to digest ingested feed more completely. However, this advantage is offset largely by lower feed intake, resulting in less net total nutrients being available to the thermal-stressed animal (Beede and Collier, 1986). Thermal stress is associated with reduced thyroid activity

(Gale, 1973; Johnson, 1976) which also reduces gut motility and rate of passage.

The absorption of nutrients along the alimentary canal is retarded during thermal stress. A major adaptation to thermal stress is peripheral vasodilatation to accommodate evaporative and convective heat losses (Thatcher and Collier, 1982) concomitantly reducing blood flow to internal organs (Oakes *et al.*, 1976; Roman-Ponce *et al.*, 1978). Engelhardt and Hales (1977) have quantified distribution of capillary blood flow to the mascular and mucosal layers of the stomach when animals experience various levels of thermoregulatory demands. Exposure to thermal stress at 40°C dry bulb and 27°C wet bulbs decreased blood flow in mucosa of rumen by 32 per cent and reticulum by 31 per cent, compared with thermoneutral environment. Evidence also suggests that blood flow to the digestive tract is influenced by level of feed intake (Lomax and Baird, 1983). Therefore, the reduction in blood flow to the digestive tract, during thermal stress may be a direct effect of temperature or a combination of temperature and reduced feed consumption. Regardless, if blood flow is decreased, concentration of nutrients absorbed per unit blood volume must increase, if absorption is to be maintained normal. Englehardt and Hales (1977) have emphasized the importance of controlling the thermal environment of animals since there were marked changes in blood flow in mucosa during even mild thermal stress.

Both acute and chronic thermal stress require metabolic adaptations to accommodate altered nutrient utilization caused by the stress. Because the endocrine systems is involved heavily in coordination of metabolism, it is not surprising that thermal stress results in alteration of harmone concentrations in blood. Among harmones associated with adaptation to thermal stress are prolactin, growth harmone, thyroxine, glucocorticoids, antidiuretic harmone (ADH) and aldosterone (Beede and Collier, 1986). Some of these harmones, such as prolactin and growth harmone are implicated in nutrient partitioning and homeostasis (Bauman and Currie, 1980). Others such as ADH and aldosterone are associated with homeostatic regulation of specific nutrients. Acute thermal stress increases blood concentration of prolactin (Wetteman and Tucker, 1974), ADH (El-Nouty <u>et al</u>., 1980), aldosterone in non-ruminants (Lipsett <u>et al</u>., 1961) and catecholamines and glucocorticoids in cattle (Alvarez and Johnson, 1973) while decreases in aldosterone occur in ruminants (Collier <u>et al</u>., 1982).

As cattle adapt to chronic thermal stress, their energy metabolism decreases, while water and electrolyte metabolism increase (Johnson *et al*., 1967; McDowell *et al*., 1968; Collier *et al*., 1982). These adaptations are reflected in lower concentrations of metabolic hormones such as thyroxine (Bianca, 1965; Collier *et al*., 1982), growth hormone (Mitra *et al*., 1972; Mitra and Johnson, 1972) and corticoids (Roman-Ponce *et al*., 1981). Although aldosterone concentrations also are lower in chronically heat stressed cattle, it is a reflection of need to increase urinary Na loss to conserve K. Collectively these results indicate that lowered energy metabolism is a major adaptation in chronic thermal stress. Likewise, increased water and electrolyte metabolism are associated with adaptation to thermal stress as evaporative cooling requirements increase with higher ambient temperatures.

Attempts to maintain homeostasis during thermal stress may alter requirements for some nutrients and energy compared with normothermic animals. The vast majority of metabolizable energy available to ruminant animals is through volatile fatty acids (VFA) from ruminal fermentation (Annison and Armstrong, 1970). Thermal stress reduces quantity of VFA production in the rumen. Lower ruminal concentrations of VFA are related to reduced feed consumption (Sangler *et al*., 1970; Martz *et al*., 1971). McDowell (1972) also reported reductions in ruminal concentrations of acetate and propionate in thermal stressed cattle. Although digestiblity of dietary energy and fibre are enhanced in a hotter environment, efficiency of utilisation of energy is reduced (McDowell, 1972; Nauheimer-Thoneick *et al.*, 1988a). This is due to higher maintenance requirements of thermal stressed animals resulting from elevated body metabolism and activity to alleviate excess heat load. Accelerated panting increases maintenance requirements from seven to 25 per cent (Bianca, 1965). Increasing digestible energy density of ruminant diets in intensive management systems during thermal stress is an effective management strategy for enhancing productivity (Beede and Collier, 1986).

Formulating diets with lower heat increments for thermal stressed animals is advantageous. Higher concentration of dietary fat may offer such an advantage. Reid (1979) reported improved energy balance by adding 9.0 per cent tallow to diets for laying hens housed at 29°C and increase in metabolizable energy consumption. However, increased energy balance resulted in greater body tissue deposition and did not enhance egg production or efficiency (Reid, 1979; Sell, 1979). Inconsistent results have occurred when fat contributed about 30 per cent of ME in diets fed to thermal stressed broilers (Cerniglia *et al.*, 1978; Dale and Fuller, 1980). Inclusion of fat in diets for heat stressed ruminants was evaluated by Moody *et al.*

(1967). Lactating cows were exposed 15 to 24°C vs 34.2°C while fed diets containing 0, 10 per cent soybean oil or 10 per cent hydrogenated vegetable fat, for two weeks period. No beneficial results could be obtained except for improved FCM production with soybean oil feeding. Only three to five per cent added dietary fat is tolerated typically by ruminal micro-organisms (Palmquist and Jenkins, 1980). However new nutritional technologies such as formation of calcium soaps of fat (Palmquist and Jenkins, 1982) or coating fat with formaldehyde treated protein (Scott and Cook, 1970) effectively reduced toxic effects of fat on ruminal fermentation. Milk production and efficiency have been enhanced by feeding protected lipids at 20 to 30 per cent of ME intake (Grenn et al., 1976; MacLeod et al., 1977; Dines et al., 1978; Kronfeld et al., 1980).

Metabolism studies have indicated that acutely heat stressed cattle were in negative nitrogen balance (Kamal and Johnson, 1970; Kellaway and Colditz, 1975) due to reduced ration consumption. In this situation, increasing protein in the diet will be advantageous. However, because of reduced energy consumption and increased energy maintenance requirement during heat stress, supplemental natural protein may be metabolized to meet energy requirements. This happens in normothermic animals in energy deficit (Crampton and Harris, 1969). However, Brink and Ames (1978) noted that in sheep, the thermal environment had little effect on protein needed to maintain nitrogen equilibrium. NRC (1981) suggested that with thermal stressed ruminants, diet formulation should be to meet protein and energy needs separately ignoring the conventional concepts of protein-to-energy ratio. This stance was based largely on the work of Ames et al.(1980) on heat stressed feed lot cattle and sheep. Efficiency of dietary protein utilization above maintenance was improved by reducing protein consumption to meet predicted decline in growth rate from thermal stress (Ames et al., 1975). Average daily gains were not different for animals fed on the protein-restricted regimen or to NRC (1975 and 1976) protein requirements.

During thermal stress, because of reduced feed intake, the mineral intake may be less than optimal, relative to potential productivity. Also, associated nutritional-physiological ramifications may affect macromineral needs (Collier et al., 1982; Beede et al., 1983; Schneider et al., 1984b and 1986). Increased sweating during hyperthermia increased loss of K in skin secretions (Johnson, 1970; Jenkinson and Mabon, 1973; Singh and Newton, 1978b; Beede et al., 1983). Jenkinson and Mabon (1973) also noted marked increases in rates of loss of Na, Mg, Ca and Cl. For lactating cows fed complete mixed diets, supplementation of K (Mallonee *et al.*, 1985) and K and Na (Schneider *et al.*, 1986) above the recommended levels (NRC, 1978) during heat stress resulted in three to 11 per cent increases in milk yield.

Dale and Brody (1954) first characterised alteration in acid-base balance during thermal stress in cattle. Ramifications of this may include blood acid-base imbalance plus a decrease in the salivary bicarbonate pool available for ruminal buffering. Typically, ruminal pH is lowered during thermal stress (Niles *et al.*, 1980). Schneider *et al.*(1984b, 1986) showed enhanced lactational performance of heat stressed lactating cows fed high concentrate diets (60 to 70 per cent) by providing 0.85 to 1.0 per cent dietary sodium bicarbonate, buffering the rumen and maintaining a higher ruminal pH. Kronfeld (1979) suggested supplementation of an acetogenic agent like ammonium chloride or ammonium sulphate to correct alkalosis induced by thermal stress and higher respiratory activity.

Three general approaches have been proposed for enhancing productivity of livestock experiencing thermal stress. They are physical protection, particularly by intercepting incoming solar radiation (Bond *et al.*, 1967; Buffington *et al.*, 1983; Wiersma *et al.*, 1984), genetic development of less heat sensitive breeds (Finch, 1984) and nutritional strategies (Beede and Collier, 1986). Physical protection with natural or artificial shade presently offers the most-immediate and cost-effective approach for enhancing productivity. Development of new nutritional technologies, for example, protected-fat feeding, may offer particular advantages in warmer environments. Adjusting dietary protein intake (Ames *et al.*, 1980; Nawabsingh *et al.*, 1987) may not result in maximum production, however, most cost effective production may be realised. Reductions in feed intake maybe recovered partially by increasing ME and nutrients densities of the diet if product price to concentrate price ratios are favourable (Van Horn, 1984). Other simple nutritional management strategies also could be instituted. Increasing the number of feedings per day may entice animals to take more and keep feed fresher. Placement of feed and water in the shade (Buffington *et al.*, 1983) minimises stress at feeding time. Total daily feed intake could be increased if the number of nocturnal feedings were more frequent (Hutson *et al.*, 1971; McDowell, 1972; Thomas and Razdan, 1973a; Ansell, 1981).

SECTION 1 - CALVES

MATERIALS AND METHODS

Experimental design:

The experiment was conducted at the University Livestock Farm of the Kerala Agricultural University, Mannuthy, in Trichur district, Kerala State. It was run for four months from 22-3-88 to 24-7-88 with a pre-experimental period of four weeks and a recording period of 14 weeks.

Twenty, weaned crossbred heifer calves, in the age group of six months to one year were selected for the study. These calves were grouped into quadruplets on the basis of similarity in body weights. One calf from each quadruplet was assigned at random to one of the following treatments:

Treatment 1: Protected from direct solar radiation and concentrate oriented feeding (shaded, concentrate-fed)

Treatment 2: Exposed to direct solar radiation and concentrate oriented feeding (unshaded, concentrate-fed)

Treatment 3: Protected from direct solar radiation and roughage oriented feeding (shaded, roughage-fed)

Treatment 4: Exposed to direct solar radiation and roughage-oriented feeding (unshaded, roughage-fed).

The tatoo number, date of birth and initial body weight details of the calves utilised in the experiment are given below:

S.No. 1	Tatoo Number 2	Date of birth 3	Initial body wt. 4	Remarks 5
1.	300	31-08-87	57.5	
2.	269	16-09-87	57.5	
3.	210	22-04-87	75.5	Treatment 1
4.	185*	21-04-87	76.0	
5.	189	04-04-87	100.0	
6.	288	14-10-87	57.0	
7.	257	30-11-87	58.0	
8.	252	27-07-87	72.5	Treatment 2
9.	144	03-06-87	76.0	
10.	217	22-04-87	90.0	
11.	266	22-05-87	56.5	
12.	195	18-08-87	60.5	
13.	165	21-04-87	72.5	Treatment 3
14.	224	16-07-87	77.0	
15.	242	30-04-87	89.0	

1	2	3	4	5
16.	272*	30-11-87	55.5	
17.	286	25-09-87	63.5	
18.	218	25-07-87	71.5	Treatment 4
19.	205	20-04-87	85.5	
20.	233	29-05-87	86.0	

* Calves died during the recording period

Treatments:

The groups that were exposed to direct solar radiation were kept loose in an enclosed open paddock with no shade, day and night. The protected groups were housed in a conventional calf pen with open ventilation and tiled roof. These calves were not exposed to the sun during the experiment. Both the locations were adjacent to each other and had cement-concrete flooring.

The body weights of all the calves were recorded initially and further weighments were done every fortnight on a platform scale and the weights recorded in kg. The daily DCP requirements were arrived at for individual calves, based on their current body weights, following the standards prescribed by Sen and Ray (1964). For the concentrate-oriented feeding groups, all the DCP requirement was met by individually feeding them with weighed quantities of concentrates. For the roughage oriented feeding group, half the daily DCP requirement was met by supplying them individually with weighed quantities of the concentrates and the rest of the DCP requirement was met by supplying each with 3 kg daily of fresh Leucaena leaves, obtained from the farm.

To all the calves, green grass was fed *ad libitum* and when green grass was not available, paddy straw was supplied.

The concentrate mix was obtained from "Milma", the Kerala Livestock Development and Milk Marketing Board.

The analysis results of the concentrate mix and Leucaena leaves fed to the experimental calves were as follows:

	Moisture percent	Dry matter percent	Crude protein percent (on fresh basis)	Crude protein percent (on dry matter basis)	Nitrogen content percent (on dry matter basis)
Concentrate mix	3.86	96.14	17.07	17.76	2.84
Leucaena leaves (Fresh)	60.84	39.16	7.81	19.94	3.19

Recording of data:

One calf each from treatment 1 and 4 died durin the experiment and for the purpose of analysis, missing plot technique was applied to arrive at the missing fortnightly values of body weight and body measurements.

Physiological variables like cardiac rate, respiration rate, rectal temperature and skin temperature of the individual calves were measured and recorded twice in a day at 0800 h and at 1400 h on a fixed day in a week and for 14 weeks of the study.

The cardiac rate and the respiration rate were directly determined by counting for a minute, using a stethescope and a stop watch. Recordings were done for individual calves with minimum of disturbance.

The rectal temperature was measured with the help of a clinical thermometer inserted to standard depth and recorded in degree celsius for each of the calves.

The skin temperature was recorded in degree celsius using an 'Aplab' make thermister telethermometer and the skin probes supplied along with it. For each of the calves, the skin probes were left in contact with the skin for 30 sec in two locations, one at the dorsal and posterior aspect of the abdomen of the calves and the other anterior and ventral. The averages of these two recordings were taken as the skin temperature. On rainy days, recordings were either suspended or done during subsequent days of the week when dry weather prevailed.

The body weights and body measurements were recorded for individual calves once in a fortnight at a fixed time in a day. Body weights were recorded in kg by individually weighing the calves in a standard platform scale meant for this purpose and with 200 g accuracy. The body measurements like the height, length and girth were recorded in cm using standard procedures, individually measuring each of the experimental calves, on the same day at the time fixed for weightment.

The climatic data were recorded daily, throughout the experimental period, once in the morning at 0800 h and again in the afternoon at 1400 h. These recordings were done at animal level close to the animals both inside the calf pen and in the open to quantify the microenvironment prevalent around the calves, in both the treatment groups, namely, the calves exposed to direct solar radiation and the group that was kept protected from direct solar radiation by housing.

The climatic factors recorded inside the calf house were the daily maximum and minimum temperatures, relative humidity, wind velocity, black globe temperature, and vapour pressure. The climatic factors recorded in the open were maximum and minimum temperatures, solar radiation, relative humidity, wind velocity, vapour pressure and rainfall.

The maximum and minimum temperatures were recorded once daily at 0800 h in degrees celsius for both the locations, namely inside the house and in the open with the help of a Six's Maximum-Minimum thermometer (Zeal make) hung at animal level inside the shed and outside, guarded in Stevensen screen.

The relative humidity was measured using a Whirling psychrometer twice daily in the morning and afternoon in both the treatment locations using standard procedures. The psychrometric tables were used to arrive at the relative humidity in percentage and vapour pressure in mm of mercury, using the wet and dry bulb readings.

The wind velocity was directly measured in meter per sec using an Anaemotherm air meter (USA make) that was earlier standardised with a Blue Kata Thermometer. The measurements were made twice daily, in the mornings and in the afternoons in both the treatment locations at animal level.

A "Black Globe Thermometer" (Casolla make) was used to record the black globe temperature inside the calf house in the mornings and the afternoons. The globe was hung at animal level and left undisturbed for 30 min for sensitization before the recordings were done. The mean radiation temperature of the surroundings was recorded in degrees celsius.

A continuous recording "Solar radiation balance meter" (Dr.Lange, Berlin) was installed to record the solar radiation in the open paddock, continuously throughout the experiment. This instrument recorded radiation from the upper hemisphere and lower hemisphere separately both day and night in a graph mounted on a rotating system. With the automatic recording in the graph, hourly readings were obtained and these values were fitted into the following formula to arrive at the hourly upper and lower radiation figures in mJ/cm^{-2}.

a) Upper hemisphere:

$$G+L = F_o \times \Delta u + \sigma T_g^4$$

where,

F_o is 2.0534

σ is 5.666 x 10^{-9}

Tg is temperature recorded +273^{o}K

b) Lower hemisphere:

$$R+L = F_3 \times \Delta u + \sigma T_g^4$$

where,

F_o is 2.155

σ is 5.666×10^{-9}

Tg is temperature recorded +273°K

The means of hourly recordings obtained from 0700 to 1800 h is taken as the day time radiation and 1900 to 2400 h and 0000 h to 0600 h as night time radiation.

Daily rainfall data in mm were obtained from the records of the Meteorological department of the College of Horticulture, Kerala Agricultural University.

For the convenience of presentation, all climatic factors were worked out as weekly means and rainfall data as weekly total.

Analysis of data:

The statistical analysis of the experimental data was carried out as per the methods suggested by Snedecor and Cochran (1967). The computer available with the Integrated Centre for Agriculture Statistics of Kerala Agricultural University was utilised for analysis.

RESULTS

I. CLIMATIC VARIABLES:

The weekly means of the climatic variables recorded in the shaded and unshaded locations of the experiment at 0800 and 1400 h for the recording period of 14 weeks from 18-4-88 to 24-7-88 have been tabulated and presented in Table 1.1.

In the shaded location, the mean weekly maximum temperature recorded ranged from 25.37 to 32.24°C during the experiment. The maximum temperatures were above 30.0° for the first five weeks and for the rest of the period, it was always below 30.0°C. The mean weekly minimum temperatures ranged from 21.28 to 27.43°C during the experimental period. The mean weekly black globe temperatures that prevailed at 0800 and 1400 h respectively were a minimum of 26.17 and 25.83°C during the 14th week of the experiment and a maximum of 30.40 and 34.30°C during the fourth week of the study. The relative humidity ranged from 76.43 to 93.14 per cent in the mornings and 56.37 to 87.60 in the afternoons, the highest values in both the ranges falling on the 13th week. Six out of 14 weeks had practically no air movement during 0800 h recording time and the rest of the weeks had a meagre wind velocity of 0.007 to 0.03 m per sec. In the

Table 1.1

The weekly means or the climate variables recorded in the shaded and unshaded locations

	Hot period					Rainy period								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Shaded														
Maximum temperature °C	32.24	31.78	31.40	31.46	31.74	29.51	27.81	26.94	28.17	27.11	27.71	27.86	25.37	25.47
Minimum temperature °C	23.56	23.44	25.09	24.87	25.36	27.43	22.86	22.40	22.65	21.61	21.60	22.10	21.76	21.28
Globe temperature °C - 0800 h	29.57	29.50	29.93	30.43	30.21	29.29	27.29	27.57	28.07	27.14	26.64	27.29	26.71	26.17
Globe temperature °C - 1400 h	34.17	33.64	34.00	34.30	34.29	31.86	29.50	29.00	29.50	29.36	30.00	29.93	27.50	25.83
RH percentage - 0800 h	79.43	76.43	83.43	79.71	78.29	84.00	88.00	89.57	86.71	88.57	85.43	84.43	93.14	88.80
RH percentage - 1400 h	60.17	64.86	67.67	60.80	56.57	70.57	81.00	82.16	80.33	79.57	75.00	74.86	87.60	87.25
Wind velocity m/sec - 0800 h	0.03	0.02	-	0.03	0.007	0.02	-	0.02	-	-	-	0.03	0.02	-
Wind velocity m/sec - 1400 h	0.02	0.11	0.24	0.27	0.47	0.13	0.08	0.15	0.12	0.03	0.14	0.14	0.11	0.10
Vapour pressure mm of Hg - 0800 h	23.34	22.45	25.40	24.79	24.21	24.10	23.42	24.18	23.75	22.76	21.41	22.02	23.09	22.33
Vapour pressure mm of Hg - 1400 h	23.29	23.98	24.87	23.22	21.92	24.56	24.56	25.15	24.33	23.65	23.09	22.66	23.39	22.23
Unshaded														
Maximum temperature °C	37.79	36.53	35.57	35.57	35.86	33.50	33.07	30.93	32.21	31.36	32.00	32.07	29.36	30.42
Minimum temperature °C	23.56	24.50	25.79	25.29	25.93	24.57	24.07	23.50	23.57	23.00	22.71	23.29	22.93	22.33
Radiation upper day mWcm^{-2}	205.80	197.22	207.56	221.45	213.89	199.73	190.31	110.56	155.78	167.69	213.79	194.04	145.77	132.11
Radiation upper night mWcm^{-2}	142.84	146.51	151.31	160.22	156.08	144.86	145.70	90.78	118.88	139.82	141.34	148.07	129.56	106.70
Radiation lower day mWcm^{-2}	151.73	143.24	153.34	169.63	162.07	149.22	150.39	88.83	115.73	119.81	160.92	154.94	123.53	105.09
Radiation lower night mWcm^{-2}	111.01	111.86	1[illegible]1.70	124.45	122.34	112.73	119.[illegible]7	76.77	103.02	113.36	106.93	122.47	114.67	88.63
RH percentage - 0800 h	76.86	73.57	81.00	78.00	78.29	82.57	86.00	87.57	84.57	86.57	84.00	82.14	91.57	87.20
RH percentage - 1400 h	55.50	63.57	64.83	58.60	55.00	68.29	78.33	82.66	79.00	78.86	71.00	72.86	87.00	86.50
Wind velocity m/sec - 0800 h	0.34	0.05	0.01	0.15	0.04	0.07	0.02	0.05	0.007	-	0.03	0.07	0.07	0.01
Wind velocity m/sec - 1400 h	0.24	0.37	0.55	0.79	0.97	0.56	0.25	0.54	0.30	0.13	0.[illegible]5	0.37	0.47	0.54
Vapour pressure mm of Hg - 0800 h	23.50	22.35	25.70	25.32	24.77	24.33	23.52	24.41	24.21	23.34	21.95	22.35	23.09	22.35
Vapour pressure mm of Hg - 1400 h	23.98	24.54	25.98	24.31	22.58	25.04	24.87	25.12	24.46	24.56	23.55	23.67	2[illegible].85	22.02
Weekly total rain fall mm	7.40	40.60	4.40	4.00	1.80	195.40	174.50	184.40	56.80	209.30	29.90	45.50	193.90	210.30

1 to 5 weeks Hot-dry period   6 to 14 weeks Rainy period

afternoons, there was recordable velocities during all the weeks, ranging from 0.02 to 0.47 m per sec. The vapour pressure in mm of mercury ranged from 21.41 to 25.40 at 0800 h and 21.92 to 25.15 at 1400 h recording time.

In the unshaded location, the maximum temperature ranged from 29.36°C to 37.79°C and the minimum 22.33 to 25.93°C. The maximum temperature was about 5°C more than what was recorded in the shaded location.

The average solar radiation measurements separately for the upper and lower hemispheres and day and night have been presented in Table 1.1. It can be generally seen that higher values of the lower hemisphere are associated with higher values of the upper hemisphere. A similar relationship exists between day and night values also with respect to both the hemispheres. It appears that lower values depend on upper values and day time values influence night time values and all the four variables are interrelated. It is also interesting to note that in the same fourth week of the experiment when the radiation figures in the unshaded location are the maximum, the globe temperature recordings in the shaded location have also touched the maximum.

The relative humidity recorded in the open area at 0800 h ranged from 73.57 to 91.57 per cent and at 1400 h ranged from 55.00 to 87.00 per cent. The relative humidity figures in the mornings were higher than the afternoons.

During the 10th week of the experiment, at 0800 h recording time, there was no recordable wind velocity. In the rest of the weeks, the wind velocity ranged from 0.01 to 0.34 m per sec in the mornings and 0.13 to 0.97 m per sec in the afternoons. The general trend was that wind velocities were always higher in the afternoons. It is also observed that when the wind velocity touched the maximum, the relative humidity recorded was the minimum and this is true for both the locations namely the environment inside the house as well as in the open.

The vapour pressure in mm of mercury ranged from 21.95 to 25.76 at 0800 h and 22.02 to 25.98 at 1400 h recordings.

The total weekly rainfall was poor for the first five weeks of the experiment amounting to 7.40, 40.60, 4.40, 4.00 and 1.80 mm respectively. Actual rainy season started from sixth week of the experiment onwards which was found to immediately bring down the ambient temperature, radiation temperature inside the house and radiation values in the open.

Out of 14 weeks of recording of climatic variables, during the first five weeks, the rainfall was scanty and the maximum temperatures recorded in the shaded area was above 30°C and in the unshaded area, above 35°C. For the rest of the period the rainfall was high and the maximum temperature was below 30°C in the shaded area and below 35°C in the unshaded area. Hence the first five weeks period has been classified as hot-dry period, and the remaining as rainy.

II. PHYSIOLOGICAL REACTIONS:

a) Rectal temperature:

The mean values of rectal temperature in degrees celsius, skin temperature in degrees celsius, respiration rate as number per minute and cardiac rate as number per minute of the experimental calves under treatments T1, T2, T3 and T4 recorded at 0800 h and 1400 h during the hot-dry and rainy periods along with the results of analysis of variance between treatment means are presented in Table 1.2 and Figure 1.1 and 1.2.

The mean rectal temperatures of the calves recorded at 0800 h of the four treatment groups T1, T2, T3 and T4 were 39.21, 40.20, 39.33 and 40.15°C respectively during the hot-dry period. By analysis of variance, highly significant differences ($P < 0.01$) were found in rectal

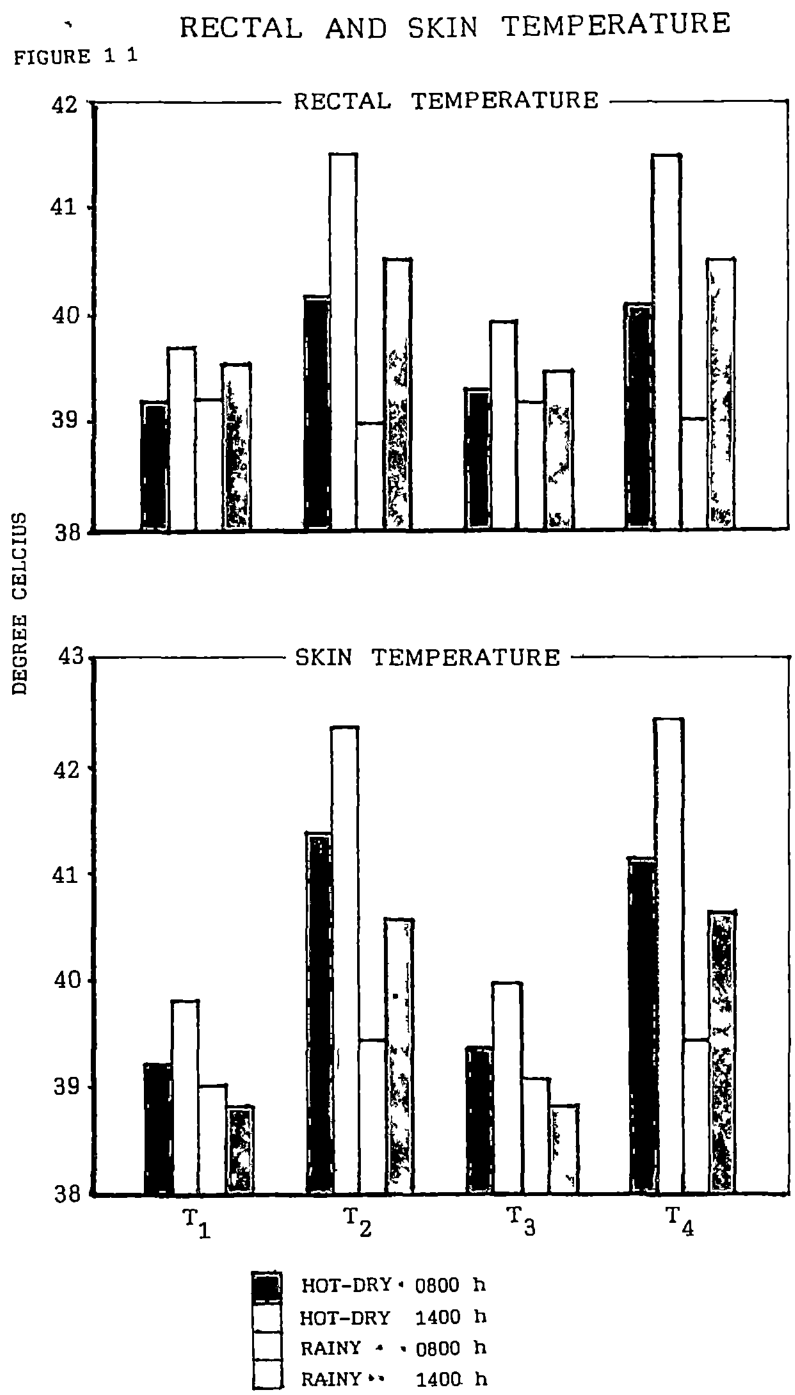
Table 1.2

Mean values of rectal and skin temperatures, respiration and cardiac rates of the calves under treatments T1, T2, T3 and T4 recorded at 0800 and 1400 h during the hot-dry and rainy periods

Physiological parameters/ Periods	Rectal temperature °C				Skin temperature °C				Respiration rate No /min				Cardiac rate No /min			
	Hot-dry		Rainy		Hot-dry		Rainy		Hot-dry		Rainy		Hot-dry		Rainy	
Time of recording	0800	1400	0800	1400	0800	1400	0800	1400	0800	1400	0800	1400	0800	1400	0800	1400
Concentrate fed.																
Shaded T1	39 21	39 69	39.23	39.55	39 22	39 82	39 01	38 83	47 38	60.38	39 70	48.16	65 69	78 23	69 00	77.00
Unshaded T2	40.20	41.51	38 99	40.52	41 34	42 38	39.42	40.57	77.33	121.75	42 52	80.11	82.92	126 08	72 71	89 40
Roughage fed.																
Shaded T3	39.33	39.95	39.21	39.50	39.34	39.92	39.09	38 84	47 33	67 96	37 00	48 44	67 06	79 26	65.25	76 80
Unshaded T4	40.15	41 50	39 04	40.56	41.20	42 41	39.40	40.62	69.09	110 60	38 57	77 72	84 09	117 80	66 07	87 86
F Value	17 42**	83 57**	2 86**	38 92**	58 67**	102 88**	4 52**	18 97**	11 46**	60 91**	1 54	21 87**	9 79**	70.56**	4.16**	8 86**
CD for comparison between means.																
T1 and T2	0 35	0 29	0.19	0.26	0.42	0 39	0.27	0 64	12 79	10.94	-	10.51	8.89	8 40	4.63	6.37
T1 and T3	0 33	0 28	0.18	0.24	0.40	0 37	0.26	0.61	12 11	10 35	-	10.04	8 41	7 95	4 45	6 09
T1 and T4	0.36	0.31	0.20	0.27	0.43	0 42	0.28	0.68	13 09	11 49	-	11.20	9.10	8 83	4 87	6.79
T2 and T3	0 34	0 28	0.18	0.24	0.40	0 38	0.26	0 61	12 38	10.58	-	9.96	8 60	8.13	4.45	6.04
T2 and T4	0.37	0.31	0.20	0 27	0.44	0.42	0 28	0.68	13 34	11 70	-	11 14	9 27	8 99	4 87	6 75
T3 and T4	0.35	0.30	0.20	0.26	0.41	0 40	0.27	0.65	12 69	11.16	-	10 69	8.81	8 57	4 70	6 48

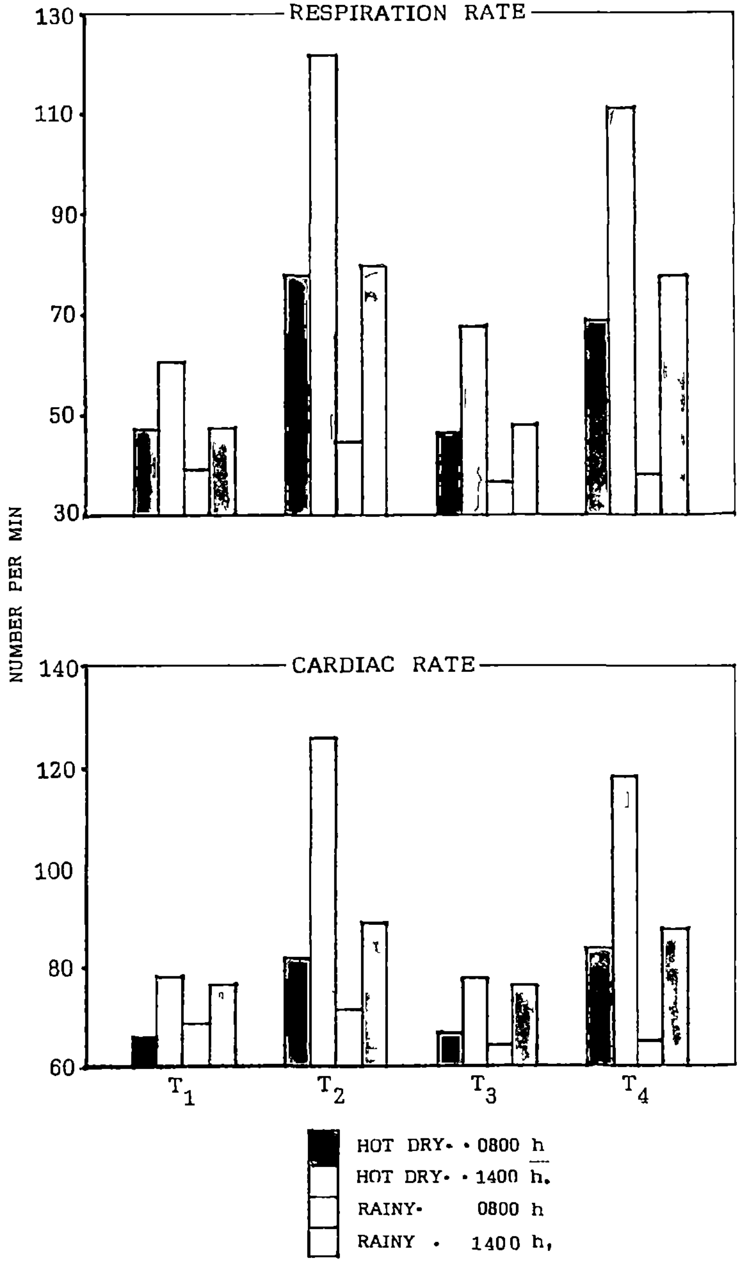
**Significant at 1 per cent level (P< 0.01)

FIGURE 1 1


RECTAL AND SKIN TEMPERATURE
RECTAL TEMPERATURE
SKIN TEMPERATURE
DEGREE CELCIUS
42
41
40
39
38
43
T1
T2
T3
T4
HOT-DRY 0800 h
HOT-DRY 1400 h
RAINY 0800 h
RAINY 1400 h

RESPIRATION AND CARDIAC RATE

FIGURE 1 2



temperatures between the treatment groups; the rectal temperatures of the calves in the unshaded location T2 and T4 being much higher than the calves in the shaded location T1 and T3. The afternoon values (1400 h) of 39.69, 41.51, 39.95 and 41.50°C respectively for treatments T1 to T4 showed highly significant differences ($P < 0.01$) between treatments with unshaded location having higher values than that of shaded location.

