THE EFFECT OF A HIGH AMBIENT TEMPERATURE ON THE PHYSIOLOGICAL RESPONSES OF FRIESIAN AND BRAHMAN X FRIESIAN CALVES FED ON TWO RATIONS

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ABSTRACT

Eight Friesian and eight Brahman x Friesian (F_1) steer calves were kept at 17 or 34.5°C in temperature controlled rooms and fed on hay or concentrate diets in a 2 x 2 x 2 factorial design for eight weeks. Then eight of the calves were used to study the effect of coat clipping at the higher air temperature, and later they were exposed each day to eight hours of artificial radiant heat load for two weeks.

In each trial voluntary feed and water intake, liveweight gain, rectal temperature and respiration rate were assessed. In addition dietary digestibility and hair coat cover were estimated in the factorial trial, while radiant heat load and sweating rates were measured in the radiation trial.

Data for feed and water intake, digestibility and liveweight gain are the subject of another thesis (King, 1978).

There were no significant differences between breeds at the cool ambient temperature of 17°C, but at the high air temperature (34.5°C) both breeds had reduced their voluntary feed intake and had significantly increased their rectal temperatures ($P<0.01$) and respiration rates ($P<0.005$). However, although the F_1 calves ate more feed at the high ambient temperature than the Friesians, rectal temperatures and respiration rates of Friesians (40.50°C, 100 counts per minute) were higher than those for the F_1 calves (39.80°C and 93 counts per minute respectively). Nevertheless, only rectal temperatures showed significant ($P<0.05$) interactions between the effects of breed and air temperature.

At the high ambient temperature concentrate fed calves consumed more DM and had slightly higher respiration rates but slightly lower rectal temperatures (40.11°C) than hay fed calves (40.20°C); F_1 calves fed this diet had the highest DMI and liveweight gain but lowest rectal temperature (39.63°C).

Coat cover was related to level of feeding, breed and air temperature. Generally F_1 calves consumed more of the concentrate diet and had significantly ($P<0.05$) less coat cover than the Friesians. Hay fed calves had significantly ($P<0.01$) heavier coats than concentrate fed calves. Coat weights were substantially heavier at 17°C (177 g/m^2) than at 34.5°C ambient (150 g/m^2), but this difference was not significant.

Although coat cover was positively correlated with body temperature at the high ambient temperature, clipping did not affect the DMI, body temperature or respiration rate of either of the genotypes.

Exposure to radiant heaters resulted in a net gain of radiant heat by the animals of 130 - 140 $kcal/m^2$ hr; this caused significant increases ($P<0.05$) in respiration rate and rectal temperature measured after 8 hours of exposure to the radiant load. However, F_1 calves were significantly ($P<0.05$) less stressed by the radiation than the Friesians.

The measured sweating rates of 153 and 60 g/m^2 hr for F_1 and Friesian calves respectively suggest that the most important cause for the genotype differences in heat tolerance is due to the superior ability of the F_1 to discharge moisture on to the skin surface for evaporative cooling.

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CHAPTER ONE

INTRODUCTION

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INTRODUCTION

1.1: Animal production statistics

According to Josiorowski (1976), tropical rangelands constitute 25 percent of the world's land surface and supports about 70 percent of the world's cattle and buffalo population, but produces only 34 percent of the world's beef. And while the world annual meat production increased at 3.4 percent annually between 1968 and 1972, the rate of growth in developing countries (mainly tropically situated) over the same period was only 2.3 percent, and this increase was attributed to an increase in the number of animals rather than production per head of animal. Animal productivity in the tropics has remained stagnant over the last decade.

1.2: Factors influencing animal production efficiency in the tropics

Bianca (1965) has indicated that when assessing the factors that determine beef production in hot countries it is difficult to disassociate direct from indirect climatic effects and from effects that are not connected with climate. This is because tropical animal productivity suffers from a multitude of problems including undernutrition, disease and a low genetic material which are interrelated to the climate.

1.2.1: Nutrition

Beef production in the tropics is primarily from natural pastures and has traditionally been a simple and inexpensive enterprise. Inadequate, unreliable and poorly distributed rainfall results in poor forage growth and composition. In the normally short rainy seasons, natural forages grow luxuriantly to form bulk grazing which is low in dry matter content and largely deficient in vital nutrients for animal growth. High radiant heat and humidity favours a characteristic development of tropical grasses which result in rapid increase in lignin content and a decrease in soluble nutrients so that palatability and digestibility are detrimentally affected and intake is curtailed (Payne, 1969). Range-raised tropical cattle are therefore often subjected to periodic undernutrition largely as a result of climatic influence on forage productivity.

1.2.2: Disease

Low animal husbandry standards in the warm tropical climate favours the development and spread of pathogenic organisms. Tropical inherent diseases like Trypanosomiasis and the tick-borne diseases, East Coast Fever and Anaplasmosis, constitute a major burden to animal development in tropical countries. Finelle (1973) has indicated that about 10 million square kilometers of tropical rangeland is devoid of animal rearing because of tsetse infestation. In Australia, the economic importance of the blue tick, *Boophilus microplus*, a carrier of Anaplasmosis has been reported to cost the Australian beef industry an estimated $8.50 per beast per year. Both tick-infested herds (Springell, 1974; Johnston, 1969 and Turner and Short, 1972) and trypanosome-infested herds (Finelle, 1974) suffer retarded growth, low reproductive rate and high mortality.

1.2.3: Climate; direct effects of

Probably the most important part played by climate in animal production is its effects on the physiology of the animal. Physiologically stressful conditions affect the animal's food intake, growth rate, lactational performance and reproductive efficiency.

The indigenous Zebu cattle constitute the main source of beef production in the tropics because of their adaptation to the prevailing climatic conditions. A great deal of information related to the performance of European breeds in the tropics has been reviewed (Vaccaro, 1973, 1974, 1975 and Preston and Willis, 1974) and suggest that although temperate cattle have superior genetic potential, they perform relatively poorly in the tropics mainly because of their high susceptibility to heat stress and to tropical inherent diseases. Hopkins (1976) has argued that differences between breeds or individual animals in their survival and adaptation to heat conditions would be reflected in the efficiency with which the various physiological systems associated with productivity function. The efficiency of these systems is in turn dependent on the animal's ability to adequately regulate its body temperature during exposure to a hot condition. Many researchers in animal climatology and environmental physiology (Vercoe, 1970; Bianca, 1965; and Turner, 1975) have shown breed differences to heat tolerance favouring indigenous stock.

Various measurements of performance including growth rate, reproductive performance and survival rate, have been used to determine the suitability of animals to a tropical climate. More important methods have been the interrelationship between endocrine activity and metabolic changes. Recently, however, environmental physiologists have used rectal temperature and respiration rate as indicators of heat stress. Due to its sensitivity to environmental heat, respiration frequency is becoming an important heat stress indicator and particularly because of its easiness to measure even in field conditions.

1.3: Experimental aims

This experiment measured the physiological responses of Friesian and Brahman x Friesian calves fed on two types of diet and exposed to a cool or a hot condition. Similar measurements were taken on one half of the calves exposed to artificial radiant heat load. The data for respiration rate, rectal temperature, coat cover and sweat rate is analysed and interpreted in this paper. Food intake, digestibility and liveweight gains were to be reported in another paper (King, 1978).

It is hoped that the findings in this experiment would provide additional or complementary information on the use of rectal temperature and respiration rate as a measure of heat tolerance; and that such information in conjunction with other physiological attributes would be used to screen animals and select a base population from which geneticists can undertake to breed more efficient producers for the tropics.

CHAPTER TWO

LITERATURE REVIEW

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LITERATURE REVIEW

2.1: The influence of climate on heat transfer in animals

Warm blooded animals (homeotherms) maintain relatively constant body temperature throughout their life. Their capacity to maintain thermal balance is dependent on the environment and its body energy status. The heat produced from physiological processes together with any heat gain from the environment must be lost in order to maintain thermal balance. And variations in environmental conditions may affect the rate of heat transfer between the animal and the environment, in which case the animal must alter its heat production to conform with the environmental demand. Although by such manipulations together with some influence of heat loss animals may survive in fairly extreme conditions, they can only do so at the expense of a reduced production.

2.1.1: Mechanisms of heat transfer

All heat transfer mechanisms are derived from the heat flow equation $H = \lambda \frac{A}{L} (T_1 - T_2)$ where (H) the rate of heat flow is proportional to the temperature gradient $(T_1 - T_2)$ and the thermal conductance of the medium (λ) through which the heat is passing, and is dependent upon the thickness of the medium and its surface area. When the thickness of the medium is expressed as a resistance the equation becomes $H = A \frac{(T_1 - T_2)}{R}$ where (R) is the 'specific insulation' and the reciprocal of this is the 'thermal conductance (C)', $H = AC (T_1 - T_2)$ which is the basic heat transfer equation. However, in evaporative heat transfer $(T_1 - T_2)$ is replaced by (es - ea) vapour pressure gradient between skin surface and the immediate surrounding air.

Essentially heat is transferred in two forms; (1) sensible heat which includes conductive convective and radiant channels and (2) evaporative heat which includes respiratory and cutaneous losses.

2.1.1.1: Radiation

Kerslake (1972) indicated that all substances containing heat radiate at a rate proportional to the fourth power of their absolute temperature ($0^{o}A = -273^{o}C$);

$R = \sigma T^4$; where

R = radiant flux per unit area per unit time

= Stefan-Boltzman constant ($5.67 \times 10^{-8} W/m^2$)

and T = absolute temperature (^oA),

and the rate of emission depends on the absorbtivity or reflectivity of the body (e) thus $R = e\sigma T^4$, and the rate of heat transfer between two bodies is directly related to the temperature difference between their surfaces; $R = hr\ (T_1 - T_2)$, where hr is the coefficient of heat exchange by radiation ($W/m^2\ ^oC$).

2.1.1.1.1: Solar Radiation

Shortwave radiation (0.3 - 3μm wavelengths) is emitted by objects with hot surfaces of which the sun which has a surface temperature of about 6000°K is the most important national radiator. In bright daylight solar radiation may become the largest single positive heat balance (Robertshaw and Finch, 1976). The amount of radiant heat which is incident on a body is the sum of (1) direct sunlight, (2) sunlight reflected off the clouds, (3) sunlight reflected off the ground and (4) scattered sunlight.

The net amount of shortwave radiation absorbed by an animal (incident-reflected) depends on the angle of the sun, cloud cover and other particles in the sky; the reflectivity of the clouds, ground and vegetation: and the reflection coefficient of the animals surface.

2.1.1.1.2: Longwave Radiation

Most natural substances are full radiators of longwave radiation 3μm - 100μ (Monteith, 1973). They would absorb shortwave radiation and re-emit some of this as longwave radiation. The total influx reaching a body is formed of; (1) infrared radiation from the atmosphere (emitted by dust particles, water vapour and carbon dioxide); (2) infrared radiation from the vegetation and (3) infrared emission from the ground.

The total radiant balance per unit area of a surface is therefore given by:

$$Rn = (S_{DIR} + S_{DIF}) + (L_A + L_G) \quad - \quad r(S_{DIR} + S_{DIF}) + L_S$$

or = incident shortwave + absorbed longwave radiation less reflected shortwave radiation + emitted longwave radiation

2.1.1.2: Convective heat transfer

This is fundamentally a process of mass transfer where heat transfer between surfaces and/or fluids is initiated by movement of particles, $C = hc\ (T_1 - T_2)$; where; hc = coefficient of heat transfer $W/m^{2\,o}C$.

2.1.1.2.1: Free convective transfer

This depends on particle density differences created by heat where warm particles are activated to displace cold ones through a process referred to as thermal buoyancy.

2.1.1.2.2: Forced convective transfer

The rate of forced convective heat transfer between a body and a fluid moving over it depends on the velocity of the fluid and it is proportional to the interface area and the temperature difference between the body and the fluid, $H_{cov}\ \alpha\ (T_S - T_A)$. Based on thermal insulation measurement Bennett and Hutchinson (1964) and Blaxter (1964) forced convective heat transfer via an air stream has been derived

$H_{cov} = X\ (V^{0\ 5})\ (T_S - T_A)$

where X is given the factor of 7.0

V = air velocity

$(T_S - T_A)$ = skin or surface temperature minus air temperature.

2.1.1.2.3: Respiratory convective transfer

This is a form of forced convective heat transfer which is dependent on the respiratory minute volume, the specific heat of air and the temperature difference between the expired and inspired air; where

$$H_{cov} = 0.02\ V\ (T_r - T_a)$$

V = respiratory minute volume or ventilation rate ($l\ min^{-1}$)

$T_r(^{o}C)$ = temperature of expired air

$T_a(^{o}C)$ = temperature of inspired air, and the factor

0.02 incorporates a mean density and specific heat of air (Monteith and Mount, 1974).

Convective heat transfer in the respiratory tract becomes important in a panting animal when the respiratory minute volume can increase to up to eightfold in the ox (Hales, 1974) in severe heat stress.

In the natural environment convective transfer happens as free and forced convections and is often referred to as mixed convective heat exchange. This way there is always a convective exchange even in still air. $H_{cov} = Y + X\ (V^{\cdot 5})\ (T_S - T_A)$

where Y is the product for free convection

X is the factor 7.0

2.1.1.3: Conductive heat transfer

It is the transfer of heat by contact and is proportional to the temperature gradient and the thermal conductivity of the material

$H_{cond} + k(T_S - T_E)$

where k = thermal conductivity $W/^{o}C$

$(T_S - T_E)$ = temperature gradient between material

Only in adverse environmental conditions may conductive heat transfer become relatively important in animals, for example, in very cold conditions, concrete floors may become major sources of heat loss and in the heat bare ground and especially metal objects may become significant sources of heat gain to the animal.

2.1.1.4: Evaporative heat transfer

When water absorbs heat it may change state from liquid to gaseous state (water vapour). The energy required to effect this is the latent heat of vapourization. Evaporative cooling occurs because the process takes place endothermically. The rate of evaporative heat loss depends on the vapour pressure gradient between skin surface and the immediate surrounding air, and is given by;

$$E = [es - \phi a \; e_W(Ta)] \times h_E \; (V,D)$$

where

E = evaporative heat loss per unit area/unit time

es = surface vapour pressure

ϕa = relative humidity of embient air

$e_W(Ta)$ = saturated air vapour pressure at ambient temperature

h_E = specific heat of vapour

(V,D) = air velocity at surface

At constant air temperature the physical demand of the environment for evaporation is increased by increasing wind velocity and by decreasing ambient humidity. And the evaporative heat loss is determined by the heat of vaporization of water at that temperature. Carlson and Hsieh (1970) estimated that the equivalent of 0.6 kcal is lost for each gram of water that is evaporated.

2.1.1.4.1: Cutaneous evaporative cooling

Apart from the factors already mentioned above, cutaneous evaporative cooling depends on the availability of moisture on the skin surface. In sweating animals, the importance of cutaneous evaporative cooling increases with increasing ambient temperature due to a corresponding decrease in sensible heat loss (Fig. 2.1.4).

2.1.1.4.2: Respiratory evaporative heat loss

Generally the inspired air is warmed to deep-body temperature and almost saturated with water vapour before it is expired thereby providing means of cooling. Evaporative cooling in the respiratory tract is dependent on the rate of water vapour loss which in turn is determined by the ventilation minute volume and the humidity of inspired air, and is given by:

$$R_E = [\phi w(T_r) - \phi a] \frac{V}{A}$$

where

R_E = respiratory evaporative heat transfer

T_r = temperature of expired air

ϕa = relative humidity (vapour content) of inspired air

$\phi w(T_r)$ = water vapour concentration in expired air

$\frac{V}{R}$ = ratio between ventilation rate and surface area

It is the major source of evaporative cooling in panting animals like the dog and may constitute an important portion of heat loss in ruminants during hyperthermia (see section 2.1.2.2).

2.1.2: Climatic factors influencing heat transfer

2.1.2.1: Ambient temperature

It has been shown that sensible heat flow is determined by the direction and size of a temperature gradient. In the natural environment sensible heat loss by an animal is largest in the cold and declines to zero as environmental temperature rises to equal skin temperature of the animal. When the body temperature is lower than environmental temperature the animal will gain heat from the surroundings (McLean, 1963a).

2.1.2.2: Air humidity

At a constant ambient temperature an increase in air humidity will reduce the rate of evaporative heat loss capacity. McLean (1963a) and McLean and Calvert (1972) did not find significant changes in cutaneous evaporation when humidity levels were varied at moderate temperatures and indicated that the effect of air humidity on cutaneous evaporation is only appreciable when sensible heat loss is lowered as a result of high ambient temperatures. Generally a reduced vapour pressure gradient between skin and air should reduce evaporative moisture loss, but McLean and Calvert (1972) have reported that in an environment of 35°C a reduction in vapour pressure gradient by a factor of 3 produced by increasing the relative humidity of the air from 32 to 72% had only a slight effect on skin evaporative loss. This has been explained by assuming that the rate of sweating was unchanged and an increase in air humidity causes a temporary reduction in evaporation and a build up of moisture on the skin. As a result the vapour pressure at the skin surface increases, automatically re-establishing the vapour pressure gradient between skin surface and air until evaporation rate is in equilibrium with rate of sweat secretion. Extreme levels of air humidity would significantly reduce the vapour pressure gradient and thus markedly reduce evaporation rate.

The ease with which evaporation occurs is influenced by humidity, thus when the humidity was raised from 35 to 72% the respiration rate increased from 100 to 160 counts per minute.

Kibler and Brody (1953) and McLean and Calvert (1972) have shown that evaporative heat transfer becomes more important at high temperatures. McLean (1963b) found that the cutaneous evaporization of Ayrshire bulls remained proportional to the humidity at 35°C until the air was saturated. McLean and Calvert reported a rise from 18 to 84 per cent of total heat loss in evaporative heat loss between 15° and 35°C in cattle.

2.1.2.3: Air movement

The effect of air movement is to accelerate the sensible heat transfer through a reduced insulation of the coat (Blaxter and Wainman, 1964; Ames and Insley, 1975; Kibler and Brody, 1954; Mount and Ingram, 1965; Joyce, Blaxter and Park, 1966). Increased heat exchange is initiated by breaking the boundary layer outside the hair coat and possibly the air trapped in the coat, thereby allowing direct air exchanges on the skin. Kibler and Brody showed that winds of 3.6 metres per second increased the sensible heat loss of cows by about a third. However, although in moderate environmental temperatures an increase in air movement may effectively cool the animal in an otherwise heat stressful condition, if the air temperature is above that of the animal, additional heat will be gained and the thermal load will be increased by an increase in air circulation.

2.1.2.4: Rain or wetness

Wetting or washing the skin will reduce the insulation of the coat to increase both sensible and evaporative heat transfer. Holmes and McLean (1975) found that rain significantly increased the heat production of calves at 5°C, but this effect diminished markedly at higher environmental temperature, 20°C. The importance of wetting the skin in hot environments is to increase the evaporative heat loss (Ingram and Mount, 1975). Wetting of the skin in buffaloes and wallowing in pigs are behavioural responses which emphasise this importance. In the cold, however, rain may induce hypothermia by causing an excessive sensible heat loss (Robertshaw, 1968).

2.1.2.5: Radiation

Bond *et al.* (1967) estimated that the normal incident solar radiation received by a spherical body could be as high as 940 W/m^2 hr. Finch (1972) found that the sensible heat flow through the coat to the skin of *B. indicus* cattle at noon in a radiant environment (27^oC, 29-32% RH) amounted to 742 $kcal/m^2/hr$ and constituted a very significant amount of the total heat dissipated. But the amount of radiant heat absorbed depends on coat characteristics (Hutchinson and Brown, 1969; Yeates, 1965). Research findings suggest that shortwave radiation has a lower penetration in dark coats and coats with higher bulk density (Hutchinson, Brown and Allen, 1973). Also Hutchinson and Brown (1969) and Robertshaw and Finch (1976) have indicated that increased solar load is associated with higher sweating rates and evaporative heat loss. Recent findings by Murray (1966) that under radiant field conditions cutaneous evaporation rates of cattle almost doubled those obtained under climate-laboratory exposures even though rectal temperatures, respiratory rates and skin temperatures were much lower under field conditions, suggest a direct stimulation of the sweat glands of cattle by direct solar radiation.

In cold environments the warming effect of solar radiation will reduce the amount of metabolic heat production required to maintain stable core temperature during the hours of sunlight (Hutchinson, Brown and Allen, 1973).

2.1.3: Animal influence on heat transfer

The effects of a coat type on radiant heat load and heat loss has been mentioned. The effects of sweating ability and panting on the maintenance of thermal balance has also been indicated. These factors together with other behavioural responses are further discussed under thermoregulation (section 2.2.3). It is through these mechanisms that animals are able to maintain a stable core temperature when exposed to hot conditions. Also variation in posture, changes in habitat, increased activity and intake, shivering and a change in coat characteristic may enhance energy conservation in the cold.

2.1.4: Thermal equilibrium

The overall effects of the climatic factors; air temperature, air movement, air humidity, solar radiation and rain; and the animal factors and responses; change of habitat, activity, shivering, sweating ability and panting, is to maintain a constant deep body temperature. In order to attain this total heat loss must equal heat production. Ingram and Mount (1975) have indicated that under such conditions the rate of heat loss is determined by the rate of heat production. The total heat loss is determined by the total effects of the heat exchange mechanisms; conduction (K), convection (C), radiation (R) and evaporation (E). An additional factor, 'S' is usually introduced to account for minor variations in the animal's heat content often referred to as heat of storage. Thus the body heat budget is described by the following fundamental equation;

$$M \pm K \pm C \pm R - E \pm S = 0 \text{ (Cabanac, 1974)}$$

which is usually written

$$M = K + C + R + E + S \text{ (Monteith and Mount, 1974)}$$

The metabolic heat production can change with sudden changes in environmental temperature. Responses to sudden change in thermal environment include shivering in the cold or sweating and panting in the heat which reach steady levels within hours. After prolonged exposure, however, animals will acquire protective measures (adaptation) which in the heat may include hair coat shedding and orientation together with maintenance of panting; sweating will increase heat loss to the environment. Also a reduced heat production partly attributed to a reduced food intake and calorigenic hormonal function (Bianca, 1965) and other behavioural responses may take place after exposure for some time.

In the cold, prolonged exposure did not increase the resting heat production (Webster, Chlumecky and Young, 1970) of heifers exposed to severe Canadian winter. These heifers maintained a heavy hair coat cover due to a reduced shedding rather than increased growth. But recent findings by Young (1975) that winter acclimatization of pregnant beef cows caused an increase in resting metabolism resulting in a downward shift of their thermoneutral zone, suggested that acclimatization could increase the maintenance requirement and therefore lower the net feed efficiency. Also, Blaxter and Wainman (1961) have indicated that in cold conditions the insulation of the coat increases due to piloerection, and internal insulation increases due to vasoconstriction. These authors found that maximum vasoconstriction and piloerection of steers below thermoneutral temperatures accounted for significant increases in tissue insulation.

These processes are responsible for the maintenance of a constant body temperature, but as indicated in Fig. 2.14, the animal can only achieve this within a restricted range of environmental temperatures. When environmental temperatures are above the upper critical temperature heat production/heat loss may not balance, in which case body temperature will rise and persistance of this increment will result in 'hyperthermia'. Excessive heat loss at low environmental temperatures may exceed the capacity of the animal to produce heat and cause a drop in body temperature. This is referred to as 'hypothermia'.

The maintenance of a constant body temperature *'milieu interiur'* is controlled by thermoregulatory mechanisms (section 2.2). Over a limited range of environmental temperatures, heat production is minimal and independent of ambient temperature, 'thermoneutral zone'. At lower and higher temperatures than thermoneutral the animal increases or decreases heat production to equal its total heat loss via evaporative and sensible heat loss mechanisms. And within the thermoneutral zone a narrower zone 'comfort zone' exists (Fig. 2.14), a region of small temperature range in which homeothermy is maintained by small variations in evaporative and sensible heat loss.

2.2: Thermoregulation in the bovine under hot conditions

As a result of metabolism animals produce heat which together with any heat gained from the environment constitutes the total amount of heat which must be dissipated in order to maintain body temperature equilibrium. In so doing, homeotherms are able to maintain a stable core temperature even in fluctuating environmental conditions which affect total heat loss by various means.

The ability to maintain thermal balance is attributed to finely tuned integrated thermal sensor and effector mechanisms which regulate the rate of heat production and/or heat loss by the animal in response to changes within the animal and in its thermal environment.

2.2.1: Temperature sensors of the body

Sensory receptors that increase their frequency of electrical activity with increase in temperature have been demonstrated in a number of animal species but not in bovines (Thompson, 1976). It is only reasonable therefore, that we assume the existence of similar thermoreceptors in cattle and that they are responsible for reflexly initiating sweating and panting in hot environments (Findlay and Ingram, 1961), and behavioural thermoregulation (Bligh, 1973). Thermoreceptors are known to exist in the skin, veins, respiratory tract, the hypothalamus, spinal cord and the scrotum of sheep.

2.2.1.1: Peripheral receptors

The fact that animals avoid very hot or very cold objects confirms the occurrence of peripheral receptors. Morphologically different nerve endings have been described by histologists to respond to specific kinds of energy inputs into particular neural signals. However, of the many postulated theories regarding the patterns of impulses produced by peripheral receptors, a high degree of selective sensitivity for 'cold' and 'warm' has been indicated by Bligh (1973). Bligh considered that sensory nerve endings which act as trigger mechanisms would be activated by a change in heat energy flow between the environment and cutaneous cells to generate nervous impulses into the spinal cord. Such a change in energy flow could be caused by a change in skin temperature via a changing environmental temperature and/or blood flow.

The conscious perception of heat and cold motivate behavioural responses to thermal comfort or discomfort. This may cause individuals to alter their habitat, insulation or posture in an attempt to maintain constant body temperature. Such activities are probably in response to stimulation of body temperature sensors. Evidence of skin temperature sensitivity has been reported in many animals including man (Gagge *et al.* 1971), and in the cat (Bligh, 1973). Localized skin temperature variations have been reported to activate thermoregulatory mechanisms, for example, in the cold, warming of an area of the skin would stop shivering and in the thermoneutral environment would cause panting. In many animals the distribution of temperature receptors favours certain areas of the skin. Kerslake (1972) has, for example, indicated that in man the face is richer in heat receptors than the legs and Bligh (1973) found that in the cat warm receptors were concentrated at the back of the nose while those for cold were abundant in the nasal area.

There is a possibility that less insulated areas of an animal are more sensitive to changes in temperature than the rest of the body. In the ram for example, the scrotum is relatively less woolly and has been found to contain specific cutaneous receptors. According to Ingram (1968) and Baldwin and Hales (1974), warming of the scrotum caused panting and lowered the deep-body temperature. Waites (1962) was able to demonstrate the differences in scrotal and skin thermosensitivity by warming an equivalent area of skin in the ram; while scrotal warming caused symptoms of thermal stress, skin heating showed little physiological change. In the pig, heating the scrotum in a thermoneutral environment caused an increase in cutaneous blood flow, while in the cold shivering was stopped (Ingram and Legge, 1972b). However, extensive research into the effect of high temperatures on the male fertility in rams (Waites and Moule, 1963; and Lindsay, 1969), in bulls (Skinner and Louw, 1966) and in boars (Wettemann *et al.*, 1976) has suggested that the testis are specially equipped with extra sensors to improve their temperature control precision because of a serious effect of high scrotal temperature on fertility.

2.2.1.2: Deep-body thermoreceptors

Selective stimulation of small parts of the body such as the hypothalamus (Findlay and Ingram, 1961; Findlay and Whittow, 1966; Findlay and Hales, 1969; Calvert, Findlay and McLean, 1972); or the spinal cord (Hales and Jessen, 1969 and Jessen *et al.*, 1972) caused sweating and panting which indicates that these areas are rich in heat receptors.