During the rainy period, the rectal temperatures recorded at 0800 h were 39.23, 39.99, 39.21 and 39.04°C for the treatments T1 to T4 in that order. Analysis of variance revealed highly significant differences ($P < 0.01$) between the recorded means of the four treatments. The highest value was obtained in concentrate feeding shaded group (T1) which was significantly higher than concentrate feeding unshaded group (T2), but no significant difference due to shade existed in the roughage oriented feeding. The 1400 h mean values for the rainy period were 39.55, 40.52, 39.30 and 40.56°C respectively for treatments T1, T2, T3 and T4. There were significant differences ($P < 0.01$) between the treatments and by critical difference, the rectal temperature of the calves in the unshaded area were significantly higher than those of shaded location.

b) Skin temperature:

The mean values of skin temperatures for the hot-dry period for the 0800 h recording were 39.22, 41.34, 39.34 and 41.20°C and for 1400 h recording were 39.82, 42.38, 39.92 and 42.41°C respectively for the treatments T1, T2, T3 and T4. By analysis of variance, highly significant differences ($P < 0.01$) between treatments were found in the skin temperatures both in the mornings and in the afternoons. By critical difference, it was found that the skin temperatures of the calves in the unshaded location were significantly higher than the housed calves at both times and irrespective of the type of feeding. Similar observations were made during the rainy period also with the respective values at 0800 h being 39.01, 39.42, 39.09 and 39.40°C and values at 1400 h being 38.83, 40.57, 38.84 and 40.62°C for treatments 1, 2, 3 and 4. There were significant ($P < 0.01$) differences between the treatment means of the skin temperatures during this season also.

c) Respiration rate:

During the hot-dry period, the respiration rates recorded for the four treatment groups T1, T2, T3 and T4 were 47.30, 77.33, 47.33 and 69.09 per min in the mornings and 60.38, 121.75, 67.96 and 110.60 per min in the afternoons. Analysis of variance revealed highly significant differences ($P < 0.01$) between treatments and critical difference had shown that calves under unshaded location had significantly faster respiration rates almost amounting to panting compared to calves under shaded location. The type of feeding did not seem to influence the respiration rate.

During the rainy period, the analysis of variance of the respiratory rates in the mornings between treatments had not revealed any significant difference and the respective respiration rates were 39.70, 42.52, 37.00 and 38.57 per min for T1, T2, T3 and T4. Neither the housing nor the type of feeding seem to influence the respiration rates of the calves in the mornings. In the afternoon, there was a highly significant difference ($P < 0.01$) in the respiration rates, the unshaded calves having a higher rate of respiration, but the type of feed did not seem to influence the respiration rate.

d) Cardiac rate:

The cardiac rate was found to be significantly higher in the unshaded calves compared to the shaded ones, both in the mornings and in the afternoons, irrespective of the type of feeding during the hot-dry period. For the treatments T1 to T4, the respective 0800 h cardiac rate per min were 65.69, 82.92, 67.06 and 84.09. Corresponding rates at 1400 h were 73.23, 126.08, 77.26 and 117.80. Highly significant differences ($P < 0.01$) between the treatment means in cardiac rates were found by analysis of variance.

During the rainy season, the average cardiac rates recorded in the mornings were 69.00, 72.71, 65.25 and 66.07 per min for the calves under treatments T1, T2, T3 and T4. By analysis of variance, highly significant differences ($P < 0.01$) were found between the treatments and by critical difference, the cardiac rate of the unshaded calves under concentrate feeding (T2) was significantly higher than the other three groups. In the afternoons, the mean heart rates of calves under treatments T1 to T4 were 77.00, 89.40, 76.30 and 87.86 per min and analysis of variance showed highly significant differences ($P < 0.01$) between these means. Critical difference analysis showed that provision of a simple tiled roof significantly ($P < 0.01$) reduced heart rate in cross-bred calves.

The treatmentwise comparative mean rectal temperature, skin temperature, respiration and cardiac rates of the calves under shaded and unshaded treatments during hot-dry and rainy periods for the 0800 and 1400 h recordings along with paired 't' test values are tabulated and presented in Table 1.3.

By paired 't' test, highly significant differences ($P < 0.01$) were found in the rectal temperatures of the calves of the shaded group compared to unshaded group. During the hot-dry period, the unshaded calves had recorded significantly higher values of 40.17 and 41.30°C for 0800 and 1400 h readings as against 39.29 and 39.83°C in the shaded group. During the rainy period, in the mornings, the opposite is true, the shaded calves have recorded significantly higher rectal temperature of 39.21 compared to 39.01°C in the open. However, in the afternoons, once again higher rectal temperatures were found with the calves in the open (40.55°C as against 39.92°C with shaded ones).

The respective skin temperature means of 41.27, 42.38, 39.39 and 40.60°C of the unshaded calves were all significantly ($P < 0.01$) higher than the means of 39.28, 39.86, 39.05 and 39.83 recorded with the calves in the shade.

The respiration rates of the shaded and unshaded calves were 47.53 and 71.21 for 0800 h recording during hot-dry period, 64.44 and 116.49 for 1400 h recording during hot-dry period, 36.24 and 40.74 for 0800 h recording of the rainy period and 48.32 and 79.66

per min for the 1400 h recording of the rainy period. By paired 't' test, the differences in the respiration rates between shaded and unshaded calves were found to be highly significant ($P < 0.01$) except in the case of 0800 h recording during rainy period.

Likewise, no significant differences could also be found in the cardiac rates of the calves subjected to shaded and unshaded treatments in the mornings of rainy days, the cardiac rate recorded for the former being 66.97 and later 69.54 per min. Otherwise, highly significant differences ($P < 0.01$) were found among the treatment groups during hot-dry season.

In general, all these variables in both the periods, showed higher values in the afternoons compared to the mornings. The only exception was that skin temperature in the housed environment during rainy period showed a lower value of 38.83 in the afternoon compared to 39.05°C recorded in the morning during that period.

The treatmentwise comparative mean rectal temperature, skin temperature, respiration rate and cardiac rate of the calves under concentrate feeding and roughage feeding treatments during hot-dry and rainy periods along with the paired 't' test results are furnished in Table 1.4.

Table 1.3

The comparative mean rectal temperature, skin temperature, respiration rate and cardiac rate of the calves under shaded and unshaded treatments during hot-dry and rainy periods

Treatment	Rectal temperature °C				Skin temperature °C				Respiration rate No./min				Cardiac rate No./min			
	Hot-dry		Rainy		Hot-dry		Rainy		Hot-dry		Rainy		Hot-dry		Rainy	
	0800	1400	0800	1400	0800	1400	0800	1400	0800	1400	0800	1400	0800	1400	0800	1400
Shaded	39.29	39.83	39.21	39.5[illegible]	39.28	39.86	39.05	38.83	47.53	64.44	38.24	48.32	66.42	78.78	66.97	76.88
Unshaded	40.17	41.50	39.01	40.55	41.27	42.38	39.39	40.60	71.21	116.45	40.74	79.06	83.47	122.54	69.54	88.72
t value	7.20**	15.61**	2.91**	11.06**	13.33**	17.66**	3.41**	7.61**	7.04**	13.05**	1.28	8.14**	5.45**	14.37**	1.48	5.17**

**Significant at 1.0 per cent level ($P < 0.01$)

Table 1.4

The comparative mean rectal temperature, skin temperature, respiration rate and cardiac rate of the calves under concentrate feeding and roughage oriented feeding treatments during hot-dry and rainy periods

tment	Rectal temperature °C				Skin temperature °C				Respiration rate No./min				Cardiac rate No./min			
	Hot-dry		Rainy		Hot-dry		Rainy		Hot-dry		Rainy		Hot-dry		Rainy	
	0800	1400	0800	1400	0800	1400	0800	1400	0800	1400	0800	1400	0800	1400	0800	1400
entrate ding	39.69	40.56	39.11	40.03	40.23	41.04	39.21	39.71	59.96	89.83	41.12	64.35	73.96	101.40	70.91	83.28
ghage ding	39.67	40.57	39.14	39.92	40.12	40.91	39.21	39.54	56.53	85.01	37.64	59.91	74.26	95.06	65.44	81.13
value	0.04	0.20	0.37	0.83	0.42	0.45	0.30	0.62	0.83	0.73	1.80*	0.98	0.87	1.20	3.25**	0.87

** Significant at 1.0 per cent level ($P < 0.01$)

* Significant at 5.0 per cent level ($P < 0.05$)

The average rectal temperature during hot-dry period for 0800 h recording was 39.69 for concentrate feeding group compared to 39.67°C for roughage feeding group. The average values at 1400 h during hot-dry period for concentrate feeding and roughage feeding groups were 40.56 and 40.51°C. The same were 39.11 and 39.14 at 0800 h and 40.03 and 39.92°C at 1400 h during rainy period for concentrate and roughage groups respectively.

The respective skin temperature values for concentrate and roughage feeding groups were 40.23 and 40.12 at 0800 h recording of hot-dry period, 41.04 and 40.91 for 1400 h recording of hot-dry period, 39.21 and 39.21 at 0800 h recording of rainy period and 39.71 and 39.54°C at 1400 h recording for rainy period.

The respiration rates were 59.96 at 0800 and 89.83 at 1400 h of hot-dry period and 41.12 at 0800 h and 64.35 per min at 1400 h of rainy period for the concentrate fed calves. For the calves under roughage oriented feeding treatment, the respiration rates recorded respectively were 56.53, 85.01, 37.64 and 59.91 per min.

For the concentrate feeding group, the cardiac rates were 73.96 at 0800 h and 101.40 per min at 1400 h during the hot-dry period and they were 70.91 and 83.28

per min respectively during the rainy period. For the roughage oriented feeding group, during hot-dry period, the heart rates were 74.26 at 0800 h and 95.08 per min at 14.00 h and during rainy period, they were 65.44 at 0800 h and 81.13 per min at 1400 h recording.

In the paired 't' test, it was found that the 8.00 A.M. heart rate of the calves fed roughage oriented diet, was significantly ($P < 0.01$) lower compared to concentrate-fed group during rainy period (65.44 vs 70.91). Similarly the morning respiration rate during rainy period was also lower in the roughage oriented feeding group (37.64 vs 41.12).

III. GROWTH:

a) Body weight:

The initial body weights in kg of the individual experimental calves and the fortnightly weights from first to seventh fortnights, under the four treatment groups with treatment wise fortnightly mean body weights, the CD values and the F values as obtained by analysis of covariance are furnished in Table 1.5 and Figure 1.3.

The mean initial body weights were 71.76, 72.24, 72.68 and 67.28 kg respectively for the four treatment groups namely concentrate-fed shaded (T1), concentrate-fed,

Table 1.5

The fortnightly body weights of the calves in kg

		X_1	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7
	R1	55.0	58.2	64.0	66.0	68.2	71.4	78.6	81.0
T1	R2	50.0	52.0	54.6	58.0	59.4	62.2	68.4	70.6
Shaded,	R3	73.2	79.0	85.4	86.6	90.0	81.4	93.0	85.0
concentrate-fed	R4	74.4	(90.34	91.11	90.01	100.71	96.42	112.64	107.9
	R5	106.2	111.0	119.0	120.0	126.0	120.0	133.4	126.0
	R1	54.4	56.0	61.8	61.4	64.0	60.8	67.0	63.8
T2	R2	59.0	61.0	63.0	62.8	64.2	67.6	73.4	80.8
Unshaded,	R3	70.4	73.8	76.4	72.0	76.6	66.6	73.6	74.8
concentrate-fed	R4	77.2	82.6	84.0	85.2	95.4	84.0	98.2	97.4
	R5	100.2	100.5	100.0	102.2	114.0	104.0	119.4	115.2
	R1	60.2	62.6	65.4	68.0	70.2	66.4	76.2	80.0
T3	R2	58.2	55.2	57.0	62.0	64.2	64.4	75.8	75.0
Shaded,	R3	81.6	87.0	93.0	95.2	96.0	82.2	104.0	94.0
roughage-fed	R4	72.0	76.8	80.0	83.8	90.0	82.0	99.4	97.0
	R5	91.4	93.2	98.0	102.4	101.6	93.4	100.0	101.4
	R1	37.4	37.6	(63.62	64.70	66.72	67.31	73.50	73.9
T4	R2	55.0	59.2	63.0	60.8	65.4	66.0	73.6	75.2
Unshaded,	R3	70.2	75.0	78.0	74.4	77.4	71.0	74.4	79.2
roughage-fed	R4	90.4	99.8	96.0	95.6	102.0	100.0	121.0	112.0
	R5	83.4	89.8	98.4	104.2	111.6	102.2	115.0	104.6
	T1	71.76	77.34	82.30	83.66	88.41	85.79	96.69	93.5
Means	T2	74.24	73.47	76.20	73.97	82.11	75.80	86.12	85.44
	T3	72.68	73.19	77.54	81.27	83.47	76.60	89.51	88.19
	T4	67.28	76.16	81.90	82.16	86.78	83.67	94.96	91.86
CD values			3.83	6.81	7.27	7.69	6.49	11.63	7.96
F values			2.77*	1.97	3.49**	1.41	5.81**	1.71	2.04

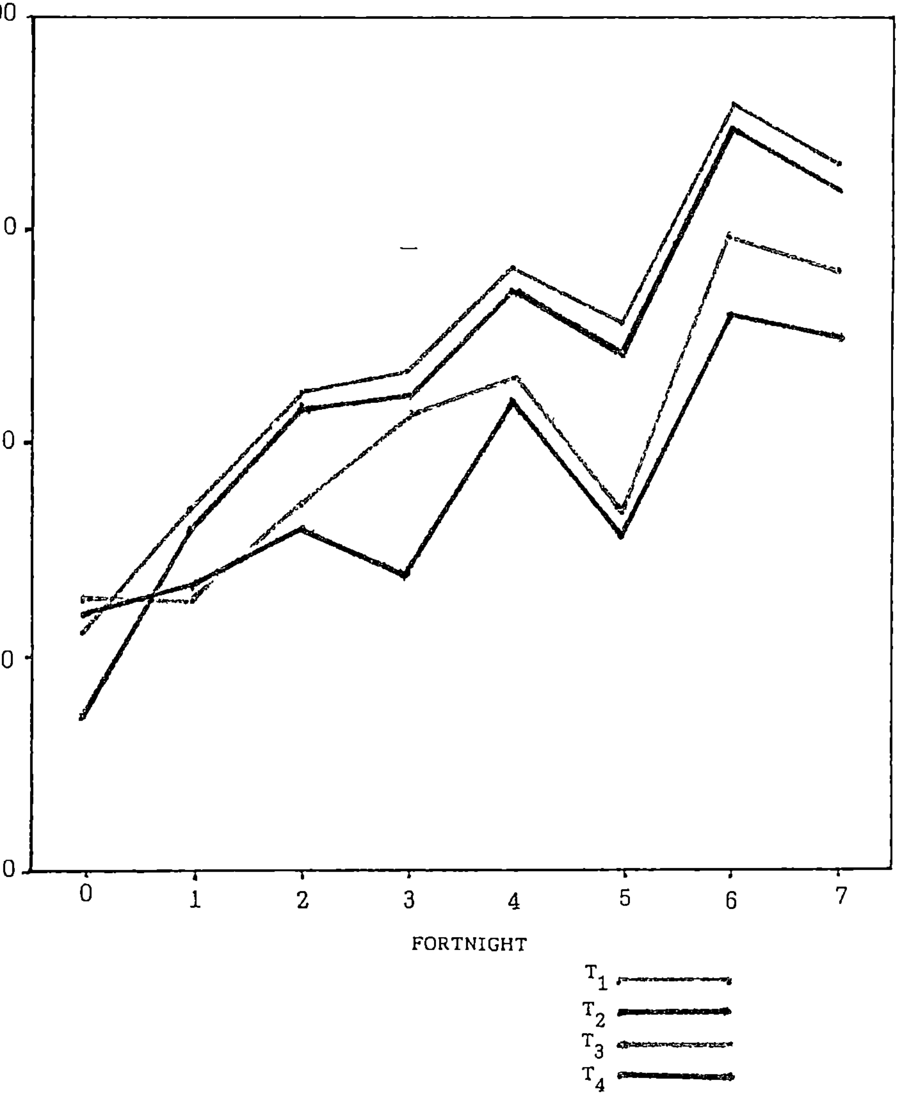
Figures in parenthesis are the missing values obtained by employing missing plot technique

* Significant at 5 per cent level ($P < 0.05$)

** Significant at 1 per cent level ($P < 0.01$)

GROWTH RATE

E 1 3



unshaded (T2), roughage-fed - shaded (T3) and roughage-fed - unshaded (T4).

The means of the first fortnightly body weights were 77.34, 73.47, 73.19 and 76.16 kg for the treatments T1, T2, T3 and T4 respectively with calves under T1 recording the highest body weight. By analysis of covariance, it was found that the differences in the body weights between the treatment groups were significant ($P < 0.05$) indicating the effect of the various treatments on the growth rate. By critical difference it was seen that the calves that were given full concentrate ration and kept in the shade (T1) had better live weight gains than the other three treatment groups T2, T3 and T4 during this fortnight.

During the second fortnight, the mean body weights recorded for the four treatments T1, T2, T3 and T4 respectively were 82.30, 76.20, 77.54 and 81.90 kg. By analysis of covariance, though no significant differences could be obtained between the body weights under the different treatments, the calves under T1 were found to maintain their superiority.

The respective means of body weights for the treatments T1, T2, T3 and T4 were 83.66, 73.97, 81.27 and 82.16 kg during the third fortnight. The calves that were given concentrate ration and housed in the shade (T1) had recorded the highest body weight and they continued to grow faster than the other three groups. Analysis of covariance of the body weights of calves revealed a highly significant ($P<0.01$) difference between the treatment groups once again indicating definite effect of the various treatments in the experiment on the growth rate. By critical difference, it was found that the group of calves T2 maintained on concentrate ration and exposed to the direct solar radiation recorded significantly ($P<0.01$) lower mean weight (73.97 kg) than all other groups.

During the fourth fortnight, once again there was no statistical difference in the mean body weights between the treatment groups but, however, calves under T1 continued to maintain the superiority, recording a mean body weight of 88.41 kg and calves under T2 recording the lowest of 82.11 kg. The other two treatments T3 and T4 recorded 83.47 and 86.78 kg respectively.

Analysis of covariance of the fifth fortnight body weights between the four treatments revealed a highly significant difference ($P<0.01$) in the growth rates due to the influence of the treatments given. During this fortnight, a uniform reduction in the weights was seen

Tra

- - - - - - - - -

- - - - - - - - -

T1 Shaded, concentrate-fed
T2 Unshaded, concentrate-fed
T3 Shaded, roughage-fed
T4 Unshaded roughage-fed
Means
CD values
F values

- - - - - - - -

I4_u
[illegible]

compared the earlier fortnightly weights, all the calves loosing weights ranging from 3 to 7 kg. By critical difference it was found that T1 still maintained its superiority and calves under roughage feeding and exposed to direct solar radiation (T4) was catching up with it, with respective weights of 85.79 and 83.67 kg. The treatment groups T2 and T3 remained inferior with 75.80 and 76.60 kg only as their mean body weights.

No statistical difference between the body weights in treatment groups could be found during the sixth and seventh fortnights. The best body weight gain was obtained in treatment T1 where the calves were fed with full concentrate ration and kept protected from direct solar radiation. The calves exposed to direct solar radiation and managed with roughage oriented feeding had also fared relatively good. The other two groups fared not so well and the treatment with concentrate feeding and exposed to direct solar radiation had resulted in recording the poorest growth rate.

b) Height:

The initial height measurements and subsequent fortnightly measurement values in cm of all the experimental calves under the different treatment groups, the fortnightly means and the results of the analysis of covariance are tabulated and presented in Table 1.6.

It is seen that the calves had started with an initial height of 87.8, 85.0, 86.4 and 85.2 cm under treatments T1, T2, T3 and T4 respectively. During the first fortnight, there was a small increase in the heights of all the groups except in T1 where there was a decrease of 1.07 cm. Such reductions in the heights was noticed to occur now and then in other groups also which might be an error in measurement.

The respective finishing heights of the calves were 90.18, 91.59, 90.03 and 92.04 cm for the four treatments, with the calves in the treatment group roughage oriented feeding and unshaded (T4), recording the maximum height of 92.04 cm though they had started with comparatively lower height of 85.20 cm. During the course of the experiment of seven fortnights, the calves in treatments 1, 2, 3 and 4 had grown in height by 2.38, 6.59, 3.63 and 6.84 cm, the maximum growth being recorded in the group under roughage oriented feeding and exposed to direct solar radiation. However by statistical analysis, no significant differences between treatment groups were found at any stage of the experiment.

c) Length:

The initial and fortnightly body length measurements of the calves in cm for all the treatment groups, fortnightly means of the length and the results of covariance analysis are presented in Table 1.7.

The initial body length measurements were 84.0, 86.0, 84.2 and 86.0 cm respectively for the treatments T1, T2, T3 and T4. During the first fortnight, the calves had attained a body length of 87.29, 85.65, 86.24 and 85.05 cm in that order. By analysis of covariance, a significant difference ($P < 0.05$) was found between the body length of the calves in the four treatment groups, the calves under the treatment of concentrate feeding and protected from direct solar radiation recording the highest values.

There was a gradual increase in the body lengths of the calves in the subsequent fortnights in all the treatments, the calves under treatment T1 always maintaining a lead, though by statistical analysis, no significant differences could be found between treatments in the body lengths. During the course of the experiment of seven fortnights, the calves had grown in length by 12.50, 8.64, 10.29 and 6.60 cm respectively with the T1 calves under concentrate feeding - protected from direct solar radiation ending up with the highest value of 96.50 cm and calves under roughage oriented feeding - unshaded treatment ending withthe lowest value of 92.60 cm. The other two groups, namely concentrate feeding - unshaded

Table 1.6

The fortnightly height measurements of the calves in cm

		x_1	y_1	y_2	y_3	y_4	y_5	y_6	y_7
	R1	83	83	83	82	83	82	84	85
T1	R2	83	84	84	86	86	86	86	86
Shaded, concentrate-fed	R3	87	88	91	90	90	91	90	92
	R4	90	(89.92	90.20	91.22	91.95	91.81	91.36	92.52)
	R5	96	96	98	100	100	100	100	100
	R1	83	84	86	87	86	88	90	90
T2	R2	84	84	97	88	88	88	88	89
Unshaded, concentrate-fed	R3	85	86	82	86	84	85	87	88
	R4	87	87	87	88	89	89	89	90
	R5	86	88	94	95	95	96	98	98
	R1	82	82	84	82	82	83	85	86
T3	R2	83	84	85	85	85	85	86	86
Shaded, roughage-fed	R3	90	90	88	88	90	90	91	92
	R4	85	86	86	88	88	88	90	90
	R5	92	92	95	95	97	97	97	97
	R1	74	75	(85.65	84.40	83.59	84.27	86.72	87.79)
T4	R2	86	87	90	91	90	90	90	92
Unshaded roughage-fed	R3	92	90	89	91	90	90	91	91
	R4	90	90	94	94	94	95	95	97
	R5	84	84	88	87	87	87	90	90
	T1	87.80	86.73	88.28	88.75	89.03	89.01	89.37	90.18
Means	T2	85.00	86.73	87.82	89.51	89.15	89.93	90.98	91.59
	T3	86.40	86.54	87.43	87.40	88.19	88.39	89.64	90.03
	T4	85.20	85.96	89.83	90.06	89.53	89.85	91.02	92.04
CD values			1.08	4.06	3.77	3.69	4.19	3.56	3.92
F values			1.11	0.68	0.91	0.23	0.29	0.34	0.60

Figures in parenthesis are the missing values obtained by employing missing plot technique

Table 1.7

The fortnightly body length measurements of the calves in cm

		x_1	y_1	y_2	y_3	y_4	y_5	y_6	y_7
	R1	76	78	79	80	82	84	86	86
T1	R2	76	77	81	80	82	83	86	86
Shaded,	R3	82	86	87	90	94	92	95	100
concentrate-fed	R4	86	(89.25	91.39	92.71	95.25	96.99	95.94	97.43)
	R5	100	101	103	102	104	105	108	110
	R1	79	79	85	87	88	86	88	90
T2	R2	82	82	82	82	80	80	86	88
Unshaded,	R3	86	86	82	88	84	86	88	90
concentrate-fed	R4	91	92	90	94	96	99	92	96
	R5	92	94	95	96	100	100	102	102
	R1	82	84	84	86	90	90	96	96
T3	R2	78	78	85	85	85	86	88	88
Shaded	R3	89	90	90	91	92	93	95	97
roughage-fed	R4	80	81	88	87	90	90	90	89
	R5	92	94	95	96	98	99	100	100
	R1	72	70	(81.30	84.32	85.98	86.17	88.67	88.80)
T4	R2	84	83	85	84	84	85	85	88
Unshaded	R3	90	89	81	88	90	90	91	91
roughage-fed	R4	92	94	93	98	96	98	100	102
	R5	92	94	93	92	94	95	94	96
	T1	84.00	87.29	88.75	89.50	91.92	92.75	94.80	96.50
Means	T2	86.00	85.65	86.37	88.89	89.17	89.69	90.64	94.64
	T3	84.20	86.24	88.72	89.45	91.38	92.05	94.29	94.49
	T4	86.00	85.65	86.03	88.79	89.57	90.32	91.17	92.60
CD values			1.77	4.07	4.02	4.66	3.93	4.93	7.12
F values			2.75*	1.23	0.78	0.76	1.23	1.71	0.47

Figures in parenthesis are the missing values obtained by employing missin, plot technique

* Significant at 5.0 per cent level ($P < 0.05$)

and roughage oriented feeding - shaded had recorded intermediary values of 94.69 and 94.49 cm.

d) Girth:

The initial and the fortnightly girth measurement as recorded for individual experimental calf for the experimental period of seven fortnights along with treatment wise fortnightly mean value and statistical analysis figures are tabulated and presented in Table 1.8.

The calves had started with a mean girth measurement of 101.4, 101.0, 102.0 and 95.4 cm respectively for the treatments T1, T2, T3 and T4.

At the closure of the experiment, calves under T1 with concentrate feeding and shaded treatment had recorded the highest mean girth measurement of 109.81 cm and others had 106.31, 105.85 and 106.96 cm as the girth measurement in the order of treatments 2, 3 and 4. Girth increased gradually during the experimental period. Statistical analysis did not reveal any significant difference due to treatments in any fortnight. However the trend appeared to be similar to body weight gain.

e) Comparison between shaded and unshaded treatments:

The fortnightly comparative mean body weight, height, length and the girth of the calves under shaded

Table 1.8

The fortnightly girth measurements of the calves in cm

		x_1	y_1	y_2	y_3	y_4	y_5	y_6	y_7
	R1	96	96	100	100	101	102	104	105
T1	R2	94	95	93	93	95	95	98	100
Shaded,	R3	102	104	106	105	105	108	106	108
concentrate-fed	R4	105	(108.08	107.96	108.89	110.73	110.87	111.88	115.02)
	R5	110	111	112	115	116	115	116	123
	R1	91	92	94	94	94	93	96	96
T2	R2	92	92	98	97	97	98	100	103
Unshaded,	R3	104	100	101	100	100	98	100	102
concentrate-fed	R4	104	102	108	106	106	106	111	112
	R5	114	114	116	116	115	114	118	120
	R1	91	92	93	96	94	94	96	98
T3	R2	98	94	92	96	94	95	99	103
Shaded,	R3	106	107	107	110	110	105	107	106
roughage-fed	R4	108	108	104	108	109	108	108	111
	R5	107	108	111	112	110	108	109	113
	R1	76	77	(93.50	93.34	94.19	94.51	98.43	97.75)
T4	R2	92	93	93	92	94	96	10[illegible]	104
Unshaded,	R3	100	100	101	100	100	99	101	102
roughage-fed	R4	103	104	106	107	108	107	109	110
	R5	106	108	110	110	112	110	115	115
	T1	101.4	101.49	103.60	104.04	105.18	105.21	106.73	109.81
	T2	101.0	99.04	102.26	102.36	102.13	101.54	104.67	106.31
Means	T3	102.0	99.93	101.13	103.93	102.88	101.49	103.17	105.65
	T4	95.4	100.53	101.29	101.50	102.78	102.42	106.48	106.96
CD values			2.74	4.19	4.17	4.48	4.14	4.62	4.33
F values			1.70	1.06	0.74	1.04	2.17	1.38	2.17

Figures in parenthesis are the missing values obtained by employing missing plot technique and unshaded treatments and paired 't' test results comparing between treatments are furnished in Table 1.9.

The mean body weights from first to seventh fortnights under the shaded treatments were 76.55, 80.75, 83.20, 86.63, 81.98, 94.24 and 91.79 kg whereas the same under unshaded treatment were 73.53, 78.22, 78.33, 83.73, 78.95, 89.41 and 87.71 kg. By paired 't' test, it was found that there was no significant difference in the weight gains of the calves between the treatments.

The mean height of the calves under shaded and unshaded groups were 87.49 and 85.50 cm for the first fortnight, they were 88.40 and 88.26 cm for the second, 88.72 and 89.14 cm for the third, 89.29 and 88.65 cm for the fourth, 89.38 and 89.22 cm for fifth, 90.03 and 90.47 cm for sixth and 90.65 and 91.27 cm for the seventh fortnight respectively. By paired 't' test, no significant differences could be found during any of the fortnights in calf heights between the treatment groups.