The activation of the hypothalamic sensor can be achieved directly or indirectly because it is the centre for co-ordinating all temperature regulating activities (Bligh, 1973). Several workers have reported some form of thermoregulatory responses including peripheral vasodilation and inhibition of shivering when the pre-optic or anterior hypothalamic region is heated. In the rabbit a rise in hypothalamic temperature of up to 0.5°C caused a proportional fall in deep-body temperature and an increase in respiratory frequency. In another experiment reported by Bligh (1973) a body temperature rise of up to 1^{o}C and substantial increase in oxygen consumption was noted when the brain of a rabbit was cooled. Local cooling of the pre-optic/anterior hypothalamus of the goat caused an increase in the rate of release of thyroid hormone (Anderson *et al.*, 1963). Baldwin and Ingram (1967) reported that trained pigs increased the rate at which they pressed bars for access to radiant heat when the hypothalamus was cooled; but the effect was reduced when the region was warmed. The evidence indicates that stimulation of the brain can induce both voluntary (behavioural) and involuntary (autonomic) temperature control mechanisms.

It is known that when the stomach or the blood in the jugular veins is cooled shivering occurs even though brain temperature may remain normal or raised (Klussmann and Pieran, 1972). The abdominal wall of sheep respond to cold stimuli independent of hypothalamic temperature (Hales, 1974). Other tests on abdominal vena cava (Bligh, 1961) and other structures of central circulation suggest the occurrence of thermosensors.

With the help of heat exchangers, Hales (1974) was able to conclude that specific thermoreceptors exist within the walls of the spinal canal. Peripheral vasoconstriction and shivering have been observed when the spinal cord was cooled without causing any change in aortic blood or brain temperature. Hales and Jessen (1969) observed that heating the spinal cord of the conscious ox increased the cutaneous moisture loss and a rise in respiratory frequency causing a fall in both rectal and hypothalamic temperature.

2.2.1.3: Integration of different thermoreceptors

The account given above confirms the existence of multiple temperature detectors near the surface of the body or deep within the body. All the detectors are capable of triggering behavioural and autonomic responses which have additive influence on the effector mechanisms. Cabanac (1974) points out that the organisation of the nervous network responsible for temperature regulation is very complex and not well understood. But from experiments it is possible to deduce the relative influence of the hypothalamic and peripheral signals on thermal behaviour. In the rat, for example, some evidence suggests that skin temperature signals are outweighed by hypothalamic temperature signals by 3:1. And in the dog anterior hypothalamic lesions did not change skin temperature perception, but internal temperature sensitivity was much reduced. Similarly treated rats failed to keep constant internal temperature.

Hammel (1972) has, however, indicated that thermoregulatory responses are dependent upon preoptic-anterior hypothalamic temperature in the resting animal. This suggests that localized stimulation of other receptors impose only a short lived thermal response after which the preoptic-anterior hypothalamus takes over via a negative feedback stimulation. This is probably determined by the difference between preoptic-anterior hypothalamic temperature and the core temperature.

2.2.2: Thermoregulatory effector mechanisms

The effector mechanisms for the regulation of body temperature involve (1) changes in the metabolic rate (heat production); (2) changes in peripheral blood flow; (3) changes in evaporative heat loss from skin and lungs both of which control heat loss (Bligh, 1973 and Hammel, 1968) and behavioural piloerection (Thompson, 1973).

A cold stimulus can initiate shivering, a contraction of both extensor and reflexor muscles via skin, spinal cord or anterior hypothalamus sensors. The shivering rhythm is thought to be controlled by a pattern of oscillations discharged in motor neurons at spinal cord level but controlled from the posterior hypothalamus, shivering centre. Impulses generated in the spinal cord cause muscle tremor to meet body heat demands.

2.2.2.1: Vasomotor Control

Heat flow from body tissues to the periphery depends on the rate of blood flow and its temperature on reaching the periphery. Bligh has indicated that particular neurotransmitters which synapse in the heat control centre (pre-optic anterior hypothalamus) are responsible for the control of vasomotor responses. A sympathetic nerve supply to some areas of the skin contains vasomotor fibres which under thermoneutral conditions reduce cutaneous blood flow by keeping the blood vessels partially constricted, while under hot conditions vasodilation increases blood flow to the periphery. Research evidence indicates that vasomotor tone can be effected by either a deep-body or peripheral sensor.

The regulation of peripheral blood flow is the principal thermoregulatory effector process in thermally neutral environments when neither of the processes of evaporative heat loss nor the shivering or non-shivering thermogenesis are active. This response is capable of maintaining thermal balance within a small range of environmental temperatures (Fig. 2.2.2.1)

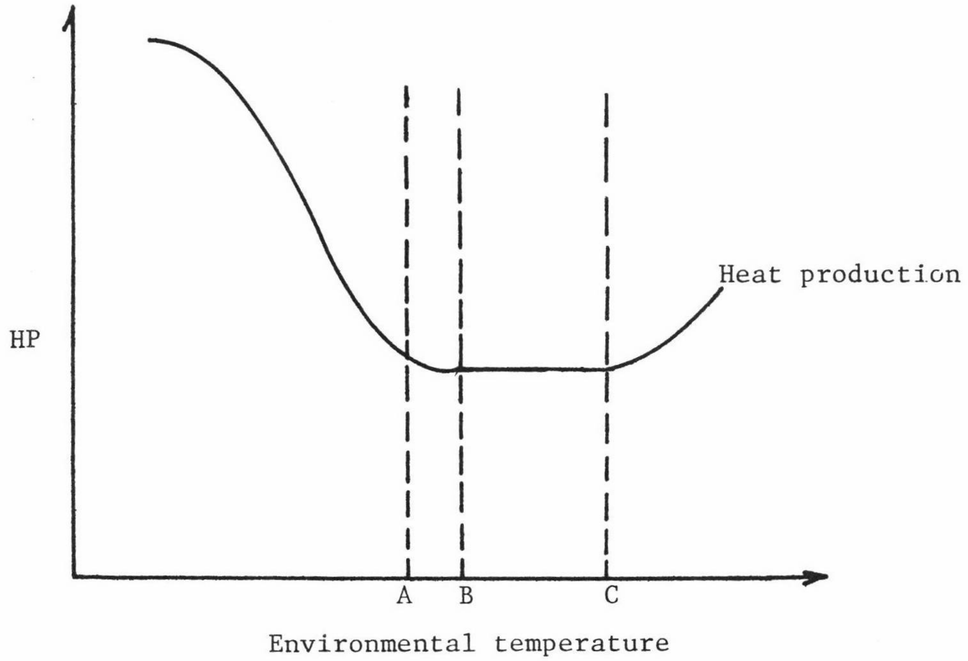


Fig. 2.2.2.1: Zone of vasomotor control. AC zone of minimal metabolism; AB zone of least thermoregulatory effort, thermal balance predominantly via vasomotor response; BC rapid increase in evaporative heat loss.

A variation in blood flow through the capillaries via aterio-venous anastomoses induce changes in heat loss. In a cool environment the aterio-venous anastomoses (AVAs) are closed and blood flow is short circuited which reduces heat transfer between arterial blood and the peripheral tissues. On the other hand, in a warm climate AVAs are open and blood flow through the capillaries is slow enough to allow for a rapid smooth heat flow to the skin surface.

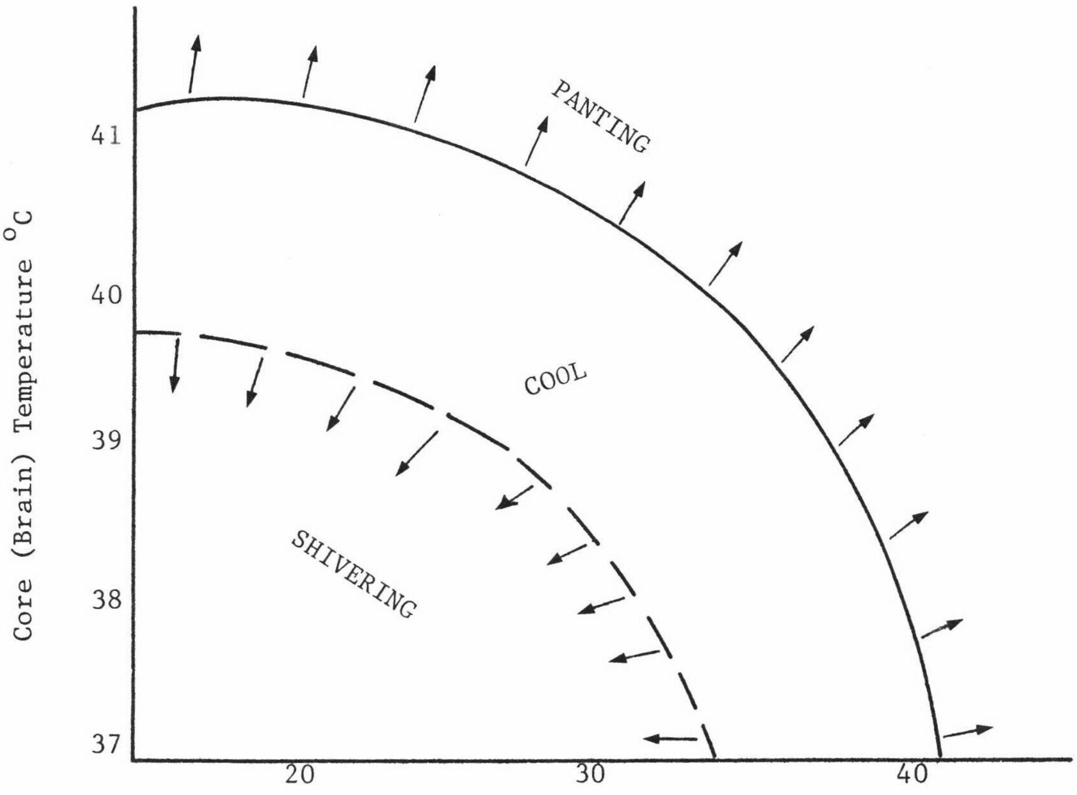
2.2.2.2: Sweating

The control of thermoregulatory sweating is almost entirely governed by the outflow from the sweat glands (Robertshaw, 1968). Sweat glands derive their moisture from the blood via interstitial fluid in the epidermis. In the bovine, water infiltrates into the lumen of the gland through an osmotic pressure (gradient) which is maintained by colloidal material in the lumen (Thompson, 1976).

No nerves supplying the sweat glands have been reported. However, Bligh (1973) has implicated a nervous reflex and since radiation exposure was observed to cause immediate increase in sweating (Murray, 1966), it is thought that both skin and core temperature sensors may be responsible for stimulation of sweating.

2.2.2.3: Panting

This is controlled by somatic outflow nerves from the brain. Other central and peripheral receptors may initiate panting. Thus Waites (1962) reported panting in the ram when the scrotum was warmed and Findlay and Ingram (1961) indicated that the ox would pant during heat exposure even when core temperatures had not risen. Similarly warming the hypothalamus initiated panting in the ox. However, when panting was initiated by extra-hypothalamus heating in the sheep, core temperatures fell progressively and carotid blood temperatures fell by more than 2°C without inhibition in panting (Bligh, 1973). It is therefore possible that a special relationship such as the one illustrated in Fig. 2.2.2.2, exists between core temperature and peripheral temperature so that inhibition of panting is determined by probably the sum of the two temperature sensors' activity. Thus very high skin temperatures could independently cause panting provided the total impulses produce a threshold signal. This development had been implicated by Baldwin and Ingram (1968) who on subjecting pigs to infra-red irradiation at various ambient temperatures, found that there was no precise temperature of the preoptic region at which respiration rates increased. Also heating the preoptic region did not increase the respiratory frequency below ambient temperatures of 30°C. These observations suggest that similar relationships exist for other thermoregulatory responses.



Adopted from Bligh (1973)

Fig. 2.2.2.2: Influence of body temperature and skin temperature on the thermoregulatory responses.

2.2.2.4: Endocrine influence on heat production

Chronic heat exposure of various breeds of cattle has been shown to depress thyroid activity (Johnson and Kamal, 1958; Thompson *et al.*, 1963; Johnson and Kibler, 1963; Johnson and Ragsdale, 1960). It is also known that in the heat, heat production by cattle is reduced via a lower food intake and hypothyroidism. Thompson (1973) reported that thyroidectomy reduces the metabolic rate of cattle and that a reduced thyroid activity in animals in a hot environment is probably important in their reduced heat output. On the other hand, Johnson and Yousef (1966) found that thyroid activity increased in the cold, while Yousef and Johnson (1966b) confirmed that injection of thyroxine in lactating cows caused an increase in heat production in a thermoneutral environment (18°C) but only after a latent period of 3 to 4 days. Similarly, Mitra and Johnson (1972) found that when steers were exposed to 39°C for 4 hrs their plasma concentration of growth hormone fell and in another experiment Yousef and Johnson (1966c) observed a simultaneous increase in thyroxine disappearance rate and increase in heat production of cows injected with growth hormone. It is suggested that growth hormone and thyroxine have a synergistic effect on metabolic rate.

Evidence that adrenal cortical hormone can influence heat production has also been reported. Yousef and Johnson (1967b) have shown that an injection of hydrocortisone acetate increases the heat production of cows in the heat. This suggests that the reduced levels of plasma glucocorticoids which occur during chronic heat exposure (Bianca, 1965) are a result of a regulatory mechanism for reducing the animal's heat production. It could be argued that since these hormonal concentrations seem to have a negative correlation to heat, it is possible that endocrine secretion has a definite role in temperature regulation.

2.2.3: Thermoregulatory responses to climatic conditions

The functioning of the thermoregulatory mechanisms is dictated by the prevailing climate where, depending on the extent of the stress and the options available to the animal, behavioural and/or autonomic responses may be used to control or modify the external thermal demands.

2.2.3.1: Autonomic responses

Whereas behavioural thermoregulatory responses effect changes in the microclimate necessary to maintain or re-establish thermal equilibrium, autonomic processes of the thermoregulation use physiological activities to modify rates of heat transfer between deep-body and body surface and between surface and environment or modify the level of heat generation. A heat stressed animal will either pant or sweat to increase its evaporative heat loss and/or decrease its heat production by lowering the rate of metabolism. Thus heat exposure increases sweating (McLean, 1963a; Allen, 1962; Murray, 1966); initiate panting (Bligh, 1973; Baldwin and Ingram, 1968); and decreased oxygen consumption in the pig (Carlisle and Ingram, 1973; Baldwin and Ingram, 1968).

2.2.3.1.1: Sweating

Sweating is the discharge of an aqueous fluid from glands on to the skin surface which on evaporation becomes an effective means of heat loss. Evaporation of sweat lowers the skin temperature thereby maintaining a thermal gradient between the deep-body tissues and the periphery. Murray (1966) has shown that solar radiation increases the sweating rate of cattle via an increase in skin temperature. Similarly increased skin temperature may contribute to higher vapourization of moisture.

Sweating is most beneficial at a low ambient humidity. In a high relative humidity, sweating will become less useful in thermoregulation due to a reduced capacity to lose evaporative heat. McLean and Calvert (1972) observed that a reduction in vapour pressure gradient between the skin and air would decrease vaporization (section 2.1.2.2).

2.2.3.1.2: Panting

Panting increases the rate of evaporative heat loss from the upper respiratory tract through a net increase in the respiratory volume. Animals exposed to severe heat stress may increase their respiratory frequency to high levels, hyperventilate and develop respiratory alkalosis. If hyperventilation persists in the less adapted animal such as cattle, it may cause hypocalcaemic tetany and eventually death may result (Bianca and Hales, 1970).

The efficiency of panting depends on the humidity and temperature differences, the exhaled (respiratory) air and inhaled (ambient) air in the immediate environment and their rate of exchange. As the humidity of the inhaled air increases, its evaporative heat loss function decreases due to a reduced capacity to gain moisture in the respiratory tract. Similarly, as ambient temperature approaches the animal's body temperature, sensible heat loss declines and may in fact result in a negative heat loss when environmental temperature is above body temperature.

2.2.3.2: Behavioural responses

Behavioural thermoregulation involves complex patterns of body movement in which animals change their habitat or modify their surface area relative to body size in order to alter their rate of heat transfer; change their thermal insulation and food intake in order to correct for heat loss and production respectively. Generally behavioural thermoregulation responses act as a measure of thermal comfort (Hammel, 1968) and act to correct for immediate variation in the rate of heat transfer, but autonomic responses would be used when behavioural responses are not practicable, such as in climatic chambers where animals may be deprived of natural shelter, shade and even positional changes.

2.2.3.2.1: Variation of habitat

In the natural environment animals avoid direct radiant heat by seeking shade. Preston and Willis (1974), Payne (1965) and Yeates (1965) have observed that cattle seek shade in hot bright days even though they may not have had enough grazing.

Many experiments reported indicate a higher frequency of lever pressing for heat in trained animals as their environmental temperature is progressively lowered. This was demonstrated in pigs (Mount, 1968), in baboons (Gale *et al.*, 1970); and with changes in hypothalamic temperature in dogs (Cabanic *et al.*, 1966), in baboons (Gale *et al.*, 1970) and in pigs (Baldwin and Ingram, 1967). In man the provision of housing, clothes, fire and use of air conditioning make them less prone to environmental temperature changes.

2.2.3.2.2: Posture changes

The effect of posture is to change the effective conductive surface area and therefore the rate of sensible heat transfer between the animal and its environment. Mount (1968) reported that cold stressed pigs reduced their sensible heat loss through huddling and/or lying down with a minimum surface area in contact with the floor. Cattle would stand in shade with their limbs well spread in a hot environment in order to promote heat loss but reduce radiant heat gain.

2.2.3.2.3: Wallowing and saliva spreading

In a hot environment pigs given the opportunity would wallow in mud or roll in their urine or faeces. These have the immediate effect of cooling the skin followed by a simulated evaporative cooling which may increase from 8 x 10^{-6} to 10 x 10^{-6} kg/m^2s^1 to a record of 200 x 10^{-6}kg/m^2s^1 (Ingram, 1965). This may effectively increase the pigs' tolerance to high ambient temperature and affect their production favourably. The buffalo and cattle are known to use similar mechanisms to increase their heat loss in hot conditions.

Saliva spreading which also initiates evaporative cooling is known to be practised by placental and marsupial animals. And whereas man can change his insulation by variation in clothes, birds could change their feathers' insulating properties to allow or reduce ventilation to the skin surface.

2.2.3.2.4: Activity and operative responses

While in the natural environment animals in heat stress may reduce their activity including feeding and seek shade and those suffering from cold stress may increase activity and feeding; experimental animals provided with devices to obtain heat or cold, usually by pushing levers, have demonstrated that the animals detained in such habitat will learn to make appropriate responses in order to restore their thermal comfort (Cabanac, 1974). Experiments with pigs (Mount, 1968) have demonstrated such behavioural responses.

2.2.3.2.5: Voluntary intake

Anderson and Larson (1961) found that when the preoptic heat loss centre of the goat was warmed, eating stopped, while Blaxter (1962) indicated that cooling the centre induced eating. More recently work by Moody *et al.* (1967); Martz *et al.* (1971); Olbrich *et al.* (1972) and Colditz and Kellaway (1972) has confirmed that voluntary intake of cattle is reduced in the heat. In a hot environment animals would reduce their food intake to decrease heat production and increase water intake to increase heat loss. Cabanac (1974) attributed the increased water intake to dehydration, but it is known that increased water intake takes place before any dehydration occurs. Therefore, increased body temperature may trigger water intake directly. Unless larger amounts of water are ingested, generally water intake responses will not be beneficial by conductive heat exchange. Thus for a drop of 1°C body temperature of say a steer weighing 400 kg, it will have to drink about 45 kg of water at 10°C colder than the body temperature of the animal. Its usefulness increases with increasing temperature difference between the animal and the water. However, this water intake response may be very beneficial if it is used in evaporative cooling due to its high latent heat of vapourization (0.6 kcal/g of water).

Whereas a decrease in appetite in the heat is thought to be a defensive behaviour against heat stress (Baldwin and Ingram, 1968), in the cold animals may complement shivering and non-shivering thermogenesis by an increase in food intake. And according to the review by Thompson (1973) the sensation of cold is a direct stimulant of appetite while a high body temperature is a satiety signal to cattle. McDowell (1972) found that the grazing time for unadapted cattle fell from 35 to 11 per cent of day time when ambient temperatures rose from 27°C to 29°C.

Increased intake in the cold results in an increased rate of metabolism, so that when the level of feeding is doubled, for example, the metabolic heat production (Fig. 2.2.3) would be increased by a factor 'a' which will lower the critical temperature T_{c1} by a factor 'b' to T_{c2}. Likewise in the heat, a reduced intake would increase critical temperature from T_{c2} to T_{c1}.

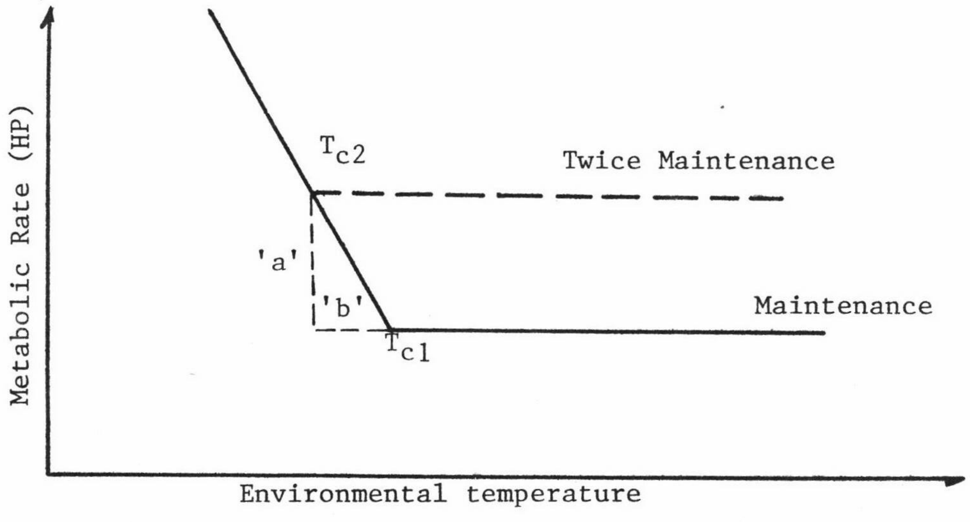


Fig. 2.2.3: Relationship between level of feeding and critical temperature.

2.3: Effect of a hot condition on metabolism

2.3.1: Endocrine activity and metabolism

To continue the discussion on endocrine influence on heat production it is generally accepted that the calorigenic hormones; thyroid, adrenocorticohormones, insulin and growth hormones; have important functions in metabolism of animals. It is known that thyroidectomy reduces metabolic rate and if complete thyroidectomy is done by radiative means, death can occur within 3 to 6 days (Yousef *et al.*, 1968) of severe cold exposure (-6°C).

Johnson and Yousef (1966) and Yousef and Johnson (1966) have done extensive work on the effect of thyroid hormone on food intake and metabolic heat. They showed that at high environmental temperature (35°C) the rate of disappearance of [131] thyroxine from the blood slowed down in both *ad lib.* fed cows and in those given the amount of food eaten in a thermal-neutral environment by putting refused food into the rumen through a rumen fistula. Injections of thyroxine increase the heat production of lactating cows in an environment of 18°C (Yousef and Johnson, 1966b). The injection also increases the [131] thyroxine disappearance rate. Earlier it was demonstrated that fasted cows exposed to 1°C had higher plasma protein bound iodine concentrations and quicker [131] thyroxine disappearance rate than when they were similarly fasted at 18°C (Johnson and Yousef, 1966). The same difference between environments of 1° and 18°C it was found if the animals are fed at 1°C the same amount of food eaten *ad lib.* at 18°C. But *ad libitum* feeding at 1°C resulted in further increase in thyroid activity (Yousef and Johnson, 1966a). The same authors have shown that thyroid (T4) treated rats increased their protein turnover indicating a possible increase in protein synthesis. These findings suggest that thyroid activity is probably related to build-up of body tissues which, in turn, are responsible for heat production.

An association between thyroid activity and growth hormone has also been suggested by Yousef and Johnson, 1966c). They observed that an injection of growth hormone (200-300 mg/cow intravenous) increased the heat production of the animals and simultaneously increased the [131] disappearance rate. Also cows exposed to 35°C ambient for 3 weeks have a reduced plasma growth hormone concentration, a fall in growth hormone secretion rate and a slower hormonal disappearance rate (Mitra, Christison and Johnson, 1972).

Similarly, Yousef and Johnson (1967b) have shown that an injection of hydrocortisone acetate increases the heat production of cows in the heat. Prolonged exposure to high ambient temperature $35^{o}C/50\%$ RH has been found to decrease cortisol turnover rate and reduce plasma concentration of cortisol (Christison and Johnson, 1972).

The importance of these hormones is probably manifested in the maintenance of stable body temperature. That through inhibitory mechanisms or catalytic influence on the metabolic activities, heat production is reduced to acceptable levels or levels which the heat loss processes are capable of dissipation to the environment. Webster (1976) indicated, however, that in acute heat exposure both adrenal medulla (catecholamines and adrenaline) and adrenal cortex steroids (including glucocorticoids and corticosterone) hormone secretions are increased. The principal metabolic action of the catecholamines in cattle is to mobilize energy rich substrates for catabolism and include lipolysis, glycogenolysis and muscle catabolism. Glucocorticoids stimulate the breakdown and inhibit the synthesis of protein in muscle, skin, the gut wall and lymphatic tissue. In this way, amino acids are mobilised for catabolism and for gluconeogenesis. This response is essentially short lived and is referred to as the 'Alarm Reaction'. Any acute distress be it cold, heat, or danger, will set off this non-specific response. The important consequences of the alarm response are a loss of stored energy as heat (Yousef and Johnson, 1967) and a loss of stored protein as urea and creatinine in the urine.

It should be appreciated that if the Alarm Reaction persists in chronic heat exposure it will result in tissue degeneration and hyperthermia and even death. However, it is noted that plasma hydrocortisone which is elevated in acute heat exposure, has a lower concentration and turnover rate after an extended exposure (7 to 10 weeks) (Christison and Johnson, 1972). Similarly, during prolonged heat exposure, both catabolic and anabolic hormone secretions are depressed which results in a slower rate of metabolism.

2.3.2: Digestive metabolism

2.3.2.1: Intake

The effect of temperature on food intake has already been covered under voluntary intake, section 2.2.3.2.5. Voluntary food intake of cattle is significantly reduced in the heat when compared to cool conditions. While lowered food consumption helps reduce heat load, the animal's productivity is detrimentally affected.

2.3.2.2: Rumen metabolism

Reduced rumen motility both in amplitude and frequency of contraction has been observed in heat stressed cattle (Atterbery and Johnson, 1969). Holstein cows exposed to 38°C for 5 days showed significant decreases in the amplitude of the rumen contractions below the levels observed at 2°C and 18°C respectively. The frequency of contractions became irregular and were slightly reduced.

Levin (1969) reported that hypothyroidism which occurs in cattle exposed to heat (Yousef *et al.*, 1967) had the effect of prolonging gastric emptying. It was also indicated that severe thyroid damage caused greater gut fill due to a prolonged retention of feed residues. It is suggested that the slower passage of food through the alimentary canal is probably physiologically activated to reduce the rate of metabolism via a reduced heat increment for fermentation and production. In support of this food intake is known to be curtailed in the heat and Martz *et al.* (1971) observed a slow disappearance rate of Volatile Fatty acids (V.F.As) from the gut of heat exposed animals which suggested an accumulation of the V.F.As resulting from either a reduced rate of absorption or a bacterial inactivity. These observations indicate a decrease in the rate of metabolism and therefore a reduced heat production.

2.3.2.3: Digestibility

Generally reduced food intake as it may occur in the heat is associated with a small increase in digestibility. Research findings has indicated that the apparent dry matter (DM) digestibility of cattle (Olbrich *et al.*, 1973; Warren *et al.*, 1974; and Christopherson, 1976) is appreciably increased in the heat. Although a reduced rumen motility

(Atterbery and Johnson, 1969) and reduction or cessation of rumination in the hyperthermic animal (Thompson, 1973) may reduce the digestibility of DM, the slower passage or longer retention of digesta in the digestive tract prolongs both microbial activity (Mishra *et al.*, 1970; Atterbery and Johnson, 1969) and enzyme action (Levin, 1969) and may account for the increased digestibility.

2.3.2.4: Dietary effects on metabolism

In a hot environment, a ration high in protein content and low in fibre content is beneficial for keeping down body temperature and improving production (Thompson, 1973). Although it is not fully understood how a hot environment affects the digestion, beneficial dietary modifications have helped in the adaptation to a hot climate. Vohnout and Bateman (1972) have indicated that the intake of digestible energy by an animal in a hot environment could be increased by feeding a diet low in fibre. Although this is also true in the cold, the intake of a high fibre diet is most probably limited to gut capacity.

Webster (1976) has argued that the heat increment resulting from a fixed quantity of food (kJ per 100 kJ metabolisable energy) is inversely related to the digestibility or nutritive value of that food. Thus the poorer the quality the higher the heat increment. In the heat, the heat increment becomes an added burden and must be lost together with other heat which is produced or gained. Blaxter (1967) indicated that the maximum amount of a diet that a ruminant will consume is directly related to its digestibility and inversely related to its heat increment. Consequently, it is expected that in the heat animals will eat more high energy feed than low energy (high fibre) feed mainly due to their difference in heat increment. According to Blaxter (1967) the high heat increment of low quality (high fibre) diets can be attributed with reasonable confidence principally to the high proportion of acetate to propionate produced during their fermentation in the rumen.

2.3.3: Nitrogen metabolism

In the experiments by Vercoe and Frisch (1970, 1972) it was indicated that at high temperatures nitrogen digestion did not suffer. But with high nitrogen feeds, elevated rectal temperatures were associated with higher total urinary nitrogen and urea nitrogen excretions. In both experiments a significant increase in creatinine concentration in the urine was apparent. In another experiment Kellaway and Colditz (1975) reported that Friesian and F_1 Brahman x Friesian heifers increased their nitrogen loss in the urine and decreased nitrogen retention with high nitrogenous feed intake. But the F_1 heifers were less heat stressed and retained more nitrogen than the pure Friesian heifers. However, in both breeds a decrease in R.N.A. (Ribonucleic acid) in muscle tissue and an increase in the excretion rate of creatinine was evident in the heat.

The 'catabolic, anabolic' glucocorticoids have been implicated in nitrogen metabolism (Munro, 1964), but recent studies at cellular level have demonstrated that thyroid (T4) stimulates protein synthesis and that its calorigenic effect is secondary to an influence on protein synthesis (Yousef and Johnson, 1966c). Thyroid (T4) treated rats showed increased protein turnover indicating an acceleration of protein synthesis. Yousef and Johnson (1966c) have also indicated that excessive (T4) may produce some catabolic effects. In another experiment Chauhan *et al.* (1969) have argued that C14 phenylalamine (amino acid) incorporation into liver proteins increased significantly under severe cold exposure (-4°C) compared with 30°C.

Kellaway and Colditz (1975) concluded that because heat stressed animals suffered a reduction in R.N.A concentration in the muscle and an increase in nitrogenous excretions including creatine and creatinine, this suggested a high protein catabolism and reduced nitrogen retention. A reduced nitrogen balance will therefore lower productivity of the animal.

2.3.4: Costs in terms of animal production function of thermoregulation

In the course of employing the various thermoregulatory responses to maintain stable body temperature, *'milieu interieur'*, animals may be deprived of energy which would otherwise be used for productive purposes. In panting, for example, a rise in respiratory frequency is marked by a decrease in tidal volume which in severe heat may be followed by a lower respiratory frequency and a higher tidal volume (Bianca, 1965). Both these phases have the effect of increasing the respiratory minute volume, but Whittow and Findlay (1968), Hales and Findlay (1968b) and McLean (1963a) found significant increase in oxygen consumption in second phase panting only. However, Hales (1974) has indicated that although an increase in metabolic rate of respiratory muscles occurs in first phase panting, this may be partly or wholly offset by a decrease in other tissues.

Panting in environmental temperatures above that of the respiratory evaporative surface will have adverse effects of increasing body temperature by gaining sensible heat. Increases in dead space ventilation and alveolar ventilation, development of respiratory alkalosis, and increase in blood pH (Thompson, 1973) may lead to death of the animal.

In the heat, reduced feed intake will necessarily mean a lowered net feed efficiency, first, because less energy will be available for growth (production) and therefore a low productive energy/total metabolizable energy ratio and, secondly, because in severe heat food intake may be below the maintenace requirement thereby initiating catabolism of body tissue. Also in the cold, increased maintenance requirement may lower net energy efficiency.

In hot humid conditions the skin moisture, sweat, is neutral or slightly alkaline and contains inorganic phosphorus (P), urea, protein nitrogen, non-protein nitrogen, reduced sugars, lactic acid and some chloride (Joshi *et al.*, 1968). Jenkinson and Mabon (1973) have found a positive correlation between the rate of sweat discharge and the concentration of sodium (Na), potassium (K), magnesium (Mg), Calcium (Ca) and Chloride (Cl) on the skin. Johnson (1970) reported very high ratios of K to Na loss through sweat (4 or 5:1) which differs considerably from their distribution in the blood and in skin tissue where there is more Na than K. If such losses are not replaced in time they may alter the buffering state that normally exists in body cells and tissues. Generally, loss of any mineral or energy compound represents a loss in productive capacity of the animal.

Apart from the high nitrogen content of sweat, research work has shown that a decrease in nitrogen retention occurs in the heat (Vercoe, 1969; Vercoe and Frisch, 1970; Colditz and Kellaway, 1972 and Kellaway and Colditz, 1975). Vercoe and Frisch (1970) and Kellaway and Colditz (1975) have shown that hyperthermic cattle given a controlled food intake increase their output of urinary nitrogen, both urea nitrogen and creatinine. And a low nitrogen diet reduced the increased urinary urea nitrogen, but the increased urinary creatinine still occurs. This together with a recent observation which indicated that R.N.A (Ribonucluic Acid) concentration in the muscle of heat stressed animals is reduced. (Kellaway and Colditz, 1975) indicate catabolism of muscle in the heat stressed animal. This happens through a reduced protein synthesis and stimulated protein catabolism to provide energy for thermoregulation, a process probably initiated through endocrine changes in the heat.

2.4: The ability of cattle to tolerate hot conditions

Heat tolerance is a term which refers to the ability of an animal to live in hot conditions without undue taxation or ill effects on the normal functioning of its physiology. It was defined by Kamal (1964) as the ability to show little changes in most of the physiological functions including growth, meat and milk production. And Bianca (1963) defined heat tolerance as the ability of the body to endure the impact of a hot environment without suffering ill effects and to maintain a constant normal body temperature. Such an animal may therefore be said to be adapted to hot conditions.

Heat tolerance can be said to be a result of both physiological and other attributes of adaptation. The non-physiological component involves mainly behavioural responses and to a lesser extent, morphological characters which dictate the patterns of heat dissipation, both sensible and evaporative. The physiological attributes favouring heat tolerance of cattle include; (1) a complicated interplay between calorigenic hormones and the metabolic rate of the animal which determine the endogenous heat production and (2) the maximum functioning of the highly efficient structures (sweat glands) for the dissipation of metabolic heat under hot environmental conditions. Johnson *et al.* (1958) and Vercoe (1970) have attributed the ability of Zebu cattle to tolerate high ambient temperatures better than *B. taurus* breeds to their having a lower metabolic rate. Earlier observations by Worstell and Brody (1953) indicated that their heat tolerance was due to a low heat production resulting from a low productivity and hence their low basal metabolism. To date the characteristics of a heat tolerant cattle could be predicted via its coat type (Yeates, 1965; Dowling, 1958a, 1959a), pigmentation of both skin and hair coat (Dowling, 1960; Bonsma, 1949), body size and shape (Nay and Hayman, 1956), water metabolism (Kibler and Yeck (1959); Taylor *et al.*, 1969; Quarterman *et al.*, 1957) and structural differences (Ledger, 1959). Table I-a gives some characteristics which may favour heat tolerance.

Table I-a: Characteristics of cattle favouring heat tolerance
Compiled from Yeates (1965), Dowling (1958, 1959) and Mount (1974)

Environmental Stress	Tolerance Indicator	Remarks
Solar radiation	Short reflecting coat Light coat colour Dark skin pigment	Applicable to Zebu cattle type
High temperature and humidity	Large surface area to body mass Short smooth medullated coat type Dense follicle population Profuse sweating Low feed intake Reduced renal and faecal water	Applicable mainly to Zeboid cattle type
	Seasonal hair shedding Reduced food intake	Mainly *Bos taurus* cattle type

2.4.1: Factors influencing heat production

2.4.1.1: Metabolic rate

The metabolic rate of an animal is proportional to the oxygen consumption and accounts for all the heat produced by the body. Standardised measurements of Basal metabolic rate are usually used to express the rate of metabolism in a thermoneutral environment when the animal is relaxed and its heat load on oxygen consumption is independent of the external temperature. The metabolic rate of an animal is usually given in watts per unit surface area per unit time as a matter of convenience since units of heat exchange are expressed in the same way.

Further to the superior ability of B. *indicus* cattle to dissipate metabolic heat (Dowling, 1955a, 1955b), and the protective mechanisms to exogenous heat load their ability to tolerate high ambient temperatures is thought to be partly due to a lower metabolic rate than B. *taurus* breeds (Kibler, 1957; Worstell and Brody, 1953; Johnson *et al.*, 1958; and Vercoe, 1970).

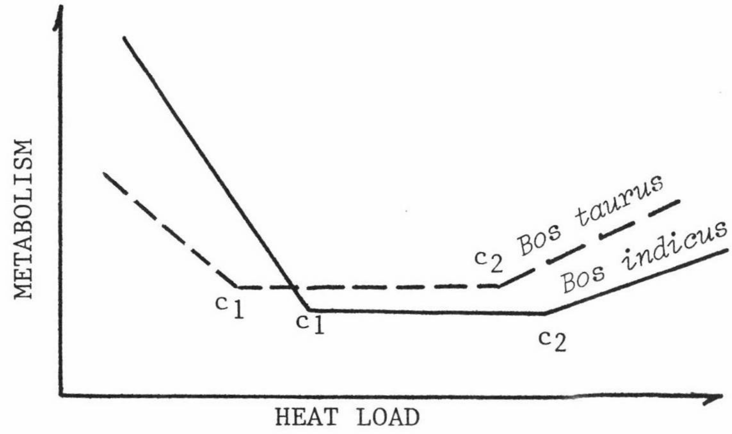


Fig. 4.1.1: The relationship between heat load and metabolism of B. *indicus* and B. *taurus*.
Adopted from Beef cattle production in developing countries, p.286. After Robertshaw and Finch.

From Figure 4.1.1 it is noted that the metabolic rate of B. *taurus* breeds is always higher than that of B. *indicus* breeds at particular heat loads or environmental temperatures. This difference seems to widen beyond the zone of thermoneutrality so that the superiority of B. *indicus* cattle increases at an increasing rate with rising ambient temperature. Johnston *et al.* (1958) observed a lower body temperature and lower respiration rate for Red Sindhi x Holstein than for pure Holstein and attributed this to a lower heat production, a factor which suggests a lower food intake, rather than a superior heat dissipation mechanism. Similar research findings between Brahmans and British breeds were reported by Preston and Willis (1974).

2.4.1.2: Food intake

According to Hamilton's review on food and temperature, in all the studies reported on food consumption by homeotherms a negative relationship between food intake and environmental temperature was indicated. This suggests a direct relationship between food intake and metabolic rate. This is further suggested by the well documented observation that both metabolic rate and food intake are elevated in the cold. The ability of cattle to restrict their intake in the heat is therefore probably a contributing factor for heat tolerance. However, this will only occur at the cost of a reduced productivity.

2.4.2: Factors influencing heat loss

2.4.2.1: Coat cover

The hair coat which represents the boundary between the body and its climatic environment may have profound influence on the animal's thermal balance. Although dense woolly coat cover may be most beneficial as an insulating layer in cold conditions, it is often disadvantageous in warm climates. Under certain conditions, however, the coat may have a beneficial thermoregulatory role in a warm radioactive environment. Its colour and texture may determine the amount of radiant heat that is absorbed by an animal. Differences in coat characteristics have been shown to dictate the ability of animals to dissipate heat from their skin surfaces.

In cattle, extensive research has been carried out to investigate hair coat types (Dowling, 1959a); its seasonal variation in length, diameter and the degree of medullation (Dowling, 1959a, 1959b); hair follicle populations (Dowling, 1955; Walker, 1957b; Carter and Dowling, 1954); and the relationship between hair coat characteristics including clipping and use of artificial covers to the functioning of the sweat glands (Berman and Kibler, 1959; Bianca, 1959; and Dowling, 1959b).

Thick, dense coat covers may reduce heat dissipation through conduction, convection and cutaneous evaporation. The thickness of the boundary layer between the skin and the immediate environment would increase by the depth of the coat. The thickness of the still air in between the skin and the surrounding air may effectively stop normal air current circulation which would also affect vapour penetration into the atmosphere, thereby establishing a high humidity region between the skin and the surface of the coat. This would drastically reduce the rate of heat loss especially at high environmental temperatures.

The effect of hair coat cover on the heat tolerance of cattle has been studied in both field and laboratory conditions. Bianca (1959) observed significantly lower skin temperature ($P<0.05$), lower rectal temperature $P<0.01$); and lower respiration rate $P<0.05$) for clipped calves which were subjected to a short (3 hour) 40°C, 62% relative humidity in a climatic chamber. The clipped calves lost 34 percent more body weight ($P<0.01$) than the control animals. Similar results were obtained in a field experiment by Turner (1962). These experiments have indicated that clipping improves the capacity to sweat and increases evaporative cooling.

The possible magnitude of the effect of a coat cover on the thermal balance of cattle has been evaluated by Dowling (1959b). It was observed that clipping of winter coats caused an immediate fall of body temperature by ½ to $^3/4$°C which increased to 1½°C in three to four weeks. But the body temperatures of both the unclipped and those wearing plastic covers after clipping did not differ from the controls, indicating that plastic covers provided similar insulation as natural coats.

In a climate room study, Berman and Kibler (1959) observed that when 20-month old heifers were exposed to moderate temperatures of 21 to 32°C 56% RH for a week before clipping, clipping did not affect their rectal temperatures. However, respiration rate, ventilation rate, total vaporization and pulmonary caporization were reduced. On the other hand, there was a significant increase in skin temperature (0.26°C) and food intake increased too. These observations suggest an enhanced sensible heat loss which would have resulted due to a direct exposure of the skin to the environment and an increase in the temperature gradient.

Similarly, direct skin exposure and increase in skin temperature would have improved evaporative heat transfer.

2.4.2.2: Coat type

Early studies conducted by C.S.I.R.O. Australia (1951) showed that the main difference between the insulating (winter) and non-insulating (summer) coat types lay in the length and degree of medullation of the fibres. The winter coats had fibres which were less medullated and of greater, but more variable, length. However, whereas the important thermal property of the winter coat was that of insulation, for summer coats to effect a thermoregulatory function they must promote heat loss (Dowling, 1958a). Based on a 0.95 correlation coefficient between the incidence of medullation and the animal's ability to regulate its rectal temperature, Dowling (1959a) was led to suggest that the medulla could have an important character which promotes heat dissipation by the animal. In this experiment of five groups of Australian bred cattle, they grew a shorter, thicker and highly medullated spring and summer coat, while winter coats were longer, thinner and less medullated. The highest percent medullation occurred in a Brahman (Zebu) cross group and the lowest percent medullation occurred in the purebred Shorthorn group. Bonsman (1949) showed that smooth coated *B. taurus* beef breeds in South Africa were more heat tolerant than woolly coated ones. Similarly, Dowling (1956) found that Shorthorn cattle with highly medullated hair fibres were more heat tolerant than their counterparts with non-medullated hair coats.

These findings suggest that a smooth, short and thick medullated summer hair coat type allows free skin ventilation thereby enhancing both sensible heat loss and evaporative heat loss. A winter coat type, however, is generally long and thin non-medullated and ideally acts as an insulating layer. The findings by Dowling (1955, 1956), Turner and Schleger (1958, 1960), Hutchinson, Brown and Allen (1973) and Yeates (1977) suggest that either heat tolerance causes hair coat type or a third character causes both coat type and heat tolerance. Thus the ability to shed winter coats for a summer coat would be linked with heat tolerance and/or the third factor.

2.4.2.3: Coat depth

Like coat type, there are inherent breed differences in coat length and basically the short Zebu coat type is associated with better heat tolerance (Yeates, 1965; and Dowling, 1958b). The advantage of a short smooth coat over a long coarse coat lies in its openness to free air movements so that heat exchange is less hampered. Turner and Schleger (1960) indicated that coat scores are hereditary and that generally crossbreds have intermediate coat scores. The regression coefficients between coat score and susceptibility to heat stress were calculated (Table I-b). The British breeds regression coefficients were highly significant but those of the Zebu cattle type were non-significant. This suggested that coat score cannot account for variations in heat stress for Zebu cattle but as far as temperate cattle are concerned coat score could account for part of the stress. Moreover, the short coats may be disadvantageous in hot bright days since most of the solar radiant heat may penetrate to act directly on the skin surface.

Table I-b: Relation between coat score and susceptibility of heat stress (Turner and Schleger, 1960)

Regression coefficients on coat score for	British type cattle	Zebu cattle
Skin temperature	0.86	0.51
Rectal temperature	0.38	0.08
Respiration rate	6.6	6.6

2.4.2.4: Coat colour and skin pigmentation

Some early work by Bonsma (1949) showed that solar heat absorption at the coat surface was greater for black than white cattle. Differential absorption of infrared and ultra-violet radiation by different combinations of coat colour and skin pigmentation was also observed. Yeates (1965) indicated that the ideal combination of white or cream coat overlying a black skin had the highest solar radiation reflectivity. This important characteristic holds true for most indigenous breeds of tropical cattle and horses. However, recent findings (Hutchinson, Brown and Allen, 1973) cast doubt on these conclusions. That although dark coats absorb more radiation at the surface, light coloured coats allow deeper penetration of solar radiation which when absorbed at the base of the coat product a twofold heat load effect.

The importance of a white coat cover has been demonstrated by Dowling (1960). In this experiment Dowling showed that animals covered by white plastic coats had lower body temperatures than those covered in a clear plastic coat ($P<0.01$). Whereas both plastic covers prevented the vaporization of skin moisture, the white covers reflected most of the solar radiation thereby reducing the amount of heat load from the atmosphere. On the other hand the clear plastic covers were penetrated by most of the radiation and could have created a microclimate similar to a green house between the skin and the plastics. In the same way it may be argued that white hair coats would reflect most of the solar radiation incident on its surface.

2.4.2.5: Body size and morphology

Generally *B. indicus* breeds of cattle have a small body mass with relatively slimmer structure and longer legs than *B. taurus* breeds. Zeboid cattle types have large ears, protruding dewlap and a fully developed hump which gives them significantly larger surface area to body mass. It has been argued that these large skin folds and appendages act as 'radiators'. This will only hold as long as body temperature remains higher than the environmental temperature. However, when environmental temperature exceeds body temperature the usefulness of these structures would only be maintained if they are superior in sweating, otherwise a net heat gain may result. Nay and Hayman (1956) have shown that the appendages and skin folds are no better supplied with sweat glands than the rest of the body. And more recently, McLean (1963b) and McDowell *et al.* (1961) showed that the cutaneous moisture vaporization from these structures did not differ significantly from the average values of the body. Further, McDowell (1958) showed that surgical removal of the hump, ears and dewlap of Red Sindhi bulls did not affect the heat tolerance of the animals. He did not observe any differences in either rectal temperature or respiration rate when the bulls were exposed to heat before and after removal of the structures.

The advantage of the small slim body is to speed up heat transfer from the body core to the surface. Also small body means lower total heat production relative to surface area.

2.4.2.6: Hair follicle density

B. indicus cattle types have denser hair fibre populations than *B. taurus* breeds (Dowling, 1955; Walker, 1957a, 1957b). Findings by Dowling (1959a) showed that hair follicle population could only be a minor factor in heat tolerance since the correlation coefficients between the density of hair and heat tolerance indicators were negative. Earlier results by Walker (1957b) showed some similarities to those by Dowling. It is also known that in cattle every hair follicle is associated with a sweat gland. The characteristics of the sweat glands hold a key role to heat tolerance.

2.4.2.7: Sweat gland population and size

The differences in sweat gland population density (Carter and Dowling, 1954), and gland size (Nay and Dowling, 1957) has been suggested to be responsible for the substantial differences in heat tolerance between breeds. A biopsy technique by Carter and Dowling (1954) established that *B. indicus* breeds had much higher follicle density (1698 follicles per cm^2) compared to *B. taurus* breeds (764 follicles per cm^2. Yeates (1955) has summed up the differences that Zebu cattle have more numerous, baggy and large sweat glands while *B. taurus* cattle have less numerous, tubular, coiled glands of low diameter; and Zebu crosses and Africander glands are characterized by club shaped morphology and are intermediate in size.

Carter and Dowling (1954) indicated that the relationship between apocrine gland density to the age of Beef Shorthorn females was asymptotic (Fig. 4.2.7.1). This suggested that the number of follicles per animal is established soon after birth and that any changes in the population density of apocrine glands would be due to changes in skin area rather than a total gland change.

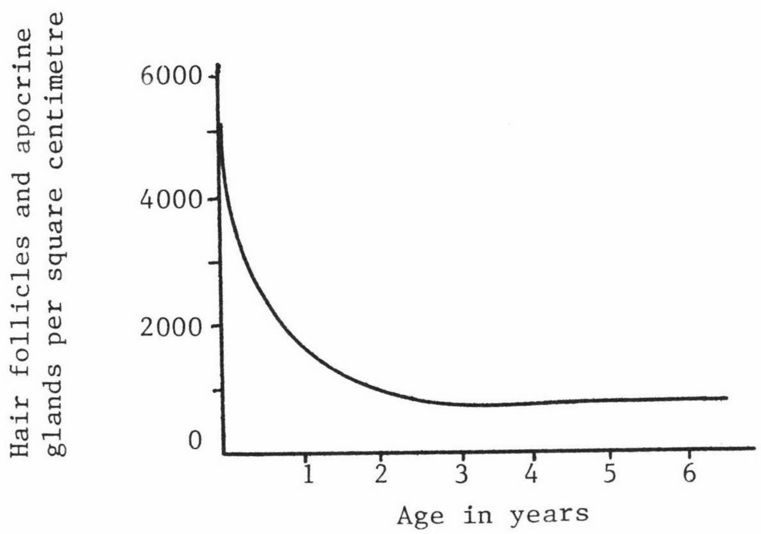


Fig. 4.2.7.1: Age changes in the population density of sweat glands in Beef Shorthorn cows up to 6 years old.

2.4.2.8: Sweating ability

Evaporation of moisture from the skin is a major channel of heat loss by which cattle maintain body temperature regulation in hot conditions. The rate of evaporation will depend on the moisture supply which in turn depends on the sweating efficiency of the animal.

There is a general agreement that sweat glands are apocrine in nature (Hafez *et al.*, 1955; Findlay *et al.*, 1950). An examination of the histology of the skin (Dowling, 1955a, 1955b) of various breeds of cattle has indicated that tropical breeds (Indian Zebu) have thinner papillary layers which is abundantly supplied with apocrine glands. The papillary layer of temperate breeds was wide, diffuse and only poorly supplied with apocrine glands. Nay *et al.* (1956) has also reported that not only the population and size of sweat glands make differences in skin moisture supply, but also the thin papillary layer which contains the sweat glands is closer to the skin surface in Zebu cattle than in European breeds. At the same time it is generally understood that cattle sweat more profusely when exposed to solar radiation than in climate chambers (Murray, 1966). This is significant because sweating is possibly enhanced by greater stimulation of local receptors by some unknown solar radiation properties.

Nay *et al.* (1956) found that the mean gland density and mean sweat gland volume were $996/cm^2$, $101 \times 10^6\ \mu^3$ and $1508/cm^2$, $21.1 \times 10^6\ \mu^3$ for *B. taurus* and *B. indicus* respectively. These findings suggest that the larger Zebu type glands allow for greater intestilial fluid filtration and according to Allen (1962) can therefore achieve a constant maximum secretion in response to heat.

2.4.2.9: Fat deposition

In addition to the favourable coat characteristic, sweating ability and other adaptive mechanisms which facilitate increased rate of heat dissipation in the heat, Ledger (1959) has argued that fat deposition in Zebu cattle is mainly intramuscular rather than subcutaneous. Evidence indicates that *B. taurus* cattle have significantly higher subcutaneous fat deposits than Zebu cattle. Whereas the subcutaneous fat layer will strengthen the insulating properties of the thick woolly skin cover of *B. taurus* cattle in winter, in summer this same layer may trap deep body heat due to its thermal resistance characteristic. On the other hand, leanness in *B. indicus* would allow rapid heat transfer from central organs to the skin where it will normally be dissipated.

2.4.2.10: Water metabolism

Hopkins (1976) has indicated that water metabolism is of paramount importance in determining an animal's adaptability to a tropical climate. Maintenance of homeothermy is dependent on the stabilizing properties of water which forms three-fourths of total body mass. Because of its high specific heat value it is an ideal buffering and heat transporting medium from the core to peripheral regions where it is dissipated. It is most beneficial in evaporative cooling because of its high latent heat of vaporization.

It has already been stated that leanness is associated with better conductivity; leanness is also associated with higher water content. But Phillips (1960) observed that Zebu type cattle appeared to have a lower water requirement than European breeds. An investigation by Fourie (1964) on the water balance in the heat found no difference in blood volume between *B. indicus* and *B. taurus*, but *B. indicus* cattle had greater decrease in interstitial fluid apparently accounted for by a higher sweating ability.

Kibler and Yeck (1959) observed that at high environmental temperatures Zeboid cattle increased their vapourization of moisture faster than their water intake; *B. taurus* cattle on the other hand increased their water intake faster than evaporative moisture. At 27°C *B. taurus* cattle drank twice as much water and their vaporization was 11 percent lower than that of their crosses. It has also been reported that Zeboid gut contents (Quarterman *et al.*, 1957) and Zeboid faeces (Taylor *et al.*, 1957) were significantly drier than those of *B. taurus* cattle maintained under similar conditions.

The advantage of Zeboid cattle types in the use of body water for evaporative purposes is indicated in the higher water turnover in sweat rather than in respiratory, renal and faecal sources.

2.5: Heat stress indicators

An animal can be said to be in a state of heat stress when its total heat production, metabolic and environmental (mainly radiant heat gain) induces a strain on the physiological responses responsible for heat loss. This strain is normally given by an increase in metabolic rate. Heat stress affects first the animal that is growing fastest or producing the most milk because of its high metabolic rate (Webster, 1976). The initial, invariable response to heat in such animals is reduced food intake.

The most noticeable early response to heat stress in cattle is first an increase in respiratory rate, then a rise in body temperature (Yeates, 1965). McDowell (1958), Johnston (1965) and Yassen (1977) have therefore used respiratory rate as an indicator to heat stress in cattle. Other indicators include rectal temperature and voluntary food intake.

2.5.1: Respiration rate

Heat stress can be caused by either metabolic heat or environmental heat independently, or by a combination of the two. Finch's (1972) finding that solar radiation could account for up to 90 percent or more of the total heat load of an animal suggests that in a radiant thermal environment solar heat would constitute the largest component of the heat dissipated by the animal. Solar heat is a critical factor in the tropics and even the adapted heat tolerant indigenous cattle show elevated ventilation rates and rectal temperatures.

A rise in ambient temperature causes an increase in respiration rate and later a rise in body temperature. Brody (1956) and Johnson (1965) have found that above the thermal neutral zone for Zebu cattle (10 to 27°C) increases in respiration rate became most pronounced. Yeates (1965) indicated that a rise in respiratory rate reflects a cooling mechanism which involves an increase in pulse rate and peripheral blood flow (vasodilation). Increased heat stress stimulates rapid breathing (panting) and sweating (Johnston, 1965).

2.5.2: Rectal temperature

An increase in rectal temperature would indicate severe heat stress when the animal's heat loss mechanism (sensible and evaporative means) is surpassed by its heat production. Elevated rectal temperatures are indicative of the amount of heat stored by an animal where only minimal increases can be stored. Adverse stress would cause heat exhaustion and ultimately death; Yeates (1955) indicated that at rectal temperatures of 107°F (41.6°C) cattle would pant with open mouth, protruding tongue and drooling saliva from the mouth.