In the same way, no statistical differences could be found between the body lengths of the calves under shaded and unshaded treatments by paired 't' test. The mean body lengths recorded for the calves under shaded treatments were 85.82, 88.33, 89.97, 91.22, 91.89, 93.99 and 94.94 cm for first to seventh fortnights respectively

Table 1.9

Fortnightly comparative mean body weight, height, length and girth of the calves under shaded and unshaded treatments

ort-ight	Mean body weights (kg)			Mean heights (cm)			Mean body lengths (cm)			Mean body girths (cm)		
	Shaded	Un-shaded	't' value	Shaded	Un-shaded	't' value	Shaded	Un-shaded	't' value	Shaded	Un-shaded	't' value
1	76.55	73.53	0.34	87.49	85.50	1.00	85.82	86.30	0.13	102.30	98.20	1.03
2	80.75	78.22	-	88.40	83.26	0.68	88.33	86.72	0.57	103.19	102.05	0.31
3	83.20	78.33	0.58	88.72	89.14	0.19	89.97	89.35	0.21	104.38	101.53	0.81
4	86.63	83.73	0.31	89.29	88.65	0.28	91.22	89.79	0.47	104.47	102.01	0.69
5	81.98	78.95	0.38	89.38	89.22	0.69	91.89	90.51	0.44	103.78	101.55	0.69
6	94.24	89.41	0.51	90.03	90.47	0.21	93.99	91.48	0.83	105.48	105.04	0.14
7	91.79	97.71	0.52	90.65	91.27	0.32	94.94	93.18	0.39	108.20	106.17	0.59

and the same for the unshaded group were 86.30, 86.72, 89.35, 89.79, 90.51, 91.48 and 93.18 cm in that order.

The shaded calves had recorded the fortnightly mean body girths of 102.30, 103.19, 104.38, 104.47, 103.78, 105.48 and 108.20 cm for the first to seventh fortnights and unshaded calves 98.20, 102.05, 101.53, 102.01, 101.55, 105.04 and 106.17 cm respectively. Paired 't' test had not revealed any significant difference in body girths of the calves between the treatments.

f) Comparison between concentrate and roughage feeding treatments:

The comparative mean fortnightly body weights, height, length and girth of the calves under concentrate feeding and roughage feeding treatments with the results of analysis by paired 't' test are presented in Table 1.10.

The mean body weights were 76.46, 79.93, 80.42, 85.85, 81.44, 92.36 and 90.25 kg respectively for one to seven fortnights in the concentrate feeding group and the respective weights for the roughage oriented feeding group were 73.62, 79.04, 81.11, 84.51, 79.49, 91.29 and 89.29 kg. By paired 't' test, no significant differences could be found between the treatment means.

Table 1.10

Comparative mean fortnightly body weights, height, length and girth of the calves under concentrate and roughage feeding treatments

Fort-nights	Body weight (kg)			Height (cm)			Body length (cm)			Girth (cm)		
	Concen-trate fed	Rough-age fed	't' value	Concen-trate fed	Rough-age fed	't' value	Concen-trate fed	Rough-age fed	't' value	Concen-trate fed	Rough-age fed	't' value
1	76.46	73.62	0.32	86.99	86.00	0.49	86.42	85.70	0.20	101.40	99.10	0.56
2	79.33	79.04	0.10	88.22	88.46	0.12	87.33	87.53	0.21	103.59	101.05	0.74
3	80.42	81.11	0.32	89.32	88.34	0.37	89.17	89.13	0.68	103.48	102.43	0.29
4	85.85	84.51	0.15	89.29	88.65	0.28	90.52	90.49	0.33	103.97	102.51	0.40
5	81.44	79.49	0.32	89.60	88.92	0.34	91.19	91.21	0.57	103.68	101.65	0.63
6	92.36	91.29	0.11	90.[illegible]	90.17	0.32	92.09	92.76	0.25	105.03	104.44	0.52
7	90.25	89.29	0.12	91.95	90.87	0.33	94.34	93.53	0.22	103.40	105.97	0.71

The calves in the concentrate feeding treatment had recorded for the first to seventh fortnights mean heights of 86.99, 88.22, 89.32, 89.29, 89.68, 90.33 and 91.05 cm and in the roughage oriented feedding group, 86.00, 88.46, 88.54, 88.65, 88.92, 90.17 and 90.87 cm respectively. Statistical analysis did not reveal any significant difference in heights between in calves under the two treatments.

The first fortnightly mean body length measurements in the concentrate feeding group and roughage oriented feeding group respectively were 86.42 and 85.70 cm, the same were 87.53 and 87.53 cm for the second fortnight, 89.17 and 89.15 cm for the third, 90.52 and 90.49 cm for fourth, 91.19 and 91.21 cm for fifth, 92.69 and 92.76 for sixth and 94.54 and 93.58 cm for the final and seventh fortnight. The differences in the mean body lengths between the treatments were not significant.

The respective girth measurements for the concentrate feeding group and roughage oriented feeding group were 101.40, 103.59, 103.48, 103.97, 105.68, 106.08 and 108.46 cm for one to seventh fortnights and 99.10, 101.05, 102.43, 102.51, 101.65, 104.44 and 105.97 cm in the same order. Paired 't' test analysis between the treatment means did not reveal any significant difference.

In all the above four growth parameters studied, the type of feeding had not shown any significant influence.

DISCUSSION

1. CLIMATIC VARIABLES:

The daily maximum air temperature that prevailed in the unshaded location during the hot-dry period was above 35°C and in the shaded location, above 30°C. As supported by literature, this range of temperature is sufficient to cause heat stress on the experimental animals. The type of housing provided in this study has somewhat helped in reducing the ambient air temperature, by a moderate 5°C. During the rainy period, the maximum temperature ranged from 25.37 to 29.31°C under the shade and 29.36 to 33.50°C in the unshaded location which cannot also be considered "comfortable". In the present study, based on the air temperature prevailed, it can be presumed that the shade had provided a mild degree of thermal protection to the growing crossbred calves.

The relative humidity had ranged from 76 to 93 per cent in the mornings and 55 to 88 per cent in the afternoons in the experimental area and with this high range of humidity, the environment can be classified as humid. At no one time, the difference in relative humidity between the housed environment and open environment was more than five per cent which indicated that there was free exchange of air in the calf house chosen for the experiment (Sainsbury, 1965).

During most of the days, the wind velocity in the mornings was either zero or very meagre inside the calf house as well as in the open environment. In the afternoons, there were recordable wind velocities in both the locations. Stolpe (1977) recommended a rate of air movement of 0.6 m per sec inside animal houses to alleviate the detrimental effect of oppressive environment but in the present study, the wind velocity inside the animal house had never reached that level. In the open environment a velocity ranging from 0.13 to 0.97 m per sec was recorded which most likely would have contributed towards the thermal comfort of calves housed outside during the afternoons.

The vapour pressure ranged from 25.98 to 21.41 mm of Hg in both the experimental locations during the period of study.

The mean radiation temperature of the surroundings recorded by the black globe thermometer in the shaded location ranged from 26.17 to 30.42°C at 8'O clock recording to 25.83 to 34.30°C at 14th hour recording. The black globe temperatures were found to be 2 to 5°C above that of air temperatures as a result of radiation effect and was also high on the days when solar radiation values in the unshaded location recorded higher figures.

The solar radiation values as recorded by radiation balance meter was as high as 221.45 m.cm^{-2} during day time for the upper hemisphere and the same was 160.22 m.cm^{-2} during night time. The lower hemisphere values were 169.63 during day time and 124.45 m.cm^{-2} for the night. All these figures had occurred during one and the same week when there was very poor rainfall. The radiation figures were found to reach the minimum when it had been continuously and heavily raining for two weeks and here again all the lowest values occurred in one and the same week. This leads to presume that the different components of radiation values obtained as upper and lower and day time and night time values are all interrelated.

Regular rains started from the sixth week of the experiment and it was a maximum of 210.30 mm of weekly total rainfall during the final week of the experiment.

II. PHYSIOLOGICAL REACTIONS:

a) Rectal temperature:

The rectal temperature of the calves in the unshaded location was significantly higher than those of the shaded ones ($P < 0.01$) both for the morning and early afternoon recordings during the hot-dry period. The calves in the shaded group were maintaining an average rectal temperature of 39.5°C, which may be considered normal (Merz and Steinhauf, 1978). The unshaded calves on the other hand had an average rectal temperature of 40.8°C which may indicate thermal stress. The type of feeding had not influenced the rectal temperature in both shaded and unshaded treatments. Many authors have suggested (NRC, 1981; Van Horn, 1984; Beede and Collier, 1986) that for thermally stressed animals, the nutrient density in the diet is to be increased, reducing the quantity of roughage to bring down the heat that will be generated during fermentation. As per their assumption, the body temperature of the calves fed with more quantity of roughage must be higher; but in the present study, such an effect was not noticed.

Significantly lower value for rectal temperature was obtained for the concentrate fed unshaded calves during the morning recording of rainy period. The calves under housed environment had higher rectal temperatures than the unshaded ones in the mornings in the rainy season. This was most likely due to the cooler environment in the open in the mornings (Table 1.1). In the afternoons, significantly higher values for rectal temperatures were recorded in the unshaded group which might be resulting out of more severe temperature and radiation stress in the unshaded location.

The afternoon rectal temperatures were found to be higher than the morning values indicating a diurnal rythm as reported by Holmes (1970). However, the differences between morning and afternoon temperatures were more than 0.5°C, especially in the unshaded calves, which does not agree with Holmes (1970) who stated that the difference between both extremes was less than 0.5°C.

b) Skin temperature:

One of the interesting phenomenon noticed in the present study was that the skin temperature of the experimental calves was always higher than the rectal temperatures in all the cases except in the shaded calves on rainy days. This may be because the animals were still not making use of cutaneous evaporation for thermolysis as the range of effective ambient temperature might not have become stressful enough to trigger sweating. While the skin temperature remained high, the rectal temperature might have been brought down slightly by other thermolytic avenues. The skin surface also would have absorbed radiated heat. Such radiated heat was to the minimum extent inside the shed during rainy days.

Significant differences ($P < 0.01$) were found between the skin temperatures of the calves in various treatments in the present study indicating the influence of treatments. The unshaded calves had recorded significantly higher ($P < 0.01$) skin temperatures than the shaded ones during the hot-dry and the rainy periods, the difference almost amounting to 2°C except during the mornings of rainy days where the difference was only around 0.3 to 0.4°C.

Thompson <u>et al</u>.(1964) demonstrated that when dairy animals were exposed to direct solar radiation, the skin temperature was significantly higher ($P < 0.01$) yet thermal balance was not altered as indicated by normal rectal temperature. They concluded that animals attempted increasing heat loss by accelerating breathing and raising the body surface temperature. In the present study also, the skin temperatures of the calves were found to be higher and even exceeded the environmental temperatures, which provided the calves with the physical advantage of connective heat loss and better acclimatisation.

The type of feeding did not seem to influence the skin temperature of the experimental calves.

c) <u>Respiration rate</u>:

During the hot-dry period, the respiration rates were significantly higher ($P < 0.01$) in the unshaded group compared to the shaded lot for the morning recordings.

The other treatment, namely the type of feeding did not influence the respiration rate. In the afternoons the highest respiration rate of 121.75 per min was recorded in the concentrate feeding unshaded group T2 which was significantly different ($P < 0.01$) from the other three groups and the respiration rate in the roughage-fed unshaded group was significantly lower than T2 but significantly higher than both shaded groups T1 and T3. The finding therefore was that providing shade for the calves reduced the stress and among the calves that were maintained in the open, the calves that were provided with more roughage appeared to be enjoying better comfort than the calves fed with concentrate ration. This finding is contradictory to the views expressed by many authors (NRC, 1951; Van Horn, 1984; Beede and Collier, 1986). The respiration rates of calves in the afternoons in all the treatments were found to be almost double of what was recorded in the mornings. Bunger et al.(1982) reported diurnal rythm in the respiratory rates of German Fresian cows. Herz and Steinhauf (1978) reported a respiratory rate of 200 per min at 38°C air temperature in Bos taurus cattle. Furukawa et al.(1979) stated that the respiratory rate reached an equilibrium of 160 per min within one to three hours of exposure of cattle to 35°C. In the present study, with ambient air temperature above 35°C during the hot-dry period in the unshaded location and relative humidity also high (about 55 per cent), the calves had recorded only a mean respiration rate of a maximum 121.75 per min even under exposure to direct solar radiation. This is indicative of the better adaptive ability of the calves used in the present study.

During the rainy period, the respiratory rates of calves in all the treatment groups were similar without statistical difference between them in the mornings. The afternoon respiration rates were found to be higher than the mornings and significantly different ($P < 0.01$) between treatments with the unshaded calves recording higher values. There was no effect due to type of feeding.

d) Cardiac rate:

Highly significant differences ($P < 0.01$) in the cardiac rate of the calves between treatments were found both for the morning and afternoon recordings during the hot-dry as well as the rainy periods, the unshaded calves generally recording higher values than the shaded ones. When cows ar subjected to heat stress in the climatic chamber, the heart rate decreases, (Neuhoimer-Thoneick *et al*., 1988a). Contrary to this, in most of the field trials, cardiac rate has been found to increase under heat-stress (Thomas and Razdan, 1973b). In the present study also, exposure to higher ambient temperature and solar radiation in the open has been found to increase the heart rate significantly in comparison to shaded calves. The picture is slightly different in the mornings during rainy days where only the concentrate fed unshaded group had recorded a significantly higher cardiac rate than the shaded. However, the same trend was observed in the roughage-oriented-feeding groups also.

In general, the cardiac rates are found to be higher in the afternoons, in all the treatment groups than in the mornings. Even the shaded calves had shown a regular increase in the afternoons which may be a physiological phenomenon. During the hot-dry period, the cardiac rates obtained in the afternoons were 126.08 and 117.80 per min which was even higher than the respiration rates. Furukawa et al.(1979) found that the heart rate started increasing only when the respiration rate and body temperature reached their equilibria. Zia-ur-rehman et al.(1982) noticed the cardiac rate to be high when the atmospheric humidity was high. Thomas and Razdan (1973b) reported an increase in the heart rates of cross-bred bull calves exposed to summer conditions which they attributed partially to decrease in blood volume. The increased cardiac rate observed in the hot-dry period and in the afternoons can thus be interpreted as a reaction of the animals to thermal stress. The cardiac rates are lower during the rainy period than the hot-dry period which may be due to lesser stress during the rainy days.

e) Effect of housing/direct solar radiation on physiological reactions:

Highly significant variations ($P < 0.01$) in all the physiological reactions measured were noticed between the housed and unhoused treatments, the calves exposed to direct solar radiation recording higher values of rectal and skin temperatures and respiration and cardiac rates. There are, however, a few exceptions. In the mornings of rainy days, in respiration and cardiac rates, there were no variations between treatments. Secondly, the rectal temperature of the unshaded calves were significantly lower ($P < 0.01$) than the shaded calves in the mornings of rainy days. It is but logical that the environment in the open, during the mornings of rainy days is much more cooler than the environment inside the calf house. Eventhough there was no significant difference between the shed and open yard in minimum temperature, drenching in rain and exposure to more air movement was most certain to facilitate greater thermolysis in the exposed calves.

This seems to be reflected in the physiological reactions in the rainy period mornings. In all other days the exposure to direct solar radiation added to the thermal stress and resulted in enhanced physiological reactions.

The higher physiological reactions of the calves in the open can be attributed to higher effective temperature caused by direct solar radiation as stated by Williams et al.(1960), Harris et al.(1960) and others. While the unshaded calves, during the hot dry and rainy periods were subjected to a mean total radiation of 365.18 and 297.57 mWcm^{-2} respectively during the day-time, they were subjected to 267.66 and 236.00 mWcm^{-2} during the night. It can be seen that during the nights also, the animals were subjected to much radiation. This might be due to long-wave radiation emanating from the ground and a number of buildings surrounding the open area and the shed.

f) Effect of type of feeding:

Comparing the means of the physiological reactions between concentrate feeding and roughage oriented feeding treatments, both for the hot-dry and rainy seasons, no significant variations could be found except with respiration and cardiac rates in the mornings of rainy period. The respiration and cardiac rates were found to be significantly higher in the concentrate-fed groups.

However, the magnitudes of these increases in the concentrate-fed groups in the mornings do not have much physiological significance as the values in all the four groups in the mornings are within normal range during the rainy period.

III. GROWTH:

The fortnightly values of live weight, body length, body height and girth were subjected to analysis of covariance. It was observed that right from the first fortnight, differences in gains of these parameters existed between treatment groups. The analysis revealed significant differences in certain fortnights only. Nevertheless the trends remained the same during all the fortnights. Table 1.11 represents the initial value, final value and the gains obtained in these variables. It can be seen that maximum gains in live weight, height and girth were obtained by the calves exposed to solar radiation and fed roughage oriented ration (Fig.1.4). However, the gain in length was the least in this group. The next best was the housed and concentrate-oriented feeding group which had the highest gain in length second highest gains in live weight and girth, but the lowest gain in height. These findings may seem contrary to normal expectations especially while taking into account the physiological reactions observed. It appears that

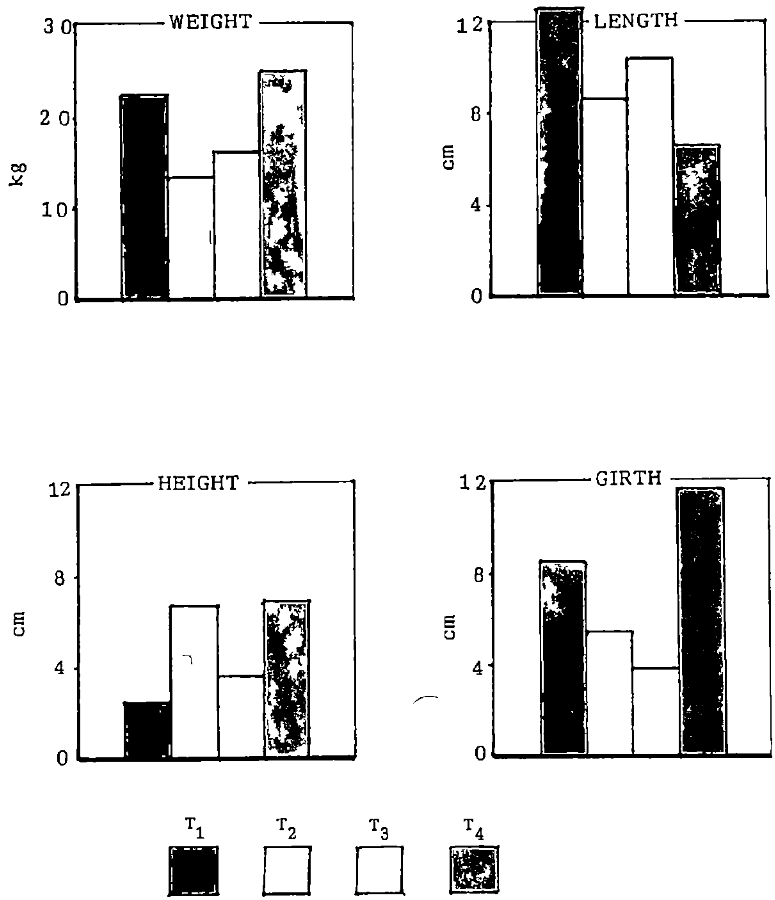
Table 1.11

The initial and final body weights in kg and body measurements in cm of the four treatment groups with total gains

Treatments	Body weight			Length			Height			Girth		
	Initial	Final	Gain	Initial	Final	Gain	Initial	Final	Gain	Initial	Final	Gain
T1	71.60	93.52	21.92	84.0	96.5	12.5	87.8	90.2	2.4	101.4	109.8	8.4
T2	72.24	85.44	13.20	86.0	94.6	8.6	85.0	91.6	6.6	101.0	106.3	5.3
T3	72.68	88.19	15.51	84.2	94.5	10.3	86.4	90.0	3.6	102.0	105.7	3.7
T4	67.28	91.86	24.58	86.0	92.6	6.6	85.2	92.0	6.8	95.4	107.0	11.6

GAINS IN BODY WEIGHT AND BODY MEASUREMENT

FIGURE 1 4



under housed conditions concentrate-oriented feeding and under exposed conditions roughage-oriented feeding favour better growth. It will be very difficult to give the reasons for such findings without investigating rumen fermentation, rate of passage and availability of 'bye-pass' proteins. It may be that exposure to solar radiation changes the rumen fermentation in such a way that the proteins in concentrates are wasted to a greater degree than the leaf proteins available in roughage-oriented feeding.

It is also interesting to note that gains in length and height behaved differently between the groups. Heifers that remained inside the shed (Groups T1 and T3) had higher gain in body length but lower gain in body height compared to heifers kept unsheltered (Groups T2 and T4). Whether it is a real difference due to the treatments and if so the reasons for the same can only be known by more detailed investigations.

Overall, it was observed that housing in open conditions increased physiological reactions significantly. But these increases were not physiologically meaningful to cause retardation of growth. Under exposed conditions, calves seem to grow faster on a roughage-oriented feeding incorporating leguminous forage than on concentrate-oriented feeding.

SECTION 2 - COWS

MATERIALS AND METHODS

a) Design of experiment:

The experiment was conducted at the University Livestock Farm, Mannuthy, from 9-3-88 to 8-11-88, comprising of eight periods of one month each. The recording of climatic data started from 22-3-88 and presented for 33 weeks till 8-11-88, 15 weeks for early lactation period and 18 weeks for late lactation period.

The crossbred cows available in the farm were utilized for the study. Eight cows that had calved within one month of commencement of the study were selected. These cows were divided into two groups based on their milk yield. The particulars of the cows utilized in the experiment are furnished below:

Group No.	Sl. No.	Cow No.	Date of birth	Date of calving	Daily milk yield in kg at the time of grouping
I	1	126	09-08-84	05-02-88	6.7
	2	096	03-05-80	13-22-88	5.4
	3	655	07-05-75	07-02-88	12.9
	4	159	08-12-84	19-02-88	6.9
II	5	290	11-04-82	15-02-88	2.5
	6	091	27-04-83	22-02-88	6.5
	7	080	17-03-80	13-02-88	8.8
	8	231	12-06-81	11-02-88	12.4

The cows of group I were kept in the open exposed to direct solar radiation while group II cows were housed in a tile-roofed shed. At the end of every month the groups were interchanged and the whole experiment was planned in a switch back design.

b) Management:

The cows that were exposed to direct solar radiation treatment, were tethered in an open paddock day and night without shade. The protected group, was tied in a conventional type of cow shed with tiled roof and open ventilation.

The cows under both the treatments were provided with weighed quantity of concentrates in individual feed troughs twice daily. The concentrate ration was the cattle feed mash supplied by "Milma", the Kerala Livestock Development and Milk Marketing Board. The quantity of feed supplied was as per the standards prescribed. The cows were given 2.0 kg of concentrates daily to meet maintenance requirements. In addition, for every 2.5 kg or part thereof of milk produced, 1.0 kg of concentrate was given. Daily concentrate requirement was worked out every fortnight based on average milk production during that period.

Drinking water was provided twice daily after concentrate feeding in individual water troughs.

Green grass obtained from the farm was fed *ad libitum* to all the cows twice daily.

Milking was by hand milking with trained milkmen and was done twice daily, once at 0400 h and again at 1530 h. During later stages of lactation, milking was for only once a day at 1100 h. The calves were weaned at the time of birth.

All the cows were individually weighed every month on the day when they were switched over to the next treatment.

c) Recording of data:

The procedure for recording of climatic data was as explained in section 1.

The physiological variables like the cardiac rate, respiration rate, rectal temperature and skin temperature of the individual cows were measured and recorded twice in a day, once at 0800 h and again at 1400 h, two days in a week. The procedure followed is explained in Section 1.

The twice daily milk yields of the cows were measured by individually weighing the quantity in kg at each milking.

The concentrate feed consumption was calculated by feeding the cows with prescribed quantity by individually weighing the feed twice daily and feeding to each of the cows. There were no left overs.

The water consumption was measured two days in a week by providing measured quantities of water in individual buckets to each of the cows and measuring back the left overs. Measured quantities were repeatedly supplied till the cows refused water.

The grass consumption was assessed two days in a week by providing weighed quantities of fresh green grass to individual cows and weighing back of left overs of the morning feeding in the afternoons and afternoon feeding on the next day morning.

Milk samples were collected once in a week for laboratory analysis, separately for individual cows and at each milking, following standard procedures. The individual milk samples were immediately analysed for fat and protein contents.

For milk fat analysis, Gerber's method was followed. Each of the cow's milk was analysed separately, carrying out duplicate analysis wherever necessary.

Milk protein content was determined by the dye-binding method using the spectrophotometer available in the laboratory, as suggested by Dolby (1961). Individual cow's milk was analysed separately for its protein content and recorded.

d) Analysis of the data:

The statistical analysis of the climatic and physiological variables were carried out as per the methods suggested by Snedecor and Cochran (1967).

The production data were analysed by the method suggested for reversal designs by Gill (1978).

To find out the effect of climatic variables on physiological responses, the multiple linear regression analysis (Heady et al., 1964) was used.

The functional model:

The physiological reactions such as cardiac rate, respiration rate, rectal and skin temperatures were considered to depend on the prevailing air temperature, solar radiation, relative humidity, wind velocity, vapour pressure, and rainfall (Bianca, 1965; McDowell, 1972; Clark, 1981). The variables that were incorporated in the model to estimate the factor-product relationship were:

CR: Cardiac rate per min recorded at 0800 h and at 1400 h for individual cows and computed at arithmatic mean.

RR: respiration rate per min recorded at 0800 and 1400 h of the individual cows and computed at arithmatic mean.

RT: rectal temperature of individual cows recorded in degrees celsius at 0800 and 1400 h and computed at arithmatic mean.

ST: skin temperature in degrees celsius recorded for the individual cows and computed at arithmatic mean.

T: environmental temperature measured daily in degrees celsius, computed at the arithmatic mean of maximum and minimum of day temperature.

S: total radiation in $m.cm^{-2}$ of the upper and lower hemispheres taken at hourly intervals every day and computed at the arithmatic mean.

G: temperature measured daily in celsius with a black globe and computed at the arithmatic mean of the 0800 h and 1400 h recordings.

H: relative humidity measured daily in percentage and computed as the arithmatic mean of 0800 and 1400 h recordings.

W: wind velocity in m per sec measured daily and computed at the arithmatic mean of the recordings done at 0800 h and 1400 h.

V: vapour pressure measured daily in mm of Hg and computed at the arithmatic mean of 0800 and 1400 h recordings.

R: total weekly rainfall measured in mm.

The linear form was specified as:

$$CR = a + b_1T + b_2S + b_3H + b_4W + b_5V + b_6R + u$$

where the variables were as defined earlier and a, b_1, b_2, b_3, b_4, b_5 and b_6 were the parameters to be estimated and u the error term. Similarly, the dependent variable cardiac rate (CR) was replaced by other dependent variables, RR, RT and ST in the series of analysis, to find the effect of the explanatory variables on each of the above. The function was estimated by Ordinary Least Square (OLS) method with classical normal assumptions (Gujarati, 1978). The OLS method gives R^2, the coefficient of multiple determination which explains the proportions of variation in the dependent variable as explained by the set of explanatory variables. It permits easy application of covariance analysis to test the homogenicity of set of regression equations and also has computational convenience and wide application.

't' and 'F' statistics were used to evaluate the precision of estimates of parameters and significance was evaluated at five and one per cent levels of probability.

RESULTS

The monthly recording of body weights of the experimental cows taken at each of the treatment switch overs are tabulated and presented in Table 2.1.

The experimental cows had started with higher body weights and during the course of the experiment, there was a uniform reduction in body weights of all the cows as lactation progressed and towards the end of the experiment, the cows had shown a tendency to regain body weights irrespective of the type of treatment given.

I. CLIMATIC FACTORS:

a) Early lactation period:

The weekly means of the climatic factors recorded during the early lactation period and the results of paired 't' test between the shaded and unshaded locations for the climatic factors are presented in Table 2.2 and Figures 2.1 and 2.2.

The mean maximum temperature recorded in the shaded and unshaded locations were 30.36 and 35.72°C respectively, the difference between locations being highly significant ($P < 0.01$). The minimums were 23.83 and 23.37°C for the two locations in that order, with no statistical difference.

Table 2.1

The body weight in kg of the experimental cows

Cow No.	Date of weighment								
	8.3.88	9.4.88	10.5.88	9.6.88	9.7.88	9.8.88	9.9.88	9.10.88	9.11.88
126	295.0	279.0	275.2	258.8	275.0	280.0	285.6	274.6	275.6
096	329.5	299.0	307.8	292.0	280.0	298.0	309.0	301.0	309.0
655	281.5	256.8	257.2	244.0	263.4	256.0	264.0	270.8	261.2
159	267.0	249.6	248.0	239.0	250.4	229.8	234.4	235.6	238.0
290	260.0	250.2	262.8	251.0	260.0	261.4	268.2	259.0	247.4
091	275.5	247.0	258.4	252.6	262.0	258.2	254.8	250.2	243.0
080	273.0	250.6	234.0	243.0	252.0	241.6	247.0	242.0	234.0
231	301.5	287.4	283.6	272.0	298.6	300.0	298.0	280.4	276.2

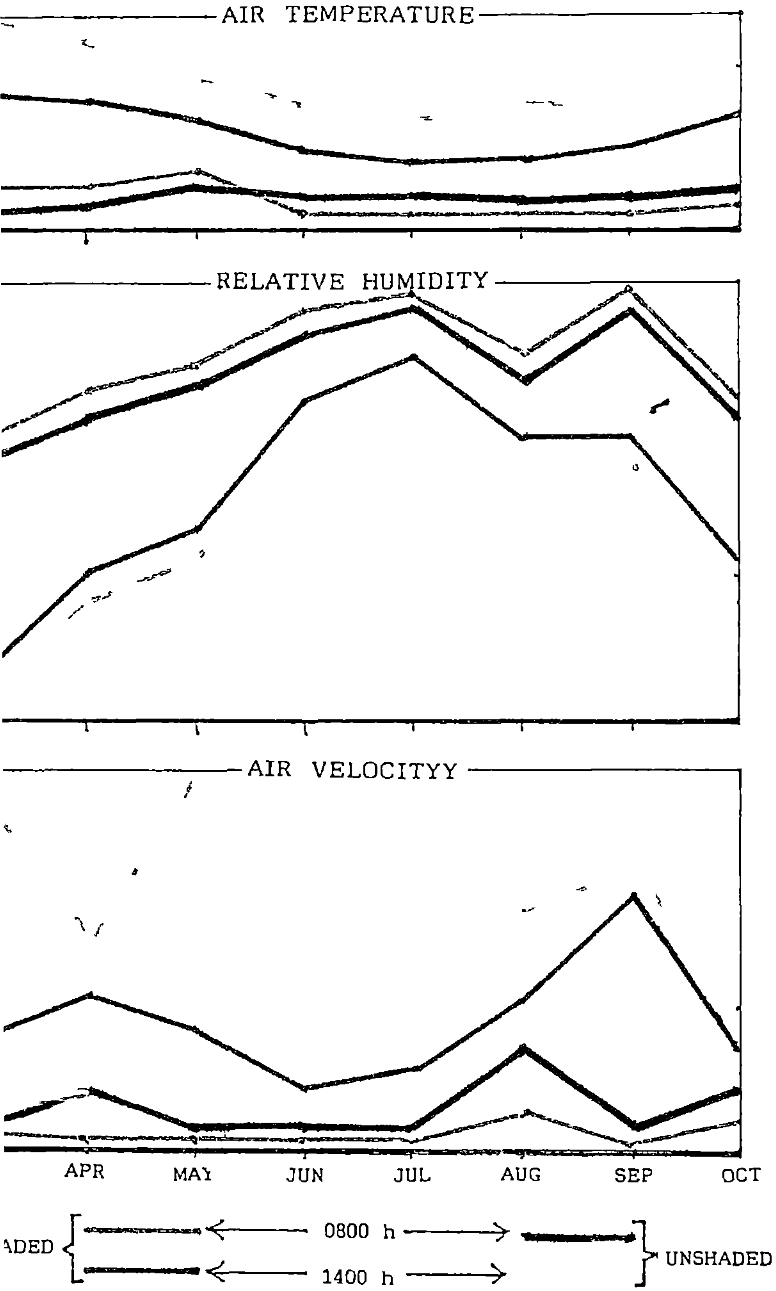
Table 2.2

Weekly means of the climatic factors recorded during the early lactation period in the shaded and unshaded locations