2.5.3: Other indicators

Many other responses to heat including raised sweating rate, blood shifts, increased water turnover, depressed food intake and changes in hormonal secretions (Turner, 1975), and changes in protein metabolism in heat stressed cattle (Kellaway and Colditz, 1975) could be used to measure the extent of heat stress.

Most of these responses to heat are negatively related to productivity except possibly increased sweating rate, which on evaporation causes substantial cooling. However, increased total nitrogen, reduced sugars, lactic acid and other mineral losses in the sweat including calcium, phosphorus, potassium, magnesium, and sodium chloride (Joshi *et al.*, 1968) account for direct loss of production in tissue and milk synthesis. But these losses would have little effect on the productivity of an animal unless food quality is a limiting factor.

2.5.4: Heat stress indices

Several scientists have attempted to develop indices which describe a precise environment which can impose heat stress. Ingram and Mount

(1975) and Kerslake (1972) have reviewed and assessed their application, They point out that the main problem is to express heat stress as a factor independent of physiological responses so that similar environment could account for equal stress.

Among the several indices for heat stress which have been developed to measure the effect of a hot environment include the wet bulb temperature; "predicted 4-hour sweat rate"; the index of physiological effect (which involves four factors, deep-body temperature, heart rate, skin temperature and sweating); and effective temperature scale which has put particular attention to comfort limits.

More recently attempts to define the thermal stress imposed on man by the environment have been based on quantitative assessment of heat exchange through the different channels. Probably the best known is the index which is based on the ratio of the total evaporative heat loss required, E_{req}, to the total available evaporative heat poss potential, E_{max}.

However, these developments have mainly been based on man who is more dependent on sweating ability than any other heat loss process. Their wide application is therefore questionable.

CHAPTER THREE

EXPERIMENTAL MATERIALS DESIGN AND METHODS

CHAPTER THREE

EXPERIMENTAL MATERIALS, DESIGN AND METHODS

Eight Friesian and eight Brahman x Friesian castrated calves were exposed to hot or cool conditions and fed on two rations in a 2^3 factorial arrangement to measure food intake, digestibility, liveweight gain, rectal temperature, respiration rate and coat cover. Later, eight of the calves were exposed to artificial radiant heat load to measure intake, liveweight gain, rectal temperature, respiration rate and sweat rate.

The data for food intake, digestibility and liveweight gain will be the subject of another thesis (King, 1978) in press.

3.1: Materials and methods

3.1.1: General information

Data was collected in three different trials lasting a total of 20 weeks. The experiment began in mid March (early autumn) and was completed at the end of July 1977. The trials were conducted in three controlled temperature rooms at the Animal Physiology Unit, Massey University, Palmerston North.

3.1.2: Experimental animals

Eight Friesian and eight first generation Brahman x Friesian calves were used in this experiment. The Brahman cross calves were obtained from a farmer who was rearing them under a contract to the New Zealand Government and the Friesians were obtained locally in September 1976. All the calves were housed in the Animal Physiology Unit, Massey University, from September 1976 and were given similar management from then on. The calves were weaned at 10 weeks and castrated at 3 months of age. Prior to this experiment, the calves had been fed on hay and a cereal pelleted meal and were generally familiar with the conditions used in the present work.

3.1.3: Measurements

Measurements on each calf included rectal temperature, respiration rate, hair coat cover, food and water intake, sweating rate and details of the exchanges of radiant heat between animal and the environment were measured in calves which were used in the radiation experiment. Room temperature and relative humidity were also measured daily.

3.1.3.1: Respiration rate

The number of respiratory flank movements were counted for one full minute and taken to represent the respiration rate of each animal. The respiratory counts were obtained at 8.00 a.m. and 2.00 p.m. daily. Most of these measurements were conducted while the animals were lying down.

3.1.3.2: Rectal temperature

Body temperature was measured by inserting a clinical thermometer 8 to 10 cm in the rectum. Readings were taken after the thermometer had been in the rectum for three to five minutes continuously. Like respiration rate, measurements were taken on each animal twice every day.

3.1.3.3: Food and water intake

Calibrated water vessels were used to estimate the individual daily water intake of each calf. Each day the amount of water provided to each calf was recorded and the amount of water not drunk was recorded on the following day; the daily intake of water by each calf was calculated from these data.

Daily feed samples were taken to determine the percentage of dry matter (DM) in the hay and pellets fed. About 100 to 200 g sample of each feed offered was dried overnight in an oven at 60^{o} to 70^{o}C to a constant weight. Similarly, the percentage dry matter in the feed left uneaten by each calf was estimated every day. The amount of dry matter eaten by each animal daily was calculated from the formula: Total feed offered (kg) x DM% - Total feed refused (uneaten) (kg) x DM% = Total intake of DM (kg). Also feed samples of each feed were taken daily and bulked for laboratory analyses for crude protein and gross energy content.

PLATE ONE

AREA CLIPPED FOR THE ESTIMATION OF HAIR COAT COVER

Fig 3.12 Locations of thermometers in the twelve-hourly ambient temperature measurements

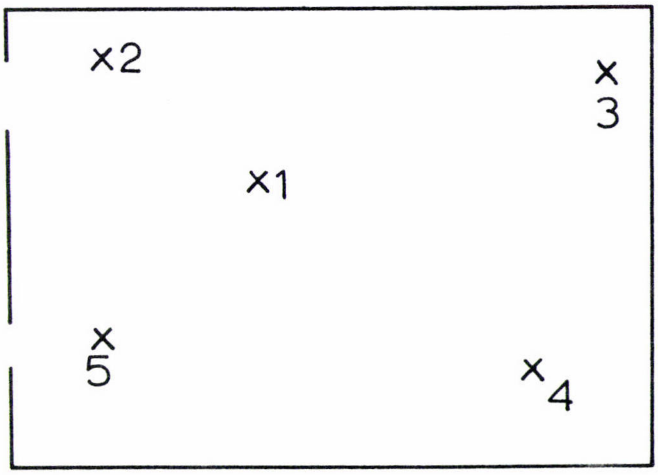
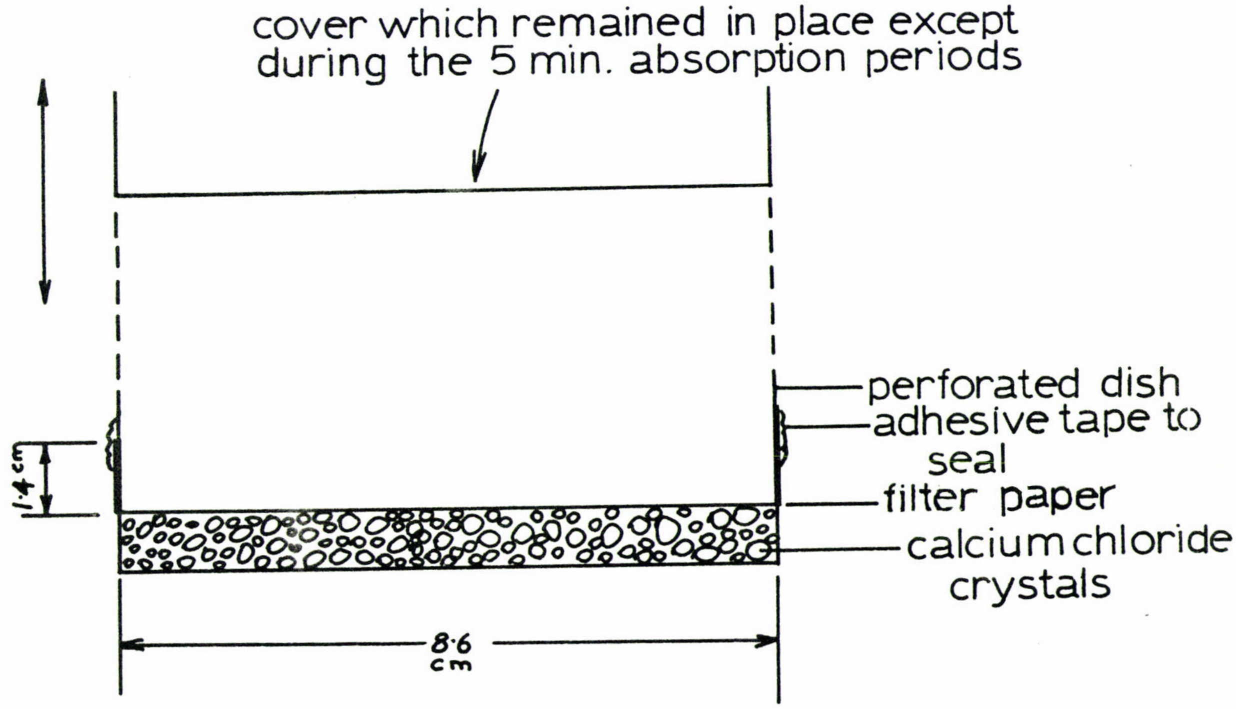


Fig. 3·13 Calcium Chloride capsule



3.1.3.4: Ambient temperature, black globe temperature and air humidity

Air temperature was measured at several places in the rooms. The temperature indicated by a thermometer in a black globe was measured in the hot rooms. Humidity measurements were calculated from measurements of wet and dry bulb temperatures made with a whirling hygrometer. These measurements were taken twice (8.00 a.m. and 2.00 p.m.) daily.

3.1.3.5: Variation in air temperature over a 12-hour period

Air temperature in the hot room was recorded hourly over a 12-hour period during trial Ia. Measurements were taken at two levels, 0.15 m and 1.2 m above the concrete floor at five different places (Fig. 3.1.2).

3.1.3.6: 24-hour rectal temperature

During trial Ia rectal temperature of all the calves were taken at two-hour intervals during a 24-hour period.

3.1.3.7: Hair coat cover

At the end of trial Ia hair was closely clipped from measured areas of skin (between 150 and 200 sq.cm) on both flanks of each calf, Plate I. The hair was dried and weighed. From this the average unit hair coat cover was estimated as g dry hair per m^2.

3.1.3.8: Sweating rate

Sweating rates were estimated in trial II. Calcium chloride capsules, Fig. 3.1.3, were weighed before and after application to closely clipped patches on the back sacral region (Schleger and Turner, 1965 and McLean, 1963) of the calves for a period of five minutes. Two capsules were applied simultaneously on both sides of the animal and the weight gains over the five minute period converted to grams per square meter per hour (g/m^2hr). Air temperature, globe temperature, rectal temperature and air humidity were also recorded when sweating rate measurements were taken.

3.1.3.9: Incident radiation

The radiation intensity at the approximate height of the calves when lying down (0.5 m) and when standing (1.2 m) were estimated using a solarimeter (Solar Radiation Instrument Australia SR13) shortwave

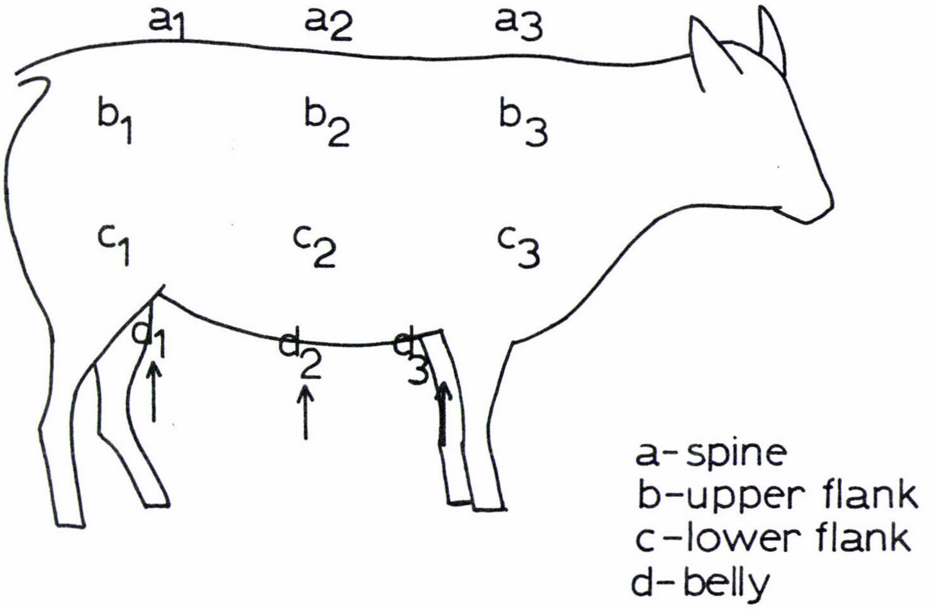


Fig 3.14 Site for net radiant transfer measurements

radiation and shortwave and longwave radiation were measured using glass and polythene shields respectively. The electrical output of the meter was indicated by a digital voltimeter; the millivoltages measured in this way were converted into values for radiant heat exchange (kcal/m^2hr) by using the manufacturers stated calibration factors.

3.1.3.10: Net radiation

One calf of each breed group was subjected to a more detailed radiant energy balance. Net radiant transfers were measured at 18 sites over the body surface; three along the spine, six on either flank and three along the belly and chest-abdomen region (Fig. 3.1.4) using a miniature net radiometer (Solar Radiation Instrument Australia SR17) fitted with polythene shields. The average total radiant load on each of the animals was estimated by converting the electrical output into heat energy per unit surface area and time (kcal/m^2hr) using the manufacturers stated calibration factor.

3.2: Specific materials and methods for each trial

3.2.1: Trial I

3.2.1.1: Trial Ia: Effect of breed, ambient temperature and diet on physiological responses

This trial started on 10 March and was completed on 25 May 1977. The sixteen calves were housed in two large airconditioned rooms, each was 6.9 m long x 5.5 m wide x 2.75 m high. Each calf was confined to a 2.4 x 0.9 x 1.4 m pen with a wooden slatted floor and raised 15 cm above the concrete floor. The rooms were continuously illuminated by four fluorescent tubes of 40 watts each.

3.2.1.1.1: Feeds and feeding

In this trial two types of diet were used, one mainly of cereal based concentrate in pelleted form called concentrate and the other mainly of a medium quality hay called hay. The composition of the two diets is given below (Table II-a). Both diets were offered *ad libitum* according to the treatment combinations.

Table II-a: Nominal composition of the two diets

	Nominal percentage of total diet made up by the two ingredients (%)	
	Concentrate	Hay
Pellets	90	10
Hay	10	90

Mineral and vitamin supplements were at first offered *ad libitum*, but later at intervals of three days when two teaspoonsful were sprinkled on the feed. This was adopted to cut down waste through spillage.

3.2.1.1.2: Allocation of calves into treatment groups

Using a table of random numbers (Snedecor, 1962), the calves were allocated into the treatment groups. First each breed group was split into two equal subgroups A and B, then each of the subgroups were further subdivided into minor subgroups A_1, A_2, B_1, B_2 to form treatment groups for each breed type (Fig. 3.2.1).

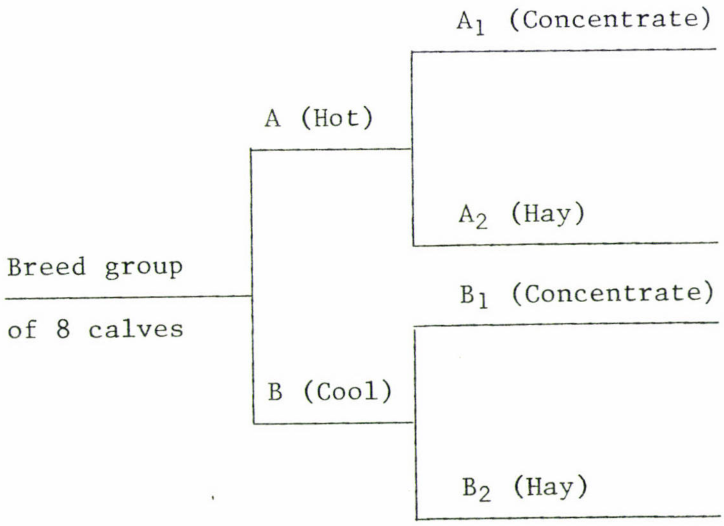
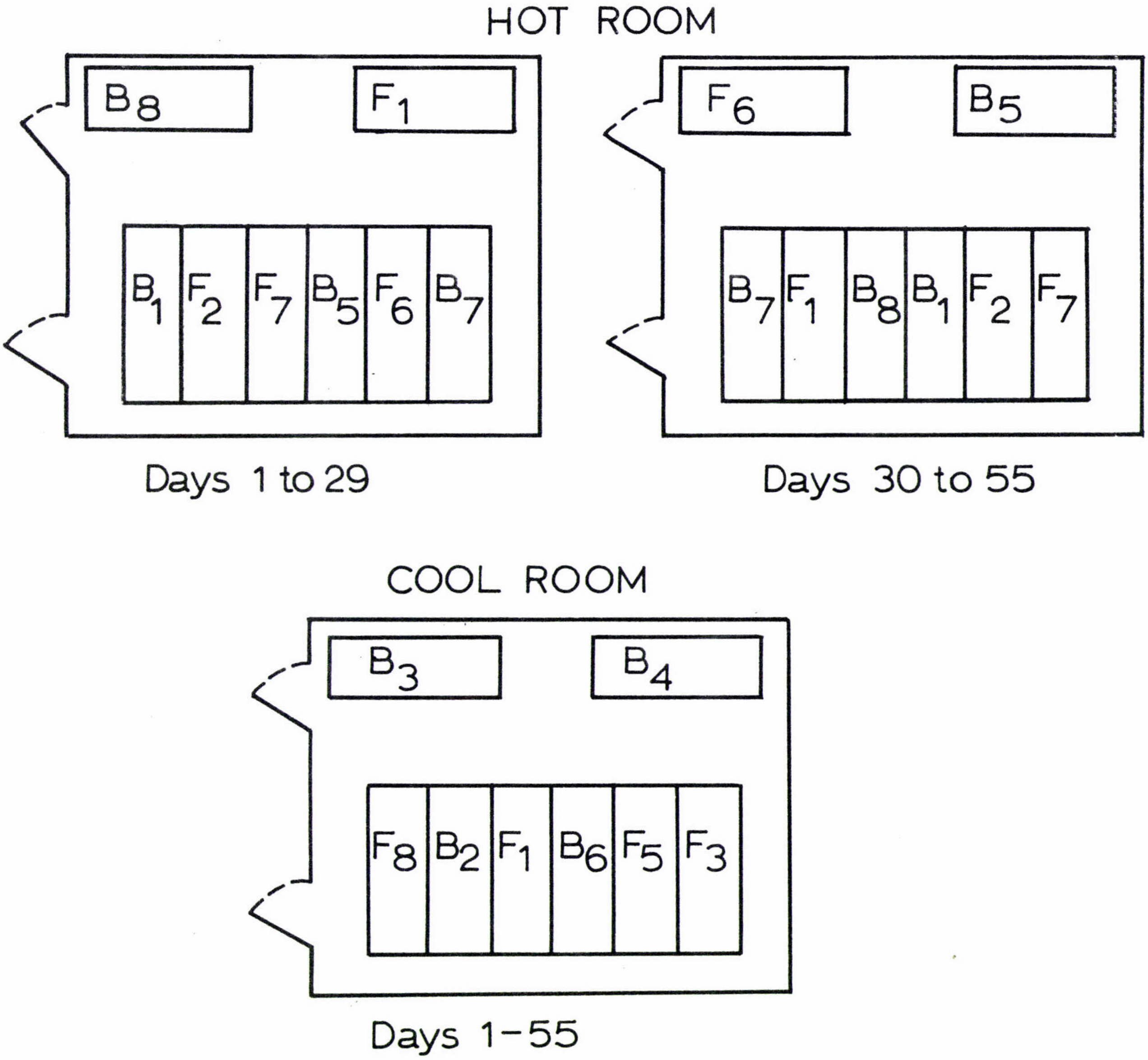


Fig. 3.2.1: Determination of treatment groups

The final treatment groups are given in Table II-b. This treatment combination formed a 2x2x2 factorial arrangement where each of the factors, breed, temperature and diet, are investigated at two levels.

Fig. 3.22 Calf positions in Trial I



F = Friesian

B = Brahman Cross

PLATE TWO

A CLIPPED CALF USED IN THE CLIPPING TRIAL

Table II-b: Treatment groups for trial Ia (initial calf liveweight (kg) in brackets; numbers represent those on ear tags).

	Hot 34°C		Cool 17°C	
Diet	Concentrate	Hay	Concentrate	Hay
Brahman Crosses	B_5 (114.9) B_8 (106.7)	B_7 (102.6) B_1 (102.6)	B_2 (109.0) B_6 (99.9)	B_3 (101.5) B_4 (109.0)
Friesians	F_7 (100.3) F_4 (102.8	F_2 (109.6) F_6 (95.6)	F_1 (82.9) F_8 (96.3)	F_5 (97.6) F_3 (94.4)

Allocation of calves into pens

The initial calf positions in both the hot and cool rooms were determined randomly. However, in order to minimize possible positional influence thought to be caused by supplementary overhead heaters and cool currents near the doors in the hot room, the positions of the calves in the hot room were changed at the end of the first half of trial Ia. The positions are given in Fig. 3.2.2.

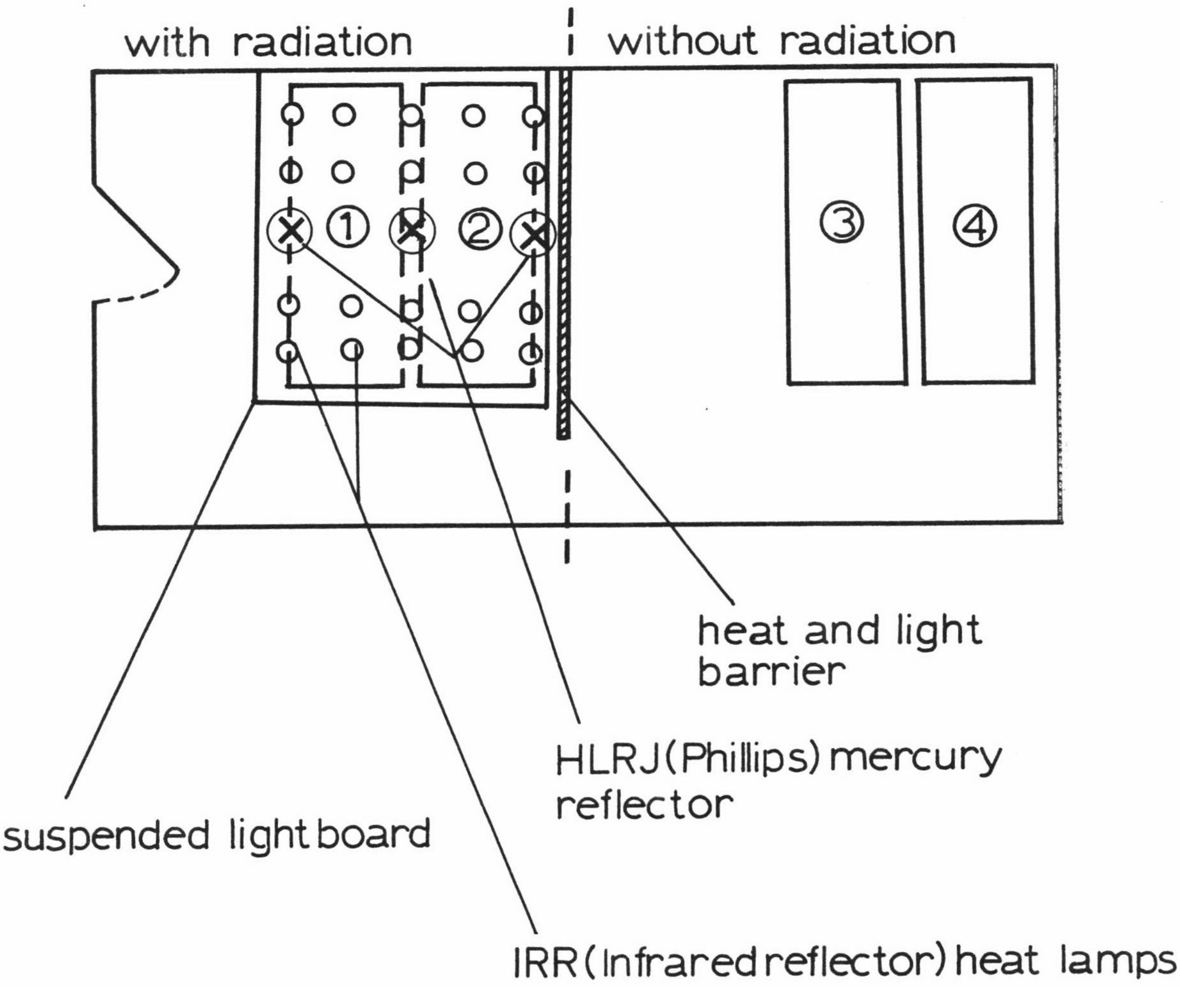
3.2.1.2: Trial Ib: Effect of clipping on respiration rate, food intake and rectal temperature

After the completion of trial Ia, the calves on the hot treatment were retained for a clipping trial. Table III gives the plan of this trial. During the first eight days all the calves remained unclipped. On the ninth day four calves were closely clipped to the neck and knees (Plate II) while the other four were left unclipped. Management and feeding remained as in trial Ia.

Table III: Treatment groupings in clipping trial

Air temperature 34°C				
Concentrate		Hay		Period
Brahman Cross	Friesian	Brahman Cross	Friesian	
B_5	F_7	B_1	F_2	Day 1-8
B_8	F_4	B_7	F_6	All unclipped
B_5	F_7	B_1	F_2	Day 9-16 Unclipped
B_8	F_4	B_7	F_6	Day 9-16 Clipped

Fig. 3·23 Radiation Room layout



1 } Individual pens under
2 } radiant lamps

3 } Individual pens which were
4 } shaded from radiant lamps

3.2.2: Trial II: Effect of radiant heat load on calves of two breeds

This trial began on 26 May 1977 and continued for 10 weeks.

3.2.2.1: Animals

The eight calves previously in hot room were retained for this experiment after completion of trial Ib.

3.2.2.2: Housing

A small (6.30 x 2.75 x 2.75 m) controlled temperature room was used for this trial. Four calves were kept in pens (2.0 x 0.7 x 1.4 m) contained in the radiation room at one time, and the other four were held in the hot room described above. A plan is given in Table IV and the radiation layout is presented in Fig. 3.2.3.

Each pair was exposed to artificial radiation for eight hours daily for 16 days using overhead HLRG 300 watt (Phillips New Zealand) mercury reflector lamps and 13344 E06 375 watt infra-red reflector heat lamps (see Fig. 3.2.3). A 14-inch fan maintained a constant air circulation at 0.36 km/hr during the radiation hours from 8.30 a.m. to 4.30 p.m. Ambient room temperature was maintained at about 34°C throughout the experimental period.

Table IV: Radiation experimental design

Calf pairs	Period with radiation	Period without radiation	Remarks
1 - B_1 F_2	Day 1 - 16	Day 17 - 32	Finish on day 33
2 - B_5 F_7	Day 17 - 32	Day 1 - 16	
3 - B_7 F_6	Day 34 - 49	Day 50 - 65	Day 1 - 32 in hot room 34°C without radiation
4 - B_8 F_4	Day 50 - 65	Day 34 - 49	

3.2.2.3: Feeds and feeding

All the animals were fed *ad libitum* on the hay ration used in trial I. Water was also provided *ad libitum*.

3.3: Statistical design and analysis

3.3.1: Design

The main trial (Ia) was designed to investigate the responses of two breeds on two diet types, under two temperature conditions. This treatment combination formed a 2x2x2 factorial arrangement in which two levels of each of the factors; breed, diet, and temperature, were investigated.

Trial Ib was designed to measure the effects of clipping at a high temperature (34°C). In trial II the effects of artificial radiation on the two breeds were measured. Both these trials were conducted in randomized block designs.

3.3.2: Statistical analysis

Separate analyses were carried out for each trial. An analysis of variance was used to determine any significant differences between the treatment groups. Data collected from the main trial allowed for a factorial analysis (Cochran and Cox, 1950, and Guenther, 1964) in which the main effects; breed, temperature, and diet; first order interactions, breed x temperature, breed x diet, and temperature x diet; and a third order interaction, breed x temperature x diet, were simultaneously estimated.