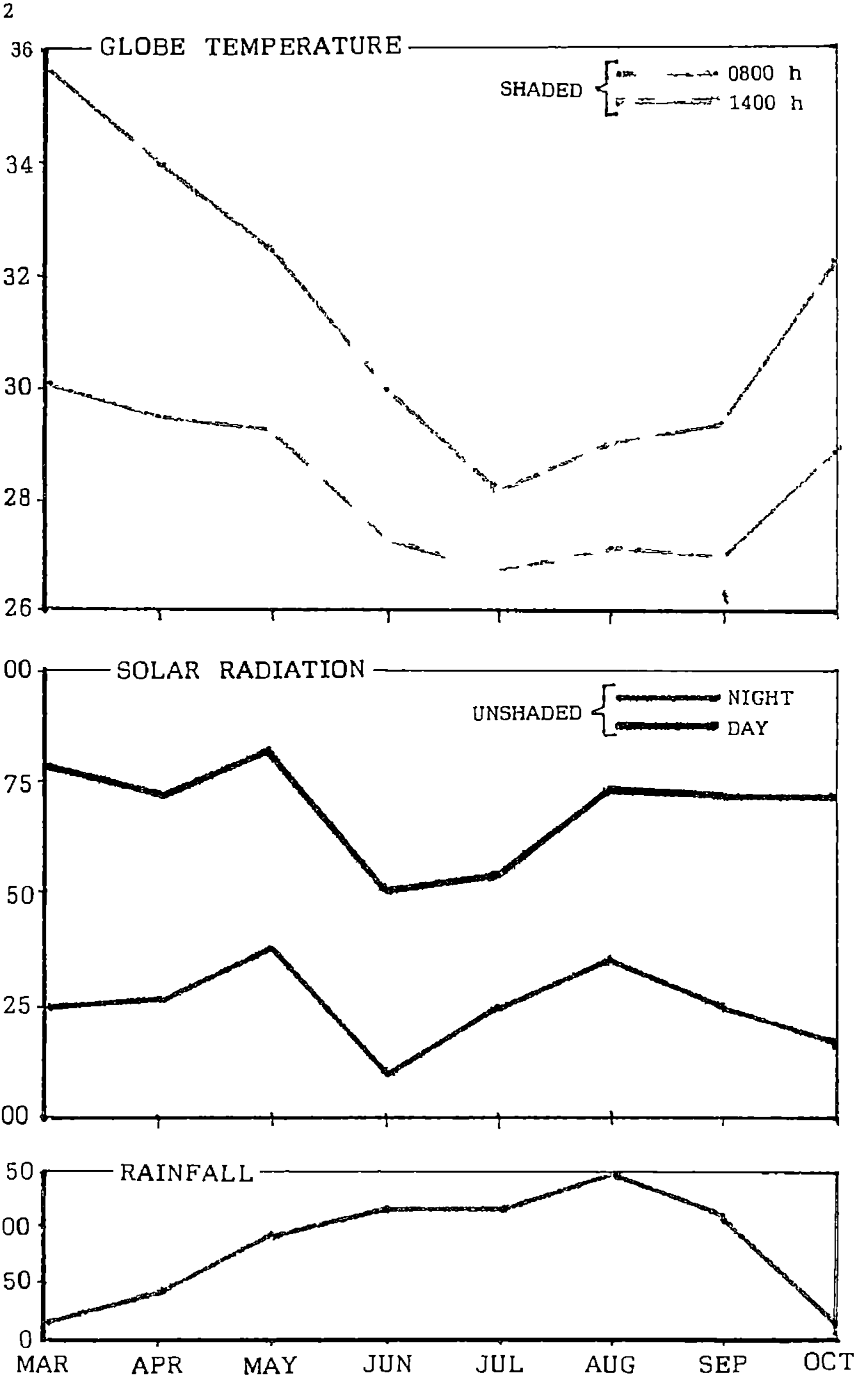
WEEKS	Air temperature (°C)				Relative humidity (per cent)				Wind velocity (m/s)				Vapour pressure (mm of Hg)				Globe temperature (°C)		Hourly mean total radiation in mWcm^{-2}		Total weekly rain fall mm
	Maximum		Minimum		0800 h		1400 h		0800 h		1400 h		0800 h		1400 h		0800h	1400h	day	night	
	Shaded	Un-shaded	Shaded	Un-shaded	Shaded	Un-shaded	Shaded	Un-shaded	Shaded	Un-shaded	Shaded	Un-shaded	Shaded	Un-shaded	Shaded	Un-shaded	Shaded		Un-shaded		Un-shaded
1	32 51	39.83	24 66	22.24	74 57	72.86	49.33	47 83	0.007	0 160	0.180	0 580	22 45	22 66	20.50	21 46	30.00	36.42	163 74	117.16	2.10
2	32 24	40.20	24 56	21.16	75.71	73.57	54 57	54.29	0.007	0 040	0 280	0.890	23.29	23 75	22 05	23.47	30.43	35 57	194 88	122.64	0.00
3	33 16	41 27	23 69	20.07	70.00	74.43	58 29	55.57	0.007	0.080	0.170	0.460	23.32	23 67	23.22	23 24	30.00	35 00	172.56	128 79	47.80
4	31 64	40.10	23 70	20.70	82.57	78.71	62.40	60 40	0.000	0.030	0.800	0.470	23 65	23 88	24.33	24.69	29 14	34 30	160.70	117 69	85 80
5	32 24	37 79	23 56	23 56	79 43	76 86	60.17	55 50	0 030	0.340	0.020	0.240	23.34	23 50	23 29	23 98	29 57	34 17	178 77	126 93	7.40
6	31 78	36.53	23.44	24 50	76 43	73 57	64 86	63 57	0 020	0.050	0.110	0 370	22 45	22.35	23 98	24 54	29 50	33 64	170 22	129 19	40.60
7	31 40	35 57	25 09	25 79	83 43	81 00	67 67	64 83	0.000	0 010	0.240	0.550	25.40	25 76	24 87	25 98	29 93	34 00	180.45	131 51	4 40
8	31 46	35 57	24 87	25 29	79 71	78.00	60.80	58.60	0.030	0.150	0.270	0.790	24 79	25 32	23 22	24 31	30.43	34 30	195.54	14[illegible] 34	4 00
9	31 74	35 86	25 36	25 93	78.29	78 29	56 57	55 00	0 007	0.040	0.470	0.970	24 21	24 77	21 92	22 58	30.21	34 29	187 98	139 21	1 80
10	29 51	33 50	27 43	24 57	84 00	82 57	70.57	68.29	0.020	0.070	0.130	0.560	24 10	24 33	24 56	25 04	29 29	31 86	174 48	128.80	195 40
11	27 81	33 07	22 86	24 07	88 00	86 00	81 00	78 33	0 000	0 020	0 080	0 250	23 49	23 52	24 56	24 87	27 29	29 50	170.35	13[illegible] 74	174 50
12	26 94	30 93	22 40	23 50	89.57	87 57	82 16	82 66	0.020	0 050	0.150	0 540	24 18	24 41	25 15	25.12	27 57	29.00	99.70	83 78	184 40
13	28 17	32 21	22 65	23 57	86 71	84 57	80.33	79.00	0.000	0 007	0 120	0.300	23 75	24 21	24 33	24 46	28 07	29 50	135 76	1 0.95	56.80
14	27 11	31 36	21 61	23 00	88 57	86 57	79 57	78.86	0.000	0 000	0.030	0 130	22 76	23 34	23 65	24 56	27 14	29 36	143 75	126.59	209 30
15	27 71	32 00	21.60	22 71	85 43	84 00	75 00	71 00	0 000	0 030	0.140	0 350	21 41	21 95	23 09	23 55	26 64	30 00	187 36	124 14	29 90
Mean	30 36	35 72	23 83	23 37	81 96	79.90	66 89	64 92	0 010	0 072	0 213	0 497	23 50	23 83	23.52	24 13	29 02	32 73	167 75	124 64	69 61
't' value	-12 18**		1 14		9 36**		5 63**		-2 [illegible]8**		4 83**		-6.45**		5 58**						

** Significant at I per cent level (P < 0 01)

1


AIR TEMPERATURE
RELATIVE HUMIDITY
AIR VELOCITYY
APR
MAY
JUN
JUL
AUG
SEP
OCT
0800 h
1400 h
UNSHADED

RECORDED DURING THE EXPERIMENTAL PERIOD



The relative humidity recorded at 0800 h in the shaded location was 81.96 per cent compared to 79.90 per cent in the unshaded location. At 1400 h recording the mean relative humidity obtained was 66.89 and 64.92 per cent respectively. By paired 't' test, it was found that the differences in relative humidity prevailed both at 0800 and 1400 h between the shaded and unshaded locations were highly significant ($P < 0.01$), with the values recorded in the unshaded location lower than that of shaded location.

The means of the wind velocity were 0.010 and 0.213 m per sec in the shaded location at 0800 and 1400 h respectively. The same were higher in the unshaded location with means of 0.072 and 0.497 m per sec at 0800 and 1400 h. By statistical analysis highly significant ($P < 0.01$) differences were found in wind velocities between locations at recordings both at 0800 and 1400 h.

The vapour pressure means were 23.50, 23.83, 23.52 and 24.13 mm of Hg for 0800 h recording at shaded and unshaded and 1400 h recording at shaded and unshaded locations respectively. Statistical analysis revealed highly significant ($P < 0.01$) differences in vapour pressure between locations, both during morning and afternoon recordings.

The mean globe temperature recorded in the shaded location was 29.02°C at 0800 h and 32.73°C at 1400 h. The globe temperature values were found to be always higher by approximately 2.0 to 5.0°C than the ambient air temperature.

The hourly mean total radiation (inclusive of long wave infra-red) recorded in the unshaded location was 167.75 mwcm^{-2} during the day and 124.64 mwcm^{-2} during nights.

Out of 15 weeks of recording during the early lactation period, the total weekly rainfall ranged from no rains during the second week to 209.30 mm during the 14th week. The mean weekly total rainfall recorded was 69.61 mm.

b) Late lactation period:

The weekly means of the climatic factors recorded during the late lactation period from 16th to 33 weeks and the results of paired 't' test between the experimental locations are presented in Table 2.3 and Figures 2.1 and 2.2.

The mean maximum temperature in the shaded location was 27.80°C and the same was 32.18°C in the unshaded location. The mean minimum temperature was 22.03°C in

Table 2 3

Weekly means of the climatic factors recorded during the late lactation period in the shaded and unshaded locations

WEEKS	Air temperature (°C) Maximum Shaded	Air temperature (°C) Maximum Un-shaded	Air temperature (°C) Minimum Shaded	Air temperature (°C) Minimum Un-shaded	Relative humidity (per cent) 0800 h Shaded	Relative humidity (per cent) 0800 h Un-shaded	Relative humidity (per cent) 1400 h Shaded	Relative humidity (per cent) 1400 h Un-shaded	Wind velocity (m/s) 0800 h Shaded	Wind velocity (m/s) 0800 h Un-shaded	Wind velocity (m/s) 1400 h Shaded	Wind velocity (m/s) 1400 h Un-shaded	Vapour pressure (mm of Hg) 0800 h Shaded	Vapour pressure (mm of Hg) 0800 h Un-shaded	Vapour pressure (mm of Hg) 1400 h Shaded	Vapour pressure (mm of Hg) 1400 h Un-shaded	Globe temperature (°C) 0800h Shaded	Globe temperature (°C) 1400h Shaded	Hourly mean total radiation in m cm⁻² day Un-shaded	Hourly mean total radiation in m cm⁻² night Un-shaded	Total weekly rain fall mm Un-shaded
16	27 86	32 07	22.10	23 29	84 43	82 14	74 86	72 86	0.030	0 070	0.140	0.370	22 02	22 35	22 66	23 67	27.29	29 93	174 49	135.27	45.50
17	25.37	29 36	21.76	22.93	93.14	91.57	87 60	87 00	0.030	0.070	0.110	0.470	23.09	23.09	23.37	23 85	26 71	27 50	134.65	122 12	193 90
18	25.47	30.42	21.28	22.33	88.80	87.20	87.25	86 50	0.000	0.010	0.100	0.540	22.33	22.35	22 22	22.02	26.17	25 83	118 60	97.67	210.30
19	26 96	30 93	22 33	23 57	88.25	87.75	82 17	80 67	0.010	0 030	0.140	0.330	23.62	23 72	23.19	24.18	27 00	28 93	186.09	145.26	74 50
20	26 96	30.71	22 40	23.43	92 14	91.14	85.14	82.14	0 020	0.040	0 280	0.450	23 67	23.44	23 65	23 98	27 00	28 57	157 51	125.09	74 20
21	26 42	31 16	21 20	23 00	84 00	84 57	79 29	76 71	0 007	0 070	0 100	0 140	21.38	22 12	22 78	22 99	26 71	28 79	178 42	144.52	80.20
22	26 60	30 62	21 60	23.12	87 20	86.00	79 00	76.00	0 200	0.090	0.360	0.360	23.22	23.21	23.06	23.85	27 30	28 80	142 72	120.56	168 70
23	27.55	32 75	21.00	22 25	82 50	82 00	78 50	77 50	0 130	0 500	0.450	1.000	22 07	22.45	23 19	23.55	27 00	29 50	191 55	135 04	139.80
24	27 30	32 07	21 79	23 21	81 00	76 00	66.00	66.00	0.050	0.100	0.220	0.310	20.59	20 96	19 22	19 89	27 50	28 90	180 17	129 23	214.50
25	27 71	32.21	22 21	23 57	88 33	87 67	70 50	62 53	0.040	0.070	0.590	0.670	23 01	24 38	23 37	23 95	26 93	29.79	183 15	131 06	57 40
26	27 26	32 07	21 96	23 21	91 00	89 85	82 50	79 83	0 040	0.040	0 160	0 220	23 75	23 55	24 43	24 99	26 93	29 08	159.27	117 54	208.40
27	26 65	31 29	21 93	22 50	92.43	93.14	80.20	79 60	0.007	0.007	0.540	0.440	23 19	23 19	24 16	24 48	26 21	28 50	157 67	127 09	220.50
28	27 87	31 93	22 00	23 21	88 86	85 29	74 17	75.33	0 030	0 050	0 800	0.860	23 42	23.31	23 01	23 55	27 21	29 75	182 99	126 82	70.10
29	28 81	32 71	22 26	23.50	88 29	87 29	73.33	72 83	0.010	0 040	0.320	0.410	24 27	24 57	23 65	23 93	27 71	30.33	181 68	123 73	21.40
30	31 10	35 80	22.30	23 00	76 50	76 50	63 50	63.00	0 000	0 000	0.130	0 180	23 19	23 19	24 71	25 12	29 50	33.50	172 93	107 59	0.40
31	29.96	33 79	22 63	23 57	82 83	85 17	62 57	64 67	0 020	0.030	0 480	0.510	23 19	23 52	22.43	23 55	28 50	30 67	176 60	121 57	6 80
32	30.26	35 21	22 13	23 00	75 86	78 29	68 40	65 60	0.080	0.110	0.070	0.110	22 86	22 19	22 76	22 94	28 71	31 60	179 03	124 58	61.00
33	30 34	34 14	23 67	24 29	78 00	77 86	63 17	61 33	0 1[illegible]0	0 310	0 100	0 260	21 71	21 64	22 76	22 40	28 79	33 58	156 39	117 35	6 80
Mean	27 80	32.18	22 03	23 17	85 75	84 97	75 45	73 89	0 046	0 126	0 283	0 424	22 81	25 96	23 03	23 50	27 40	29 64	167 44	125 62	103.02
't' value	39 19**		22 25**		1 85		3.10**		1 98		3 65**		1 58		5 06**						

**Significant at 1 per cent level (P<0 01) the shaded and 23.17°C in the unshaded place. By paired 't' test, highly significant differences ($P < 0.01$) were found between shaded and unshaded places in both maximum and minimum temperatures recorded.

The mean relative humidity prevailed at 0800 h recording in the shaded location was 85.75 per cent compared to 84.97 per cent in the unshaded location. There was no statistical difference between locations in relative humidity percentage in the mornings. At 1400 h recording, the relative humidity values were 75.45 and 73.89 per cent respectively for shaded and unshaded places, the difference being highly significant ($P < 0.01$) among locations, with the relative humidity around the animals in the shaded place showing higher values in the afternoons.

The mean wind velocity was 0.046 m per sec at 0800 h and 0.283 m per sec at 1400 h in the shaded place. The respective values for unshaded place were 0.126 and 0.424 m per sec. Statistical analysis did not reveal any significant difference in wind speed between locations at 0800 h recording but this difference was found to be highly significant ($P < 0.01$) during the 1400 h recording, the air velocity in the unshaded location being almost double as that of the shaded place in the afternoons.

There was no significant difference in vapour pressure recorded at 0800 h between locations, the mean values being 22.81 and 22.96 mm of Hg in the shaded and unshaded locations respectively. The difference in the mean vapour pressure values of 1400 h recording between locations was highly significant ($P < 0.01$), with mean vapour pressure of 23.04 and 23.50 mm of Hg respectively in shaded and unshaded places.

The globe temperature at 0800 h in the shaded location ranged from 26.17 to 28.79 with a mean of 27.40°C. The range for 1400 h recording was 25.83 to 33.58 and the mean was 29.64°C.

In the unshaded location, the hourly mean total radiation during day time was 167.44 and during night time 123.62 mWcm^{-2}.

The minimum rainfall recorded during the late lactation period was a weekly total of 0.40 mm during the 30th week and the maximum amount of 220.50 mm of rains was recorded during the 27th week of the experiment. In general, there was more rain during the late lactation period compared to early lactation period with a mean weekly total of 103.02 mm.

II. PHYSIOLOGICAL REACTIONS:

a) early lactation period:

The means of the cardiac rate, respiration rate, rectal temperature and skin temperature of the experimental cows for the 0800 h and 1400 h recordings during the early lactation period, along with the results of statistical analysis are presented in Tables 2.4 to 2.11 and Figure 2.3.

The mean cardiac rates of the cows recorded during the forenoons were 60.73 and 63.12 per min respectively for shaded and unshaded cows with no statistical difference between them. The cardiac rates in the afternoons were 74.41 and 85.93 per min respectively for the cows remaining in the shade and for those that were in the unshaded location. By statistical analysis, a highly significant ($P < 0.01$) difference was found between treatments.

The means of the respiration rates during the forenoons were 32.25 for shaded cows and 37.83 per min for the unshaded cows, the difference between treatments being significant ($P < 0.05$). During the afternoons, the respective values were 48.86 and 84.65 per min, with the cows in the unshaded location recording double the respiration rate than that of the shaded ones the difference between treatments, being highly significant ($P < 0.01$).

During the forenoons, the mean rectal temperatures recorded were 38.69°C for the shaded cows and 38.49°C for

Table 2.4

Mean cardiac rates per minute of the cows on the forenoons during the early lactation period

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	71.0	65.0	63.3	59.0
	096	56.7	53.5	53.3	56.6
	655	59.0	57.5	57.5	56.8
	159	63.7	60.0	60.0	59.6
		Shaded	Unshaded	Shaded	Unshaded
II	290	65.3	74.3	72.3	66.4
	091	57.0	64.8	65.5	62.0
	080	58.7	67.3	63.8	61.6
	231	57.3	64.8	63.8	62.2

Mean values: Shaded : 60.73

Unshaded : 63.12

't' value: 1.36

Table 2.5

Mean cardiac rates per minute of the cows on the afternoons during the early lactation period

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	96.0	78.5	82.3	71.8
	096	83.7	70.0	71.3	71.6
	655	84.0	76.6	72.8	68.2
	159	85.3	71.0	81.3	72.8
		Shaded	Unshaded	Shaded	Unshaded
II	290	72.7	113.3	81.5	83.8
	091	66.0	97.3	80.5	78.5
	030	73.7	104.3	83.3	87.6
	231	69.3	125.8	82.8	80.2

Mean values: Shaded : 74.41

Unshaded : 89.53

't' value: 3.27**

Table 2.6

Mean respiration rates per minute of the cows on the forenoons during the early lactation period

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	38.0	36.3	41.5	23.8
	096	34.7	31.3	31.8	28.6
	655	43.0	31.0	35.5	28.4
	159	46.3	27.5	33.0	28.4
		Shaded	Unshaded	Shaded	Unshaded
II	290	32.3	52.3	40.0	30.8
	091	31.0	41.3	39.3	24.8
	080	34.7	52.0	37.3	26.8
	231	31.7	45.5	34.5	28.0

Mean values: Shaded : 32.25

Unshaded : 37.83

't' value: 2.30*

[illegible]

Table 2.7

Mean respiration rates per minute of the cows on the afternoons during the early lactation period

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	100.3	53.3	73.8	39.2
	096	98.0	45.8	68.5	43.0
	655	91.3	46.3	65.8	42.4
	159	89.7	49.5	69.8	41.4
		Shaded	Unshaded	Shaded	Unshaded
II	290	59.7	103.8	54.5	83.4
	091	52.0	73.5	49.5	69.3
	080	56.0	103.3	43.5	73.4
	231	48.7	120.3	53.0	70.2

Mean values: Shaded : 48.86

Unshaded : 84.65

't' value. 3.16**

**Significant at 1 per cent level (P< 0.01)

Table 2.8

Mean rectal temperature in degrees celsius of the cows on the forenoons of early lactation period

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	38.78	39.15	38.65	38.69
	096	38.32	38.55	38.34	38.85
	655	38.38	38.26	38.29	38.27
	159	38.48	38.51	38.35	38.59
		Shaded	Unshaded	Shaded	Unshaded
II	290	38.97	38.70	38.55	38.55
	091	39.08	38.55	38.88	38.76
	080	38.43	38.59	38.54	37.69
	231	38.93	38.96	39.30	38.39

Mean values - Shaded : 38.69

Unshaded : 38.49

't' Value: 1.97

Table 2.9

Mean rectal temperature in degrees celsius of the cows on the afternoons of early lactation period

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	40.32	39.29	39.83	38.94
	096	40.48	39.46	39.69	39.32
	655	41.17	39.08	39.85	38.90
	139	40.53	39.43	39.85	39.25
		Shaded	Unshaded	Shaded	Unshaded
II	290	39.43	40.68	39.28	40.16
	091	39.45	40.81	39.99	40.16
	080	39.23	40.18	39.11	39.26
	231	39.57	41.64	40.03	40.35

Mean values:- Shaded : 39.42

Unshaded : 40.31

't' value: 5.28**

**Significant at 1 per cent level ($P < 0.01$)

Table 2.10

Mean skin temperature in degrees celsius of the cows on the forenoons during the early lactation period

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	39.75	39.03	39.00	39.18
	096	39.96	39.13	39.07	39.50
	655	39.88	39.07	39.13	39.28
	159	40.00	39.26	39.28	39.35
		Shaded	Unshaded	Shaded	Unshaded
II	290	38.59	40.07	39.38	39.33
	091	38.71	40.07	39.25	39.44
	080	39.17	40.38	39.38	39.23
	231	39.25	40.26	39.53	39.28

Mean values:- Shaded : 39.19

Unshaded : 39.63

't' value: 3.38**

**Significant at 1 per cent level ($P < 0.01$)

Table 2.11

Mean skin temperature in degrees celsius of the cows on the afternoons during the early lactation period

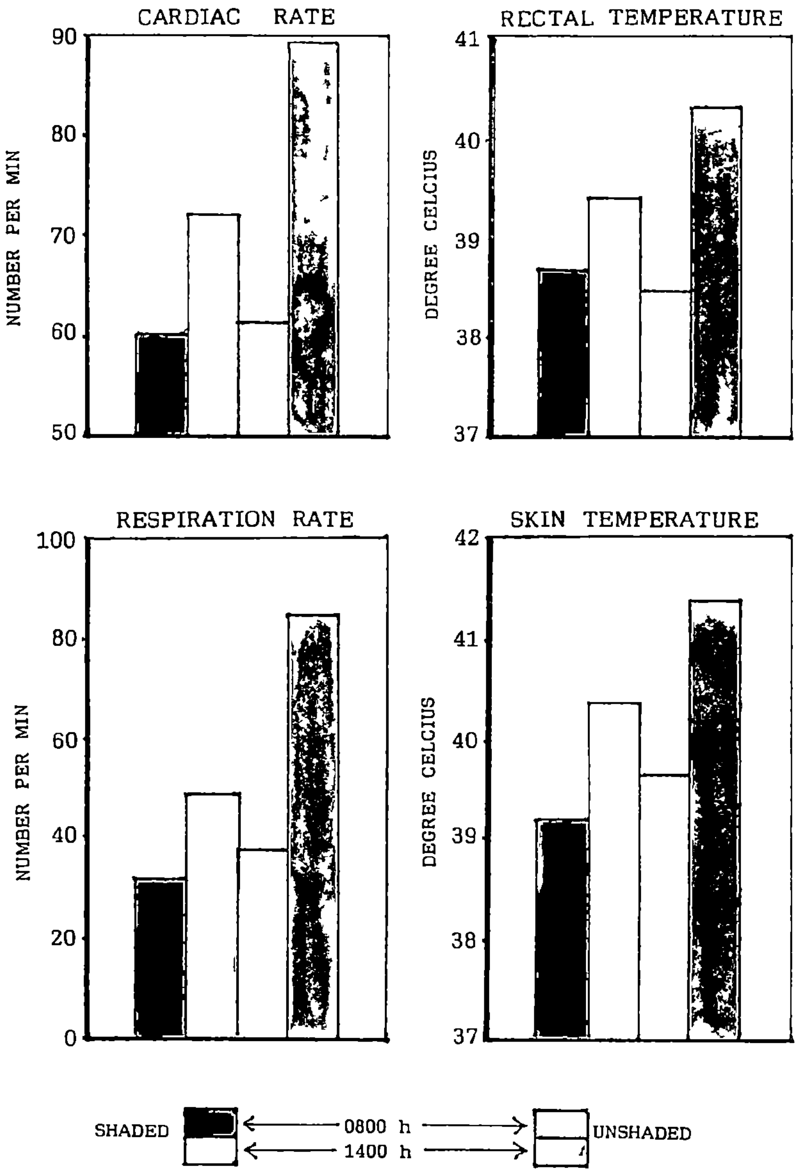
Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	42.04	40.47	40.88	39.75
	096	42.21	40.50	40.91	40.10
	655	42.04	40.38	41.19	39.95
	159	41.96	40.50	41.07	40.20
		Shaded	Unshaded	Shaded	Unshaded
II	290	40.79	41.63	39.91	40.70
	091	40.84	42.07	40.19	40.47
	080	40.88	41.85	40.16	40.68
	231	41.25	41.97	40.47	40.50

Mean values :- Shaded : 40.39
Unshaded : 41.38
't' value: 5.23**

**Significant at 1 per cent level ($P < 0.01$)

PHYSIOLOGICAL RESPONSES
DURING EARLY LACTATION PERIOD

FIGURE 2 3



the unshaded cows, the difference between treatments being non-significant. In the afternoons, the rectal temperatures recorded were 39.42 and 40.31°C respectively for the shaded and unshaded cows. By statistical analysis, the difference in rectal temperatures between treatments were found to be highly significant ($P < 0.01$).

The unshaded cows had recorded a higher mean skin temperature of 39.63°C compared to 39.19°C of the shaded ones during 0800 h recording and this difference was found to be highly significant ($P < 0.01$). The afternoon recordings revealed mean values of 40.39 and 41.38°C for shaded and unshaded cows and this difference was also found to be highly significant ($P < 0.01$).

b) <u>Late lactation period</u>:

The means of the above physiological reactions measured during the late lactation period are presented in Tables 2.12 to 2.19 and Figure 2.4.

The shaded cows had a mean cardiac rate of 55.80 per min and the unshaded, 58.63 during the forenoons. Statistical analysis did not reveal any significant difference. During the afternoons, the cardiac rates of the unshaded cows were higher with a mean of 72.24 compared to 64.33 per min of the shaded cows. A highly significant difference ($P < 0.01$) was noticed between the treatments.

Table 2.12

Mean cardiac rates per minute of the cows on the forenoons during the late lactation period

Group	Cow No.	Period 5	Period 6	Period 7	Period 8
		Unshaded	Shaded	Unshaded	Shaded
I	126	57.0	56.7	59.4	62.8
	096	55.5	54.7	51.8	52.0
	653	53.0	50.0	50.0	57.0
	139	55.3	53.3	58.8	55.0
		Shaded	Unshaded	Shaded	Unshaded
II	290	63.5	62.7	60.6	63.5
	091	56.3	58.0	53.0	61.0
	080	52.5	64.0	50.6	70.3
	231	58.5	60.7	56.4	57.0

Mean values:- Shaded : 55.80

Unshaded : 58.63

't' value: 1.73

Table 2.13

Mean cardiac rates per minute of the cows on the afternoons during the late lactation period

Group	Cow No.	Period 5	Period 6	Period 7	Period 8
		Unshaded	Shaded	Unshaded	Shaded
I	126	62.8	63.7	74.2	68.0
	096	64.3	56.7	73.0	60.0
	655	60.8	59.3	75.8	63.8
	159	63.8	58.0	72.8	65.5
		Shaded	Unshaded	Shaded	Unshaded
II	290	68.5	77.3	69.6	74.8
	091	63.3	72.3	67.4	77.8
	080	63.8	75.3	63.6	80.3
	231	67.8	75.3	70.4	75.3

Mean values:- Shaded : 64.33

Unshaded : 72.24

't' value: 4.36**

**Significant at 1 per cent level ($P < 0.01$)

Table 2.14

Mean respiration rate per minute of the cows on the forenoons of the late lactation period

Group	Cow No.	Period 5	Period 6	Period 7	Period 8
		Unshaded	Shaded	Unshaded	Shaded
I	126	24.3	19.0	24.0	23.3
	096	19.3	13.7	17.6	22.0
	655	19.3	15.7	19.2	22.3
	159	21.5	16.7	18.8	17.5
		Shaded	Unshaded	Shaded	Unshaded
II	290	23.0	23.3	18.0	53.5
	091	20.8	19.3	16.4	33.0
	080	20.0	18.6	14.8	48.5
	231	23.0	17.7	17.6	36.5

Mean values:- Shaded : 18.98

Unshaded : 25.90

't' value: 2.37*

*Significant at 5 per cent level ($P < 0.05$)

Table 2.15

Mean respiration rate per minute of the cows on the afternoons of the late lactation period

Group	Cow No.	Period 5	Period 6	Period 7	Period 8
		Unshaded	Shaded	Unshaded	Shaded
I	126	48.0	24.0	84.2	40.8
	096	44.5	22.0	81.0	30.0
	655	38.3	27.0	83.8	38.0
	159	39.3	20.3	77.2	28.3
		Shaded	Unshaded	Shaded	Unshaded
II	290	36.0	76.3	32.2	103.5
	091	39.3	45.7	26.0	81.8
	080	37.5	71.0	26.0	103.8
	231	39.3	63.0	26.2	109.5

Mean values:- Shaded : 30.81

Unshaded : 72.06

't' value: 6.76**

**Significant at 1 per cent level ($P < 0.01$)

Table 2.16

Mean rectal temperature in degrees celsius of the cows on the forenoons of late lactation period

Group	Cow No.	Period 5	Period 6	Period 7	Period 8
		Unshaded	Shaded	Unshaded	Shaded
I	126	38.43	38.77	38.16	38.83
	096	38.41	38.30	37.97	38.54
	655	37.76	37.87	37.40	38.06
	159	37.99	38.27	37.74	38.40
		Shaded	Unshaded	Shaded	Unshaded
II	290	38.74	38.23	38.83	38.55
	091	38.54	38.07	37.97	38.56
	080	37.94	37.87	37.89	38.11
	231	38.65	38.00	38.31	38.50

Mean values :- Shaded : 38.37

Unshaded : 38.10

't' value : 2.18*

*Significant at 5 per cent level ($P < 0.05$)

Table 2.17

Mean rectal temperature in degrees celsius of the cows on the afternoons of late lactation period

Group	Cow No.	Period 5	Period 6	Period 7	Period 8
		Unshaded	Shaded	Unshaded	Shaded
I	126	39.19	38.73	39.95	39.56
	096	38.95	39.03	39.80	39.21
	655	38.46	37.97	39.48	38.64
	159	39.45	38.63	40.05	39.04
		Shaded	Unshaded	Shaded	Unshaded
II	290	39.00	39.93	39.10	40.06
	091	38.89	39.53	39.02	40.31
	080	38.45	39.30	38.31	40.19
	231	39.13	40.03	39.00	41.09

Mean values:- Shaded : 38.85

Unshaded : 39.74

't' value: 4.88**

**Significant at 1 per cent level ($P<0.01$)

Table 2.18

Mean skin temperature in degrees celsius of the cows on the forenoons during the late lactation period

Group	Cow No.	Period 5	Period 6	Period 7	Period 8
		Unshaded	Shaded	Unshaded	Shaded
I	126	38.47	36.33	38.38	37.75
	096	38.56	36.42	38.20	38.06
	655	38.28	36.50	38.25	38.00
	159	38.50	36.33	37.83	37.88
		Shaded	Unshaded	Shaded	Unshaded
II	290	38.41	38.42	37.80	39.41
	091	38.31	38.50	37.95	39.50
	080	38.22	37.75	38.05	39.60
	231	38.41	37.75	37.85	39.50

Mean values:- Shaded : 37.64

Unshaded : 38.56

't' value: 3.69**

**Significant at 1 per cent level ($P < 0.01$)

Table 2.19

Mean skin temperature in degrees celsius of the cows on the afternoons during the late lactation period

Group	Cow No.	Period 5	Period 6	Period 7	Period 8
		Unshaded	Shaded	Unshaded	Shaded
I	126	39.57	38.33	40.73	39.41
	096	39.66	38.00	40.55	39.60
	655	39.35	38.67	40.58	39.35
	159	39.50	38.33	40.65	39.38
		Shaded	Unshaded	Shaded	Unshaded
II	290	39.47	38.67	39.43	40.88
	091	39.47	38.50	39.40	40.66
	080	39.32	38.25	39.23	41.16
	231	39.47	38.25	39.40	41.19

Mean values:- Shaded : 39.14

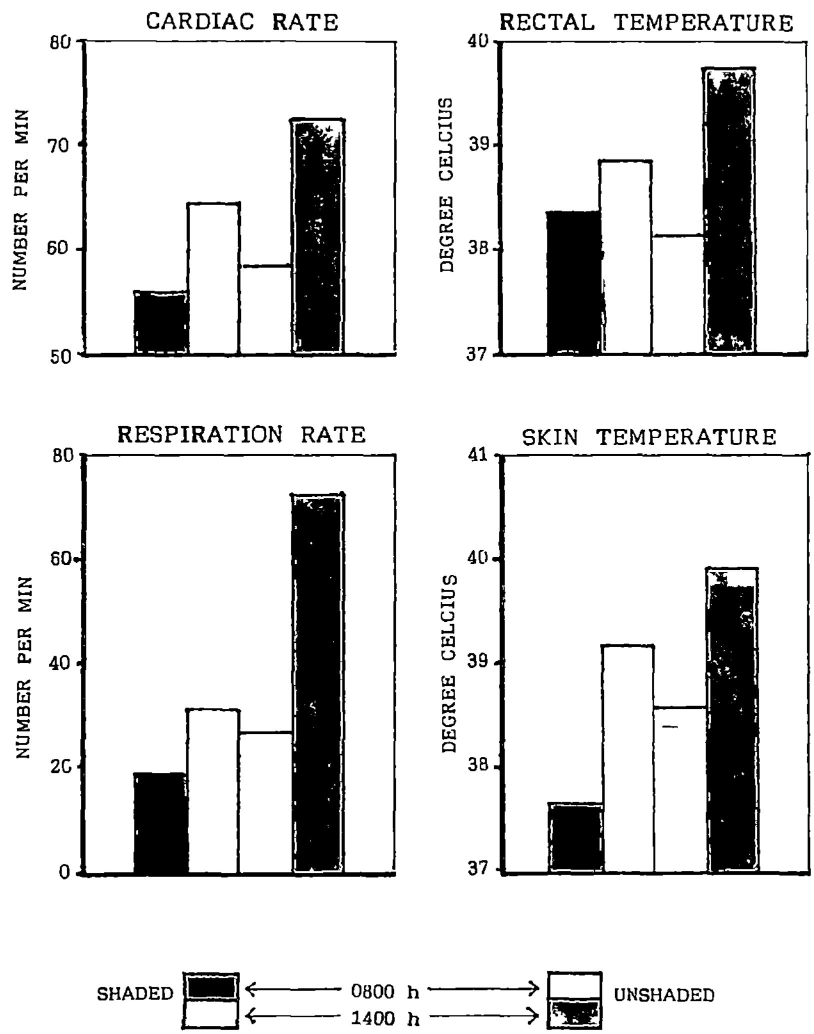
Unshaded : 39.88

't' value: 2.56*

*Significant at 5 per cent level ($P < 0.05$)

PHYSIOLOGICAL RESPONSES
DURING LATE LACTATION PERIOD

FIGURE 2 4



The mean forenoon respiration rates were 18.98 and 25.90 per min for shaded and unshaded cows respectively with significant ($P < 0.05$) difference between them. The afternoon respiration rates were 30.81 and 72.07 per min respectively and the difference between treatments was highly significant ($P < 0.01$).

The mean values of rectal temperatures at 0800 h recordings for the shaded and unshaded cows were 38.37 and 38.10°C respectively. By statistical analysis, it was found that the difference in rectal temperatures due to treatment was significant ($P < 0.05$), with the shaded cows recording higher rectal temperatures in the mornings than the unshaded ones. During the 1400 h recording, the shaded cows had lower mean rectal temperature (38.85) compared to the unshaded (39.74°C). The difference between treatments was highly significant ($P < 0.01$).

The mean skin temperatures recorded for the shaded and unshaded cows were 37.64 and 38.56°C in the forenoons and 39.14 and 39.88°C in the afternoons respectively. Statistical analysis revealed significant differences between treatments, both for 0800 and 1400 h recordings, the cows that remained in the shade always recording significantly lower skin temperatures.

Table 2.20

Mean weekly milk yield in kg of individual cows during the early lactation period under shaded and unshaded treatments

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	46.47	44.05	41.83	36.30
	096	47.90	39.68	34.70	30.88
	655	39.03	31.38	27.85	27.08
	159	42.37	37.28	31.85	28.88
	Total	175.77	152.39	136.23	123.14
		Shaded	Unshaded	Shaded	Unshaded
II	290	32.70	28.95	25.90	23.80
	091	44.50	43.68	39.18	31.45
	080	43.17	38.23	34.75	32.53
	231	43.27	40.38	31.53	32.43
	Total	163.64	151.24	131.36	120.21

Mean weekly milk yield:- Shaded : 35.06

Unshaded : 36.47

't' value: 2.998*

*Significant at 5 per cent level ($P < 0.05$)

III. MILK PRODUCTION:

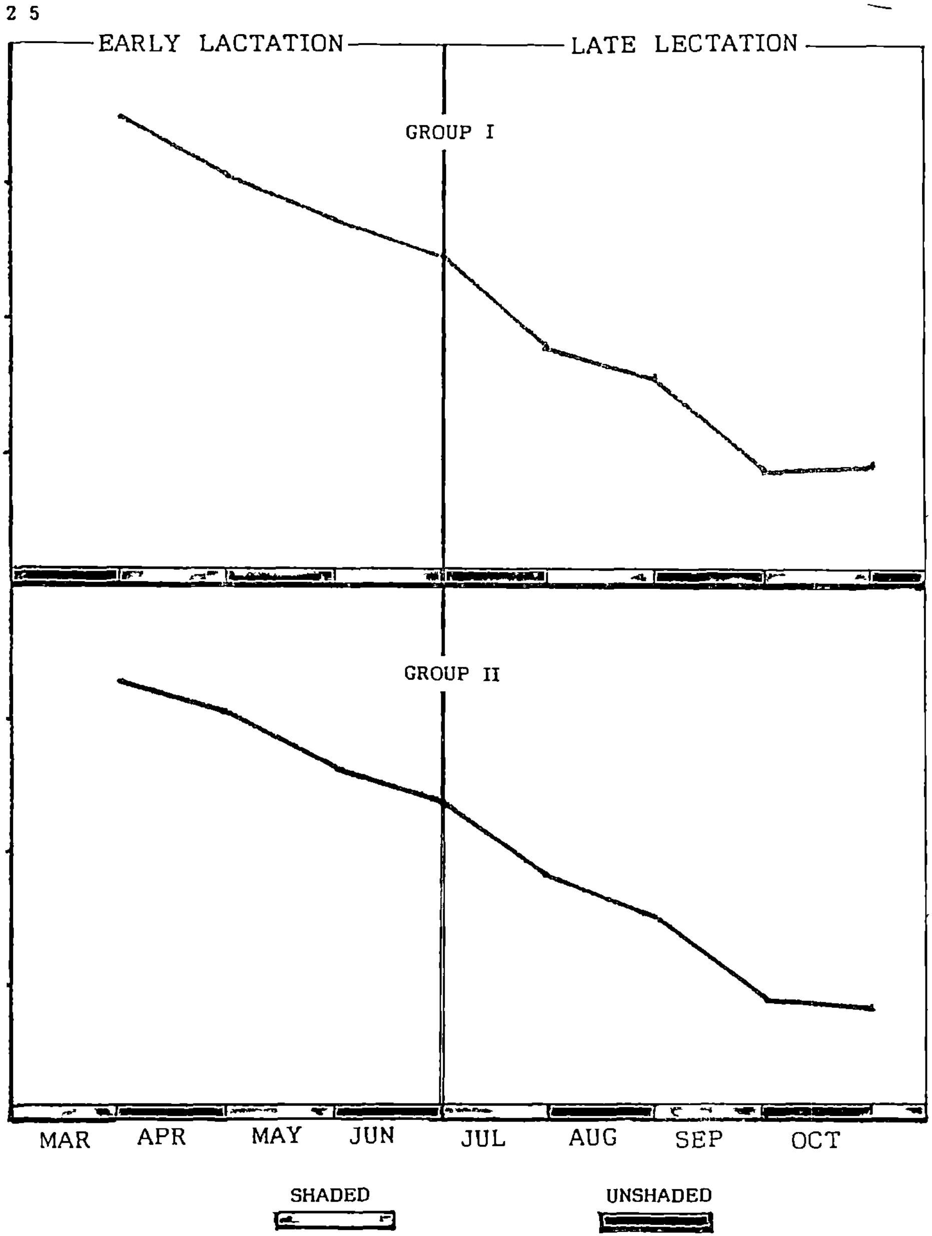
a) Early lactation period:

The mean weekly total milk yield in kg of the individual cows during the early lactation period with results of statistical analysis between shaded and unshaded treatments are presented in Table 2.20 and Figure 2.5.

The mean weekly total milk yields of the four cows of group I when they were exposed to direct solar radiation in the unshaded location during period 1 and period 3 respectively were 175.77 and 136.30 kg. These cows, when they were shaded during periods 2 and 4, their milk yields were 152.39 and 123.14 kg respectively. The second set of four cows in group 2, during periods 1 and 3 when they were shaded, their weekly mean total milk yields were 163.64 and 131.36 kg respectively and the same were 151.24 and 120.21 kg during periods 2 and 4 when they were in the unshaded location, exposed to direct solar radiation.

The mean weekly milk yield of all the cows when they had remained in the shade was 35.66 kg and in unshaded location 36.47 kg. Statistical analysis revealed a significant ($P < 0.05$) difference in milk yields between treatments during the early lactation period, the exposed cows yielding more milk.

BY ALTERNATING SHADED AND UNSHADED TREATMENTS



b) Late lactation period:

The mean weekly total milk yield of the individual cows in both the groups during the late lactation period, under shaded and unshaded conditions and the results of statistical analysis are presented in Table 2.21 and Figure 2.5.

The mean weekly total milk yields under unshaded condition of group 1 cows during periods 5 and 7 were 88.70 and 42.96 kg and for group 2 cows during periods 6 and 8 respectively were 66.77 and 42.30 kg. Group 1 cows when they were shaded during periods 6 and 8, their milk yields were 77.19 and 43.00 kg and for group 2 cows during 5 and 7 shaded periods 91.90 and 46.02 kg respectively.

The mean weekly milk yield of all the cows during periods when they were shaded (16.13 kg) was higher compared to their yields under unshaded conditions (15.04 kg). By statistical analysis no significant difference in milk yield due to the effect of treatment could be obtained during the late lactation period.

IV. MILK FAT AND MILK PROTEIN CONTENT:

a) Early lactation period:

The period wise mean fat content of the morning milk of the cows when they were subjected to shaded and unshaded

Table 2.21

Mean weekly milk yield in kg of individual cows during the late lactation period under shaded and unshaded treatments

Group	Cow No.	Period 5	Period 6	Period 7	Period 8
		Unshaded	Shaded	Unshaded	Shaded
I	126	25.02	21.45	11.36	10.90
	096	12.14	14.38	12.04	12.90
	655	28.26	21.38	9.30	9.85
	159	23.28	19.98	10.26	9.35
	Total	88.70	77.19	42.96	43.00
		Shaded	Unshaded	Shaded	Unshaded
II	290	17.70	9.78	5.40	2.57
	091	26.48	25.33	18.48	17.55
	080	23.64	14.68	9.82	12.85
	231	24.08	16.98	12.32	9.33
	Total	91.90	66.77	46.02	42.30

Mean weekly milk yield:- Shaded : 16.13

Unshaded : 15.04

't' value : 2.306

treatments groupwise during the early lactation period, along with statistical analysis results are presented in Table 2.22 and Figure 2.6.

The group 1 cows, when they were protected from direct solar radiation by housing, recorded mean fat percentages of 4.70 and 5.25. Whereas when they were left in the open, the fat percentages obtained were 5.33 and 6.13. For group 2 cows, fat percentages in the shade were 4.93 and 6.35 and in the open were 4.13 and 5.33.

The mean values of fat percentage obtained for the entire early lactation period while in the shade was 5.31 whereas for the unshaded treatment it was 5.23. By statistical analysis, the difference in the fat percentages between treatments were found to be highly significant ($P < 0.01$) with the fat content of the milk of protected cows higher than the exposed.

The individual cow's milk fat content in the afternoons during the early lactation stage and the results of statistical analysis are presented in Table 2.23 and Figure 2.6.

The group 1 cows, when they were in the unshaded location during periods 1 and 3, recorded 4.63 and 6.05 per cent milk fat. The same cows when they were kept under

Table 2.22

Mean fat content in percentage of morning milk of the cows subjected to shaded and unshaded treatments during the early lactation period

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	5.7	5.0	6.7	5.9
	096	4.4	4.5	5.8	5.4
	635	6.1	4.6	6.0	5.3
	139	5.1	4.7	6.0	4.4
	Mean	5.33	4.70	6.13	5.25
		Shaded	Unshaded	Shaded	Unshaded
II	290	4.7	4.8	6.0	5.4
	091	5.0	4.5	6.6	6.3
	080	5.3	3.9	7.1	5.1
	231	4.7	3.3	5.7	4.5
	Mean	4.93	4.13	6.35	5.33

Mean of Shaded : 5.41

Unshaded : 5.23

't' value: 0.55

Insignificant at 5 per cent level (P < 0.05)

Table 2.23

Mean fat content in percentage of afternoon milk of the cows subjected to shaded and unshaded treatments during the early lactation period

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	5.7	4.8	6.8	6.7
	096	4.1	6.5	6.0	4.8
	655	4.6	5.2	6.2	6.0
	159	4.1	4.5	5.2	5.9
	Mean	4.63	5.25	6.05	5.85
		Shaded	Unshaded	Shaded	Unshaded
II	290	4.6	3.6	5.8	5.3
	091	4.5	3.9	5.9	5.4
	080	4.5	5.7	6.0	5.3
	231	4.3	4.1	4.3	4.6
	Mean	4.49	4.33	5.50	5.15

Mean values: Shaded : 5.27

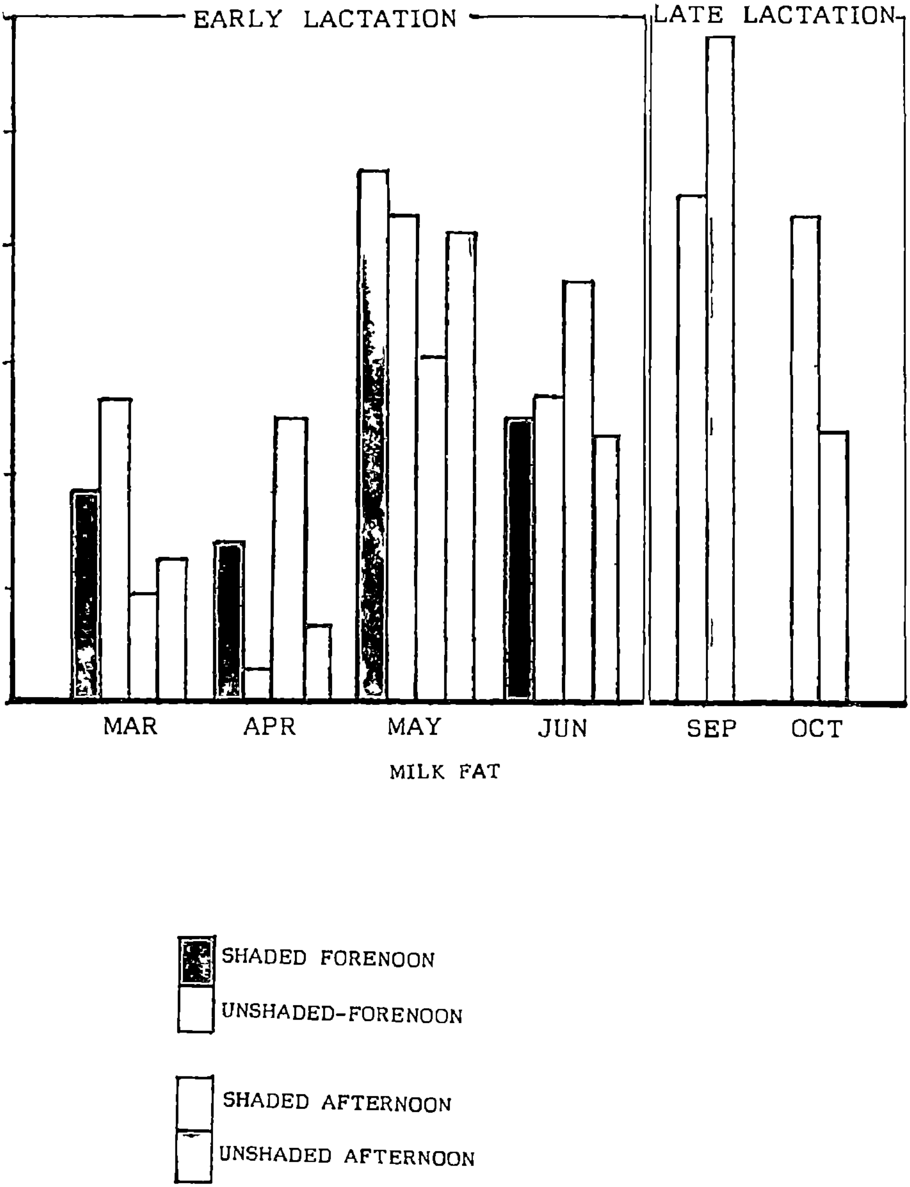
Unshaded : 5.04

't' value: 7.49**

**Significant at 1 per cent level ($P < 0.01$)

MILK-FAT PRODUCTION

2 6



housed conditions, during periods 2 and 4, had fat content in milk of 5.23 and 5.85 per cent respectively. The fat percentage of group 2 cows for the periods 1 to 4 respectively were 4.48, 4.33, 5.50 and 5.15, the values for periods 1 and 3 being under shaded treatment and values for periods 2 and 4 for unshaded treatment.

The mean values of fat content in the afternoon milk during early lactation for all the four periods put together were 5.27 per cent when shade was provided and 5.04 per cent when unshaded. By statistical analysis, the milk fat content was found to differ significantly ($P < 0.01$) between treatments, the milk fat per cent remaining higher when the cows were housed.

Table 2.24 details the periodwise mean protein content in percentage of morning milk of the experimental cows during early stage of lactation and also the results of statistical analysis.

For periods 1 to 4, the protein contents in morning milk of group 1 cows respectively were 2.52, 2.82, 1.98 and 2.11 per cent, periods 1 and 3 being unshaded and 2 and 4 shaded treatments. For group 2 cows, the protein contents in milk were 2.50, 3.00, 1.96 and 2.23 per cent in that order, periods 1 and 3 being shaded and periods 2 and 4 unshaded treatments.

Table 2.24

[illegible] protein content in percentage of morning milk of the cows subjected to shaded and unshaded treatments during the early lactation period

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	2.76	3.07	2.10	2.02
	096	2.68	2.75	2.00	1.81
	655	2.26	2.54	1.64	2.70
	159	2.35	2.90	1.98	1.91
	Mean	2.52	2.82	1.98	2.11
		Shaded	Unshaded	Shaded	Unshaded
II	290	2.73	3.03	2.22	2.16
	091	2.39	2.74	1.93	2.81
	080	2.40	3.11	1.84	1.85
	231	2.45	2.70	1.84	2.09
	Mean	2.50	3.00	1.96	2.23

Mean values:- Shaded : [illegible].34

Unshaded : 2.41

't' value: 1.78

The overall mean protein content was 2.34 per cent for shaded and 2.41 for unshaded treatments. Statistical analysis did not reveal any significant difference between treatments in the morning milk protein content.

The early lactation afternoon milk protein content of the experimental cows with results of statistical analysis have been presented in Table 2.25.

During unshaded treatments, the group 1 cows in periods 1 and 3, recorded a mean protein content of 2.72 and 2.14 per cent and group 2 cows in periods 2 and 4, a mean protein content of 2.50 and 2.12 per cent in the milk obtained in the afternoons. The protein content values during shaded treatment for group 1 cows in periods 2 and 4 were 3.05 and 2.08 per cent and group 2 cows in periods 1 and 3, 2.61 and 2.20 per cent respectively.

The overall mean milk protein content in the afternoons was 2.48 per cent for shaded and 2.37 per cent for exposed cows. By statistical analysis, a highly significant ($P < 0.01$) difference was found between the treatments.

b) Late lactation period:

During the late lactation period, the cows were milked only once a day in the mornings and the details of

Table 2.25

Mean protein content in percentage of afternoon milk of the cows subjected to shaded and unshaded treatments during the early lactation period

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	3.06	2.90	2.30	2.08
	098	2.68	3.03	2.36	2.26
	655	2.41	3.23	1.85	2.09
	159	2.53	3.03	2.06	1.96
	Mean	2.72	3.05	2.14	2.08
		Shaded	Unshaded	Shaded	Unshaded
II	290	2.98	2.73	2.36	2.39
	091	2.73	2.68	2.16	1.94
	080	2.33	2.16	2.26	2.10
	231	2.39	2.43	2.00	2.05
	Mean	2.61	2.50	2.20	2.12

Mean values:- Shaded : 2.48

Unshaded : 2.37

't' value: -8.38**

** Significant at 1 per cent level (P< 0.01) milk fat content have been furnished in Table 2.26 and Figure 2.6. and milk protein content in Table 2.27.

For group 1 cows during period 7 and for group 2 cows during period 8, both being unshaded treatments, the mean milk fat contents were 6.95 and 5.20 per cent. For shaded treatments in period 8 for group 1 and period 7 for group 2 the milk fat contents respectively were 6.13 and 6.23 per cent. The overall mean fat content during the late lactation period for shaded treatment was 6.20 and unshaded treatment 6.08 per cent. Statistical analysis did not reveal significant difference between treatments.

The difference in milk protein content during the late lactation period due to the effect of treatment was also found to be not significant. The overall means of milk protein contents were 2.55 per cent for shaded and 2.52 per cent for exposed cows.

V. FEED, WATER AND GRASS CONSUMPTION:

a) Early lactation period:

Periodwise, mean, per day, concentrate feed, water and grass consumption during the early lactation period of the individual experimental cows under shaded and unshaded treatments with statistical analysis results have been presented in Tables 2.28 to 2.30 and Figure 2.7.

Table 2.26

Mean fat content in percentage of the milk of cows subjected to shaded and unshaded treatments during the late lactation period

	Cow No.	Period 7	Period 8
		Unshaded	Shaded
Group I	126	6.6	6.2
	096	5.9	5.5
	655	6.7	7.0
	159	8.6	5.8
	Mean	6.95	6.13
		Shaded	Unshaded
Group II	290	6.5	3.0
	091	6.3	5.8
	080	6.5	6.3
	231	5.8	5.7
	Mean	6.23	5.20

Mean values:- Shaded : 6.20

Unshaded : 6.08

't' value: 1.98

Table 2.27

Mean protein content in percentage of the milk of cows subjected to shaded and unshaded treatments during the late lactation period

	Cow No.	Period 7	Period 8
		Unshaded	Shaded
Group I	126	3.41	3.15
	096	2.61	2.22
	655	2.31	2.63
	159	2.13	2.23
	Mean	2.62	2.56
		Shaded	Unshaded
Group II	290	3.17	3.00
	091	2.47	2.17
	C30	2.30	2.30
	231	2.19	2.20
	Mean	2.53	2.42

Mean values:- Shaded : 2.55
Unshaded : 2.52
't' value: 1.00

Table 2.28

Mean feed consumption per day in kg during the early lactation period under shaded and unshaded treatments

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	1?6	5.0	5.0	5.0	4.8
	095	5.0	5.0	5.0	5.0
	635	5.0	5.0	5.0	4.8
	159	5.0	5.0	5.0	4.8
	Mean	5.0	5.0	5.0	4.85
		Shaded	Unshaded	Shaded	Unshaded
II	290	4.5	5.0	5.0	4.8
	091	5.5	5.0	5.0	5.0
	080	5.0	5.0	5.0	4.8
	231	5.5	5.0	5.0	4.8
	Mean	5.13	5.0	5.0	4.85

Mean values:- Shaded : 4.99

Unshaded : 4.96

't' value: 0.92**

**Significant at 1 per cent level (p< .01)

Table 2.29

Mean water consumption per day in litre during the early lactation period under both the treatments

Group	Cow No.	Period 1 Unshaded	Period 2 Shaded	Period 3 Unshaded	Period 4 Shaded
I	126	35.37	19.60	20.63	7.22
	096	24.77	19.78	20.85	11.28
	653	26.67	13.23	15.78	5.42
	159	28.17	18.20	20.58	12.36
	Mean	28.75	17.70	19.46	9.07
		Shaded	Unshaded	Shaded	Unshaded
II	290	19.96	33.93	17.05	12.12
	091	23.20	23.60	21.90	14.40
	080	28.83	26.83	24.35	19.70
	231	27.10	23.55	23.10	17.52
	Mean	24.77	26.98	21.60	15.94

Mean values:- Shaded : 18.29

Unshaded : 22.16

't' value: 6.15**

**Significant at 1 per cent level (P< 0.01)

Table 2.30

Mean grass consumption per day in kg during the early lactation period under both the treatments

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	15.23	19.43	18.95	23.46
	096	15.50	19.28	20.15	24.50
	655	16.23	19.90	19.80	23.86
	159	15.30	20.05	19.53	24.88
	Mean	15.57	19.67	19.61	24.18
				Shaded	Unshaded
	080	13.56	19.13	19.70	23.48
	231	13.27	18.40	19.03	24.34
		13.97	18.75	20.30	23.78
		13.00	19.05	19.95	23.56
	Mean	13.45	18.83	19.75	23.79

Mean values: Shaded : 19.23

Unshaded : 19.45

't' value: 8.70**

Table 2.30

Mean grass consumption per day in kg during the early lactation period under both the treatments

Group	Cow No.	Period 1	Period 2	Period 3	Period 4
		Unshaded	Shaded	Unshaded	Shaded
I	126	15.23	19.43	18.95	2[illegible].46
	096	15.50	19.28	20.15	24.50
	655	16.23	19.90	19.80	23.86
	159	15.30	20.05	19.63	24.88
	Mean	15.57	19.67	19.61	24.18
		Shaded	Unshaded	Shaded	Unshaded
II	290	13.56	19.15	19.70	23.48
	091	13.27	18.40	19.03	24.34
	086	13.97	18.75	20.30	23.78
	231	13.00	19.08	19.95	23.56
	Mean	13.45	18.83	19.75	23.79

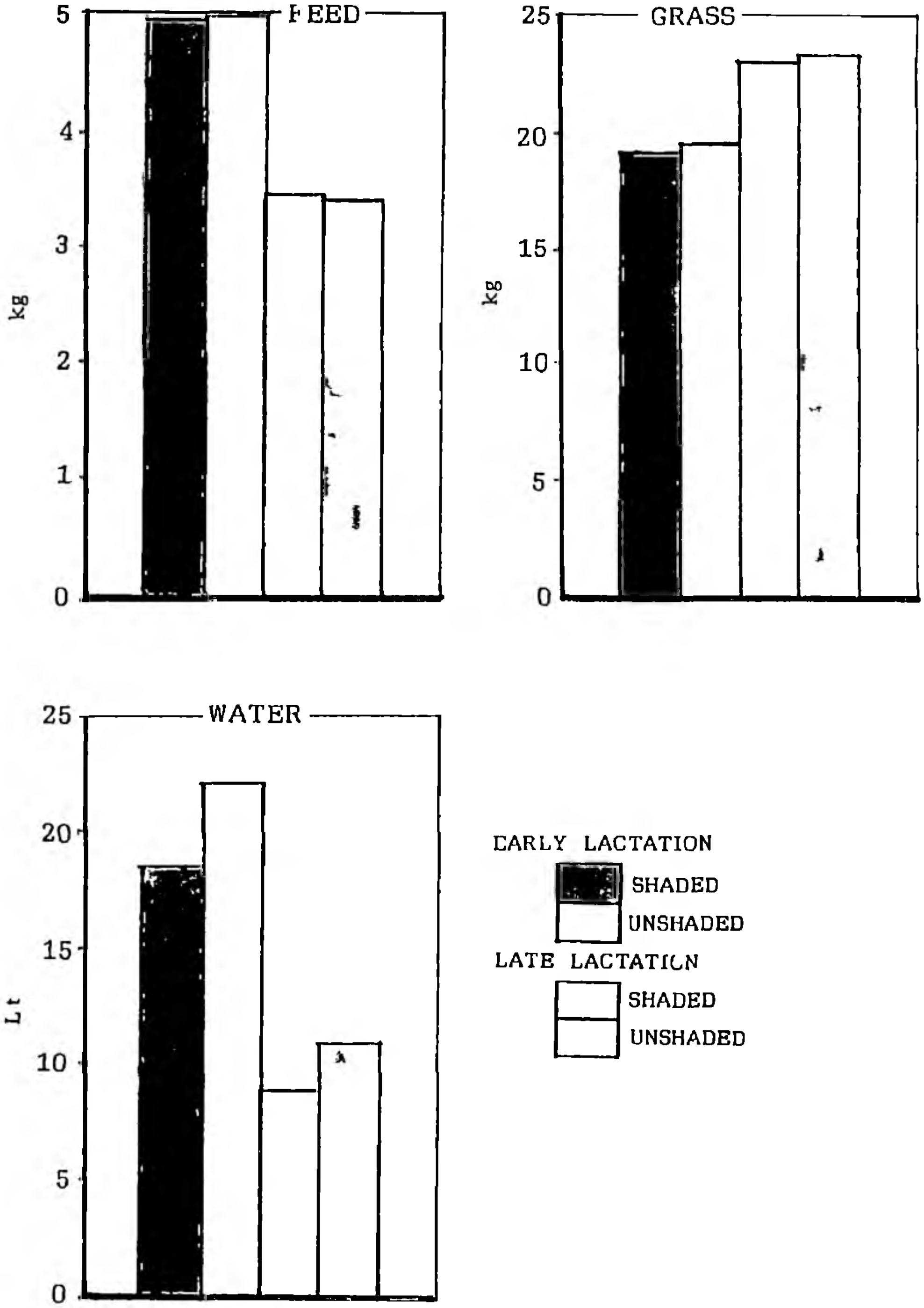
Mean values. Shaded : 19.23

Unshaded : 19.45

't' value: 8.70**

FEED, GRASS AND WATER CONSUMPTION

FIGURE 2 7



The mean feed consumption per day in kg of the cows in group 1 during the periods 1 and 3 for unshaded treatments were 5.00 and 5.00 kg and periods 2 and 4 shaded treatments were 5.00 and 4.85 kg. For the group 2 cows, for periods 1 to 4 respectively were 5.13, 5.00, 5.00 and 4.85 kg, periods 1 and 3 being shaded and 2 and 4 being unshaded treatments. By statistical analysis, the feed consumption between treatments were found to be highly significant ($P < 0.01$).

During the unshaded treatment periods of 1 and 3, the group 1 cows consumed a mean quantity of 28.73 and 19.46 litre of water per day and during shaded treatment periods of 2 and 4, the mean water consumptions per day respectively were 17.70 and 9.07 litre. The group 2 cows consumed 24.77 and 21.60 litre for shaded treatment periods 1 and 3 and 26.98 and 15.94 litre per day of water for unshaded treatment periods 2 and 4. The overall mean water consumption per day during shading treatment was 18.29 litre per cow whereas it was 22.16 litre when the cows were exposed. By statistical analysis, these differences were found to be highly significant ($P < 0.01$).

In general, an increasing trend was observed in the quantity of grass consumed per day in both the groups of cows as periods advanced. For periods 1 to 4, the respective mean grass consumption per day of group 1 cows were 15.57, 19.67, 19.61 and 24.18 kg and for group 2, they were 13.45, 18.83, 19.75 and 23.79 kg in that order. The unshaded treatment was given to group 1 cows during periods 1 and 3 and group 2, during periods 2 and 4. The overall mean grass consumption during the entire early lactation period under shading treatment was 19.23 kg per day per cow compared to 19.45 kg for unshaded. Statistical analysis revealed this difference to be highly significant ($P < 0.01$).

b) Late lactation period:

The period wise mean concentrate feed, water and grass consumption per day of all the experimental cows during the late lactation period along with the results of statistical analysis are presented in Tables 2.31 to 2.33 and Figure 2.7.