The main trial (Ia) was classified as a three factor completely randomized factorial design with the effects of the treatments fixed. Using the assumptions of the fixed effect model;

X_{ijkm} are independently $N(\mu_{ijk} \sigma^2)$

where:

$$X_{ijkm} = \mu_{ijk} + (X_{ijkm} - \mu_{ijk}) = \mu_{ijk} + e_{ijkm}$$

$$= \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + e_{ijkm}$$

and

$i = 1, 2 \ldots a$

$j = 1, 2 \ldots b$

$k = 1, 2 \ldots c$

$m = 1, 2 \ldots n$

and e_{ijkm} are independently $N(0, \sigma^2)$

The analysis of variance table is illustrated below (Table V) and the general model for this analysis is presented in appendix one.

Table V: Analysis of variance model for trial I-a

Source	SS	d.f.	MS	F value
Breed	B_{SS}	1	B_{SS}	$\frac{B_{SS}}{E_{SS}}$
Temperature	T_{SS}	1	T_{SS}	$\frac{T_{SS}}{E_{SS}}$
Diet	D_{SS}	1	D_{SS}	$\frac{D_{SS}}{E_{SS}}$
Breed x Temperature	$B \times T_{SS}$	1	$B \times T_{SS}$	$\frac{B \times T_{SS}}{E_{SS}}$
Breed x Diet	$B \times D_{SS}$	1	$B \times D_{SS}$	$\frac{B \times DSS}{E_{SS}}$
Temperature x Diet	$T \times D_{SS}$	1	$T \times D_{SS}$	$\frac{T \times D_{SS}}{E_{SS}}$
Breed x Temperature x Diet	$B \times T \times D_{SS}$	1	$B \times T \times D_{SS}$	$\frac{B \times T \times D_{SS}}{E_{SS}}$
Error	E_{SS}	8	$\frac{E_{SS}}{8}$	
Total	T_{SS}	15		

The mean square (MS) for each treatment is obtained by dividing the sum of squares of the treatment by the respective degrees of freedom (df) and the error sum of squares (E_{SS}) are obtained by subtracting the treatment sum of squares from the total sum of squares ($T_{SS} - Tr_{SS}$).

In trials Ib and II simple analysis of variance for group comparisons were carried out. In both cases comparisons were made between the two breed groups using the fixed effects model for randomized block design with the assumptions that:

$$X_{ij} = \mu + \sigma^2 + \beta_j + eij, \quad i = 1, \; 2 \text{ -- } n$$
$$j = 1, \; 2 \text{ -- } r$$

eij are independently $N(0, \sigma^2)$ and the table for the general analysis of variance is given below.

Table VI: Analysis of variance for randomized blocks

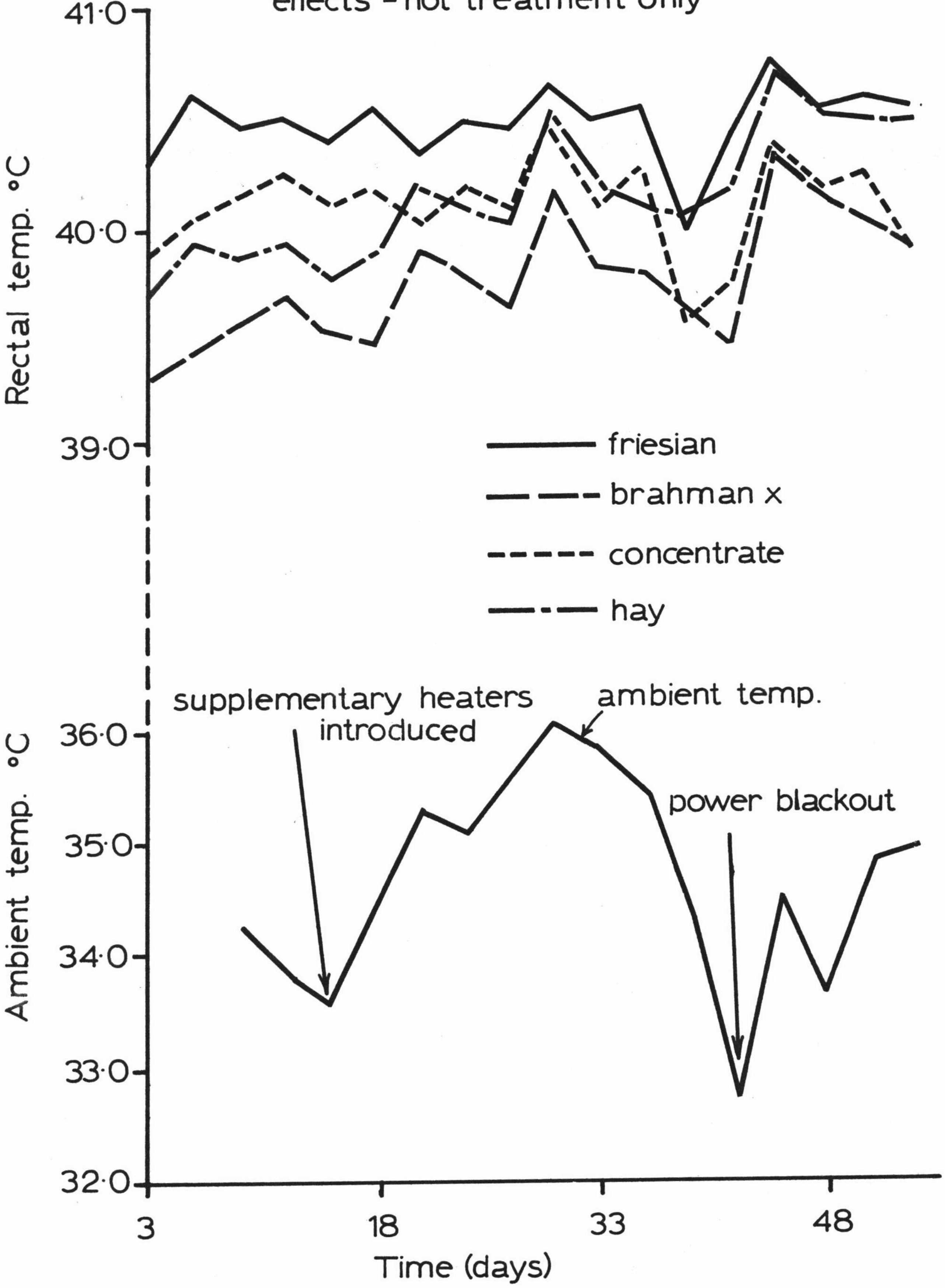
Source	SS	D.F.	MS	EMS	F
Blocks	SS_B	n-1	MS_B	$\sigma^2 + \frac{r}{n-1} \sum_{i=1}^{n} \sigma_i^2$	
Treatments	SS_{Tr}	r-1	MS_{Tr}	$\sigma^2 + \frac{n}{r-1} \sum_{j=1}^{r} \beta_j^2$	$\frac{MS_{Tr}}{MS_E}$
Error	SS_E	(n-1)(r-1)	MS_E	σ^2	
Total	SS_T	nr-1			

Simple correlation coefficients and regression analyses between calf liveweights and food intake and between food intake and heat stress indicators were performed according to Snedecor (1956). Similar analyses between rectal temperature and respiratory frequency were carried out to determine and/or examine the relationship between the two stress indicators.

CHAPTER FOUR

RESULTS

Fig. 4.1 Three-day mean Ambient Temperature and Rectal Temperature showing breed and diet effects - hot treatment only



CHAPTER FOUR

RESULTS

4.1: Trial I

4.1.1: Environmental conditions

The overall mean values for ambient temperature, globe temperature and relative humidity are presented in Table VII.

Table VII: Room environment

Treatment	Measurement *	Trial Ia	Trial Ib
Hot	Mean ambient temperature, °C Mean globe temperature, °C Mean relative humidity, %	34.5 ± 0.1 35.1 ± 0.2 45.2 ± 0.5	34.3 ± 0.2 35.7 ± 0.2 43.4 ± 0.7
Cool	Mean ambient temperature, °C Mean relative humidity, %	16.9 ± 0.1 86.0 ± 0.6	

* ± Standard Error of the Mean (S.E.M)

In the earlier part of the experiment hot room temperatures fell below 30^{o}C in the overnight (Fig. 4.1), but the problem was overcome by use of supplementary heaters. Hot room relative humidity was briefly elevated to a maximum of 75% R.H. on washing days.

The average twelve-hourly recordings of hot room ambient temperature measured at 0.15 m and 1.0 m above the floor at five different locations* in the room are shown in Table VIII. It was cooler close to the doors than away from the doors and warmer at one meter above the floor than at 0.15 m above the floor. An analysis of variance for these data revealed significant differences ($P<.05$) for location and height (see appendix I-a). Although there could be differences between the rectal temperature measured while an animal was lying down and that taken while it was standing due to the differences in air temperature at 0.15 m and 1.0 m; it is, however, likely that such effects, if any, would be distributed randomly between treatments in the hot room treatment.

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* For locations see Fig. 3.1.2.

Fig. 4.2 a Mean values for Rectal Temperature for Trial I-a showing significant effects

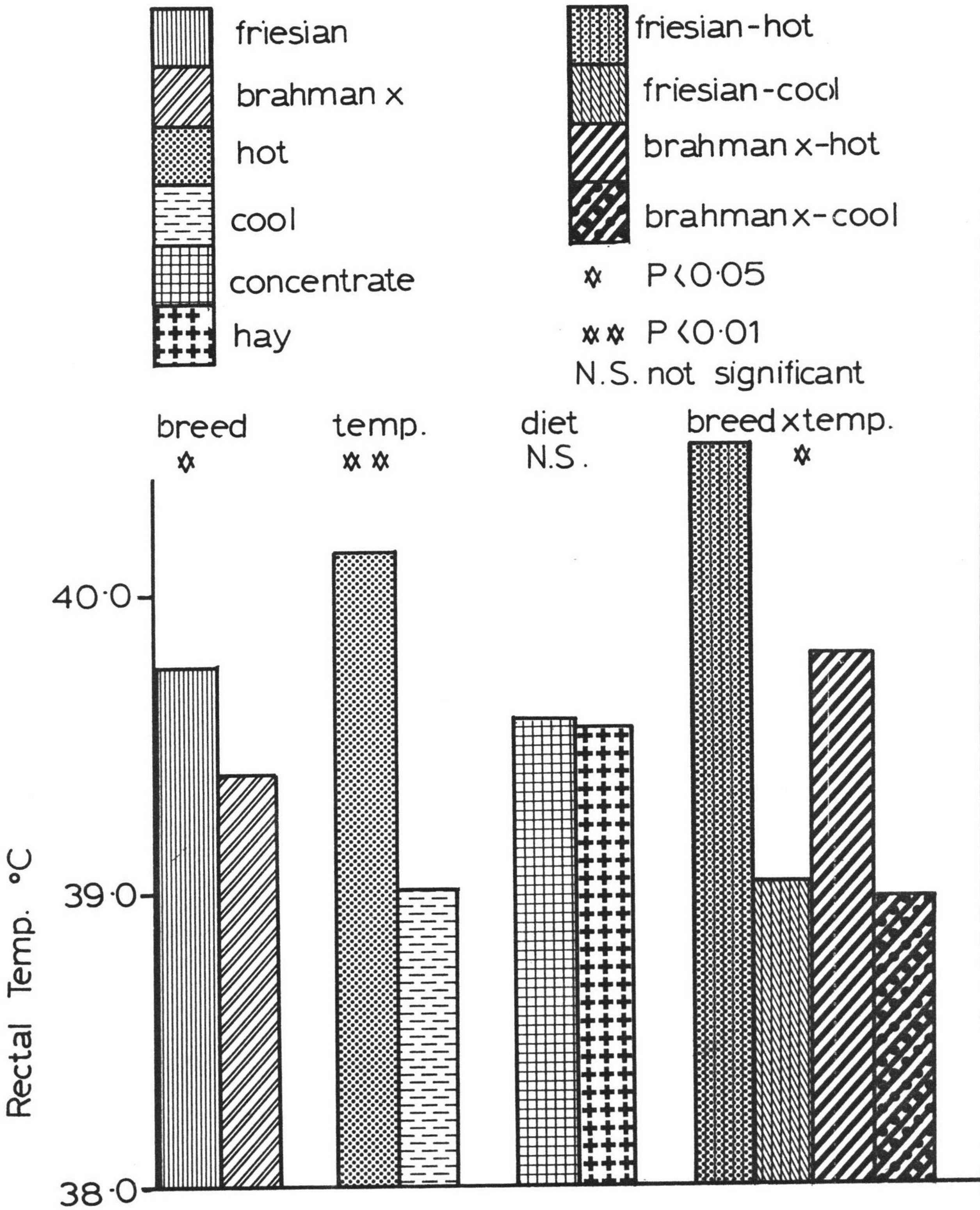


Table VIII: Average positional ambient temperatures in hot room

Height above floor	Location in room					Average
	1	2	3	4	5	
0.15 m	32.8	31.0	32.4	32.8	30.4	31.9
1.0 m	34.9	34.1	35.0	34.7	34.3	34.6
Average	33.8	32.5	33.7	33.7	32.3	33.3

4.1.2: Treatment effects on rectal temperature and respiration rate

The mean values for rectal temperature and respiration rate are presented in Tables IX and X respectively. A summary of the analysis of variance is included in each table.

4.1.2.1: Main treatment effects

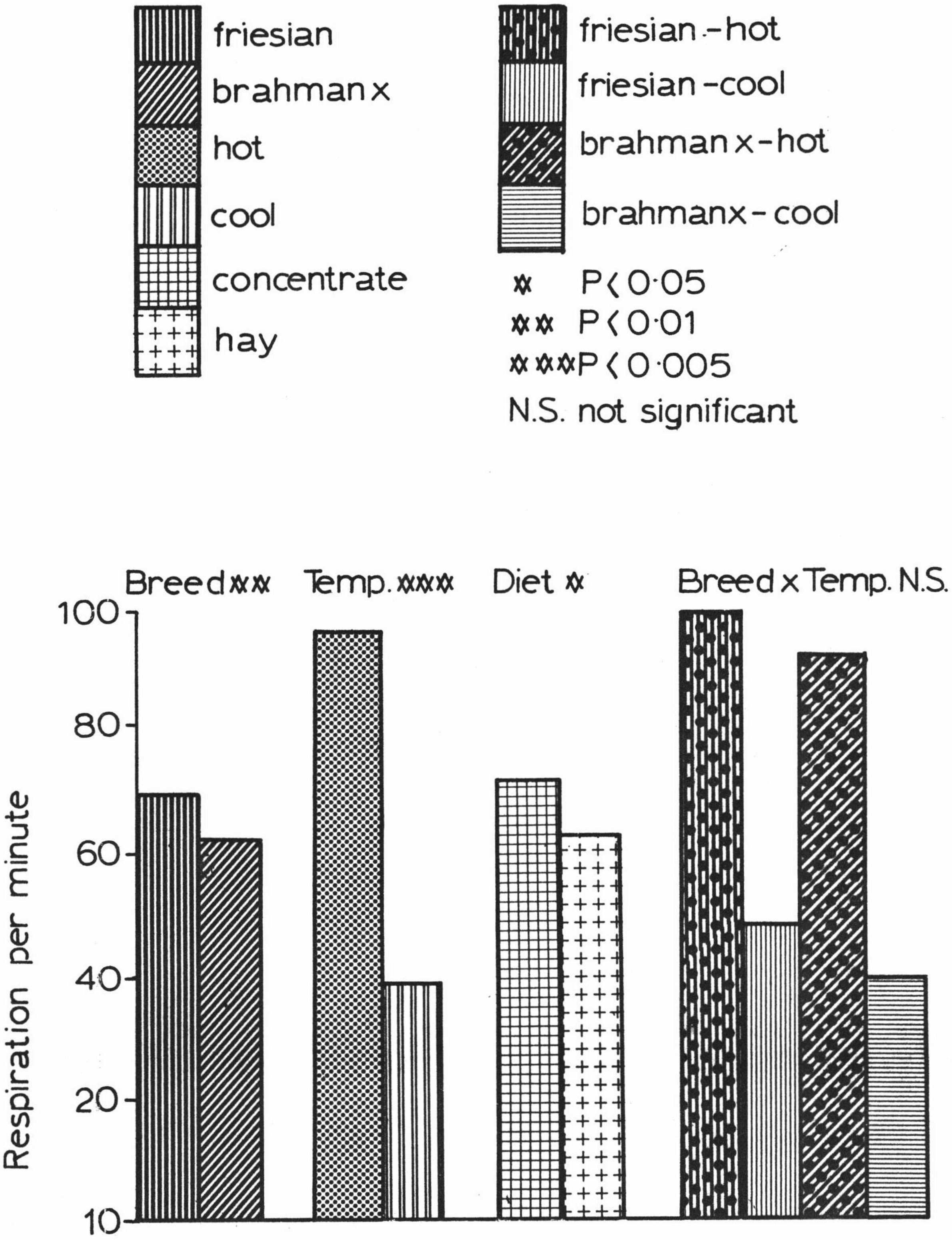
Animals on the high temperature treatment had higher rectal temperatures and respiration rates than those on the cool temperature treatment. Friesian calves had consistently higher rectal temperatures than the Brahman cross calves at both the high and the cool temperature treatments, but these differences were considerably reduced in the cool temperature treatment, see Fig. 4.2-a. Fig. 4.2-b shows similar effects for respiration rate.

Analyses of variance for rectal temperature and respiration rate indicate that in both measurements there were significant differences due to breed and temperature treatments. Diet did not have significant effect on rectal temperature, but it did on respiration rate. These effects are illustrated in Fig. 4.2-a and 4.2-b.

4.1.2.2: Interactions

The analysis of variance for rectal temperature showed significant interactions between the effects of breed and temperature ($P<.05$). Such interaction was, however, not evident for respiration rate. At the high temperature Brahman crosses on the concentrate diet had lower rectal temperatures than the other Brahman crosses on the hay diet; whereas in the cool treatment the Brahman crosses on the concentrate diet had higher rectal temperatures than those on the hay diet. However, at both temperature treatments, the Friesians on the concentrate diet had

Fig. 4.2 b Mean values for Respiration rate for Trial I-a, showing significant effects



higher rectal temperatures than those on the hay diet. Therefore, there was no significant interaction between the effects of temperature and diet. Similarly, there were no interactions between the effects of temperature and diet treatments on respiration rate. Breed x Diet was not significant for either measurement.

Table IX: Individual mean rectal temperature values and treatment effects

Temperature	Breed and Diet treatments				Pooled S.E.M.	Analysis of variance	
	Friesian		Brahman X			Main Effects	Interactions
	Hay	Concentrate	Hay	Concentrate			
Hot	40.65 40.21	40.36 40.80	40.14 39.79	39.63 39.63	40.15 ± 0.2	Breed * Temp.**	Breed x Temp.* Breed x Diet NS
Cool	38.90 39.04	39.13 39.05	38.95 38.77	39.23 38.94	39.00 ± 0.05	Diet NS	Temp. x Diet NS B x T x D NS

Table X: Individual mean respiration rate values and treatment effects

Temperature	Breed and Diet treatments				Pooled S.E.M.	Analysis of variance	
	Friesian		Brahman X			Main Effects	Interactions
	Hay	Concentrate	Hay	Concentrate			
Hot	96.6 102.3	100.7 100.5	93.6 83.3	91.1 103.7	96.5 ± 2.4	Breed** Temp.***	Breed x Temp.NS Breed x Diet NS
Cool	40.6 39.9	58.2 47.0	25.8 20.5	32.4 44.6	38.6 ± 4.3	Diet *	Temp. x Diet NS B x T x D NS

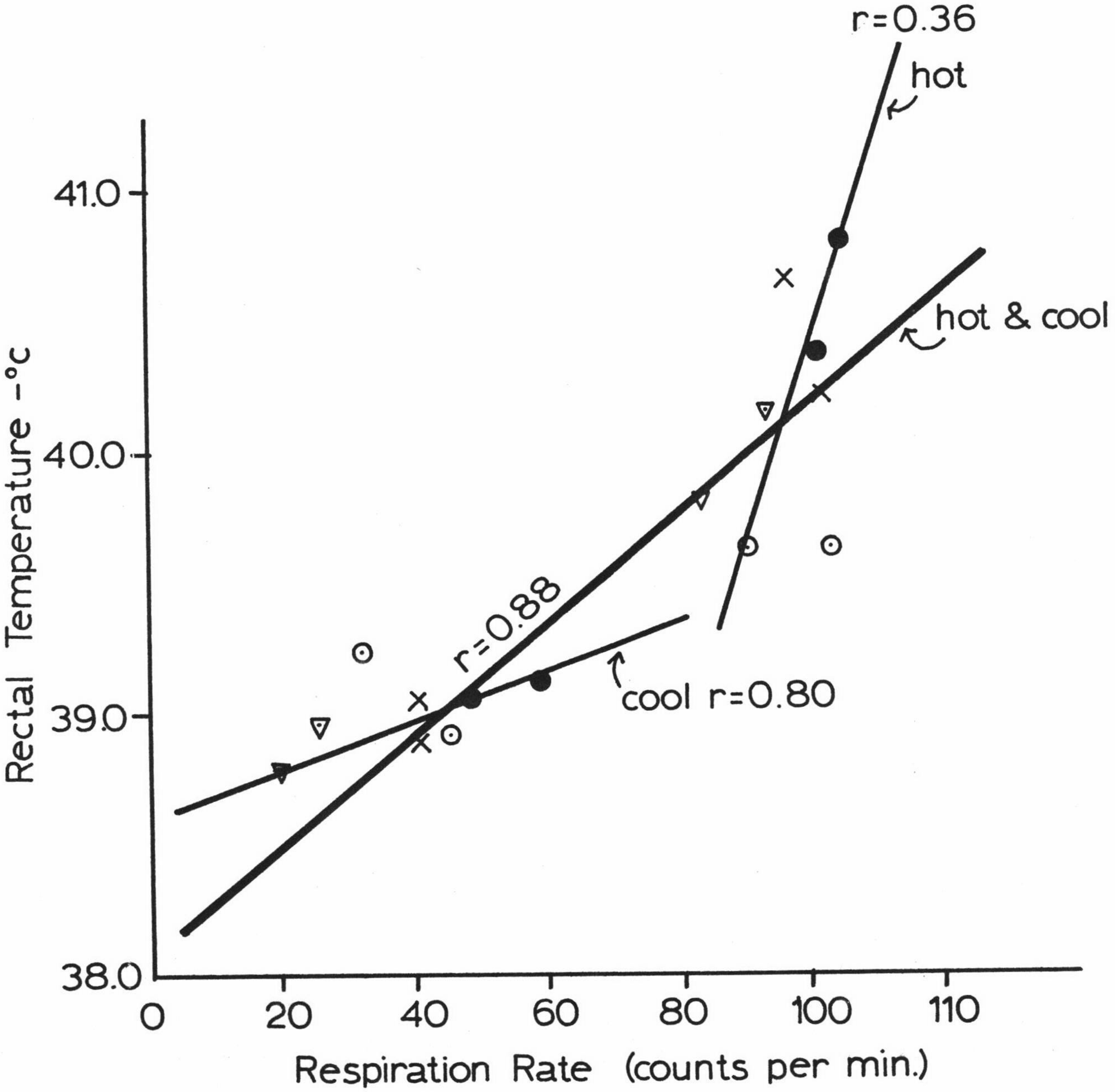
N.B. S.E.M. Standard Error of the Mean

*	$P<.05$
**	$P<.01$
***	$P<.005$
NS	Not significant

The complete analyses of variance tables can be found in Appendix I-b

Fig. 4.3 c Relationship between rectal temperature and respiration rate, trial I-a

breed diet	F	BX
concent- -rate	●	⊙
hay	×	▽



When the results of trial Ia were partitioned and analysed in three consecutive periods of 20, 15 and 20 days of observation, there were successive declines in the levels of significance for breed, temperature and breed x temperature effects with respect to rectal temperature; similar changes with time were noted for respiratory rate as well. In the third period breed x temperature effect had become non significant.

For respiratory rate the effect of breed was not significant in the second period, but was significant again in the third period. In this third period, breed and temperature effects were significant for both measurements, and the rest of the treatments were not significant. These changes in the levels of significance are illustrated in Figs. 4.3-a and 4.3-b. Individual mean values for rectal temperature and respiration rate are shown in Tables XI and XII respectively.

4.1.2.3: Relationship between rectal temperature and respiration rate

The correlations between rectal temperature and respiration rate are presented in Table XIII, a graph is also presented (Fig. 4.3-c). Both breeds show very high positive correlations, 0.89, 0.96 and 0.88 for Brahman X, Friesian, and all calves respectively. But when the correlations were calculated for calves within breed and temperature treatments, the relations were not significant. Individual breed groups on the hot treatment showed negative correlations while those on the cool treatment showed positive correlations. Pooled correlations within each temperature treatment group were positive, .36 and .80 for the hot and the cool treatment respectively, but only the cool treatment relationship was significant ($P<.05$).

Relationships within Breed x Temperature treatment groups were positive and only the Brahman X x Hay group failed to reach a significant level. Pooled correlations within diet treatment groups were significant; 0.959 ($P<.005$) and 0.799 ($P<.05$) for hay and concentrate diets respectively. There were no significant relationships within the Temperature x Diet treatment groups.