The mean concentrate feed consumption per day of the group 1 cows during periods 5 and 7 of unshaded treatments were 3.94 and 3.00 kg and for periods 6 and 8 of shaded treatments 3.38 and 3.00 kg. The group 2 cows had a mean feed consumption of 4.06 and 3.25 kg for periods 5 and 7 of shaded treatment and 3.50 and 3.00 kg for periods 6 and 8 of unshaded treatments. The overall mean daily feed consumption for shaded cows was 3.42 kg

Table 2.31

Mean feed consumption per day in kg during the late lactation period under both the treatments

Group	Cow No.	Period 5	Period 6	Period 7	Period 8
		Unshaded	Shaded	Unshaded	Shaded
I	126	4.00	3.50	3.00	3.00
	096	3.75	3.00	3.00	3.00
	655	4.00	3.50	3.00	3.00
	159	4.00	3.50	3.00	3.00
	Mean	3.94	3.38	3.00	3.00
		Shaded	Unshaded	Shaded	Unshaded
II	290	4.00	3.00	3.00	3.00
	091	4.25	4.00	4.00	3.00
	080	4.00	3.50	3.00	3.00
	231	4.00	3.50	3.00	3.00
	Mean	4.06	3.50	3.25	3.00

Mean values:- Shaded : 3.42

Unshaded : 3.36

't' value: 1.35

Table 2.32

Mean water consumption per day in litre during the late lactation period under both the treatments

Group	Cow No.	Period 5	Period 6	Period 7	Period 8
		Unshaded	Shaded	Unshaded	Shaded
I	126	5.53	7.40	11.88	6.75
	096	3.08	10.00	12.88	8.58
	655	3.58	9.15	11.70	8.83
	159	7.08	13.60	10.88	10.50
	Mean	4.82	10.04	11.84	8.67
		Shaded	Unshaded	Shaded	Unshaded
II	290	6.33	6.60	6.33	15.13
	091	4.78	7.40	5.75	13.83
	080	16.90	17.50	19.75	25.00
	231	4.00	6.50	3.75	17.00
	Mean	8.00	9.50	8.90	17.74

Mean value:- Shaded : 8.90

Unshaded : 10.98

't' value: 4.89**

** Significant at 1 per cent level ($P < 0.01$)

Table 2.35

Mean grass consumption per day in kg during the late lactation period under both the treatments

Group	Cow No.	Period 5	Period 6	Period 7	Period 8
		Unshaded	Shaded	Unshaded	Shaded
I	126	24.05	26.80	23.40	20.70
	096	21.10	25.50	24.50	21.88
	655	24.38	25.40	23.85	21.93
	159	24.08	24.05	24.18	19.68
	Mean	23.90	25.44	23.98	21.02
		Shaded	Unshaded	Shaded	Unshaded
II	290	22.08	26.10	22.30	20.35
	091	[illegible].65	25.85	23.90	20.70
	080	24.80	25.10	22.58	15.75
	201	23.20	25.80	23.73	19.88
	Mean	23.16	25.9[illegible]	23.10	19.17

Mean value for shaded : 23.19

Unshaded : 23.29

't' value: 1.05

and for unshaded 3.36 kg, the difference between treatments being not significant.

The water consumption pattern revealed considerable variation. The group 1 cows consumed 4.82 and 11.84 litre of water per day during periods 5 and 7 of unshaded treatment and 10.04 and 8.67 litre during periods 6 and 8 of shaded treatment. The group 2 cows consumed 8.00 and 8.90 litre per day during periods 5 and 7 of shaded treatment and 9.50 and 17.74 litre during periods 6 and 8 of unshaded treatment. The overall mean daily water consumption was 8.90 litre for shaded and 10.98 litre for unshaded. Statistical analysis revealed significant difference ($P < 0.01$) in the water consumption between treatment groups.

The mean grass consumption per cow per day for periods 5, 6, 7 and 8 for group 1 cows respectively were 23.90, 25.44, 23.98 and 21.02 kg. The same for group 2 cows were 23.18, 25.96, 23.10 and 19.17 kg. The unshaded treatment for group 1 cows were during periods 5 and 7 and group 2 cows 6 and 8. The overall mean daily grass consumption of shaded cows was 23.19 kg per cow compared to 23.29 kg when they were exposed to direct solar radiation. The difference between treatments was not statistically significant.

Relationship between climatic variables and physiological reactions:

a) Unsheltered conditions:

The parameters of the estimated linear functions and the corresponding test statistics are presented in Table 2.34.

In the case of cardiac rates of the experimental cows, the R^2 value as explained by the variables taken for the study was 66.00 per cent with the variance ratio highly significant ($P < 0.01$). The solar radiation exerts significant ($P < 0.05$) negative influence on the cardiac rates of the cows, with every unit increase in solar radiation decreasing the cardiac rate by 0.17 units. The wind velocity had positive and highly significant ($P < 0.01$) influence on the cardiac rate with each unit increase in wind velocity resulting in 0.65 unit increase in cardiac rate.

The total variation R^2 was 67.00 per cent due to the climatic variables observed in the study in the case of respiration rates of the cows and the variance ratio was highly significant ($P < 0.01$). Wind velocity alone had a negative and highly significant ($P < 0.01$) influence on the respiration rate indicating that increase in wind velocity reduced the respiratory rate of the cows.

Table 2.34

Estimated coefficients of the environmental variables in the unshaded regime

Dependent variable	Mean tempe-rature	Solar radia-tion	RH	Wind velocity	Vapour pressure	Total rainfall	R^2	F	Constant
Cardiac rate	4.61	-0.17*	-0.41	0.65**	-4.28	-0.03	0.66	8.31**	42.80
Respiration rate	7.05	-0.11	-0.37	-0.60**	-1.59	-0.03	0.67	8.88**	-30.23
Rectal temperature	1.13	-0.05	-0.05	-0.32**	1.70	-0.02	0.53	4.80**	34.11
Skin temperature	1.42	-0.06	-0.05	-0.33**	1.64	-0.02	0.53	4.94**	27.65

** Significant at 1 per cent level } both for 't' and 'F'
* Significant at 5 per cent level }

The rectal and skin temperatures also were found to be influenced ($P < 0.01$) by the wind velocity in a negative manner. One unit increase in wind velocity reduced rectal temperature by 0.32 units and skin temperature by 0.33 units. In both the cases of rectal and skin temperatures, the total variation R^2 as explained by the independent climatic variables amounted to 53.00 per cent each and the variance ratios were highly significant ($P < 0.01$).

b) Sheltered conditions:

The paramoters of the estimated linear functions and the corresponding test statistics for the housed treatment, are presented in Table 2.35.

The total variation R^2 explained by all the explanatory variables such as air temperature, black globe temperature, RH, wind velocity and vapour pressure in the cases of cardiac rate, respiration rate, rectal temperature and skin temperature, respectively were 22.00, 59.00, 7.00 and 10.00 per cent. The variance ratios were found to be highly significant ($P < 0.01$) in the case of respiration rate only.

None of the climatic variables chosen had any significant influence on cardiac rate, rectal temperature and skin temperature of the cows under the housed condition.

Table 2.35

Estimated coefficients of the environmental variables in the shaded location

Dependent variable	Mean temperature	Globe temperature	RH	Wind velocity	Vapour pressure	R^2	F	Constant
Cardiac rate	1.83	2.23	0.52	-0.12	55.61	0.22	1.55	-141.37
Respiration rate	1.41	7.06*	1.20	-[illegible].87	10.10	0.59	7.89**	-316.86
Rectal temperature	0.68	0.75	0.23	-5.43	9.84	0.07	0.44	- 28.26
Skin temperature	0.79	1.08	0.30	-5.50	7.37	0.10	0.60	-43.65

**Significant at 1 per cent level } [illegible] 't' and 'F'
*Significant at 5 per cent level }

The black globe temperature alone had a positive and significant ($P < 0.05$) influence on respiration rate.

DISCUSSION

I. CLIMATIC FACTORS:

a) Early lactation period:

The maximum temperatures recorded in the shaded location ranged from 26.94 to 33.16°C while it ranged from 30.93 to 41.27°C in the unshaded location. The overall means for the 15 weeks of the early lactation period were 30.36 for shaded and 35.72°C for unshaded location, the difference between locations being highly significant ($P < 0.01$). This indicated that providing housing had considerably reduced the ambient air temperature. The minimum temperature ranged from 21.60 to 27.43 with a mean of 23.83°C in the shaded location and 20.07 to 25.93 with a mean of 23.37°C in the unshaded location. Statistical analysis had not revealed any significant difference in the minimum temperatures recorded between the locations. However the air temperatures prevailed in the open was slightly lower than what was prevalent under housed conditions during the cooler hours of the day. In general, the air temperature prevailed during the period was higher than what was reported as comfortable or ideal for better livestock production (McDowell et al., 1961; Bianca, 1965; McDowell, 1972; Berman et al., 1985).

Highly significant ($P < 0.01$) differences were found between the shaded and unshaded locations in the relative humidity levels recorded both at 0800 h and 1400 h indicating that relative humidity recorded inside the cow house was always higher than what was at large. For shaded and unshaded locations, the relative humidity recorded respectively was 81.96 and 79.90 per cent at 0800 h and 66.89 and 64.92 per cent at 1400 h with a difference of about 2.0 per cent. This may probably be due to accumulation of moisture in the atmosphere inside the animal house resulting out of interference with free exchange of air by housing arrangements. This way, part of the benefit obtained due to reduction in ambient air temperature by housing was lost due to increase of relative humidity of the ambient air. Starr (1981) while signifying the housing needs of livestock has questioned the wisdom of providing shelters in areas that are hot and humid. Caro-costas <u>et al</u>.(1965) and Wiersma and Stott (1965) have suggested that for humid tropics, the more suitable system of management would be to provide access to animals to shade during warmer part of the day and to leave the animals in the open after sunset to promote loss of heat accumulated in the body. Gangwar (1988) stated that shade was desirable for animal comfort in hot humid environments but the shade was to be in the form of tree shade and not the shade provided by sheds.

In general, the relative humidity recorded in the present experiment was always higher than 50.00 per cent and sometimes even crossing 90.00 per cent. Starr (1981) suggested that heat balance could become a problem at 20°C and above, when relative humidity was in excess of 60.00 per cent. With such high humidity levels recorded, the local climate can well be classified as humid and hot (Sainsbury, 1965; McDowell, 1972).

The mean vapour pressure recorded in the shaded location was 23.50 at 0800 h and 23.52 mm of Hg at 1400 h. For the unshaded location, the respective figures were 23.82 and 24.13 mm of Hg. The differences in vapour pressure between the locations, both in the morning and afternoon recordings were found to be highly significant ($P < 0.01$) indicating that the atmosphere inside the cow house had significantly lower levels of vapour pressure throughout the day compared to the open.

It may be seen that inside the shed, inspite of a lower vapour pressure, the relative humidity was higher due to the lower ambient temperature. In the open, inspite of slightly higher vapour pressure, the higher ambient temperature caused the relative humidity to be lower and thereby afforded scope for greater evaporative cooling to the animals.

The wind velocity recorded in the shaded location was very meagre with practically no measurable air movement in the mornings during six out of 15 weeks and the overall mean wind velocity was 0.010 m per sec. In the afternoons, it was slightly higher with a mean of 0.213 m per sec. The unshaded location had higher wind velocities with a mean of 0.072 at 0800 h and 0.497 m per sec at 1400 h. Statistical analysis revealed highly significant ($P < 0.01$) difference in wind velocities between locations. Once again the benefit of housing, thereby a reduction in ambient air temperature has been partially offset by reduced wind velocities which results in reduced comfort of the housed animals. The wind velocities recorded in the present experiment generally were lower than what had been suggested as ideal for tropical animal husbandry (McDowell, 1972). Stolpe (1977) recommended that a rate of air movement of 0.6 m per sec was effective as a means of offsetting the deleterious effects of very high temperatures in modern animal housing.

The globe temperature recorded in the shaded location at 0800 h ranged from 26.64 to 30.43°C and at 1400 h, from 29.00 to 36.42°C. It was found that the temperature recorded with the black globe thermometer was always higher by 2.0 to 5.0°C than the air temperature which goes to show that the animals housed in the shaded location were under additional stress due to the radiated heat from the surroundings apart from experiencing stress of the high air temperature. The overall mean of the globe temperature recorded in the present study was only 32.73°C during the 1400th h recording, the hotter part of the day which was lower than the globe temperature of 45°C reported by Boren *et al.* (1961) under a sunroof made out of GI sheet. The mean globe temperature recorded at 0800 h was 29.02°C which was only about 3.0°C less than what was recorded at 1400 h.

The same phenomenon was observed with the total radiation measured in the unshaded location also, both the day and night radiation values remaining equally high with only a small difference between them. This indicates that even in the absence of the sun, its radiant heat continues to exist mainly due to long wave radiation from the heated ground and surroundings. During the first 15 weeks of early lactation period, the mean hourly total radiation during the day time ranged from 99.70 to 195.44 mWcm^{-2} and during night time from 83.78 to 142.34 mWcm^{-2}. The overall mean for day time total radiation was 167.75 and for the night 124.64 mWcm^{-2}.

This goes on to show that during the 12 'night' hours, the total radiation load on the animal in the hot-humid tropical summer was only 25 per cent less in a brick paved paddock surrounded by a half wall and buildings.

The rainfall distribution was not uniform during the period of study. There was no rainfall during the second week of the experiment and during the rest of the weeks, the weekly total rainfall ranged from 1.80 mm to a maximum of 209.30 mm with an overall mean of 69.61 mm.

b) <u>Late lactation period</u>:

During the late lactation period of 16 to 33 weeks, the air temperature recorded was about 3.0°C lower than what was recorded during early lactation period. Here again, provision of housing had helped to reduce the air temperature by around 5.0°C during the hotter part of the day. The means of the maximum temperature recorded in the shaded and unshaded locations respectively were 27.80 and 32.18°C and the means of the minimum were 22.03 and 23.17°C. Statistical analysis by paired 't' test revealed highly significant ($P < 0.01$) differences in both maximum and minimum temperatures recorded between the locations indicating the favourable influence of housing throughout the day in reducing the temperature of the ambient air.

There was no significant difference between the relative humidity recorded at 0800 h in the shaded and unshaded locations, the respective means being 85.75 and 84.97 per cent. The difference in relative humidity between locations for the 1400th h recording was highly significant ($P < 0.01$) with the mean relative humidity in shaded location higher, 75.45 per cent compared to 73.89 per cent in the open. The humidity levels during the late lactation period had generally remained higher compared to the early lactation period which might have resulted out of regular rainfalls during this period. During this period also, the relative humidity remained higher by about 2.0 per cent inside the animal house compared to what was in the unshaded location.

The overall means of the vapour pressure were 22.81, 22.96, 23.04 and 23.50 mm of Hg respectively for 0800 h recording for shaded and unshaded locations and 1400 h recording for shaded and unshaded locations in that order. No significant difference was found between locations for the 0800 h measurement but this difference for the 1400 h measurement was highly significant ($P < 0.01$), to indicate that the vapour pressure was higher in the unshaded location compared to the shaded location.

As in the case of early lactation, the lower relative humidity and higher vapour pressure in the unshaded conditions can be explained by the prevalence of higher ambient temperature. Thus, the higher ambient temperature by lowering the relative humidity gives greater scope for evaporative cooling.

During the 30th week of the experiment there was no measurable wind velocity at 0800 h in both shaded and unshaded locations. Otherwise, compared to early lactation stage, the means of the wind velocities recorded during the late lactation period were slightly better with 0.046 and 0.126 m per sec at 0800 h recording and 0.283 and 0.424 m per sec for the 1400 h recording respectively for shaded and unshaded locations. Statistical analysis did not reveal any significant difference in wind velocity between locations for the 0800 h recording but there was a highly significant ($P < 0.01$) difference for the 1400 h measurement. During the afternoons, the interference by housing arrangement had almost halved the beneficial wind movement to the disadvantage, of the housed animals. Under both the locations the wind velocity prevailed was much below the recommended levels (McDowell, 1972).

The means of the black globe temperature recorded in the shaded locations were 27.40 and 29.64°C respectively for 0800 h and 1400 h recordings and these temperatures continued to be higher than that of air temperatures by 2.0 to 5.0°C.

As in the previous period, the solar radiation continued to be high, day-time radiations ranging from 118.60 to 191.55 mWcm^{-2} and night-time from 97.67 to 145.26 mWcm^{-2}. The overall mean values obtained were 167.44 mWcm^{-2} for the day and 125.62 mWcm^{-2} for the night radiation and these values were slightly higher than the values recorded for the early lactation period inspite of more rains during this period.

The weekly total rainfall ranged from 0.40 to 220.50 mm with a overall mean of 103.02 mm which was marginally higher than what was recorded in early lactation period.

II. PHYSIOLOGICAL REACTIONS:

a) Early lactation period:

The experimental cows in the two treatment locations had not shown any significant difference in their cardiac rate during the 0800 h recording though the mean cardiac rate of the cows remaining in the unshaded location had shown slight tendency to be higher than that of shaded ones. In the afternoons the cardiac rates were significantly higher ($P < 0.01$) in the exposed cows (89.53) compared to the housed (74.41). Significant differences ($P < 0.05$) were found between treatments in the respiration rates recorded at 0800 h. In the afternoons the unshaded cows had a respiration rate almost double that of sheltered cows, the differences being highly significant ($P < 0.01$). With rectal temperature, no significant differences was found between treatments for the 0800 h recording. The rectal temperature recorded at 1400 h was higher than the values obtained for 0800 h recording and a highly significant difference ($P < 0.01$) was also found between treatments. The skin temperature of the cows while they were in the unshaded location was significantly ($P < 0.01$) higher than when they were housed for both 0800 and 1400 h recordings.

b) <u>Late lactation period</u>:

The results obtained with the physiological reactions of the cows during the late lactation period had given a similar picture like the early lactation period. The cardiac rates were not significantly different between treatments for 0800 h recording whereas for the 1400 h recording, the difference was highly significant ($P < 0.01$). The diff rences in respiration rates between treatments were significant at 5.00 per cent level in the mornings and at 1.00 per cent level in the afternoons as was noticed during the early lactation period. Interestingly, in the mornings the rectal temperature of the unshaded cows was significantly ($P < 0.05$) lower than the shaded. During the afternoons, the unshaded cows had significantly ($P < 0.01$) higher rectal temperatures. The skin temperature also had shown a highly significant ($P < 0.01$) difference between treatments in the forenoon and a significant ($P < 0.05$) difference in the afternoon.

In general, the physiological variables reacted to the treatments given, in predictable manner. At 0800 h some of the physiological reactions like respiratory rate and cardiac rate showed slightly higher values among the exposed cows. Even skin temperature was higher in them. But rectal temperature was not affected. It was even slightly lower in the forenoons. This showed the effect of cooler conditions during the night in the open as well as greater wind speed. In the afternoons, however, the exposed cows had higher values in all the physiological variables studied including rectal temperature. During the nights the exposed cows not only dissipated this excess heat, but by increased heat loss due to cooler environment brought back the rectal temperature lower than cows kept sheltered.

In both the treatment groups, all the physiological parameters recorded were on the higher side than the normally accepted standards to denote that the cows, whether housed or not, remained under stress in the prevalent hot-humid climatic conditions. The observed reactions were definitely diurnal in nature as reported earlier by Holmes (1970), Shafie and El-Sheikaly (1970), Sastry et al.(1973), Amakiri and Funsho (1979), Bunger et al.(1982), Flamenbaum et al.(1986), Wolfenson et al. (1988) and many others.

One of the interesting observations was that the cows had the physiological ability to bring the skin temperature on par with their body temperature and sometimes even higher than that of the temperature recorded in the rectum. Also, the morning rectal temperatures of the cows, while they were in the unshaded location, were significantly lower than the rectal temperatures they recorded when they remained housed. Thompson et al.(1964) demonstrated that when dairy animals were exposed to direct solar radiation, the skin temperature and respiratory rate were significantly higher in the sun ($P < 0.01$), yet thermal balance was not altered as indicated by normal rectal temperature. They concluded that animals attempted preventing rise in body temperature by effectively increasing heat loss by accelerated breathing and raising the body surface temperature. The same phenomenon was observed to occur in the present study.

Herz and Steinhauf (1978) suggested that higher body temperature during the day improved direct heat output. Caro-Costas *et al.* (1963) and Wiersma and Stott (1965) put forth the idea that in the humid tropics, the suitable system of housing of animals would be to provide access to shade during the warmer part of the day and to leave the animals in the open after sunset so that the heat accumulated in the body was easily lost, to the cooler atmosphere in the open.

III. MILK PRODUCTION:

In the 15 weeks of early lactation the eight experimental cows had a weekly average milk yield of 35.66 kg during the period when they were housed compared to 36.47 kg when they remained in the open. Statistical analysis revealed significant ($P < 0.05$) difference in milk yield between treatments, indicating that the milk production was significantly higher when the cows were unshaded.

The same cows during the late lactation stage (16 to 33 weeks) had a weekly average milk yield of

16.13 kg when sheltered and 15.04 kg when unsheltered. Statistical analysis did not reveal significant difference in milk production between treatments.

The type of shed provided, eventhough, kept the maximum ambient temperature lower, could not contribute to higher productivity. Eventhough the respiratory and cardiac rates were higher throughout and rectal and skin temperatures higher in the afternoons, the cows when in the open seem to compensate during the night and bring down their body temperature to the level of sheltered and eat as much or more grass and feed. This resulted in similar milk yield in late lactation and slightly higher yield in early lactation when cows were kept in the open. Under hot humid conditions, the higher wind velocity in the open seems to favour the cows considerably. The generally held view that under hot humid conditions ventilation is most important and animals do not need much elaborate housing gets further strengthened from these findings.

IV. MILK FAT AND MILK PROTEIN CONTENT:

a) Early lactation period:

The mean values of fat percentage in the milk obtained at 0400 h milking were 5.31 when the cows were shaded and 5.23 when the cows were unshaded. For the

1530 h milking, the mean fat percentages were 5.27 and 5.04 for shaded and unshaded treatments respectively. Statistical analysis revealed a highly significant ($P < 0.01$) difference in fat percentages between treatments for both morning and afternoon milk obtained from the experimental cows, the milk fat content being significantly lower in animals when they were exposed to direct solar radiation. The exposed cows, though they had maintained their milk production higher, the milk fat content had dropped.

The mean values for milk protein content were 2.34 per cent when shaded and 2.41 per cent for unshaded treatments for the milk obtained at 0400 h milking. Statistical analysis did not reveal significant difference between treatments. The values for the milk obtained at 1530 h milking respectively were 2.48 and 2.37 per cent of protein in milk. By statistical analysis a highly significant ($P < 0.01$) difference had been found between treatments in protein content of the afternoon milk indicating that exposure of cows to day time stress in the open sun considerably altered milk composition and reduced the protein percentage.

Shibaita and Mukai (1979) recorded 20 per cent less fat in the milk of cows exposed to 30°C, compared to cows at 18°C ambient air temperature. In the experiment by Fuquay *et al.*(1980), one set of cows were exposed to 22 to 31° and another to 17 to 26°C, air temperature. Milk yields did not differ but milk fat percentage was lower in the hot section group of cows. Pan *et al.*(1978) reported decrease in milk protein yield when Sahiwal x Jersey crossbred cows were subjected to 40°C ambient temperature. Bandaranayaka and Holmes (1976) found that when cows were changed over from an environment with 15°C air temperature to 30°C, the milk fat declined by 0.3 and 1.0 per cent whereas the milk yield was not affected by the temperature. These authors concluded that the elevated temperature caused changes in metabolism which affected milk composition independently of feed intake and milk yield.

b) Late lactation period:

During the late lactation period, milking was done only once in a day at 1100 h. The respective fat and protein contents recorded were 6.20 and 2.55 per cent for shaded treatment and 6.08 and 2.52 per cent for unshaded treatment. Here again both fat and protein content in milk were lesser for the unshaded treatment but statistically there were no significant differences between treatments.

V. FEED, GRASS AND WATER CONSUMPTION:

a) Early lactation period:

The overall mean concentrate feed consumption per day per cow was 4.99 kg for the shaded and 4.96 kg for the unshaded treatment groups. The cows were fed concentrate mixture according to their requirements calculated on the basis of body weight, milk yield and milk fat percentage. They invariably consumed the whole quantity given.

The cows ate slightly more grass when in the open (19.45 kg) compared to what they ate when housed in a shed (19.23 kg). These differences were significant at 1.00 per cent level.

The overall mean water consumption under shaded treatment was 18.29 l per cow per day whereas it was 22.16 l when the cows were exposed. By statistical analysis, this difference was found to be highly significant ($P < 0.01$). Nearly 21.0 per cent more water was consumed by the cows when they were subjected to stress under direct solar radiation.

Observations on physiological reactions revealed that the cows in the unsheltered condition made physiological compensations through increased circulatory and respiratory activities and by physical means during the night to bring down the rectal temperature in the morning to normal levels. The fact that the feed intake was not much affected, rather the grass consumption was slightly higher in the unsheltered condition further shows that the cows when kept unsheltered could adapt well to the situation. This is again substantiated by slightly higher milk yield by the cows when they are unsheltered. The unsheltered cows drank 21 per cent more water. This higher water consumption may indicate a higher water turn-over rate. The higher wind velocity observed in the open yard might have favoured higher surface evaporation and water turn-over in the cows when they were unsheltered.

Thomas (1969) and Thomas et al.(1969) found that provision of shelter apparently had a negative influence on feed intake. They reported that unsheltered animals consumed ($P < 0.01$) more of dry matter and TDN than the sheltered ones.

Many authors have reported the water intake to increase when cows were subjected to heat stress (Blanca, 1965; McDowell et al., 1968; Dunger et al., 1982). Mullick (1964) showed that water intake increased by 38 to 40 per cent in buffalos and 75 per cent in cattle from winter to summer. Satyapal et al.(1973) also found that in Murrah buffalos, the water intake was significantly higher during summer than in winter. Richards (1985) reported a 12.2 per cent increase in water consumption by cows when they were changed over from a thermoneutral environment to an environment with 38°C air temperature and 60 per cent relative humidity. In the present study water consumption had increased by 21.0 per cent due to exposure. The maximum ambient temperature in the open was on an average 35.72°C compared to 30.36°C inside the shed.

b) Late lactation period:

During the late lactation period, no significant differences were found in the consumption of grass and concentrate feed by the cows between treatments. A highly significant difference ($P < 0.01$) was found only with water consumption. The overall mean feed consumption and grass consumption respectively for shaded treatment were 3.42 kg and 23.19 kg and for unshaded treatments, 3.36 kg and 23.29 kg. The mean water consumption was only 8.90 l for shaded treatment and 10.98 l for unsheltered cows. In the unsheltered condition cows drank about 23 per cent more water.

The results in general followed the same trend as in early lactation. Inspite of higher ambient temperature and direct solar radiation during the day time, the cows when tethered in the open could cope up with the situation and maintain their concentrate feed and grass intakes and milk yields similar to what they ate and produced under a shelter inside the shed.

The relationship of climatic factors with the physiological reactions:

a) Unsheltered conditions:

The solar radiation was found to exert a negative, significant ($P < 0.05$) influence on the cardiac rates. Thermal stress is known to reduce heart rates (Nauheimer-Thoneick *et al.*, 1988a). This has been explained to be due to an expansion of blood volume (Thomas, 1969). The influence by wind velocity on heart rate was positive and highly significant ($P < 0.01$). Higher wind velocity may result in greater surface evaporation, reduced blood volume and consequently higher heart rate. Thomas and Razdan (1973b) also observed higher heart rate in bull-calves kept unsheltered and subjected to higher wind velocity. The respiration rate was affected by wind velocity alone in a negative and highly significant ($P < 0.01$) manner. This is understandable because higher wind velocity is known to enhance surface evaporation resulting in enhanced thermolysis and consequent thermal comfort. In the same way, the rectal and skin temperatures also were influenced significantly only by the wind velocity, the effect being negative and highly significant

($P < 0.01$). This further reiterates the belief that higher wind velocity resulted in greater thermal comfort to the cows.

Wind velocity was negatively correlated with respiration rate, rectal temperature and skin temperature whereas it was positively correlated with cardiac rate. This highlights the beneficial effects of air movement in a hot-humid environment.

b) Sheltered conditions:

The physiological variables studied had not been influenced by the explanatory variables chosen except in the case of respiration rate which was positively and significantly ($P < 0.05$) influenced by black globe temperature.

The relationships between climatic variables and animal responses were not as intense when they were housed as when they remained exposed. This is but natural because the housing has been found to reduce extremes in maximum and minimum temperatures. However, the black globe thermometer readings which represent the combined influence of ambient temperature, wind speed and solar radiation, was found to have significant influence on the respiration rate.

This may indicate that the black globe thermometer deserves to be used more extensively for evaluating thermal characters of animal environments.

SUMMARY AND CONCLUSIONS

An experiment was conducted to evaluate the performance of crossbred calves and cows, housed in a common type of cattle shed *vis-a-vis* open conditions without any housing, under the prevailing climatic conditions of Mannuthy in Kerala state. The effect of substituting concentrates partially with roughages on the growth rate of housed and unhoused calves during the summer and rainy seasons was also investigated. Important components of climate, such as solar radiation, mean radiation temperature of the surroundings (black globe temperature) and wind velocity were quantified and these, along with ambient temperature, relative humidity, vapour pressure and rainfall were related to the responses of the experimental stock.

In one part of the experiment, twenty weaned crossbred heifer calves aged six months to one year were grouped into quadruplets and one calf from each group was subjected to one of the following treatments. The calves in treatment I (T1) were protected from direct solar radiation by housing in a common type of calf shed and fed with concentrate-oriented ration. In treatment 2 (T2) calves were exposed to direct solar radiation in an open paddock and fed with concentrate-oriented ration while in treatment 3 (T3) calves were protected from direct solar radiation and fed with roughage-oriented ration and in treatment 4 (T4) calves were unsheltered and fed roughage-oriented diet.

The cardiac rate, respiration rate, rectal temperature and skin temperature and the growth parameters like body weight, length, height and girth were measured systematically for all the calves under the four treatment groups. The climatic factors were assessed daily at 0800 and 1400 h inside the calf shed and in the open paddock. The experiment was run for three months with the first five weeks of hot-dry period and the remaining seven weeks of rainy period.

The maximum air temperature recorded in the open paddock ranged from 35.57 to 37.79°C during the hot-dry period and 29.36 to 33.50°C during the rainy period. The same under shaded conditions were 31.40 to [illegible].24 and [illegible] to 29.51°C respectively. The housing provided had somewhat helped in reducing the maximum ambient temperature by a moderate 5°. However, the range of temperature prevailed during the experimental period was high enough to cause heat stress on the calves. The relative humidity had ranged from 76 to 90 per cent in the mornings to 59 to [illegible] per cent in the afternoons and with this of high range of humidity, the environment could be classified as humid.

During most of the days, the wind velocity in the mornings was either zero or very meagre. Only in the afternoons there were recordable wind velocities which ranged from 0.02 to 0.47 m per sec inside the calf shed as against 0.13 to 0.97 m per sec in the open paddock. The higher wind velocities recorded in the open had contributed towards the thermal comfort of the unshaded calves. The vapour pressure ranged from 21.41 to 25.[illegible] mm of Hg. Inside the shed, the black globe temperatures ranged from 5.83 to 34.30°C which was 2 to 3°C higher than the air temperatures. The black globe temperatures were high on the days when solar radiation intensity was also high. The mean solar radiation values were 110.73 m.cm^{-2} during day time and 80.11 m.cm^{-2} for night time for the upper hemisphere. The lower hemisphere values were 169.6[illegible] during the day and 1[illegible]4.45 m.cm^{-2} for the night. It was observed that during the night also, the radiation values were high which was due to long-wave radiation emanating from the ground and a number of buildings surrounding the open area and the shed. The maximum weekly total rainfall of 210.30 mm was recorded during the final week of the experiment.

The mean rectal temperature of the calves in the unshaded location, during the hot-dry period was [illegible] , which was significantly ($P < 0.01$) higher than the shaded ones (39.56°C). During the rainy period, the rectal temperatures of these calves at 0800 h recording was significantly ($P < 0.01$) lower (39.01°C) than the housed ones (39.21°C) which was due to relatively a cooler environment that prevailed in the open. Drenching in the rain and exposure to free air movement had also facilitated greater thermolysis in the exposed calves. Diurnal variations of more than 0.5°C in the rectal temperatures were recorded. The skin temperature values (41.27 at 0800 h and 42.38°C at 1400 h) recorded were always higher than the rectal temperatures which may be because the calves were still not making use of cutaneous evaporation for thermolysis whereas the body temperature had been brought down by other thermolytic avenues. The calves had attempted increasing heat loss by raising the skin temperature, even exceeding the environmental temperature which had provided the calves with the physical avenue of convective heat loss. The mean respiration rate of 121.75 per min was highest in T2 group which was significantly ($P < 0.01$) different from the other three groups. Eventhough, both T2 and T4 were maintained unhoused, T4 calves that were supplied with roughage feeding had lower respiration rates. The unshaded calves also had significantly ($P < 0.01$) higher cardiac rates. The cardiac rates during the hot-dry period was higher than during the rainy period. In general, the higher physiological reactions of the calves in the exposed location could be attributed to higher effective temperature caused by direct solar radiation.

The maximum gains in live weight (24.98 kg), height (6.8 cm) and girth (11.6 cm) were obtained by the calves (T4) exposed to direct solar radiation and fed with roughage-oriented ration. The next best was the housed and concentrate-fed group (T1) which had the highest gain in length (12.5 cm), second highest gains in live weight and girth and lowest gain in height. Thus, under housed conditions, concentrate feeding and under exposed conditions, roughage feeding had favoured better growth. This is contrary to normal expectations especially while taking into account the physiological reactions observed. It is difficult to give the reasons for such finding without investigating rumen fermentation, rate of passage etc. However it is concluded that exposure to solar radiation would have changed the rumen fermentation in such a way that the proteins in the concentrate were wasted to a greater degree than the leaf protein supplied for the roughage group. The gain in length and height had behaved differently between the groups. Heifers that were housed (T1, T3) had higher gain in body length but lower gain in height compared to heifers kept unsheltered (T2, T4). Whether it is a real difference due to the treatment and if so, the reason for the same can only be known by more detailed investigation.

Overall, it was observed that housing in the open conditions increased the physiological reactions significantly. But these increases were not physiologically meaningful to cause retardation in growth.

The second experiment with a switch back design was done on eight crossbred cows that had calved within one month of commencement of study. They were equally divided into two groups based on their milk yield. One group at random was kept in the open exposed to direct solar radiation while the other group was kept housed in a tiled shed. At the end of every month, the groups were interchanged. The experiment was conducted for eight months comprising of early and late lactation periods. The climatic components, the physiological reactions of the cows, the milk yield, milk fat, milk protein and feed, water and grass consumption were measured during the treatment period. Analysis of variance was carried out to differentiate physiological responses between treatments, the production data were subjected to double reversal design analysis. To find out the relationship of climatic variables with physiological responses, the multiple linear regression analysis was used.

The overall mean maximum temperature for the early lactation period was 30.36°C for shaded and 35.72°C for the unshaded location and the respective mean minimum were 23.83 and 23.37°C. These values were higher than what was recommended as comfortable or ideal for production. Highly significant ($P < 0.01$) differences were found in the relative humidity levels between the locations, values inside the cow shed (81.96 at 0800 h and 66.89 per cent at 1400 h) higher than what was at large. With air temperature always above 20°C and relative humidity 50 per cent or more, the local climate could well be classified as hot-humid. The vapour pressure measurements inside the shed and the open paddock showed a picture opposite to that of relative humidity in that the vapour pressure was significantly ($P < 0.01$) lower inside the shed compared to the paddock. It was seen that inside the shed, inspite of a lower vapour pressure, the relative humidity was high due to lower air temperature. In the open, inspite of slightly higher vapour pressure, the higher ambient temperature and increased air velocity had helped to lower the relative humidity which afforded scope for greater evaporative cooling to the animals. Compared to inside the shed, the unshaded location had significantly ($P < 0.01$) higher wind velocities of 0.072 at 0800 h and 0.497 m per sec of 1400 h. The wind velocity recorded was generally below what was suggested to be ideal. The black globe temperatures (29.02°C at 0300 h and 32.73°C at 1400 h) inside the shed were higher by 2.0 to 5.0°C than the ambient temperature indicating that there was lot of radiant heat load on the housed cows also. The diurnal difference in black globe temperature was narrow so also the solar radiation values in the open. The overall mean for day time total radiation in the open was 167.75 and for the night 124.64 $mW.cm^{-2}$. Even during night hours, the total radiation load on the animal in the hot-humid tropical summer was only 25 per cent less. The overall weekly total rainfall ranged from no rains to 209.30 mm during the early lactation period. The ambient temperatures and radiation values recorded slightly lower values during the late lactation period and relative humidity, wind velocity and rainfall higher values.

During the early lactation period, the cardiac rates were significantly higher ($P < 0.01$) in the exposed cows (8[illegible].53 per min) compared to the housed (74.41 per min). In the mornings the respiratory rates when cows were exposed (37.33) were only slightly higher than when sheltered (32.25). In the afternoons, the unshielded cows had a respiration rate (36.43 per min) almost double that of the shaded cows with a highly significant difference ($P < 0.01$). For rectal temperatures, no differences could be found between treatments for 0800 h recording whereas at 1400 h, the unshaded cows recorded a mean of 40.31°C which was significantly ($P < 0.01$) higher than shaded (39.42°C). The skin temperatures also remained significantly ($P < 0.01$) higher in the unshaded cows both for 0800 h (39.63°C) and 1400 h (41.38°C) measurements.

During the late lactation period also, the picture was almost similar except for in the mornings, when the unshaded cows had significantly ($P < 0.05$) lower rectal temperatures than the shaded ones.

In general, the physiological variables reacted to the treatments given in a predictable manner. At 0800 h the cardiac rate, respiration rate and the skin temperature showed a slightly higher values in the exposed cows but rectal temperature was significantly lower than the sheltered cows. This showed the effect of cooler conditions during the night in the open as well as greater wind speed. In the afternoons, all these physiological variables, including the rectal temperature recorded higher values in the exposed cows. During the nights, the unsheltered cows could not only dissipate this excess heat but also bring back the rectal temperature lower by increased heat loss due to cooler environment in the open paddock. The cows also had the physiological ability to bring the skin temperature on par with their body temperature or sometimes even higher than that. The cows had not allowed their body temperature to go very high by effectively increasing heat loss by accelerated breathing and raising the body surface temperature.

During the early lactation period of 15 weeks, the cows in total, produced 4615.12 kg milk of which 2281.32 kg was when they were sheltered and 2333.8 kg was when they were kept in the open. The difference between treatments was significant ($P < 0.05$) indicating better milk production when cows were unsheltered. In the late lactation period, there was no significant difference in milk yield between treatments. The type of shed provided, eventhough kept the ambient temperature lower, it could not contribute to higher productivity. With higher cardiac and respiratory rates throughout and rectal and skin temperatures higher in the afternoons, the exposed cows seem to compensate during the night and bring down their body temperature in level with sheltered cows and eat as much feed and grass. This could probably maintain similar milk yield in late lactation and higher yield in early lactation in unsheltered cows. Under hot-humid conditions, higher wind velocity in the open seems to favour the cows considerably. The generally held view that under hot-humid conditions, ventilation is most important and animals do not need much elaborate housing gets further strengthened from these findings.

The milk fat content in the sheltered and unsheltered cows during the early lactation was 5.31 and 5.23 per cent for morning milk and 5.27 and 5.04 for afternoon milk respectively. The differences between treatments were highly significant ($P < 0.01$), the exposed cows, though they had maintained their milk production higher the fat content had dropped. The difference in milk protein content in the afternoon milk was significant ($P < 0.01$) between shaded (2.48 per cent) and unshaded (2.37 per cent) cows. Exposure of cows to day time stress in the open sun reduced the fat and protein content in milk. During late lactation period there was no significant effect of treatments either on milk fat or on milk protein content.

Significant differences ($P < 0.01$) were observed in feed, grass and water consumption of the cows between treatment groups during the early lactation period. The concentrate feed consumption (4.99 kg per day) was slightly more in the sheltered cows, grass consumption (19.45 kg per day) was higher under exposed conditions and water consumption (22.16 l per day) was 21 per cent higher in the cows exposed to direct solar radiation. During the late lactation stage, the feed and grass consumption between treatments remained similar, whereas water consumption continued to be significantly ($P < 0.01$) high with the cows, while unsheltered, drinking 23 per cent more water. Observations on physiological reactions revealed that the cows in the unsheltered conditions made physiological compensations through increased circulatory and respiratory activities and by physical means to bring down the rectal temperature in the morning to normal levels. The fact that the feed intake was not much affected, rather the grass consumption was slightly higher in the unsheltered condition further showed that the cows when kept unsheltered could adapt well to the situation. This was again substantiated by slightly higher milk yield by the cows when they were unsheltered. These cows had also significantly increased their water consumption indicating a higher water turn-over rate. The high wind velocity observed in the open yard had favoured higher surface evaporation and water turn-over in the cows while unsheltered. During the late lactation also, inspite of higher ambient temperature and direct solar radiation during day time, the cows when tethered in the open could cope up with the situation and maintain their feed and grass intakes and milk yield equal to what they ate or produced under a shelter inside the shed.

The multiple linear regression analysis revealed that under unsheltered conditions, the solar radiation had exerted a negative and significant ($P < 0.05$) influence and wind velocity had exerted positive and highly significant ($P < 0.01$) influence on cardiac rates. The respiratory rate was affected by wind velocity alone in a negative and significant ($P < 0.01$) manner. In the same way, the rectal and skin temperatures also were influenced significantly only by wind velocity, the effect being negative and highly significant ($P < 0.01$). Wind velocity was negatively correlated with respiration rate, rectal temperature and skin temperature whereas it was positively correlated with cardiac rate. This had highlighted the beneficial effects of air movement in a hot-humid environment.

Under sheltered conditions, the black globe temperature alone was found to exert a positive and significant influence on respiration rate. When the animals were housed, the relationship between climatic variables and animal responses were not as intense as when they remained exposed since housing had reduced the extremes in maximum and minimum temperatures. However, the black globe thermometer readings which represented the combined influence of ambient temperature, wind speed and solar radiation was found to have a significant influence on respiration rate. This had indicated that the black globe thermometer deserved to be used more extensively for evaluating the thermal character of animal environments.

The findings from the two experiments in general indicate the beneficial effects of 'open air' housing on growing and lactating crossbred cattle. While interpreting these results in terms of actual management procedures, other aspects of management such as comfort of men attending the animals, hygiene and disease problems and wet and slushy conditions due to rain cannot be overlooked. Because of these, one cannot recommend to dispose off with housing totally. Instead, we may recommend simple shaded areas with roofs supported on pillars affording maximum ventilation. Simple open type loose houses having paddocks with trees into which animals have access at will, day and night, seems an ideal system of housing for hot-humid tropical regions.

EFFECT OF ENVIRONMENTAL HEAT STRESS ON PERFORMANCE OF CROSSBRED DAIRY CATTLE

BY

A. THILAGARAJAN

ABSTRACT OF THE THESIS

submitted in partial fulfilment of the requirement for the degree

DOCTOR OF PHILOSOPHY

Faculty of Veterinary and Animal Sciences
Kerala Agricultural University
Department of Livestock Production Management
COLLEGE OF VETERINARY AND ANIMAL SCIENCES
Mannuthy, Trichur.

ABSTRACT

Ample evidences are available on the poor performance of livestock inhabiting the tropical regions of the world, compared to their counterparts in the temperate zones. By and large, the management practises adapted in the warmer areas are to be quite different from cooler regions to reach optimum productivity. Among the management practises, housing and feeding aspect needs to be given more emphasis in bringing about the much desired results to meet the ever increasing demand for livestock products.

In the present work, an attempt has been made to investigate the effects of housing and feeding *inter alia*. on the growth and production of *B. taurus* x *B. indicus* crossbred cattle. Besides these, some of the important climatic components, such as solar radiation, mean radiation, temperature of the surrounding and the wind velocity, the factors which have hitherto been widely neglected, were tried to be methodically quantified and presented in relation to their direct effect on the physiological and productive responses of cattle.

To assess the effect of shelter and the type of ration on the physiological responses and growth performance of crossbred cattle, an experiment involving 20 weaned heifer calves, was conducted at the University

Livestock Farm (KAU), Mannuthy. The experiment included four treatments encompassing protection and exposure to solar radiation, and concentrate and roughage-oriented feeding in different combinations. The selected calves were distributed equally to the four treatments, observing the standard statistical procedures.

Physiological variables like cardiac rate, respiration rate, rectal temperature and skin temperature were measured and recorded for all the calves twice a day on a fixed day in a week and for 14 weeks of the study by using standard equipments and procedures. The body weights and body measurements were recorded once in a fortnight at a fixed time in a day. The body measurements included height, length and girth. All the measurements were made on individual calves.

The climatic data, atmospheric temperature, relative humidity, wind velocity, black globe temperature and vapour pressure were recorded inside the shed and atmospheric temperature, solar radiation, relative humidity, wind velocity, vapour pressure and rainfall were recorded in the open paddock. A continuous recording "Solar Radiation Balance Meter" was used to record the solar radiation continuously throughout the experiment.

The average daily maximum air temperature that prevailed in the unshaded location during the hot-dry period was 35°C and in the shaded location, 30°C. During the rainy period the maximum temperature ranged from 25.37 to 29.31°C under the shade and 29.36 to 33.50°C in the unshaded location. The relative humidity ranged from 76 to 93 per cent in the mornings and 55 to 88 per cent in the afternoons. The wind velocity ranged from 0.13 to 0.97 m per sec in the unshaded area and almost zero in the shaded area. The vapour pressure ranged from 21.41 to 25.98 mm of Hg.

The rectal temperature of the calves in the unshaded location was significantly higher than those of the shaded ones ($P < 0.01$) during the hot-dry period. Significantly lower value for rectal temperature was obtained for the concentrate-fed unshaded calves during the morning recording of rainy period and higher values were obtained in the afternoons indicating a diurnal rythm. The skin temperature of the calves was always higher than the rectal temperature in all the cases except in the shaded calves on rainy days.

During the hot-dry period, the respiration rates were significantly higher ($P < 0.01$) in the unshaded group compared to the shaded lot for the morning recordings and in the afternoons, in all the treatments, it was almost double of what was recorded in the mornings. In general, the cardiac rates were found to be higher in the afternoons, than the mornings and lower during the rainy period. Highly significant variations ($P < 0.01$) in all the physiological reactions measured were noticed between the housed and unhoused treatments, the calves exposed to direct solar radiation recording higher values of rectal and skin temperature and respiration and cardiac rates, with few exceptions. The higher physiological reactions of the calves in the open could be attributed to higher effective temperature caused by direct solar radiation.

The analysis of growth parameters indicated significant differences in certain fortnights only. It was observed that maximum gains in live weight, height and girth were obtained by the calves exposed to solar radiation and fed roughage-oriented ration but the gain in length was the least in this group. The next best was the housed and concentrate oriented feeding group which had the highest gain in length, second highest gains in live weight and girth, but the lowest gain in height which implies that under housed conditions concentrate-oriented feeding and under exposed conditions roughage-oriented feeding favour better growth. In general, it was observed that housing in open conditions increased physiological reactions significantly but these increases were not physiologically meaningful to cause retardation in growth.

With a view to study the effects of housing on cows with respect to milk production and other traits, eight cows were subjected to a switch over trial in which sheltered and unsheltered conditions alternated. The experiment ran for eight periods of one month each and in total, milk production for 33 weeks were partitioned into 15 weeks of early lactation and the remaining 18 weeks of late lactation periods. The cows were divided into two groups based on their milk yield. The cows of one of the groups at random were kept in an open paddock exposed to direct solar radiation while cows of the other group were housed in a tile-roofed shed. At the end of every month the groups were interchanged. For feeding the cows, adequate measures were taken to meet both maintenance and production requirement and requirements were worked out every fortnight.

The physiological variables like the cardiac rate, respiration rate, rectal temperature and skin temperature of the individual cows were measured and recorded twice in a day, two days in a week, by following standard procedures. The twice daily milk yields of the cows were measured by individually weighing the quantity in kg at each milking. Milk fat and protein were estimated from samples collected with due precautions at every milking. The feed, grass and water consumption were measured for individual cows. Standard statistical methods were employed to analyse the data. Multiple regression analysis was resorted to find out the relationship of climatic variables with physiological responses.

Highly significant ($P < 0.01$) differences were found between the shaded and unshaded locations in the relative humidity levels. This may probably be due to accumulation of moisture in the atmosphere inside the animal house resulting out of interference with free exchange of air by housing arrangements.

Analysis also revealed highly significant ($P < 0.01$) difference in wind velocities between locations. The wind velocities recorded in the present experiment generally were lower than what had been suggested as ideal for tropical animal husbandry. The analysis of climatic factors revealed that the animals housed in the shaded location were under additional stress due to radiated heat from the surroundings apart from experiencing stress of the high air temperature. The same phenomenon was observed in the unshaded location also. Both the day and night total radiation values remained high. The rainfall distribution was not uniform during the period of study.

In the early lactation period, the cardiac rates, respiration rates, rectal temperature and skin temperature of cows under exposed condition were high in the afternoons. Similar trend was observed in the late lactation period also. In both the treatment groups, all the physiological parameters recorded were on the higher side than the normally accepted standards. The cows had the physiological ability to bring the skin temperature on par with rectal temperature and sometimes even higher than that.

The cows in the open seem to compensate during the night and bring down their body temperature to the level of sheltered and eat as much or more of grass and feed. This resulted in similar milk yield in late lactation and slightly higher milk yield in early lactation. Under the hot humid conditions, the higher wind velocity in the open seem to favour the cows considerably. The generally held view that under hot humid conditions ventilation is most important and animals do not need much elaborate housing gets further strengthened from these findings.

It was observed that the fat percentages varied significantly ($P < 0.01$) between treatments from both morning and afternoon milk obtained from the cows, the milk fat content being lower when they were exposed to direct solar radiation. The exposed cows though they had maintained their milk production higher, the milk fat content had dropped. A highly significant ($P < 0.01$) difference had been found between treatments in protein content of the afternoon milk indicating that exposure of cows to day time stress in the open sun considerably altered milk composition and reduced the protein percentage. During late lactation period, both fat and protein content in milk were lesser for the unshaded treatment but statistically there was no significant difference between treatments.

A highly ($P < 0.01$) significant difference was observed in concentrate feed intake between shaded and unshaded treatments during early lactation and the reverse was observed in the case of grass consumption. The difference in overall mean water consumption under shaded and unshaded condition was highly ($P < 0.01$) significant, cows remaining in the open paddock drinking 21 to 23 per cent more water.

Observations on physiological reactions revealed that the cows in the unsheltered condition made physiological compensations through increased circulatory and respiratory activities and by physical means during the night to bring down the rectal temperature in the morning to normal levels.

During the late lactation period, no significant differences were found in the consumption of grass and concentrate feed by the cows between treatments. A highly significant difference ($P < 0.01$) was found only with water consumption.

During the early lactation, the solar radiation was found to exert a negative, significant ($P < 0.05$) influence on the cardiac rates but the influence by wind velocity was positive and highly significant ($P < 0.01$). In the same way, the rectal and skin temperatures also were influenced significantly only by the wind velocity, the effect being negative and highly significant ($P < 0.01$). During the late lactation stage, the physiological parameters studied had not been influenced by the explanatory variables chosen except in the case of respiration rate which was positively and significantly ($P < 0.05$) influenced by black globe temperatures. The relationships between climatic variables and animal responses were not as intense when they were housed as when they remained exposed.

However, the black globe thermometer readings which represented the combined influence of ambient temperature, wind speed and solar radiation, was found to have significant influence on the respiration rate. This may indicate that the black globe thermometer deserves to be used more extensively for evaluating thermal characters of animal environments.

The results of the study clearly indicate the beneficial effects of 'open-air' conditions in a hot-humid tropical environment. Factors such as comfort of men tending animals and hygiene preclude cattle keeping without housing structures. The result of these experiments however point to the advisability of loose housing system in which cattle have continuous access to an open paddock shaded by trees. The sheltered area of the loose houses also should be simple roofs on pillars allowing maximum ventilation and air movement. It was also found that growing heifers can be maintained equally well on a roughage-oriented feeding schedule.

REFERENCES

Al-Hassan, W.S., J.G.B. Smith, T.J. Burgess, G.C. Ashton and G.C. Smith, 1975. Performance and energy metabolism of steers fed a concentrate (or) roughage diet in conventional semienclosed slatted and enclosed slatted floor feedlots in summer. Canadian J. Anim. Sci., 55:683.

Allen, T.E. and S.M. Donegan, 1974. _Bos indicus_ and _Bos taurus_ crossbred dairy cattle in Australia. III. A climate room test of heat tolerance used in the selection of young sires for progeny testing. Australian J. Agric. Res., 25:1023.

Alvarez, M.B. and H.D. Johnson, 1973. Environmental heat exposure on cattle plasma catecholamine and glucocorticoids. J. Dairy Sci., 56:189.

Amakiri, S.F. and O.N. Funsho, 1979. Studies on rectal temperature, respiration rate and heat tolerance in cattle in the humid tropics. Anim. Prod., 28:329.

Amble, V.N. 1965. Feed requirements of bovines and possibilities of meeting them. Indian J. Agric. Econ., 20:70.

Ames, D.R., D.R. Brink and R.R. Schalles, 1975. Relationship of ambient temperature and ADG. J. Anim. Sci., 41:263 (Abstr.).

Ames, D.R., D.R. Brink and C.L. Willms, 1980. Adjusted protein in feedlot diets during thermal stress. J. Anim. Sci., 50:1.

Andersson,M. 1985. Effect of drinking water temperature on water intake and milk yield of tied-up dairy cows. Livestock Prod.Sci., 12:329.

Annison,E.F. and D.G.Armstrong, 1970. Volatile fatty acid metabolism and energy supply. In: A.T.Philipson (ed). Physiology of digestion and metabolism in the ruminant. Oriel Press, Newcastle upon-Tyne, UK.

Ansell,R.H. 1974. Observations on the reactions of British Fresian cattle to the high ambient temperature of United Arab Emirates. Anim.Breed.Abstr., 43:979.

Ansell,R.H. 1981. Extreme heat stress in dairy cattle and its alleviation; a case report; Environmental aspects of housing for animal production. Ed: J.A.Clark. Butterworths, London, pp.285-306.

Araki,C.T., R.M.Nakamura, L.W.G.Kam and R.L.Clarke, 1985. Diurnal temperature patterns of early lactating cows with milking parlour cooling. J.Dairy Sci., 68:1496.

Attebery,J.T. and H.D.Johnson, 1969. Effect of environmental temperature, controlled feeding and fasting on rumen motility. J.Anim.Sci., 29:727.

Aziz,A.S.A., A.Obeidah, M.A.Aziz and A.Mostageer, 1979. A statistical study on the heat tolerance of Fresian cattle and buffalos. Egyptian J.Anim.Prod., 19:11.

Baile,C.A. and J.M.Forbes, 1974. Control of feed intake and regulation of energy balance in ruminants. Physiol.Rev., 54:160.

Bandaranayaka,D.D. and C.W.Holmes, 1976. Changes in the composition of milk and rumen contents in cows exposed to a high ambient temperature with controlled feeding. Trop.Anim.Hlth.Prod., 8:38.

Bauman,D.E. and W.B.Currie, 1980. Partitioning of nutrients during pregnancy and lactation. A review of mechanisms involving homeostasis and homeorhesis. J.Dairy Sci., 63:1514.

Bayer,W., H.Hippen, D.Steinhauf and J.H.Weniger, 1980. Some effects of high ambient temperature and different levels of RH on thermoregulation and performance traits of lactating cows. Vet.Bull., 50:6082.

Beede,D.K., P.G.Mallonee, R.J.Collier and C.J.Wilcox, 1981. Milk yield, feed intake and physiological responses of dairy cows to varying dietary K during heat stress. J.Anim.Sci., 53(Suppl):381.

Beede,D.K., P.G.Mallonee, P.L.Schneider, C.J.Wilcox and R.J.Collier, 1983. Pottassium nutrition of heat-stressed lactating dairy cows. South African J.Anim.Sci., 13:198.

Beede,D.K., R.J.Collier, C.J.Wilcox and W.W.Thatcher, 1985. Effects of warm climates on milk yield and composition (short-term effects). In: A.J.Smith (ed). Milk production in developing countries. Univ. of Edinburgh, Scotland.

Beede,D.K. and R.J.Collier, 1986. Potential nutritional strategies for intensively managed cattle during thermal stress. J.Anim.Sci., 62:543.

Berman,A. 1971. Thermoregulation in intensively lactating cows in near natural conditions. J.Physiol.London, 215:477.

Berman,A., Y.Folman, M.Kaim, M.Mamen, Z.Hertz, D.Wolfensen, A.Arieli and Y.Graber, 1985. Upper critical temperature and forced ventilation effects for high yielding dairy cows in a subtropical climate. J.Dairy Sci., 68:1488.

Beslin,R. and B.Anojcic, 1979. The effect of temperature and humidity in the byre on milk production and milk fat percentage of cows. Dairy Sci.Abstr., 43:1150.

Bhattacharya,A.N. and R.G.Warner, 1968. Influence of rumen temperature on central cooling or warming and on the regulation of voluntary feed intake in dairy cattle. J.Dairy Sci., 51:1481.

Bhattacharya,A.N. and F.Hussain, 1974. Intake and utilization of nutrients in sheep fed different levels of roughage under heat stress. J.Anim.Sci., 38:877.

Bhattacharyya,N.K. and K.Singh, 1981. Physiological responses of crossbred heifers under undulating and constant temperature-humidity complex. Indian J. Anim.Sci., 51:282.

Bhosrekar,M.R., S.J.Daniel and D.N.Mullick, 1967. The growth of Red Sindhi, Sahiwal and Tharparkar female calves maintained under experimental feeding schedule. Indian J.Dairy Sci., 20:57.

Bhupalsingh and D.P.Sadhu, 1970. Skin temperature responses of the Hariana and Murrah bulls as related to four environmental variables. Indian J.Dairy Sci., 23:240.

Bianca,W. 1962. Relative importance of dry and wetbulb temperatures in causing heat stress in cattle. Nature (London), 195:251.

Bianca,W. 1964. Thermoregulatory responses of the dehydrated ox to drinking cold and warm water in a warm environment. Res.Vet.Sci., 5:75.

Bianca,W. 1965. Reviews of the progress of dairy science - Section A. Physiology - cattle in a hot environment. J.Dairy Res., 32:291.

Bines,J.A., P.E.Brumby, J.E.Storry, R.J.Fulford and G.D.Braithwaite, 1978. The effect of protected lipids on nutrient intakes rumen and blood metabolites and milk secretion in dairy cows during early lactation. J.Agric.Sci.(Camb), 91:135.

Bond,T.E., 1967. Environment control in poultry production. Ed: T.C.Carter, Oliver and Boyd. Edinburgh, pp.200-211.

Bond,T.E., C.F.Kelly, S.R.Morrison and N.Pereira, 1967. Solar, atmospheric and terretrial radiation received by shaded and unshaded animals. Transactions ASAE, 10:622.

Boren,F.W., E.F.Smith, T.J.Hodges, G.H.Larson and R.Cox, 1961. Tech.Bull.Kaus.Agric.Exp.Sta.No.120. Cited Bianca, 1965.

Brink,D.R. and D.R.Ames, 1978. Effect of thermal stress on protein for maintenance. J.Anim.Sci., 47 (Suppl):407.

Brown,W.H., S.S.Iyengar and J.W.Fuquay, 1973. Air and radiant temperature reduction by roof sprinkling in animal shelters. Proc. 70th Annu.Conv.Soc. Agric. Workers Inc. pp.33 (Abstr).

Brown,W.H., J.W.Fuquay, W.H.McGee and S.S.Iyengar, 1974. Evaporative cooling for Missisippi Dairy cows. Transactions ASAE, 17:513.

Bruce,J.M. 1981. Ventilation and temperature control criteria for pigs: In: Enviromental aspects of housing for animal production. Ed: J.A.Clark, Butterworths, London. pp.197-216.

Buffington,D.E., C.A.Arocho, G.H.Canton, D.Pitt, W.W.Thatcher and R.J.Collier, 1981. Black-globe humidity index as comfort equation for dairy cows. Transactions ASAE,24:711.

Buffington,D.E., R.J.Collier and G.H.Canton, 1983. Shade management systems to reduce heat stress for dairy cows in hot humid climates. Transactions ASAE, 26:1798.

Bunger,G., D.Moreau, D.Steinhauf and J.H.Weniger, 1982. Influence of fluctuating temperature and RH on thermoregulation in lactating German Fresian cows in a climatic chamber. Vet.Bull., 52:7363 (Abstr.).

Canton,G.H., D.E.Buffington and R.J.Collier, 1982. Inspired air cooling for dairy cows. Transactions ASAE, 25:730.

Carpenter,G.A. 1974. Heat loss from animals and man. Ed: J.L.Monteith and L.E.Mount. Butterworths, London. pp.389-404.

Caro-Costas,R., R.Vicente-Chandler and J.Figarella, 1965. Productivity of intensively managed pastures of five grasses on steep slopes in the humid mountains of Peurto Rico. J.Agric.(Univ.Peurto Rico), 54:99.

Cerniglia,G., K.L.Koonce and A.B.Watts, 1978. Effects of ambient temperature on broilers. Louisiana Agric., 21:14.

Christensen,E., E.J.Stone, S.C.Tanner and A.Aguilar, 1975. Effect of variations in feeding and climatic factors on production and composition of milk of Holstein cows. Dairy Sci.(Abstr.) 38:4626.

Clark,J.A. 1981. Environmental aspects of housing for animal production. (Ed) Butterworths, London.

Colditz,P.J. and R.C.Kellaway, 1972. The effect of diet and heat stress on feed intake, growth and nitrogen metabolisms in Fresian, F1 Brahman x Fresian and Brahman heifers. Australian J.Agric.Res., 23:717.

Collier,R.J., S.G.Doelger, H.H.Head, W.W.Thatcher and C.J.Wilcox, 1982. Effect of heat stress during pregnancy on maternal harmone concentrations, calf birth weight and post-partum milk yield of Holstein cows. J.Anim.Sci., 54:309.

Crampton,E.W. and L.E.Harris, 1969. Applied animal nutrition. II Edn. W.H.Freeman and Co., San Francisco.

Dalal,S.K. 1979. Genetic differences in adaptability parameters in crossbred cattle and their correlation with production and reproduction traits. Thesis Abstr. Haryana Agric.Univ., 6:5.

Dale,H.E. and S.Brody, 1954. Thermal stress and acid based balance in dairy cattle. Mo.Agric.Exp.Sta. Res.Bull.No.562. Cited Bianca, 1965.

Dale,N.M. and H.L.Fuller, 1980. Effect of the diet composition on feed intake and growth of chicks under heat stress. II. constant vs cycling temperatures. Poult.Sci., 59:1434.

Daniel,J.W., J.W.Fuquay, W.H.McGee, W.H.Brown and J.T.Cardwell, 1973. Roof insulation in a free stall barn for lactating cows during the summer. J.Dairy Sci., 56:306 (Abstr.).

Dantzer,R. and P.Mormede, 1983. Stress in farm animals. A need for reevaluation. J. Anim.Sci., 57:6.

Dolby,R.M. 1961. Dye-binding method for the estimation of protein in milk. J.Dairy Res., 28:43.

Dragovich,D. 1979. Effect of high-temperature - humidity conditions on milk production of dairy herds grazed on farms in a pasture based feed system. International J.of Biometeorol., 23:15.

Elloy,R. ., R.J.Collier, D.L.Bruss, H.H.Van Horn and C.J.Wilcox, 1978. Interrelationship between heat stress parameters and milk composition and yield in dairy cattle. J.Dairy Sci., 61 (Suppl.1):147.

Ellis, W.C., J.H.Matis, T.M.Pond, C.E.Lascano and J.P.Telford, 1984. Dietary influences on flow rate and digestive capacity. In: F.M.C.Gilchrist and R.I.Mackie (ed). Herbivores Nutrition in the subtropics and tropics. The Science Press Pvt.Ltd., Craighill, South Africa.

El-Nouty,F.D., J.M.Elbanna, T.P.Davis and H.D.Johnson, 1980. Aldosterone and ADH response to heat and dehydration in cattle. J. Appl.Physiol., 48:249.

Engelhardt,W.V. and J.R.S.Hales, 1977. Partition of capillary blood flow in rumen, reticulum and omasum of sheep. American J.Physiol., 232:53.

Ferguson,W. 1970. Poultry housing in the tropics: applying the principle of thermal exchange. Trop.Anim.Hlth. Prod., 2:44.

Finch,V.A. 1984. Heat as a stress factor in herbivores under tropical condition. In: F.M.C.Gilchrist and R.I.Mackie (ed). Herbivore nutrition in the subtropics and tropics. The Science Press Pvt.Ltd., Craighill, South Africa.

Flamenbaum,I., D.Wolfenson, M.Mamen and A.Berman, 1986. Cooling dairy cattle by a combination of sprinkling and forced ventilation and its implementation in the shelter system. J.Dairy Sci., 69:3140.

Folman,Y., A.Berman, Z.Hertz, M.Kaim, M.Rosenberg, M.Mamen and S.Gordin, 1979. Milk yield and fertility of high yielding dairy cows in a subtropical climate during summer and winter. J.Dairy Res., 46:411.

Fuquay,J.W. 1981. Heat stress as it affects animal production. J.Anim.Sci., 52:165.

Fuquay,J.W., A.B.Zook, J.W.Daniel, W.H.Brown and W.E.Poe, 1979. Modifications in free stall housing for dairy cows during the summer. J.Dairy Sci., 62:577.