Fig. 4.3 a Mean values for Rectal Temperature during the three periods in Trial I-a °C

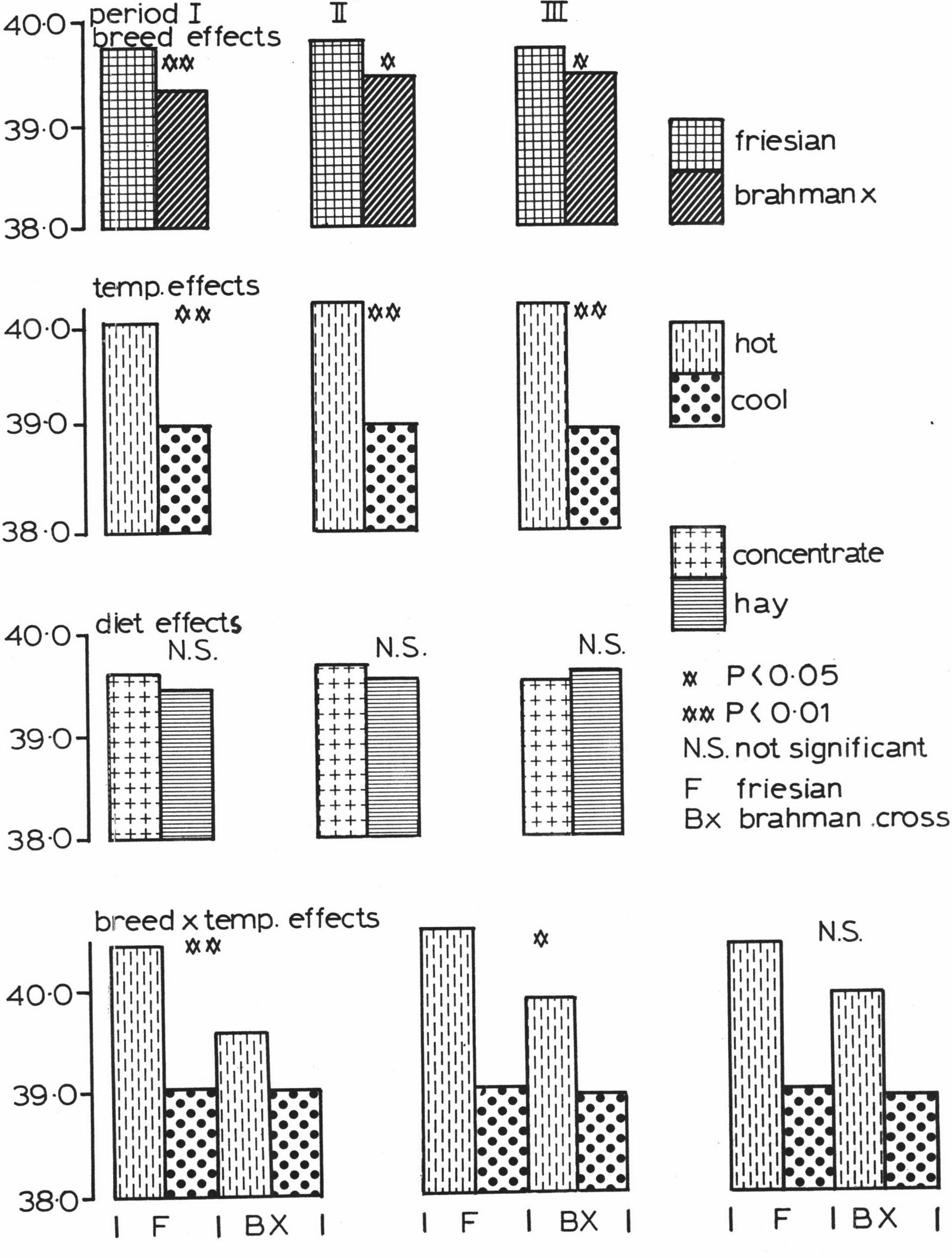


Table XI: Changes in rectal temperature and the effects of treatments over the three periods during trial Ia

	Breed, Diet and Period effects											
	Period I				Period II				Period III			
	Friesian		Brahman X		Friesian		Brahman X		Friesian		Brahman X	
	Hay	Concentrate	Hay	Concentrate	Hay	Concentrate	Hay	Concentrate	Hay	Concentrate	Hay	Concentrate
Hot	40.52	40.66	39.75	39.56	40.64	40.42	40.21	39.90	40.54	40.02	40.49	39.49
	40.07	40.64	39.46	39.64	40.25	41.01	39.86	39.58	40.33	40.80	40.07	39.67
Cool	38.93	39.17	39.05	39.17	38.78	39.23	38.95	39.36	38.96	39.01	38.86	39.19
	39.12	39.01	38.77	39.04	39.03	39.09	38.70	38.95	38.99	39.05	38.83	38.85
Overall mean and SEM	39.54 ± 0.2				39.62 ± 0.2				39.57 ± 0.2			
Significant effects	Breed ** Temperature ** Breed x Temperature **				Breed * Temperature ** Breed x Temperature *				Breed * Temperature ** Breed x Temperature NS			

* P<0.05
** P<0.01

Table of Analyses of Variance in Appendix I-b_1

Fig. 4.3-b Mean Values for Respiration rate during the three periods in trial I-a *Resipiration/Min.*

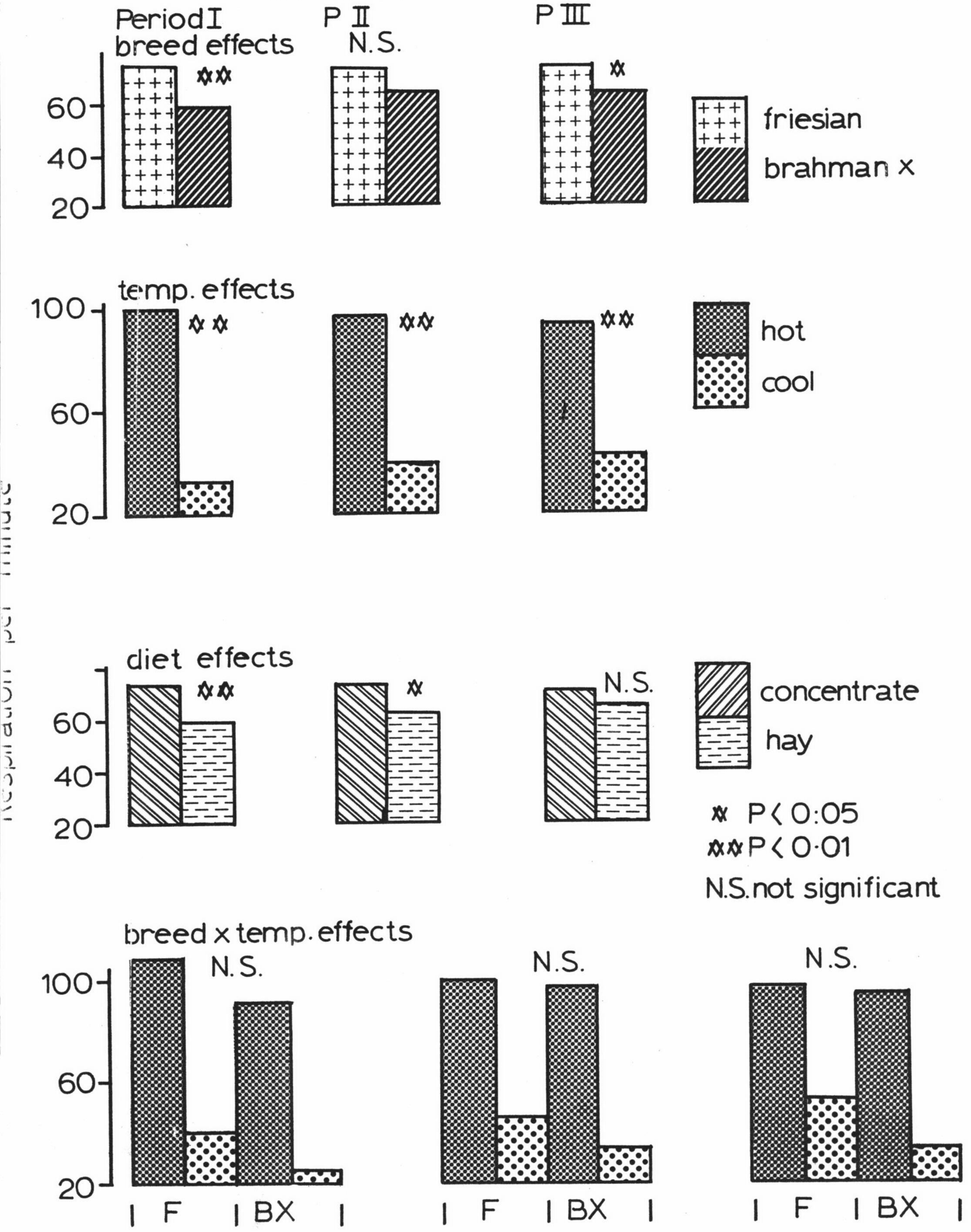


Table XII: Changes in respiratory frequency and the effects of treatments over the three periods during trial Ia

	Period, Breed and Diet											
	Period I				Period II				Period III			
	Friesian		Brahman X		Friesian		Brahman X		Friesian		Brahman X	
	Hay	Concentrate	Hay	Concentrate	Hay	Concentrate	Hay	Concentrate	Hay	Concentrate	Hay	Concentrate
Hot	108.2	114.8	90.1	95.9	95.1	95.1	93.3	96.2	86.8	90.9	97.2	86.9
	97.0	111.4	70.4	110.7	101.9	101.3	91.9	102.0	107.7	94.1	89.1	98.2
Cool	34.6	56.3	23.1	28.4	38.0	65.8	27.8	37.0	47.6	54.3	26.5	32.5
	33.2	37.6	16.6	35.0	37.2	42.0	18.3	47.7	47.6	58.0	24.4	50.3
Overall mean and SEM	66.5 ± 9.2				68.2 ± 7.9				68.3 ± 7.1			
Significant effects	Breed ** Temperature ** Diet **				Breed NS Temperature ** Diet *				Breed * Temperature ** Diet NS			

* P<0.05
** P<0.01

Table of Analyses of Variance in Appendix I-b_2

Fig. 4.4 Relationship between DMI and Rectal Temperature, Trial I-a

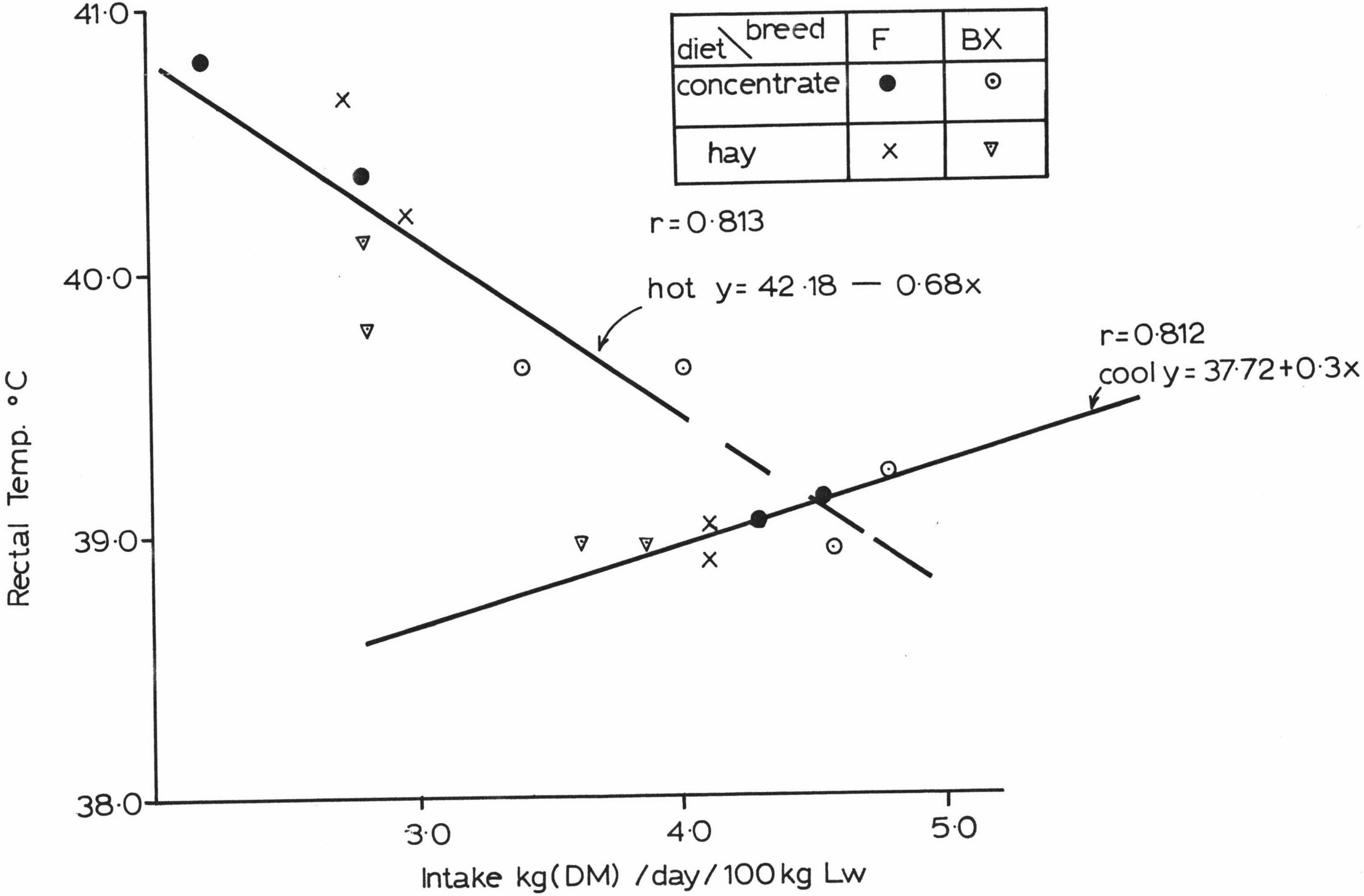


Table XIII: Correlation coefficients for the relationship between rectal temperature and respiration rate

Breed or Diet	d.f.	Temperature		Diet	
		Hot	Cool	Hay	Concentrate
Brahman X	2	-0.192	+0.360	+0.865	+0.993**
Friesian	2	-0.569	+0.739	+0.971*	+0.959*
Brahman X + Friesian	6	+0.36	+0.804*	+0.959***	+0.799
Concentrate	2	+0.315	-0.321		
Hay	2	+0.671	+0.676		
All Brahman X	6	+0.890**		* P<.05	
All Friesian	6	+0.959***		** P<.01	
All animals	14	+0.883***		*** P<.005	

4.1.2.4: Relationship between rectal temperature and food intake

The correlation coefficients and regression coefficients between rectal temperature and DMI are presented in Table XIV. The main effects are illustrated in Fig. 4.4. The correlations indicate that in the hot treatment rectal temperatures are negatively correlated to DMI whereas in the cool treatment these variables are positively correlated. All diet treatment groups except the cool-hay and cool-concentrate treatments show negative values. The pooled values for Friesian, Brahman X and all the experimental animals are negative.

4.1.2.5: Relationship between respiration rate and food intake

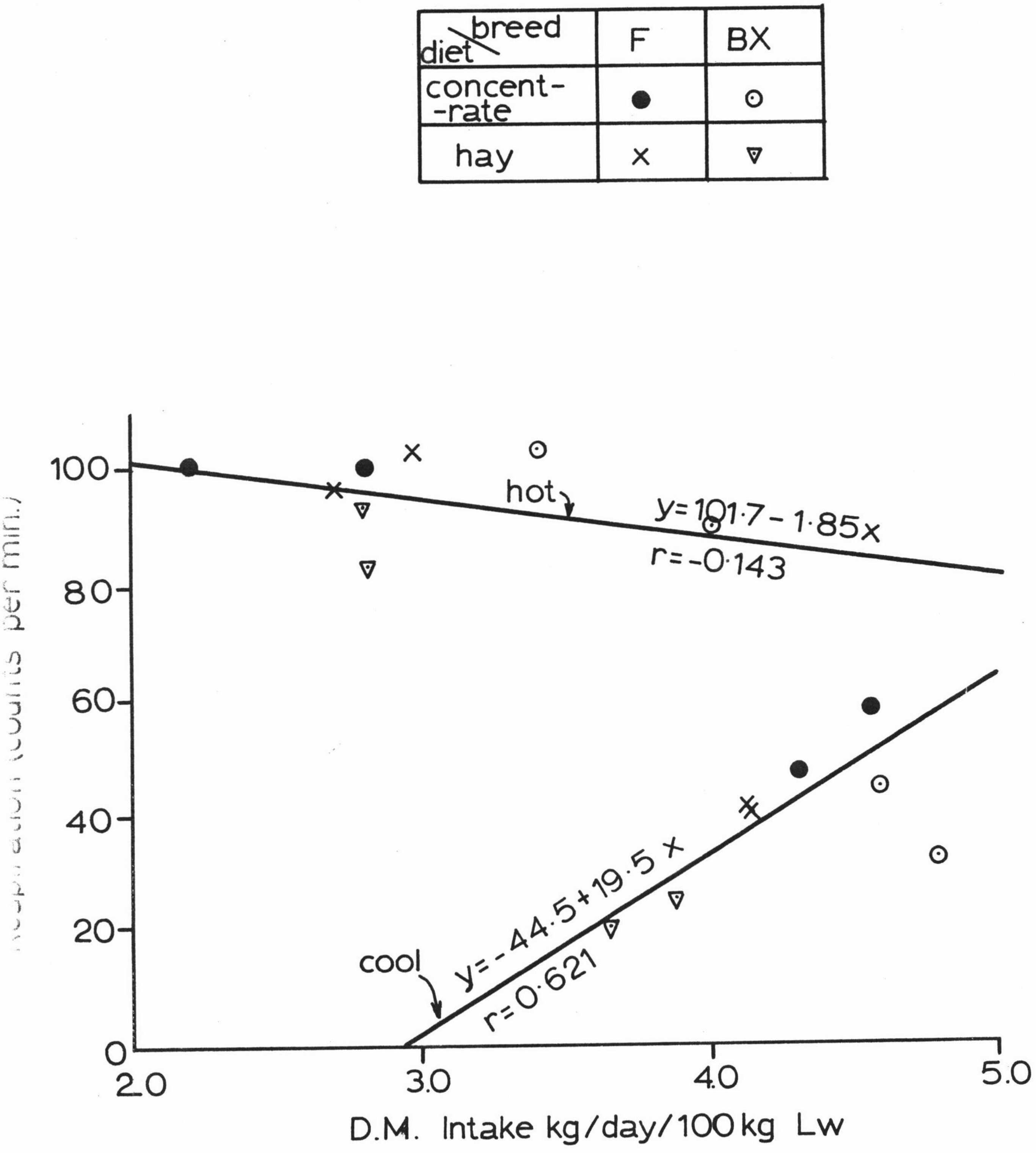
The correlation coefficient and regression coefficient values between respiration rate and DMI are given in Table XV. The relationships are illustrated in Fig. 4.5. Generally they show a similar pattern to that obtained between rectal temperature and DMI except that in the hot, breed groups and the hay diet group they show positive relationships betwee rectal temperatures and DMI. The cool contentrate group shows a negative relationship between respiration rate but a positive one between rectal temperature and DMI.

Table XIV: Correlation coefficient values between rectal temperature and DMI (kg/100 kg Lw) and the regression coefficient values

Treatment Group	d.f.	Correlation coefficient	Regression coefficient	
			DMI on T_R	T_R on DMI
Brahman X - Hot	2	-0.731 NS	-1.738***	-0.307 NS
Friesian - Hot	2	-0.880 NS	-1.091***	-0.707 NS
All animals - Hot	6	-0.813*	-0.972***	-0.684 NS
Brahman X - Cool	2	+0.826 NS	+2.391***	+0.285 NS
Friesian - Cool	2	+0.822 NS	+1,668*	+0.394 NS
All animals - Cool	6	+0.812*	+2.169***	+0.301 NS
Brahman X - Hay	2	-0.938 NS	-0.785***	-1.120 NS
Friesian - Hay	2	-0.994**	-0.844***	-1.171 NS
All animals - Hay	6	-0.897***	-0.753***	-1.067 NS
Brahman X - Conc.	2	-0.801 NS	-1.477***	-0.435 NS
Friesian - Conc.	2	-0.992**	-1.279***	-0.772 NS
All Animals - Conc.	6	-0.958*	-1.338***	-0.685 NS
Hot - Hay	2	-0.279 NS	-0.078***	-1.003 NS
Hot - Conc.	2	-0.948 NS	-1.257***	-0.706 NS
Cool - Hay	2	+0.789 NS	+1.630***	+0.380 NS
Cool - Conc.	2	+0.522 NS	+0.854***	+0.320 NS
All Friesians	6	-0.970***	-1.059***	-0.889 NS
All Brahman X	6	-0.655 NS	-0.986***	-0.435 NS
All animals	14	-0.801***	-0.883***	-0.727 NS

*	$P<0.05$
**	$P<0.01$
***	$P<0.005$
NS	Not significant
DMI	Dry Matter Intake
T_R	Rectal temperature °C
Lw	Liveweight (kg)

Fig. 4.5 Relationship between DMI and Respiration rate, Trial I-a



diet \ breed	F	BX
concent-rate	●	⊙
hay	×	▽

Table XV: Correlation coefficient and regression coefficient values between respiration rate and DMI (kg/100 kg Lw)

Treatment Group	d.f.	Correlation coefficient	Regression coefficient	
			DMI on RR	RR on DMI
Brahman X - Hot	2	+0.289 NS	+0.020*	+4.259 NS
Friesian - Hot	2	+0.127 NS	+0.017*	+0.924 NS
All animals - Hot	6	-0.143 NS	-0.011***	-1.848 NS
Brahman X - Cool	2	+0.791 NS	+0.042 NS	+14.894 NS
Friesian - Cool	2	+0.997**	+0.023 NS	+43.001***
All animals - Cool	6	+0.621 NS	+0.020 NS	+19.546 NS
Brahman X - Hay	2	-0.969*	-0.014 NS	-66.830*
Friesian - Hay	2	-0.981*	-0.021 NS	-45.809*
All animals - Hay	6	-0.878**	-0.016 NS	-49.327***
Brahman X - Conc.	2	-0.967*	-0.017 NS	-54.211*
Friesian - Conc.	2	-0.945 NS	-0.038 NS	-23.406 NS
All animals - Conc.	6	-0.856**	-0.027 NS	-27.198***
Hot - Hay	2	+0.491 NS	+0.006 NS	+39.793***
Hot - Conc.	2	-0.595 NS	+0.084***	-4.200*
Cool - Hay	2	+0.979*	+0.023 NS	+42.430***
Cool - Conc.	2	-0.576 NS	-0.011 NS	-30.360***
All Friesians	6	-0.910***	-0.028 NS	-30.080***
All Brahman X	6	-0.577 NS	-0.012*	-27.129***
All animals	14	-0.743**	-0.019*	-29.304***

* P<0.05
** P<0.01
*** P<0.005

NS Not significant
DMI Dry Matter Intake
RR Respiration Rate
Lw Liveweight (kg)

Table XVI-a: Correlation coefficient and regression coefficient values between rectal temperature and liveweight gain

Treatment group	d.f.	Correlation coefficient 'r'	Regression coefficient	
			T_R on Liveweight gain	Liveweight gain on T_R
Brahman X Hot	2	-0.766	-0.547	-1.073
Friesian Hot	2	-0.776	-1.290	-0.467
Brahman X Cool	2	+0.810	+0.485	+1.353
Friesian Cool	2	+0.826	+0.463	+1.475
Concentrate Hot	2	-0.924	-1.570	-0.544
Concentrate Cool	2	-0.048	-0.003	-0.034
Hay Hot	2	-0.772	-2.988	-0.199
Hay Cool	2	+0.730	+1.176	+0.453
All animals Hot	6	-0.760 *	-1.187	-0.486
All animals Cool	6	+0.696	+0.403	+1.205
Friesians (all)	6	-0.869 **	-2.364	-0.320
Brahmans (all)	6	-0.497	-0.683	-0.362

Table XVI-b: Correlation coefficient and regression coefficient values between respiration rate and liveweight gain

Treatment group	d.f.	Correlation coefficient 'r'	Regression coefficient	
			RR on Liveweight gain	Liveweight gain on RR
Brahman X Hot	2	+0.321 NS	+8.014	+0.013
Friesian Hot	2	+0.625 NS	+9.373	+0.042
Brahman X Cool	2	+0.834 NS	+26.90	+0.025
Friesian Cool	2	+0.996 **	+48.48	+0.020
Concentrate Hot	2	-0.632 NS	-10.176	-0.039
Concentrate Cool	2	-0.094 NS	-31.610	-0.009
Hay Hot	2	-0.022 NS	-4.240	-0.001
Hay Cool	2	+0.249 NS	+36.048	+0.002
All animals Hot	6	-0.033 NS	-0.784	-0.001
All animals Cool	6	+0.395 NS	+19.306	+0.008
Friesians (all)	6	+0.161 NS	+30.526	+0.001
Brahman X (all)	6	+0.366 NS	-35.580	-0.004

* $P<0.05$
** $P<0.01$
*** $P<0.005$

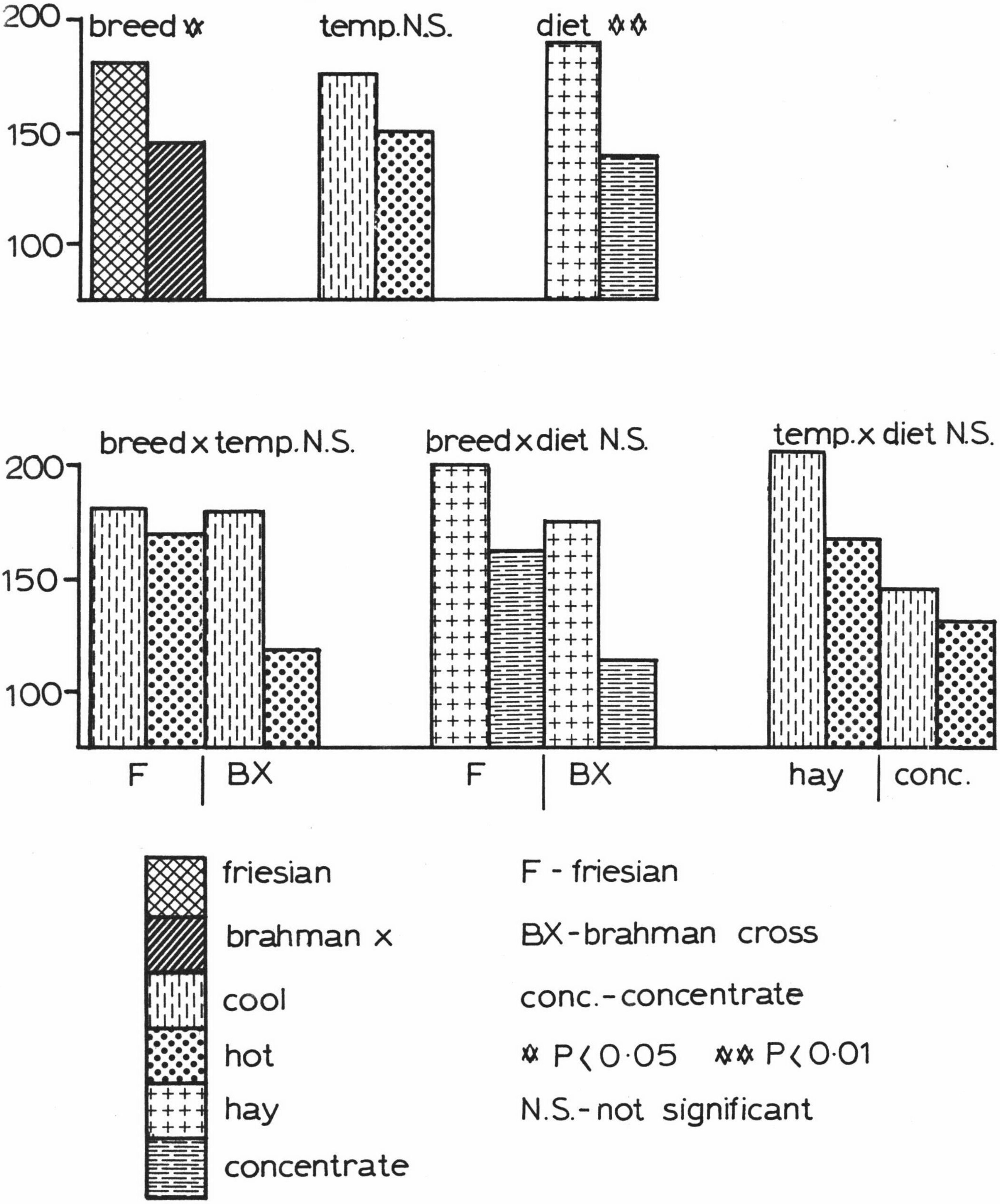


Fig. 4.6 Hair coat cover (g/m ^{2}) showing significant effects

4.1.2.6: Relationship between rectal temperature and liveweight gain

Table XVI-a gives the coefficients of correlation and regression between rectal temperature and liveweight gain during trial Ia. All hot treatment groups show negative values. Significant relationships were obtained between measurements for all the animals in the hot treatment, $r = -0.760$ ($P<.05$) and between measurements for all the Friesians, $r = -0.869$ ($P<.01$).

4.1.2.7: Relationship between respiration rate and liveweight gain

The correlation coefficient and regression coefficient values between respiration rate and liveweight gain for trial Ia are given in Table XVI-b. All cool treatment groups except the cool contentrate group had positive values. Individual breed groups in the hot treatment had positive values. The value for the Friesians in the cool, $r = 0.996$ was significant ($P<0.01$).

4.1.2.8: Hair coat cover

The weight of the hair coat cover for individual calves is given in Table XVII. Generally calves on the hot treatment had lighter hair coats than those on the cool treatment, but this difference although substantial, was not significant. Hay fed calves had significantly heavier coats ($P<.01$) than concentrate fed calves. Brahman X calves wore significantly lighter coats ($P<.05$) than Friesian calves. Fig. 4.6 illustrates these relationships. In the hot treatment rectal temperature was positively correlated with coat weight, $r = +0.868$ ($P<0.01$), whereas in the cool treatment rectal temperature was negatively correlated with coat weight, $r = -0.794$ ($P<0.05$).