Fuquay,J.W., L.T.Chapinand W.H.Brown, 1980. Short term post-partum heat stress in dairy cows. International J.Biometeorol., 24:141-148.

Furukawa,R., H.Matsumoto and Y.Kariya, 1979. Effect of rapid change of environmental temperature on physiological function in cattle. I. Reactions of cattle to elevation of temperature in respiration rate, body temperature and heart rate. Bulletin of the National Grassland Research Institute No.15:142-151.

Gale,C.C. 1973. Neuroendocrine aspects of thermoregulation. Annu.Rev.Physiol., 35:391.

Gangwar,P.C. 1988. Environmental control as a means of improving animal productivity in the tropics. Indian J.Anim.Sci., 58:487.

Garcia,L. and S.Rodriguez, 1976. Genetic aspects of tolerance to humid heat in Holstein females. ii. Genetic parameters. Anim.Breed.Abstr., 46:1239.

Gengler,W.R., F.A.Martz, H.D.Johnson, G.F.Krause and L.Hahn, 1970. Effect of temperature on food and water intake and rumen fermentation. J.Dairy Sci., 53:434.

Ghosal,A.K. and S.Guha, 1974. Heat loss by respiration in Hariana, Tharparkar and Sahiwal breed under hot dry and hot humid conditions. Indian J.Anim.Hlth., 13:111.

Gill,J.L. 1978. Reversal designs - Design and analysis of experiments in the animal and medical sciences. Vol.II. The Iowa State University Press, Ames, USA. pp.183-190.

Goel,V.K., D.C.Joshi and S.N.Kaushik, 1979. Heat tolerance of Hariana x Holstein, Hariana x Brown Swiss and Hariana x Jersey crossbred heifers. Indian J.Anim. Sci., 49:507.

Gujarati,D. 1978. Multiple regression analysis - the problem of estimation. In: Basic econometrics. McGraw-Hill Kogakusha Ltd., Tokyo, pp.98-124.

Gulyani,R. 1984. Effect of environmental cooling on blood levels of estradiol-17β and progesterone in buffalos. Ph.D. Thesis, Punjab Agric.Univ., Ludhiana.

Guthrie,L.D., J.L.Johnston, J.Rainey and J.A.Lee, 1967. Effects of solar radiation and levels of fibre on production and composition of Holstein cows milk. J.Dairy Sci., 50:608 (Abstr).

Hahn,G.L. 1969. Predicted versus measured production differences using summer air conditioning for lactating dairy cows. J.Dairy Sci., 52:800.

Hahn,G.L. 1976. Progress in Biometeorology. (Ed) H.D.Johnson, Swets and Zeitlinger, Amsterdam, pp.496-503.

Hahn,G.L. 1981. Housing and management to reduce climatic impacts on livestock. J.Anim.Sci., 52:175.

Hahn,L., M.D.Shawklin and H.D.Johnson, 1965. Relation of humidityto lactation and some related physiological responses of dairy cattle. In: Humidity and Moisture (Ed) A.Wexler, Reinhold, London.

Hahn,G.L., J.D.Sikes, M.D.Shanklin and H.D.Johnson, 1969. Dairy cow responses to summer air conditioning as evaluated by switchback experimental design. Transactions ASAE, 12:202.

Hahn,L. and D.D.Osburn, 1970. Cited Macfarlane, 1981.

Hancock,J. and W.Payne, 1955. The direct effects of tropical climate on the performance of European type cattle. 1. Growth. Emp.J.Agric., 23:55.

Harris,D.L., R.R.Shrode, I.W.Rupel and R.E.Leighton, 1960. A study of solar radiation as related to physiological and production responses of lactating Holstein and Jersey cows. J.Dairy Sci., 43:1255.

Hassall,E.N.H. 1973. Reflective insulation and the control of thermal environments. St.Regis- CI, Sydney.

Hassan,A., A.El-Komy and A.Badawy, 1979. Seasonal variations in body reactions, daily milk yield and milk composition of crossbred cows and buffalos. Indian J.Dairy Sci., 32:264.

Hassan,A., M.Samak and A.Badawy, 1981. Seasonal variation in lactational performance and blood haematological characteristics of crossbred (Egyptian x Holstein) and buffalo cows under subtropical conditions. World Rev.Anim.Prod., 17:65.

Heady,E.O., J.P.Maddew, N.L.Jacobson and A.E.Freeman, 1964. Milk production function incorporating variables for cow characteristics and environment. J.Farm.Econ., 46:1.

Her,E., D.Wolfonsen, I.Flamenbaum, Y.Folman, M.Kain and A.Berman, 1988. Thermal, productive and reproductive responses of high yielding cows exposed to short term cooling in summer. J.Dairy Sci., 71:1085.

Herz,A. and D.Steinhauf, 1978. The reaction of domestic animals to heat stress - Animal research and development Vol.7. Institute for Scientific Cooperation, Landhausstr, FRG.

Hilliger,H.G. 1969. The assessment of house climate as part of animal hygiene. In: Tierarztl.Umsch. p.522. Cited: Herz and Steinhauf, 1978.

Holmes,C.W. 1970. Effects of air temperature on body temperatures and sensible heat loss of Friesian and Jersey calves at 12 and 76 days of age. Anim.Prod., 12:493.

Holmes,C.W., C.T.King and P.L.L.Sauwa, 1980. Effects of exposure to a hot environment on Friesian and Brahman x Friesian cattle with some measurements of the effects of exposure to radiant heat. Anim.Prod., 30:1.

Hutson,F.A., J.R.Fuquay, J.T.Cardwell and W.R.Brown, 1971. Influence of activity on the comfort and performance of lactating cows during hot, humid weather. J.Dairy Sci., 54:459 (Abstr.).

Igono,M.O., B.J.Steevens, M.D.Shanklin and H.D.Johnson, 1985. Spray cooling effects on milk production, milk and rectal temperature of cows during a moderate temperate summer season. J.Dairy Sci., 68:979.

Ingraham,R.H. 1968. Milk production and rectal temperature response of Holstein cattle to cooled drinking water in a subtropical climate. Ph.D.Thesis, Iowa State Univ., Ames. Cited: Fuquay, 1981.

Ingraham,R.H., R.W.Stanley and W.C.Wagner, 1979. Seasonal effects of tropical climate on shaded and nonshaded cows as measured by rectal temperature, adrenal cortex harmones, thyroid harmone and milk production. American J.Vet.Res., 40:1792.

Ingram,D.L. and L.E.Mount, 1975. Man and animals in hot environment. Springer Verlag, New York.

Jenkinson, D.M. and R.M. Mabon, 1973. The effect of temperature and humidity on skin surface pH and ionic composition of skin secretions in Ayrshire cattle. British Vet. J., 129:282.

Johnson, K.G. 1970. Sweating rate and the electrolyte content of the skin secretions of Bos taurus and Bos indicus crossbred cows. J. Agric. Sci. (Camb), 75:397.

Johnson, H.D. 1976. Effect of temperature on animals. In. Progress in Animal Biometeorology. Vol.1. Part I. (Ed.) Swets and Zeitlinger, Amsterdam, Netherlands.

Johnson, H.D. (Jr). 1977. Influence of high temperatures on body temperature regulation in lactating cows. Vet. Bull., 49:475.

Johnson, H.D., L. Hahn, H.H. Kibler, M.R. Shanklin and J.E. Edmondson, 1967. Heat and acclimation influences on lactation of Holstein cattle. Mo. Agric. Exp. Stn. Res. Bull. No. 916.

K[illegible]un, J. 1971. Heat tolerance in West African cattle. Ghana J. Sci., 11:19.

Kamal, T.H. and H.D. Johnson, 1970. Whole body 40K loss as a predictor of heat tolerance in cattle. J. Dairy Sci., 53:1734.

Kellaway, R.C. and P.J. Colditz, 1975. The effect of heat stress on growth and nitrogen metabolism in Friesian and F1 Brahman x Friesian heifers. Australian J. Agric. Res., 26:615.

Koilpillai, [illegible], [illegible] Michael, [illegible] Prabakaran and [illegible] Thiagarajan, 1979. Physiological responses of crossbred cows [illegible] natural and evaporative cooler environments. Cheiron, 8:56.

Kronfeld, [illegible] 1979. Sodium, osmolarity and hydration. In: [illegible] and P. Reinhardt (ed.). Regulation of acid base [illegible]. Church and Dwight Co. Inc., Piscataway, [illegible]

Kronfeld, [illegible], [illegible] Donoghue, [illegible] Naylor, [illegible] Johnson and [illegible] Bradley, 1980. Metabolic effects of feeding protected tallow to dairy cows. J. Dairy Sci., 63:545.

Kundu, [illegible] and [illegible] Bhatnagar, 1980. [illegible] heat tolerance in crossbred cows and its relation with milk yield. Indian J. Anim. Sci., 50:567.

Loben, [illegible] 1963. Symposium: factors responsible for variations in milk composition. J. Dairy Sci., 46:129[illegible]

Lippke, [illegible] 1975. Digestibility and volatile fatty acids in steers and wethers at 2[illegible] and 3[illegible] °C ambient temperature. J. Dairy Sci., 58:1860.

Lipscott, [illegible], T.L. Schwartz and [illegible] Thon, 1961. [illegible] control of sodium, potassium, chloride and water metabolism. In: [illegible] (ed.) Mineral metabolism. Vol. 1, [illegible] Academic Press, New York.

Little, . and S.n..haw, 1973. Note on the individuality .. the intake of drinking water by dairy cows. Anim. Prod., 26:225.

Lomax,M.A. and G.D.Baird, 1983. Blood flow and nutrient exchange across liver and gut of the dairy cow: Effects of lactation and fasting. British J.Nutr., 49:481.

Lucci,C..e.S., J.Filho, ..e.de.M.Gasotti and ..Chion, 197.. Behaviour of Holstein calves in natural and heated environments. Anim.Breed.Abstr., 46:2373.

Ludri,R... 1979. A note on the effect of air movement on the body during hot and humid climate on dry matter consumption, physiological reactions and milk yield in crossbred cows. Indian J. Anim. Sci., 49:958.

Macfarlane, .V. 1981. The housing of large animals in hot climates: In: Environmental aspects of housing for animal production. (Ed). J.M.Clark, Butterworths, London, pp.259-284.

MacLeod,G...., Y.Yu and L.A.Schaefter, 1977. Feeding of protected tallow for high yielding dairy cows. J. Dairy Sci., 60:726.

Mallone..., ..R.Beede, ..J.Collier and C.J.Wilcox, 198.. Production and physiological responses of dairy cows to varying dietary potassium during heat stress. J. Dairy Sci., 63:1479.

Kortz,F..., ...Olbrich, H.D.Johnson, T....biloy and ...Lippincott, 1971. Temperature effect on ... in highland cattle ... U.A. J. Anim. Sci., 33:1 (...).

McArthur, .J. 1981. Thermal insulation and heat loss from animals: In: Environmental aspects of housing for animal production. (Ed) J. ...Clark. Butterworths, London, pp.37-...

McDowell,R.E., J.I.McDaniel, ...S.Barrada and ...K.Lee, 1961. Rate of surface evaporation from the normal body surface and with sweat glands inactivated under hot conditions. J.Anim.Sci., 20:380.

McDowell,R.E., C.O.Moody, P...Van Soest, ...P.Lehmann and ...L.Ford, 1968. Effect of heat stress in energy and water utilization of lactating cows. J.Dairy Sci., 52:188.

McDowell,... 1972. Improvement of livestock production in warm climates. ...Freeman and Co., San Francisco, U.S.

Mehta,..., 1970. Effect of cooling on reproductive efficiency and certain blood constituents of buffaloes. M.Sc Thesis, Punjab Agric.Univ., Ludhiana

Mitra,... and ...D.Johnson, 1972. Growth hormone response to acute thermal exposure in cattle. Proc.Soc.Exp. Biol. ..., 139:1086.

Mitra,R., G.I.Christinson and H.D.Johnson, 1972. Effect of prolonged thermal exposure on growth harmone secretion in cattle. J.Anim.Sci., 34:776.

Monteith,J.L. 1973. Principles of environmental physics, Arnold, London.

Moody,E.G., P.J.Van Soest, R.E.McDowell and G.L.Ford, 1967. Effect of high temperature and dietary fat on performance of lactating cows. J.Dairy Sci., 50:1909.

Mudgal,V.D. and S.Mallikarjunappa, 1986. Influence of various roughage and concentrate ratios on lactation performance and feed conversion efficiency of Murrah buffalos. Indian J.Dairy Sci., 39:378.

Mullick,D.N. 1964. A study on the metabolism of food nutrients in cattle and buffalo bulls under climatic stress. Environ.Physiol. and Psychol. in Arid.Cond. Rev.Res. (Arid Zone Res. 14), Paris, Unesco, pp.137.

Murphy,M.R., C.L.Davis and G.C.McCoy, 1983. Factors affecting water consumption by Holstein cows in early lactation. J.Dairy Sci., 66:35.

Nauheimer-Thoneick, Von,H., C.K.Thomas and J.H.Weniger, 1988a. Investigations on energy metabolism of lactating cows. III. Effects of long term high environmental temperature on parameters of thermoregulation, food intake and milk yield. "Züchtungskunde", 60:376.

Nauheimer-Thoneick Von, I., C.K. Thomas and J.H. Honiger, 1988b. Investigation on energy metabolism of lactating cows under heat stress. IV. Effects of long term high environmental temperature on heat production and energy utilisation. "Züchtungskunde", 60:388.

Nawab Singh, T.A. Walli and V.D. Mudgal, 1987. Level of green fodder in the ration of buffalos for optimum milk production. Indian J. Dairy Sci., 40:195.

Nelson, G.L., G.A. Mahoney and E.R. Jerousek, 1961. Hot weather shelter for lactating dairy cattle. Okla. Agric. Exp. Sta. Tech. Bull. No. T-87.

Neuworth, J.G., J.K. Norton, C.A. Rawlings, P.N. Thompson and G.O. Ware, 1979. Physiological responses of dairy calves to environmental heat stress. International J. Biometeoral., 23:243.

Niles, M.A., R.J. Collier and W.J. Croom, 1980. Effects of heat stress on rumen and plasma metabolites and plasma hormone concentrations of Holstein cows. J. Anim. Sci., 50 (Suppl.1):152.

NRC, 1975. Nutrient requirements of domestic animals. No.3, National Research Council, Washington, DC.

NRC, 1976. Nutrient requirements of domestic animals. No.4, National Research Council, Washington, DC.

NRC, 1978. Nutrient requirements of domestic animals No.3, National Research Council, Washington,DC.

NRC, 1981. Effect of environment on nutrient requirements of domestic animals. National Academy Press, Washington,DC.

Oakes,G.K., A.M.Walker, R.A.Ehrenkranz, R.C.Cefalo and R.H.Chez, 1976. Uteroplacental blood flow during hyperthermia with and without respiratory alkalosis. J.Appl.Physiol., 41:197.

O'Donovan,P.B. 1979. Potential of crossbred and native cattle on local feeds and by-products in Ethiopia. World Anim.Rev., 30:23.

Palmquist,D.L. and T.C.Jenkins, 1980. Fat in lactation rations; review. J.Dairy Sci., 63:1.

Palmquist,D.L. and T.C.Jenkins, 1982. Calcium soaps as a fat supplement in dairy cattle feeding. In: Proc.XII World Congr.Dis.Cattle, Amsterdam, Netherlands.

Pan,Y.S., D. McLean, [illegible] and [illegible].Ellis, 1978. Effect of heat stress on the protein composition and manufacturing properties of milk from two diverse breeds of dairy cattle. 20th International Dairy Congress Vol.E:28-29. New South Wales, Australia, 1978.

Pandey, M.D. and A.Roy, 1969. Studies on the adaptability of buffalo to tropical climate; II. Seasonal changes in the body temperature, cardiorespiratory and haemotological attributes in buffalo cows. Indian J.Anim.Sci., 39:378.

Payne, W.J.A. 1963. Proc. Sixth Int.Congr.Nutr.E and S. Livingstone, Edinburgh and London, p.213. Cited Bianca, 1965.

Ragsdale, A.C., H.J.Thompson, D.M.Worstell and S.Brody, 1950. Milk production and feed and water consumption of Brahman, Jersey and Holstein cows to changes in temperatures 50-105°F and 50-80°F. Mo.Agric.Exp. Stn.Res.Bull., 460.

Ragsdale, A.C., H.J.Thompson, D.M.Worstell and S.Brody, 1951. Mo.Agric.Exp.Stn.Res.Bull., 471. Cited: Bianca, 1965.

Randel, P.L. and L.L.Rusoff, 1963. Effect of heat stress on growth, feed consumption and digestibility in Holstein calves from birth to 90 days of age. J.Dairy Sci., 46:368.

Rathi, S.S. and D.S.Balaine, 1985. Effect of some genetic and environmental factors on body weights in dairy heifers. Indian J.Dairy Sci., 37:378.

Razdan, M.N. and S.N.Ray, 1968. Physiological behaviour of Tharparkar cattle under different environments. I. Feed consumption and growth. Indian J.Dairy Sci., 21:75.

Razdan,M.N., M.R.Bosrekar and S.N.Ray, 1968. Physiological behaviour of Tharparkar cattle under different environments. 2. Physiological reactions and zone of thermoneutrality. Indian J.Dairy Sci., 21:82.

Regan,W.M. and G.A.Richardson, 1938. Reactions of the dairy cow to changes in environmental temperature. J.Dairy Sci., 21:73.

Reid,B.L. 1979. Feeding and management practices for improving performance in hot weather. Proc.Florida Nutr.Cong. pp.61.

Renner,E. 1976. Effect of climatic factors on performance of dairy cows. Dairy Sci.(Abstr), 40:1159.

Richards,J.I. 1985. Effect of high day time temperature on the intake and utilization of water in lactating Friesian cows. Trop.Anim.Hlth.Prod., 17:209.

Robertshaw,D. and V.A.Finch, 1976. Beef cattle production in developing countries. (Ed) A.J.Smith. University of Edinburgh, Edinburgh, pp.281-293.

Robertshaw,D. 1981. The environmental physiology of animal production. In: Environmental aspects of housing for animal production. (Ed) J.A.Clark, Butterworths, London, pp.3-18.

Rodriguez, L.A., G.Mekonnen, C.J.Wilcox, F.G.Martin and W.A.Krienke, 1985. Effects of relative humidity, maximum minimum temperature, pregnancy and stage of lactation on milk composition and yield. J.Dairy Sci., 68:973.

Roman-Ponce, H., W.W.Thatcher, D.E.Buffington, C.J.Wilcox and H.H.Van Horn, 1977. Physiological and production responses of dairy cattle to a shade structure in a subtropical environment. J.Dairy Sci., 60:424.

Roman,Ponce, H., W.W.Thatcher, D.Canton, D.R.Barron and C.J.Wilcox, 1978. Thermal stress effects on uterine blood flow in dairy cows. J.Anim.Sci., 46:175.

Roman-Ponce, H., W.W.Thatcher, R.J.Collier and C.J.Wilcox, 1981. Hormonal responses of lactating dairy cattle to TRH and ACTH in a shade management system within a subtropical environment. Theriogenology, 16:131.

Roussel, J.D. and J.F.Beatty, 1970. Influence of zone cooling on performance of cows lactating during stressful summer conditions. J.Dairy Sci., 53:1085.

Sainsbury, D.W.B. 1965. The housing of large animal livestock. Vet.Rec., 77:945.

Sainsbury, D.W.B. 1967. Animal health and housing, Bailliere, Tindall and Casell, London.

Saseendranath,M.R., C.K.Thomas and P.I.Geevarghese, 1983. Effect of two types of housing and two concentrate feeds on growth of crossbred calves. Indian J.Anim. Sci., 53:591.

Sastry,N.S.R., C.K.Thomas, V.N.Tripathi, R.N.Pal and L.R.Gupta, 1973. Effect of shelter and water sprinkling during summer and autumn on some physiological reactions of Murrah buffalo heifers. Indian J.Anim.Sci., 43:95.

Satyapal, R.N.Pal and C.K.Thomas, 1973. Water intake by Murrah buffalo cows. Indian J.Dairy Sci., 26:253.

Satyapal, R.N.Pal and C.K.Thomas, 1975. Effect of restricted access to water supply and shelter on the physiological norms and production of Murrah buffalos. Indian J. Dairy Sci., 28:41.

Schneider,P.L., D.K.Beede, E.A.Wirchert and C.J.Wilcox, 1984a. Influence of heat stress on rate of passage of digesta and acid base balance. J.Dairy Sci., 67 (Suppl.1):120.

Schneider,P.L., D.K.Beede, C.J.Wilcox and R.J.Collier, 1984b. Influence of dietary sodium and pottassium bicarbonate and total pottassium on heat stressed lactating dairy cows. J.Dairy Sci., 67:2546.

Schneider,P.L., D.K.Beede and C.J.Wilcox, 1986. Responses of lactating cows to dietary sodium source and quantity and potassium quantity during heat stress. J.Dairy Sci., 69:99.

Scott,T.W. and L.J.Cook, 1970. Poly-unsaturated milk fat; A new development from Australia. Agric.Sci.Rev., 8:25.

Sejrsensen,K. and J.B.Larsen, 1977. Effect of silage: concentrate ratio on feed intake, growth rate and subsequent milk yield of early calving heifers. Livestock Prod.Sci., 4:313.

Sen,K.C. and S.N.Ray, 1964. Nutritive values of Indian cattle feeds and feeding of cattle. Tech.Bull.No.25. Indian Coun.Agric.Res., pp.112-133.

Sell,J.L. 1979. Use of supplemental fat to improve productive efficiency of poultry. Proc.Florida Nutr.Conf. pp.43.

Shafie,M.M. and A.M.El-Sheikh aly, 1970. Heat tolerance of Friesian cattle under Egyptian climatic conditions. UAR J.Anim.Prod., 10:99.

Sharma,D.C. 1968. Intake and digestion of nutrients by the bovine under climatic stress. J.Nutr., 94:317.

Sharma,K.M. and S.K.Talapatra, 1963. Growth responses in buffalo calves. Indian J.Dairy Sci., 16:236.

Sharma,U.V. and B.M.Jhanwar, 1973. Effect of supplementation of wheat straw with concentrate on voluntary intake, digestability and growth in cattle. Indian J.Anim. Sci., 43:688.

Sharma,V.D. and C.K.Thomas, 1981. Economic level of concentrate supplementation in the ration of buffalo heifers. Indian J.Anim.Sci., 51:157.

Sharma,A.K., L.A.Rodriguez, C.J.Wilcox, R.J.Collier, K.C.Bashman and F.G.Martin, 1988. Interactions of climatic factors affecting milk yield and composition. J.Dairy Sci., 71:819.

Shebaita,M.K. 1984. Differences in physiological reactions between Friesian and Brown Swiss in the tropics. "Z.Tierzuchtg, Zuchtgsbiol", 101:131.

Shibaita,M. and A.Mukai, 1979. Effect of heat stress and hay-concentrate ratios on milk production, heat production, and some physiological responses of lactating cows. Japanese J.Zootechnical Sci., 50:630.

Shivprasad, V.N.Tripathi and J.S.Tomar, 1986. Effect of different type of housing management on the growth-rate and feed efficiency of crossbred calves during winter. Indian J.Dairy Sci., 39:28.

Shrode,R.R., F.R.Quazi, I.W.Rupel and R.E.Leighton 1960. Variations in rectal temperature, respiration rate and pulse of cattle as related to variation in four environmental variables. J.Dairy Sci., 43:1235.

Schmidt-Nielsen,K. 1972. Recent advances in the comparative physiology of desert animals. Symp.Zool. Soc.London, 31:371.

Siegel,H.S. and L.N.Drury, 1968. Physiological responses to high lethal temperature and air velocity in young fowl. Poult.Sci., 47:1230.

Singh,M., I.Saran and M.G.Jackson, 1972. Value of concentrate supplements to sorghum forage for milk production and growth in cows and buffalos. Indian J.Anim.Sci., 42:16.

Singh,S.P. and W.M.Newton, 1978a. Acclimation of young calves to high temperatures; physiological responses. American J.Vet.Res., 39:795.

Singh,S.P. and W.M.Newton, 1978b. Acclimation of young calves to high temperatures; composition of blood and skin secretions. American J.Vet.Res., 39:799.

Smith,W.K. 1981. Poultry housing problems in the tropics and subtropics. In: Environmental aspects of housing for animal production. (Ed) J.A.Clark, Butterworths, London, pp.235-258.

Snedecor,G.W. and W.G.Cochran, 1967. Statistical methods. Oxford and IBH Publishing Co. New Delhi, pp.299-338.

Somanathan,V.L. and T.G.Rajagopalan, 1983. Bioclimatological studies on growing livestock. II. Effect of ambient temperature and RH on rectal temperature and respiration rate of crossbred cattle. Kerala J.Vet.Sci., 14:137.

Starr,J.R. 1981. Climate and the need for housing. In: Environmental aspects of housing for animal production. (Ed) J.A.Clark, Butterworths, London, pp.19-35.

Starr,J., L.Neubauer and D.Molzer, 1978. Transactions ASAE, 78:4003. Cited Starr, 1981.

Stewart,R.E., J.C.Hotostine, D.L.Pfost and G.L.Schrug, 1966. Field test of summer air-conditioning for dairy cattle in Ohio. Transactions ASAE, 7:271.

Stolpe,J. 1977. Air movement and animal performance in temperature above optimum. Vet.Bull., 48:0956.

Stott,G.H. and F.Wiersma, 1974. Response of dairy cattle to an evaporative cooled environment. Proc.Internat'l Livestock Env.Symp.ASAE, SP 0174:88. Cited Fuquay, 1981.

Syamasunder,N. and P.C.Choudhuri, 1988. Effect of environmental temperature on crossbred calves in mid summer. Indian J.Dairy Sci., 41:12.

Tarui,S., S.Ishino, K.Matsuda, Y.Shoji, K.Ambo and T.Tsuda, 1979. Effect of experimental high environmental temperature and humidity on steers. Tohoku J.Agric.Res., 30:95.

Thatcher,W.W. 1974. Effects of season, climate and temperature on reproduction and lactation. J.Dairy Sci., 57:360.

Thatcher,W.W. and R.J.Collier, 1982. Effect of heat on animal productivity. In: M.Rechcigl Jr (ed). Handbook of Agricultural Productivity. Vol.II. CRC Press, Inc., BocaRaton,FL.

Thiagarajan,M., R.D.Michael, P.Kothandaraman and S.Shanmugasundaram, 1973. A study of experimental environments and their effects of factors related to broiler production. Indian J.Poult.Sci., 8:151.

Thiagarajan,M. and R.D.Michael, 1978. Shelter engineering - choice of roofing material for tropical poultry housing. Poult.Guide, 15:63.

Thiagarajan,M., R.D.Michael and R.Prabaharan, 1978. Effect of sprinkling water on crossbred cows during summer. Kerala J.Vet.Sci., 9:215.

Thom,E.C. 1958. A new concept for cooling degree-days; Air-conditioning, heating and ventilation. Cited, Bianca, 1965.

Thomas,C.K. 1969. Studies on the adaptability of Sahiwal-Brown swiss crossbred cattle to tropical conditions. Ph.D. Thesis, Punjab Univ., Chandigarh.

Thomas,C.K., G.C.Georgie and M.N.Razdan, 1969. Studies on the performance of crossbred cattle. Part II: Effect of shelter and different environmental conditions on nutrient utilization by Sahiwal x Brown Swiss (F1) and purebred Sahiwal cattle. Indian J. Dairy Sci., 22:173.

Thomas,C.K. and M.N.Razdan, 1973a. Adaptability of ½ Sahiwal x ½ Brown Swiss cattle to subtropical conditions. 1. Feeding Behaviour. Indian J.Anim.Sci., 43:5.

Thomas,C.K. and M.N.Razdan, 1973b. Adaptability of ½ Sahiwal x ½ Brown Swiss cattle to subtropical conditions. 2. Physiological reactions. Indian J.Anim.Sci., 43:358.

Thomas,C.K. and M.N.Razdan, 1974. Adaptability of ½ Sahiwal x ½ Brown Swiss cattle to subtropical conditions. 3. Body water distribution. Indian J.Anim.Sci., 44:432.

Thomas,C.K., V.N.Tripathi and N.S.R.Sastry, 1975. Effect of concentrate supplementation and thermal protection on the growth rate of Murrah buffalo heifers. Indian J.Anim.Sci., 45:828.

Thomas,C.K. and R.A.Acharya, 1981. The effect of physical environment on milk production in <u>Bos indicus</u> x <u>Bos taurus</u> crosses. Indian J.Anim.Sci., 51:351.

Thomas,C.K. and K.P.Nair, 1982. A note on raising heifers on *ad lib* forages and reduced concentrates. Kerala J.Vet.Sci., 13:165.

Thompson,R.D., F.T.Wratten, J.E.Johnston and C.P.Breidenstein, 1964. Solar radiation receipt and physiological responses of dairy animals in the sun and under natural and artificial shade. J.Dairy Sci., 47:301.

Tomar,S.S., S.S.Dhillon and M.N.Razdan, 1969. Studies on the performance of crossbred dairy cattle. 1. Effect of shelter and different environmental conditions on water metabolism and body water distribution of Sahiwal x Brown Swiss F1 and purebred Sahiwal cattle. Indian J.Dairy Sci., 22:73.

Turner,H.G. 1972. Selection of beef cattle for tropical Australia. Australian Vet.J., 48:162.

Tripathi,V.N., C.K.Thomas, N.S.R.Sastry, R.N.Pal and L.K.Gupta, 1972. Effect of shelter and water sprinkling on buffalos:Growth rate. Indian J.Anim. Sci., 42:745.

Van Horn,H.H. 1984. Effect of level of concentrate feeding on milk production; 18th Annu.Conf.Livestock and Poultry; Latin Amer.Inst.Food Agric.Sci.Univ., Florida, Gainsville, Fl.

Voigtlander,K.H., C.Schneider and M.Dorn, 1973. Studies on seasonal variations of milk yield and milk composition. Anim.Breed.Abstr., 42:3083.

Warren,W.P., F.A.Martz, K.H.Asay, E.S.Hilderbrand, C.G.Payne and J.R.Vogt, 1974. Digestibility and rate of passage by steers fed tall fescue, alfalfa, and orchardgrass hay in 18 and 32°C ambient temperatures. J.Anim.Sci., 39:93.

Wayman,O., H.D.Johnson, C.P.Merilan and I.L.Berry, 1962. Effect of ad libitum or force feeding of two rations on lactating dairy cows subject to temperature stress. J.Dairy Sci., 45:1472.

Webster,A.J.F. 1974. In: Heat loss from animals and man. (Ed) J.L.Monteith and L.E.Mount, Butterworths, London. pp.205-231.

Wetteman,R.P. and H.A.Tucker, 1974. Relationship of ambient temperature to serum prolactin in heifers. Proc.Soc.Exp.Biol.Med., 146:908.

Wiersma,F. and G.H.Stott, 1965. Microclimate modifications for hot weather stress and relief in dairy cattle. Transactions ASAE, 65:404.

Wiersma,F.D., V.Armstrong, W.T.Welchert and O.G.Lough, 1984. Housing system for dairy production under warm weather conditions. World Anim.Rev., 50:16.

Williams,J.S., ?.R.Shrode, R.E.Leighton and I.…Rupel, 1960. A study of the influence of solar radiation on physiological responses of dairy cattle. J.Dairy Sci., 43:1245.

Williamson,G. and W.J.A.Payne, 1978. An introduction to animal husbandry in the tropics. Third Edn. Longmans, London.

Wolfenson,D., I.Flamenbaum and A.Berman, 1988. Dry period heat stress relief effects on prepartum progesterone, calf birth weight and milk production. J.Dairy Sci., 71:809.

Wolff,L.K. and J.E.Monty Jr. 1974. Physiological response to intense summer heat and its effect on the oestrous cycle of non-lactating and lactating HF cows in Arizona. American J.Vet.Res., 35:187.

Wrenn,T.R., J.Bitman, J.R.Weyant, D.L.Wood, D.L.Stronzuisl and …Hooven, 1976. Protected tallow fed to lactating cows. J.Anim.Sci., 43:309.

Wurster,R.D. and R.D.McCook, 1969. Influence of rate of change in skin temperature on sweating. J.Appl. Physiol., 22:237.

Yasson, … 1977. Respiratory responses of N'Dama and Borar cattle to climatic conditions in Nigeria. World Rev.Anim.Prod., 13:33.

Young, B. A. 1981. Cold stress as it affects animal production. J. Anim. Sci., 52:154.

Yousri, R. M. 1976. Effect of environmental temperature on some physiological and nutritional aspects of animals. World Rev. Anim. Prod., 12:79.

Zia-ur-rehman, A. H. Gilani, M. Ahmed and S. S. Ali, 1982. Adaptability of crossbred dairy heifers to summer season measured by rectal temperature, pulse rate and respiration rate. Vet. Bull., 53:1466.