Fig. 4.7 24 hr Ambient Temperature and Rectal Temperature

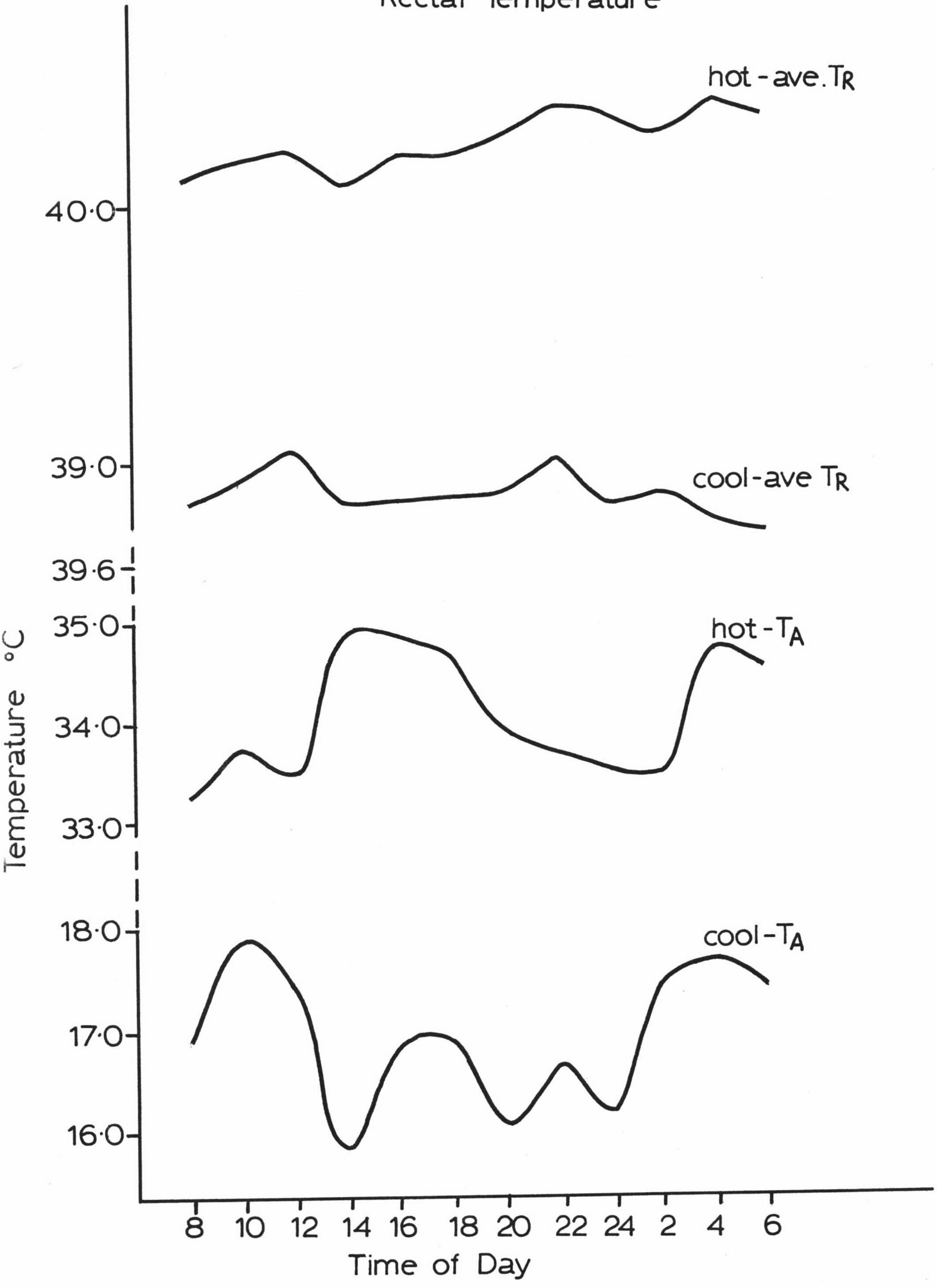


Table XVII: †Individual hair coat weight (g/m^2)at the end of trial Ia

Temperature	Breed and Diet				Mean and pooled SEM	Significant effects
	Friesian		Brahman X			
	Hay	Concentrate	Hay	Concentrate		
Hot	221	162	171	110	149.6±16.1	Breed*
	172	170	111	80		Diet**
Cool	210	167	237	134	176.8±13.1	
	197	155	183	131		

† A table of analysis of variance for hair coat weight is presented in Appendix I-d

* P<.05

** P<.01

4.1.2.9: 24-hour measurements

The variation in ambient temperature and rectal temperature over a 24-hour-period are presented in Fig. 4.7. The average measurements recorded at intervals of 2 hours over the 24-hour-period together with the average for the 8.00 a.m. and 2.00 p.m. measurements are presented in Appendix I-c. The relationship between these two indicates a very close association, r = 0.98 (P<.005) (see Fig. 4.8). This suggests that the average of the two (8.00 a.m. and 2.00 p.m.) measurements used in this experiment provided an accurate estimate of the animals' average body temperature over the 24 hours of a day.

4.1.3: Trial I-b Effect of clipping on respiration rate and rectal temperature changes

The environmental conditions and the individual average rectal temperatures are presented in Table XVIII. There were no appreciable environmental differences between periods A and B.

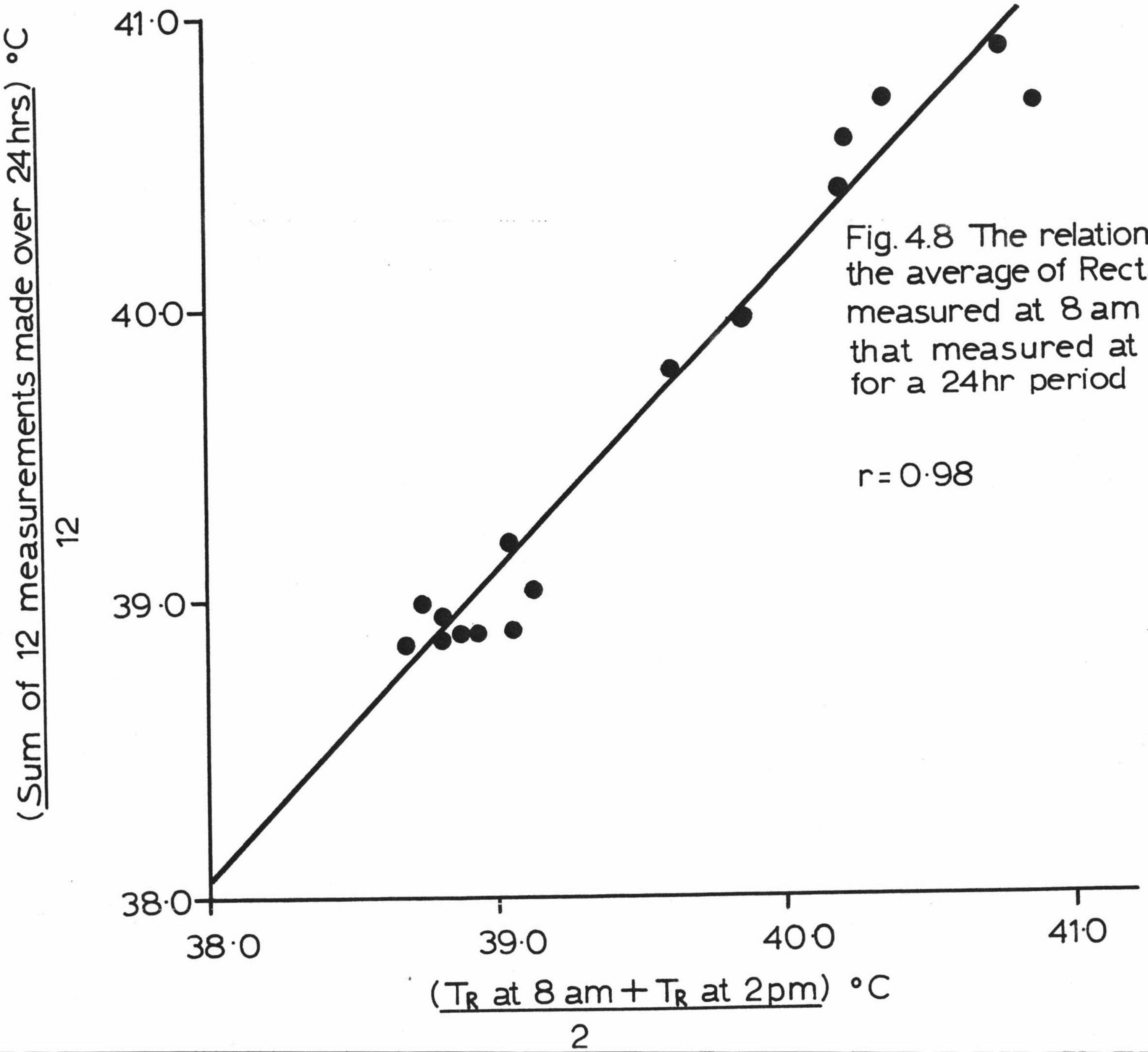


Fig. 4.8 The relationship between the average of Rectal Temperatures measured at 8 am and 2 pm and that measured at 2 hour intervals for a 24hr period

Table XVIII-a: Individual rectal temperature and room environment values during the clipping trial

Treatment		Period		Difference (A-B)
		A	B	
Mean ambient temperature, °C		34.3 ± 0.3	34.3 ± 0.2	
Mean globe temperature, °C		35.8 ± 0.2	35.7 ± 0.1	
Mean relative humidity, %		42.4 ± 1.3	44.3 ± 0.4	
Unclipped	Friesian	39.72	40.04	-0.32
		40.30	40.58	-0.28
	Brahman X	39.07	39.41	-0.34
		40.23	40.25	-0.02
Clipped	Friesian *	40.22	40.55	-0.33
		40.68	40.63	+0.05
	Brahman X *	40.36	40.25	+0.11
		39.59	40.09	-0.50

Table XVIII-b: Individual breathing frequency during the clipping trial

Treatment		Period		Difference (A-B)
		A	B	
Unclipped	Friesian	83.3	89.1	-5.8
		103.1	103.9	-0.8
	Brahman X	69.6	80.4	-10.8
		84.3	87.5	-3.2
Clipped	Friesian *	81.0	89.1	-8.1
		87.0	81.6	+5.4
	Brahman X *	88.0	84.4	+3.6
		86.8	98.0	-11.8

* These calves had been clipped before period B

All the unclipped calves had higher rectal temperatures in period B than in period A. Of the clipped calves, one Brahman X and one Friesian had lower rectal temperatures after clipping, whereas the other two calves had higher rectal temperatures after clipping.

Similar results were obtained for respiratory rate. The clipped calves which had lower rectal temperatures in period B showed a corresponding decrease in respiration rate.

Analyses of variance showed no significant effect of clipping; breed and interactions between breed and clipping were not significant either, Tables XIX-a and XIX-b. The respective analyses of variance tables can be found in Appendix I-e.

Table XIX-a: Rectal temperature differences between periods A and B, °C

Treatment	Brahman X	Friesian	Means ± SEM	Significant effects
Unclipped	-0.34 -0.02	-0.32 -0.28	-0.24 ± .07	Breed NS Clipping NS
Clipped*	+0.11 -0.50	-0.33 +0.05	-0.17 ± .15	Breed x Clipping NS

* Clipping was done before period B

Table XIX-b: Respiration rate differences between periods A and B, count per minute

Treatment	Brahman X	Friesian	Means ± SEM	Significant effects
Unclipped	-10.8 -3.2	-5.8 -0.8	-5.2 ± 2.1	Breed NS Clipping NS
Clipped	+3.6 -11.8	-8.1 +5.4	-2.7 ± 4.3	Breed x Clipping NS

4.2: Radiation trial

4.2.1: Environmental conditions

Mean values for ambient temperature, globe temperature and relative humidity are presented in Table XX below.

Table XX: Mean ambient temperature, mean globe temperature and mean relative humidity values for the radiation trial

Measurement *	AM - without radiation	PM - with radiation
Mean ambient temperature, °C	30.5 ± 0.5	32.4 ± 0.4
Mean globe temperature, °C	31.2 ± 0.2	46.6 ± 0.3
Mean relative humidity, %	51.4 ± 0.7	50.0 ± 0.6

* ± Standard Error of the Mean (SEM)

4.2.2: Incident radiant heat load

The average incident radiant heat fluxes in the pens measured at 0.5 m and 1.2 m above the floor are given in Table XXI. The average total incident radiant heat load measured at the calves' withers (1.2 m) was 977 kcal/m^2 hr. Shortwave radiation (SWR) accounted for more than 93% of the total flux.

Table XXI: *Incident radiant fluxes in radiation pens, kcal/m^2 hr

Radiant flux	Height measured		Difference
	1.2 m	0.5 m	1.2 m - 0.5 m
Total (SWR + LWR)	977	819	158
SWR	917	768	149
LWR †	60	51	9

* For measurement methods see section 3.1.3.9

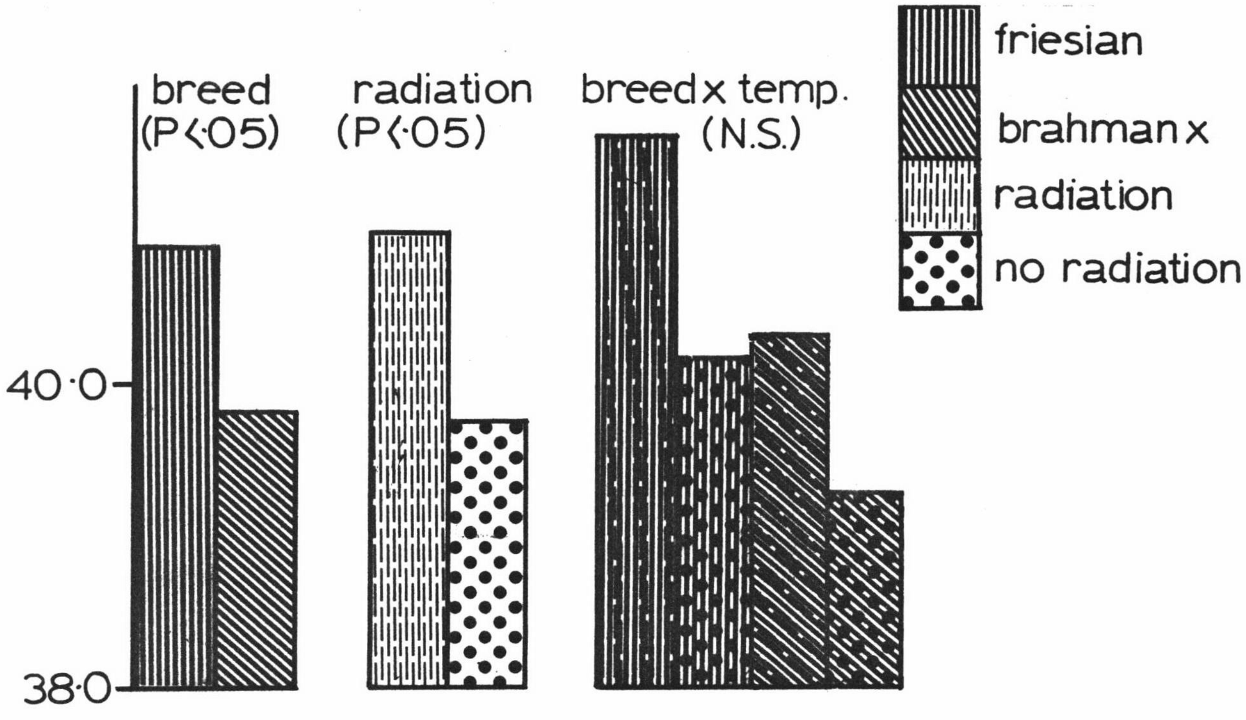
† By difference

4.2.3: Net radiant heat load

The measured net radiant energy on two calves is presented in Table XXII.

Fig. 4.9 Effect of Radiation during the day on:-

A-Rectal Temperature °C at 4pm



B-Respiration Rate at 4pm

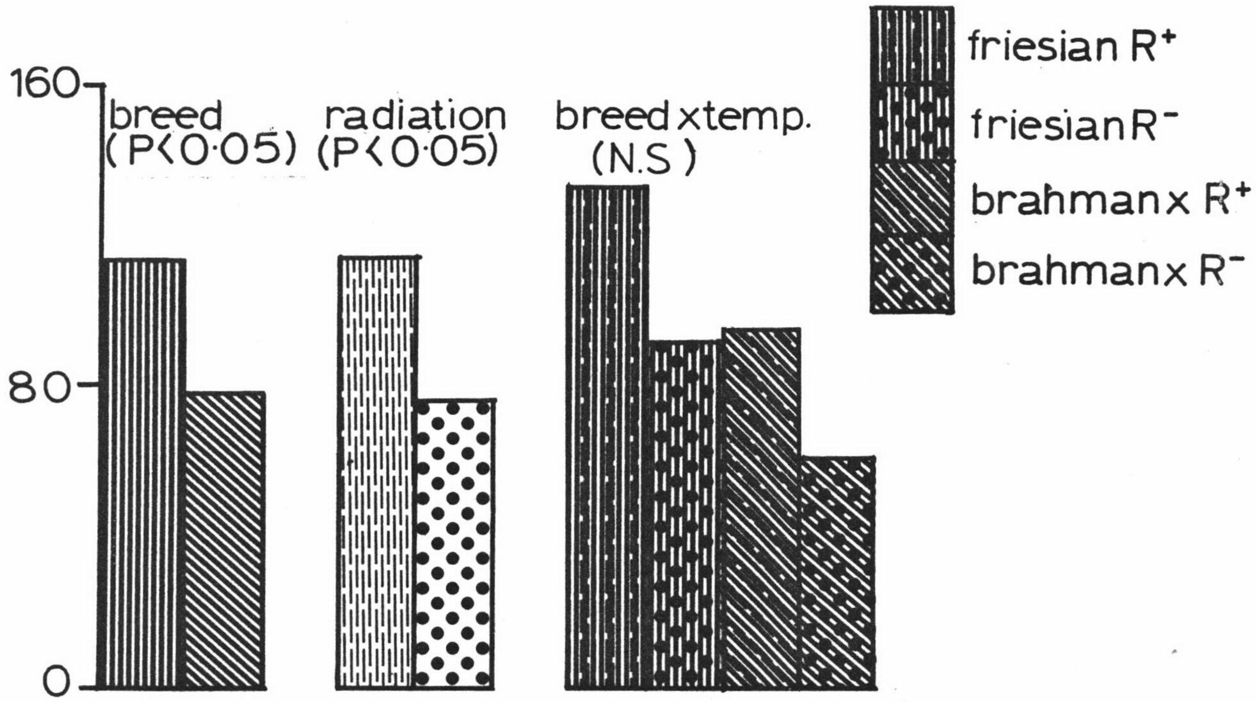


Table XXII: Average net radiant exchange at calves' coat, kcal/m^2 hr

Measurement site *	Breed	
	Brahman X	Friesian
Spine	333	383
Upper right flank	164	231
Upper left flank	266	225
Lower right flank	-42	25
Lower left flank	40	-7
Belly	-37	-25
Total	725	832
Mean value	121	139
†Total calfs' skin area (m^2)	2.74	2.32
Total net radiant energy per animal kcal/hr	332	322

* See Fig. 3.1.4

† Body surface area was estimated according to Brody 1945; SA = 0.097 x Lw(kg)$^{.633}$

4.2.4: Effect of radiant heat load on rectal temperature and respiration rate

The artificial radiation had the effect of increasing the ambient temperature by 2°C and the black globe temperature by 15°C. This rise in environmental heat load caused increases in rectal temperature and respiration rate of the exposed animals. Rectal temperature values and respiration rate values are presented in Tables XXIII-a and XXIII-b respectively.

Table XXIII-a: Mean values for rectal temperature °C for the radiation trial

	PERIOD WITH RADIATION (8 hrs during daytime)			PERIOD WITHOUT RADIATION		
Calf Pairs	AM	PM	(ΔR) PM-AM	AM	PM	PM-AM
F2*	40.59	42.13	1.54	-	-	-
B1	40.24	41.46	1.22	39.76	39.44	-0.32
F7	40.09	41.33	1.24	40.46	40.14	-0.32
B5	38.72	39.41	0.69	38.98	39.08	+0.10
Ave	39.91	41.08	1.17	39.73	39.55	-0.18
F6	39.79	41.56	1.77	40.02	40.07	+0.05
B7	38.81	40.11	1.30	38.74	38.80	+0.06
B8+	39.32	40.71	1.39	39.04	39.16	+0.12
Ave	39.31	40.79	1.48	39.26	39.34	+0.08
Pooled Ave	39.65	40.96	1.31	39.50	39.45	-0.05

Table XXIII-b: Mean values for respiration rate for the radiation trial (counts per minute)

	PERIOD WITH RADIATION (8 hrs during daytime)			PERIOD WITHOUT RADIATION		
Calf Pairs	AM	PM	(ΔR) PM-AM	AM	PM	PM-AM
F2*	104.8	151.8	47.0	-	-	-
B1	89.3	132.2	42.9	68.0	58.6	-9.4
F7	90.0	120.9	30.9	92.3	78.6	-13.7
B5	44.9	65.9	21.0	50.5	55.2	+4.7
Ave	82.3	117.7	35.5	70.3	64.1	-6.1
F6	79.8	126.9	47.1	86.4	82.6	-3.8
B7	50.0	83.2	33.2	42.7	41.3	-1.4
B8+	71.7	109.8	38.1	59.9	58.3	-1.6
Ave	67.2	106.6	39.5	63.0	60.7	-2.3
Pooled Ave	75.8	113.0	37.2	66.7	62.4	-4.3

* F2 died after 10 days of radiant heat exposure

\+ B8 was not paired as F1 was too weak and was consequently excluded from the radiation trial

ΔR Effect of radiation (afternoon R^+ - morning R^- measurements) during radiation period

Table XXIII-c: Breed influence on radiant heat load

Pairing	ΔR - Rectal temperature		ΔR - Respiration rate	
	Friesian	Brahman X	Friesian	Brahman X
F2, B1	1.54	1.22	47.0	42.9
F7, B5	1.24	0.69	30.9	21.0
F6, B7	1.77	1.30	47.1	33.2
Ave	1.52	1.07	41.7	32.4

During the non-radiant heat exposure period there were small variations between morning and afternoon measurements for both rectal temperature and respiration rate (Tables XXIII-a and XXIII-b). The pooled average morning meausrements were slightly higher than the afternoon averages but did not approach significant levels. However, during the radiation period, the afternoon measurements were significantly higher ($P<0.05$) than the morning measurements.

Brahman X calves were significantly less affected ($P<0.05$) by radiation than Friesian calves (Table XXII-c). These effects are illustrated in Fig. 4.9-a and 4.9-b. The analyses of variance are included in Appendix II-a.

4.2.5: Sweating rates of calves under radiant heat load

The mean sweating rate of the calves under radiant heat are given in Table XIV. A 't' test showed that Brahman crosses had faster sweating rates than Friesians ($P<0.001$) and had lower rectal temperatures.

Table XXIV: Individual mean sweat rate values (g/m^2 hr) measured simultaneously for each pair, values for rectal temperature in brackets

		Breed		
Pair No.	No. of measurements*	Brahman X	Friesian	Bx-F
1	6	170.33 (39.06)	92.00 (41.15)	78.33
2	8	137.0 (39.38)	28.00 (40.99)	109.00
Average		157.67 (39.22)	60.00 (41.07)	93.67

* Individual measurements and 't' test in Appendix II-b.
Sweat rate measured simultaneously on both sides of rump in each individual measurement.

CHAPTER FIVE

DISCUSSION

CHAPTER FIVE

DISCUSSION

5.1: Trial I-a

5.1.1.: Main effects

5.1.1.1: Effect of ambient temperature on rectal temperature and respiration rate

The results presented in Tables VII, IX and X show that when ambient temperature rose from 17° to 34.5°C, the calves respiration rate and rectal temperature increased by 58 counts per minute and 1.15°C respectively on average. These observations support previous findings by:

Author	Air temperature treatments °C		Change in T_R	Change in R_R
	Low	High		
Olbrich *et al.* (1972)	10	31	+ 0.75	+ 31
Colditz and Kellaway (1972)	17	38	+ 0.90	+ 42
Olbrich, Martz and Hilderbrand (1973)	18	31	+ 0.57	+ 40
Kellaway and Colditz (1975)	20	38	+ 1.3	+ 58

Similar rises in rectal temperature (Vercoe and Frisch, 1970) and in respiration rate (Yassen, 1977) have also been observed in cattle exposed to high air temperatures.

These increases in rectal temperature and respiration rate occurred despite significant ($P<0.01$) decreases in DMI at the high temperature treatment (King, 1978). This indicates the calves were in a state of heat stress and their thermoregulatory mechanisms had responded accordingly; via a reduced voluntary food intake, and raised respiration rate, increasing ventilation rate and in turn respiratory evaporative cooling (McLean, 1963c). Further, the negative relationship between rectal temperature and respiration rate in the heat (Table XIII) suggests that an increase in respiration rate has the effect of decreasing the rectal temperature. The thermoregulatory significance of respiratory ventilation is increased at the high temperatures. This is in agreement with McLean's (1963c) and McLean and Calvert's (1972) observation that at high temperatures non-evaporative heat loss is severely curtailed and evaporative cooling becomes the only heat loss channel through which effective physiological regulation of body temperature can be maintained. Panting was described as a normal means of temperature regulation where a decrease in the depth of breathing enables an animal to increase the rate of ventilation without hyperventilation of the alveoli. However, Hales (1974) has observed that during severe heat stress of cattle 7-25% of the total oxygen consumption is attributed to the energy cost of panting. This suggests that panting could become a metabolic cost.

The pooled correlation coefficient values between rectal temperature and DMI (Table XIV), respiration rate and DMI (Table XV); liveweight gain and rectal temperature (Table XVI-a); and between liveweight gain and respiration rate (Table XVI-b) and their corresponding regression coefficient values were positive in the cool, but negative in the hot treatment. Thus the regression coefficients may be interpreted to suggest that in the cool treatment rectal temperature and respiration rates increased as a result of increased food intake and liveweight gain whereas in the heat food intake and liveweight gain decreased because of increased rectal temperatures and respiration rates. The regression equation presented below illustrates these relationships.

Regression of DMI on rectal temperature

(a) Hot treatment; $Y = 42.18 - 0.68\ X$;
or 1 kg DMI $\equiv -0.68^{\circ}C$;
or an increase of $1^{\circ}C$ in rectal temperature
$\equiv$ a decrease of 1.47 kg DMI.

(b) Cool treatment; $Y = 37.72 + 0.3\ X$
or an increase of 1 kg DMI
$\equiv 0.3^{\circ}C$ increase in rectal temperature.

N.B. Y is rectal temperature
X is DMI (kg)

5.1.1.2: Breed effects

The results presented in Tables IX and X show that the two genotypes differ significantly in rectal temperature ($P<0.05$) and respiration rate ($P<0.01$) and that despite a higher mean DMI, the Brahman X calves were able to maintain a lower rectal temperature and lower respiration rate than the Friesians. Tables IX and X show that these differences are larger at the higher environmental temperature and that differences at the cooler temperature are associated with food intake (King, 1978). These effects are further discussed under breed x temperature interactions.

5.1.1.3: Diet effects

Calves on the concentrate diet ate more DM than those on the hay diet (King, 1978) and respiration rate was significantly ($P<0.05$) higher for calves fed the concentrate diet than calves fed the hay diet (Table X). However, the corresponding difference in rectal temperature was small and not significant. The regression coefficients presented in Tables XIV and XV show that the concentrate diet caused smaller increases in rectal temperature and respiration rate than the hay diet. These relationships are examined under breed x diet interactions.

5.1.2: Interactions

5.1.2.1: Breed x temperature interactions

A significant ($P<0.05$) interaction was noted (Table IX) between the effects of breed and temperature on rectal temperature measurements. The corresponding interaction for respiration rate was not significant. At the high temperature the rectal temperature of the Friesian calves was increased significantly ($P<0.05$) more than that of the Brahman X calves, 1.47 and 0.83^{o}C respectively. Respiration rate increases were not significantly different between breeds although the Brahman X calves did register a greater increase + 62 counts per minute, compared with + 54 counts for the Friesians. Nevertheless, the Friesian calves still maintained higher respiration rate counts than the Brahman X calves. Thus despite a lower voluntary DMI (King, 1978) and a higher respiratory rate, the Friesians exhibited higher rectal temperatures than the Brahman X calves. It would therefore seem probable that despite a lower metabolic heat load the Friesians were stressed to a greater degree than the Brahman X calves. This suggests that the heat dissipation mechanisms of the Friesians, in particular cutaneous evaporation, are less effective than those of the Brahman X.

This proposal is supported by the measurements of sweating rate presented in Table XXIV which indicate that the rates of cutaneous evaporation from the Brahman X calves were much higher ($P<0.001$) than the Friesians. Previous investigations (Dowling, 1958) showed that thermoregulatory differences between strains are ascribable to differences in sweating. Schleger and Turner (1965) have indicated that at high levels of thermal stress, high sweating capacity was associated with low body temperatures.

These findings are in support of previous reported findings by Vercoe and Frisch (1970) who observed that the ambient temperature at which rectal temperatures were increased by 1.3°C was 35°C for British cross steers and 43°C for Brahman X steers; and Kellaway and Colditz (1975) who observed that under stressful conditions, 30 and 38°C ambient temperatures, respiration rates and rectal temperatures of Friesians were higher than those for Brahman x Friesian (F_1) heifers.

The findings of this experiment indicate that the most important difference between the genotypes in heat tolerance is due to their different capabilities to discharge moisture on to the skin surface for evaporative cooling. Thus despite their higher DMI in the heat, the Brahman X steers were able to maintain significantly lower body temperatures than the Friesians. However, the possibility of the F_1 calves having a lower rate of heat production could not be discounted.

5.1.2.2: Temperature x diet interactions

The results presented in Tables IX and X have shown no significant diet x environmental temperature interactions. However, at the high air temperature the hay fed group had relatively higher rectal temperature (40.20°C) but lower respiration rate (94 counts per minute) when compared with the concentrate fed group (40.11°C and 99 counts per minute respectively). These differences occurred despite a higher DMI by the concentrate fed group. In the cool treatment, the concentrate fed calves ate more DM and had higher rectal temperature (39.09°C) and higher respiration rate (45.5) than the hay fed calves (38.92°C and 31.7 counts per minute). However, using the regression coefficients presented in Table XII, the heat increment coefficient calculated from increases in rectal temperature were higher for the hay diet than for the concentrate diet at both temperatures.

Table XXV: Effect of diet and ambient temperature on heat increment coefficients (ΔT_R); T_R °C per kg DMI

Diet	Increase in Rectal Temperature (ΔT_R)	
	Cool Treatment	Hot Treatment
Concentrate	0.32	0.71
Hay	0.38	1.00

The differences in the rectal temperature increases (ΔT_R) between the hot and the cool treatment groups are probably due to differences in environmental heat stress. In the cool a larger percentage of total heat loss is essentially lost through non-evaporative channels, whereas in the hot environment evaporative cooling becomes the most important single channel of heat loss (McLean, 1963c). This is because in the cool the physical demand of the environment determines the rate of heat loss and thus heat production, while in the hot environment heat loss is controlled by the animal's physiological responses and the physical properties of the environment in relation to evaporation.

Thus in the cool treatment (17°C) a rapid heat flow to the environment was responsible for higher DMI and lower rectal temperature, while in the hot condition (34.5°C) physiological responses (in particular evaporative cooling) failed to keep pace with the decreased rate of sensible heat loss, so that despite a lowered DMI, it resulted in higher rectal temperature. Heat storage only occurred when rectal temperature increased initially. The calculated increases in rectal temperature are probably related to the true heat increment values of the diets; according to Webster (1976) the increment resulting from a fixed amount of food is inversely related to the digestibility or the nutritive value of the food. Since the digestibility of the concentrate diet was higher than that of the hay (King, 1978) it is likely that the heat increment of the hay diet was in fact higher than that of the concentrate diet.

5.1.2.3: Breed x diet interactions

There were no significant breed x diet interactions (Tables IX and X), but the difference between the concentrate and hay fed groups in respiration rate was greater for the Brahman F_1 than for the Friesian calves at both temperatures. The corresponding difference in rectal temperature was greater for the Brahman X calves in the cool environment only. In the hot environment, concentrate fed Brahman X calves had lower rectal temperature than the hay fed calves while concentrate fed Friesians had higher rectal temperature than the hay fed calves.

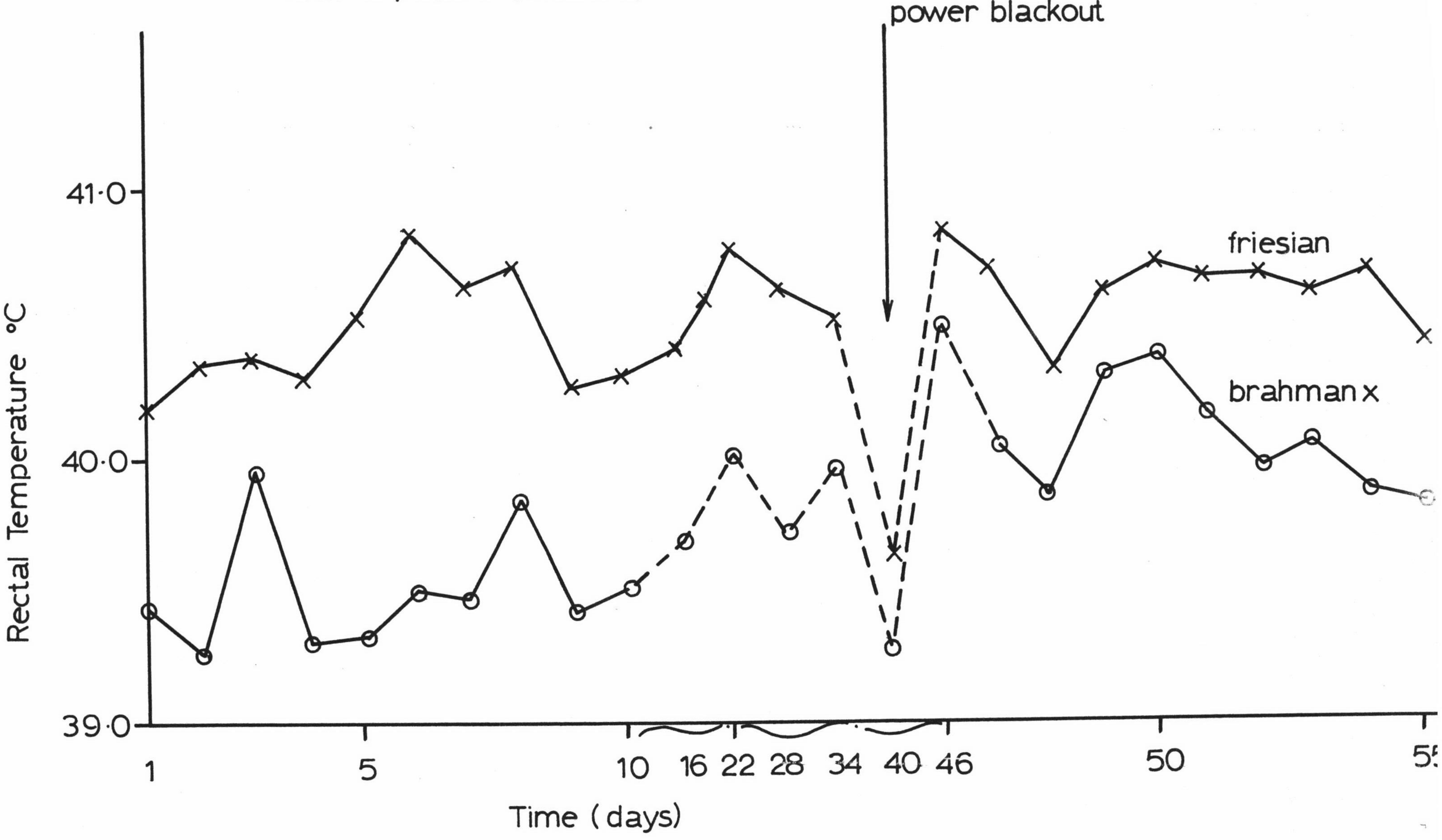
5.1.3: Effect of prolonged heat exposure

Fig. 4.1 indicates that the hot room temperature fluctuated from 32.7^{o} to $36.1^{o}C$ and was highest during the second period. The mean ambient temperatures for the three consecutive periods were 34.1, 35.4 and $34.1^{o}C$ respectively; the corresponding rectal temperatures and respiration rates are given in Tables XI and XII and are illustrated in Figs. 4.3a and 4.3b. Mean rectal temperatures for the Friesian steers rose to a peak in the second period after which they tended to decrease. The small drop in the third period was probably due to the overnight power cut which caused a substantial drop in ambient room temperature on one day. At the same time the Friesian mean respiration rate was highest during the first period then dropped steadily to its lowest level in the third period.

This suggests that the Friesians depended heavily on respiratory evaporative heat loss in the early stages of heat exposure, and that this dependance diminished with prolonged exposure. This decline in respiratory rate indicates that either the calves were adjusting to a more comfortable level of feeding or their cutaneous evaporative cooling was increasing or both. This process is fundamentally one of acclimatization.

On the other hand, the Brahman X calves showed a steady rise in rectal temperature over the three periods while their mean respiration rate rose to a maximum in the second period and fell slightly in the third period. It is possible that the cutaneous evaporative moisture loss was still rising in the third period because an increase in rectal temperature was coincidental to a fall in respiration rate.

Fig 5·0 Mean daily Rectal Temperatures showing the effect of prolonged heat exposure (Trial I-a)



Also the Brahman X allowed a rise in their body temperature despite increased food intake compared with the Friesians which indicated that they were still fairly comfortable.

These changes tended to reduce the differences between the two breeds in rectal temperature (Fig. 5.0) and respiration rate as time progressed which gave rise to the declining levels of significance between the breeds, breed x temperature interactions and diet effects (Figs. 4.3a and 4.3b). Respiration rate measurements were not significantly different between breeds in the second period but became significant again in the third period mainly because of a substantial breed difference in the cool treatment.

5.1.4: Measurement of heat stress

It has been shown that in the heat, both rectal temperature and respiration rate were elevated, but the effect on rectal temperature was less significant ($P<0.01$) than on respiration rate ($P<0.005$). In the heat the two measurements were negatively correlated. Low rectal temperatures were associated with high respiration rates suggesting that rectal temperature was probably influenced by respiration rate; that increased ventilation rate meant greater respiratory evaporative heat loss which caused rectal temperature to be controlled at a lower level. But the correlation coefficients have very low values which indicates that this influence varies widely between individuals.

Rectal temperature measurements show a larger variation in the heat than in the cool, while respiration rate measurements show a smaller variation in the heat than in the cool treatment; this is indicated by the standard error of the mean (SEM) in Tables IX and X respectively. However, larger variations in both rectal temperature and respiration rate were expected in the stressful (hot) condition because differences in physiological reactions and functions are best expressed in stressful conditions. In this experiment an even wider variation was expected because of the different genotypes involved.

However, while the mean rectal temperature for the Brahman X increased by 0.83°C, respiration rate increased by 62 counts per minute in the hot treatment; the corresponding rises for the Friesians were

1.47°C and 54 counts per minute respectively. Although this higher increase in respiration for the Brahman X has been accounted for partly by a smaller reduction in DMI in the heat, there is no explanation as to why the respiration rate for the Friesians did not increase even further in order to reduce the highly elevated rectal temperature.

Nevertheless, while the mean rectal temperatures showed that the Friesian calves were more hyperthermic, 40.50°C, than the Brahman X calves, 39.80°C, the corresponding respiration rate measurements, 100 and 93 counts per minute, did not show such a clear cut difference. Further, in the analyses of variance only rectal temperature measurements showed a significant interaction between breed and temperature.

It would therefore seem more accurate and more reliable to measure heat stress by rectal temperature changes rather than respiration rate. Besides, although respiration rate is easily measured especially in the field, the fact that changes in respiration rate precede changes in rectal temperature responses (Yassen, 1977; Bianca, 1963), larger fluctuations would be expected in an otherwise stable body temperature.

5.1.5: The effect of air temperature, breed and diet on hair coat weight

5.1.5.1: Main effects

5.1.5.1.1: Effect of ambient temperature on coat weight

The mean coat weight in the hot treatment group (150 g/m^2) was much lower than that for the cool treatment group (177 g/m^2), but the difference was not significant. This difference is possibly due to a differential hair shedding at the two temperature treatments (Yeates, 1955, 1977). However, the calculated correlation coefficients between rectal temperatures and coat cover weights were +0.868 ($P<0.01$) and -0.794 ($P<0.05$) for the hot and cool treatment groups respectively. These findings suggest that a heavy coat cover caused increased rectal temperature in the heat, whereas in the cool conditions increased rectal temperature caused decrease in coat cover, probably through an effect on shedding. Previous observations by Dowling (1959a) and Yeates (1955, 1977) have shown that hair coat shedding is positively correlated to heat tolerance. However, all the authors have indicated that the effects of air temperature on hair coat shedding were not significant.

5.1.5.1.2: Breed effects on coat cover

The results presented in Table XVII indicate that the Friesian steer calves had significantly ($P<0.05$) heavier coats than the Brahman X calves. These results are in accordance with the observations made by Turner and Schleger (1960) that coat characteristics are hereditary and bear relationship to the general view that cattle of *Bos indicus* origin have short lighter weight coats than *B. taurus* breeds (Dowling, 1956).

5.1.5.1.3: Effect of diet on coat weight

Calves on the concentrate diet wore significantly lighter ($P<0.01$) coats than those on the hay diet. The weights of their hair coat cover at the end of Trial I-a were 139 and 189 g/m^2 respectively. Since calves on the concentrate diet had higher DMI than those on the hay diet (King,1978), it is assumed that these hair coat cover differences were associated with the feeding levels. Accordingly these findings are similar to Murray's (1964) observation that coat shedding was influenced by the plane of nutrition.

Although it is not quite clear what part the level of nutrition plays in hair coat development, it is believed that the hair fibres are thought to be broken below the epidermis and that the root (new hair) must push the broken hair fibre some distance before it is actually lost. This implies that a high plane of nutrition speeds up hair growth and the emergence of the new hair ultimately pushes loose the cut hair more rapidly.

5.1.5.2: Interactions

5.1.5.2.1: Breed x temperature interactions

Table XVII shows that there was little coat weight difference between the two genotypes in the cool treatment; coat weight measurements were 182 and 171 g/m^2 for Friesian and Brahman X calves respectively. However, in the hot treatment, coat weights differed substantially; 181 and 118 g/m^2 for Friesian and Brahman X calves respectively. The difference at the high temperature was largely responsible for the significant effect ($P<0.05$) observed between the two breeds.

The Friesians showed no difference in coat weights between the two temperature treatments, whereas the Brahman X calves' coat weights were much lighter in the hot treatment. This suggests that the Brahman X calves had a greater coat shedding ability than the Friesians. It is also possible that the significant difference ($P<0.05$) between their rectal temperature measurements was possibly related to the hair coat weights. These observations are similar to those reported by Dowling (1959a), Turner and Schleger (1960) and Yeates (1975) which led to the suggestion that the adaptation of temperate cattle to hot conditions was dependent on the ability to shed their hair coats over the summer season.

5.1.5.2.2: Breed x diet effects

Both breeds had higher coat weights when fed on the hay diet than when on the concentrate diet. In each case the Friesians had heavier coats than the Brahman X calves, Table XVII, but the differences were not large enough for a significant interaction. The average coat weights for Friesians and Brahman X calves fed on the hay diet were 200 and 176 g/m^2 respectively. The corresponding values for the concentrate fed groups were 164 and 114 g/m^2.

Generally these coat weights were related to the feeding levels where concentrate fed calves had high DMI (King, 1978) and lighter coat weight covers than hay fed calves. However, although the Friesians had slightly higher DMI for the hay diet, their coat weights were still heavier than those of Brahman X calves on this diet at the higher temperature treatment which suggests a possible genetic influence on the shedding ability independent to some extent of nutrition and ambient temperature.

5.1.5.2.3: Temperature x diet effects

The DMI for both diets were significantly ($P<0.01$) reduced at the higher environment temperature (King, 1978). Coat weights were likewise reduced in the hot treatment, but not significantly. This indicates that the effect of air temperature on coat cover is independent of the type of diet. Thus at both temperatures concentrate DMI was higher than hay DMI and the corresponding coat covers were lighter for the concentrate fed than the hay fed groups.

These findings suggest a generally differing influence of ambient temperature and diet on coat cover of the two genotypes. Assuming that light has an independent fixed effect on coat weight, then temperature and the nutritional level could be said to have modifying effects on the shedding of coat. It is, however, noted that thyroid activity has been implicated in hair coat shedding (Yeates, 1975), but its influence has not been defined clearly. Nevertheless, research findings indicate that thyroid activity is reduced in the heat (Yousef and Johnson, 1967), while in the cold and at high levels of feeding its activity is increased (Yousef and Johnson, 1966a). It is, therefore, possible that the Brahman X calves in the heat had higher thyroid activity because their rectal temperatures and DMI were less affected than those of the Friesians. Moreover, at the high air temperature, Brahman X calves fed the concentrate diet had the highest DMI (King, 1978), lowest rectal temperature (Table IX) and the lowest coat weight (Table XVII) compared to the other groups in the hot treatment. The combination of low rectal temperature and high voluntary intake suggests a higher metabolic rate and relatively high thyroid activity. Thus it is probable that heat tolerant cattle are more able to shed their hair in the summertime because their low body temperature allows them to consume adequate amounts of feed and maintain relatively high levels of thyroid activity which in turn triggers coat shedding.

5.2: Clipping Trial:

5.2.1: Effect of clipping on rectal temperature and respiration rate

From the hair coat measurements (section 4.1.2.8) it was shown that an effect of air temperature was evident but was not significant on coat weights; nevertheless, the correlation coefficient between the coat weights and rectal temperatures of the high air temperature treated group (+0.868, $P<0.01$) implied that hair coat weights were related to body temperature. Accordingly, higher rectal temperatures seemed to have been caused by heavy coat covers which presumably interfered with heat loss processes at the high air temperature.

It was, therefore, expected that clipping would cause a decrease in rectal temperature and in respiration rate or an increase in DMI in response to improved heat dissipation. However, there were no changes in either voluntary food intake (King, 1978), rectal temperature or respiration rate (Tables XIX-a and XIX-b). These findings differ significantly from those implicated by the coat weight measurements and indicate that the efficiency of heat dissipation was not influenced by hair coat cover, at least after acclimatization. This suggests that clipping did not improve the heat transfer between the calves and the environment contrary to the author's expectation. It is, therefore, probable that clipping did not affect the rate of cutaneous evaporation and that at the air temperature of 34-35^{o}C sensible heat loss would be small in relation to total heat loss (McLean and Calvert, 1972).

The results of the clipping trial are similar to those reported by Berman and Kibler (1959) who observed that pre-acclimatized 20-month old heifers did not change their rectal temperatures after clipping. However, these findings differ significantly from those reported by Bianca (1959) who showed the unacclimatized clipped calves examined over a 3-hour exposure period to 40^{o}C ambient temperature and 62% RH exhibited significantly lower respiration rate ($P<0.05$) and lower rectal temperature ($P<0.01$) than unclipped calves. Observations by Turner (1975) have also indicated that clipping of British-bred cattle during the summer period reduced their average rectal temperature by 0.7^{o}C.

5.2.2: Breed x clipping interaction effects

The analyses of variance for rectal temperature, respiration rate and coat weights and the correlation coefficient between rectal temperature and coat weight present an interesting relation to the clipping results. Friesian calves had significantly higher ($P<0.05$) rectal temperature, higher respiration rate counts ($P<0.05$) and heavier coat weights ($P<0.05$) than Brahman X calves. Further, the correlation coefficient between the rectal temperatures and coat weights in the heat indicate that elevated rectal temperatures were associated with heavier coat weights. This suggests that the Friesians were hotter because they maintained heavier coats than the Brahman X calves.

However, since clipping did not expose any disadvantage related to the coat weight before clipping, it was thought that the coat weights were results of rather than causes of heat stress. From the sweating rate measurements (section 4.2.5), it is evident that differences in rectal temperature and respiration rate between the two genotypes have probably been influenced by the highly significant ($P<0.001$) differences in their sweating rates. It seems likely that any influence of the coat on the evaporative cooling would have been minimal at least in the Friesians. This is because the Friesian sweating rates measured under radiation were so low (averaged 60 g/m^2 hr) that if maintained before clipping the coat would have hardly created a significant barrier to its total vapourization. Because the calves had been fully acclimatized prior to the clipping it is most probably that their sweating rates would have stabilized near their peak discharges even before the clipping. Nevertheless, any increase in sweat discharge would have been numerically small when compared to the value obtained under radiant heat. On the other hand the higher sweating rate values for the Brahman X calves (2½ times that of the Friesians) would suggest a possible change in vapourization and/or sweating rate after clipping. Since there were no changes in rectal temperature, respiration or food intake, it is assumed that there were no significant changes in cutaneous evaporative cooling. This suggests that the Brahman X calves had reached their peak moisture discharge at the prevailing experimental conditions and that hair coat weights which were lighter than the Friesians did not interfere with cutaneous evaporative cooling. It is also assumed that any change in sensible heat exchange after clipping would have been very small.

Therefore, the findings imply that clipping did not improve heat dissipation and especially cutaneous evaporative cooling presumably because in the case of the Friesians sweating rates were so low that the coat did not interfere with its total evaporation. And in the case of the Brahman X calves, low initial coat density and possibly coat type allowed free evaporation of the moisture from the skin even before clipping.

5.3: Trial II: Effect of artificial radiation on sweating rate, rectal temperature and respiration rate

5.3.1: Effect of radiant heat load on sweating rate

Brahman X calves had significantly higher sweating rates ($P<0.001$) and lower rectal temperatures than the Friesian calves (Table XXIV).

The Brahman X calves' superior sweating ability (approximately 2½ times more than the Friesians) were associated with lower rectal temperatures. This indicates that cutaneous evaporation has a very high cooling efficiency. Previous observations by McLean (1963) have shown that skin and rectal temperatures and respiration rates decline as sweating rates rise. This suggests that sweating rate is probably the most important factor contributing to the Brahmans' superior heat tolerance and adaptation to the hot conditions compared to the Friesians.

The average sweating rates for the Brahman X (150 g/m^2 hr) and for the Friesians (60 g/m^2 hr) differ considerably from those reported by Murray (1966) for $^3/_4$ Santa Gertrudis (220 g/m^2 hr) and Hereford (240 g/m^2 hr) measured from the back-thoracic region at 35°C climate room temperature. Similarly, chamber measurements on Ayrshire calves (Hales, Findlay and Robertshaw, 1968) were much higher than the present values for the Friesians. However, Schleger and Turner (1965) have indicated that variation between animals within breeds can be high.

The present sweating rates measured under artificial radiation are much lower than measurements made in the field (Murray, 1966 and Schleger and Turner, 1965). Murray (1966) indicated that despite lower rectal temperatures, respiratory rates and skin temperatures, cutaneous evaporation rates measured under field conditions were almost twice those obtained in climate room exposures. This indicates that artificial radiation probably does not stimulate the sweat glands to the same extent as solar radiation.

The differences in sweating rates between the genotypes are in accordance with skin biopsy observations that Zebu cattle and their crosses have more numerous sweat gland populations (Turner *et al.* 1962; Nay and Hayman, 1956; Dowling, 1958; and Taneja, 1960) and larger gland size (Allen, Pan and Hayman, 1963 and Nay, 1959) than *Bos taurus* breeds.

Very high sweating rates if sustained for long periods may cause excessive loss of mineral and other body building substances including; urea, protein nitrogen, non-protein nitrogen, reducing sugars and lactic acid (Joshi *et al.* 1968, and Johnson, 1970). However, according to

Johnson (1970), the estimated sodium and potassium loss through the sweat at 40/45°C is relatively small, 1 to 3 percent of the total intake in the feed. Assuming that the other substances are lost at similar rates it would be unlikely for such losses to cause significant decrease in production. Therefore until comprehensive measurements are made, the increased comfort and the higher DMI resulting directly from higher cutaneous evaporative cooling should be taken to be an important advantage to the greater sweating animal.

5.3.2: Effect of radiation on rectal temperature and respiration rate

Eight hours of radiant exposure caused significant ($P<0.05$) increases for both respiration rate and rectal temperature. The measured net radiation absorbed at the calves' skin surface (130 kcal/m^2 hr) was very large in comparison to their estimated standing heat production (90 kcal/m^2 hr, Holmes, Hughes and Christensen, in press). The net absorbed value of 130 kcal/m^2 hr was numerically smaller than Finch's (1972) estimated values for the eland of 266 kcal/m^2 hr and for the hartbeest (140 kcal/m^2 hr). Similar measurements on *Bos indicus* cattle in a radiant environment at noon resulted in a very high value of 280 kcal/m^2 hr net absorbed solar heat (Finch, 1976).

However, despite the lower net radiant flux recorded in this experiment, rectal temperature and respiration rate were increased considerably. The increase in rectal temperature indicated that the calves were not able to dissipate all the heat gained from radiation through the various channels of heat transfer, instead a positive heat storage occurred during the eight hours of exposure. Respiration rate was particularly very sensitive to radiation and increased by 37 counts per minute on average during the radiation hours. One calf recorded an increase of more than 60 respirations per minute (actual count of over 160) and its rectal temperature rose above 42°C. This calf died during the early days of the trial. The high increase in respiration rate was attributed to greater urgency for evaporative cooling. Calves kept in the same room but sheltered from the direct radiation did not show similar variations between morning and afternoon measurements. Food intake measurements (King, 1978) did not show any significant difference between the calves when exposed to radiation and when not exposed. This was probably because body temperatures after the radiant exposure period decreased sufficiently overnight to allow for equal DMI to the non-radiant exposure period.

Observations of similar kind have been reported by Kibler and Brody (1964) who showed that both rectal temperature and respiration rate were more elevated at 21°C ambient with 500 kcal/m^2 hr incident radiant flux than at 26.6°C without radiation. However, in a study by Murray (1966) rectal temperatures and respiration rates were less elevated in the field than in a climate laboratory. This occurred despite a probable higher heat load in the field (20.5 to 27.2°C ambient and 40-48°C globe temperature) compared with the climate room air temperature of 35°C but without radiation, because sweating rates in the field were much higher (380-640 g/m^2 hr) than those recorded in the chamber (220 g/m^2 hr).

The average incident radiant flux reaching the calves withers was very large (977 kcal/m^2 hr), but only about $^1/_8$ of this was absorbed at the calves body. This low radiation exchange was due partly to the animals body shape and partly to the posture. Only about ½ of the body surface was under direct radiation. The rest of the body surface was only exposed to diffuse radiation. Because the radiation source was localized, longwave radiation from the surroundings was low in comparison to natural environments. Accordingly, Table XXII shows that $^2/_3$ of the lower half of the body surface had negative radiant heat exchange values. In addition, although the total radiant heating potential decreased by 158 kcal/m^2 hr at 0.5 m above the floor (estimated height of calves when lying down), the calves spent most of their time standing. It is thought that lying down does not only expose a larger skin surface to direct solar radiation, but also substantially reduces the total effective surface for sensible and cutaneous evaporative cooling which could have been realized by the skin in contact with the floor. Therefore, standing could have increased the rate of heat dissipation through radiation, convection, conduction and cutaneous veporization from the lower half of the body surface.

5.3.3: Effect of radiation on the different genotypes

The net radiant energy values given in Table XXII represent the net radiant energies and do not take into account the heat losses through channels other than re-radiation. The individual net radiant fluxes of

139 and 121 kcal/m^2 hr for Friesian and Brahman X calves represent a small difference in potential heat gains from radiation. Therefore the differences between the breeds in relation to the increase in rectal temperature (0.45°C) must be related to the variations in the efficiency of heat dissipation through convection, conduction and vapourization (both cutaneous and respiratory ventilation) between the genotypes. Nevertheless the effect of the interaction between breed and radiation on rectal temperature and respiration rate was not significant.

Differential increases in heat loss through sensible channels may have favoured the Brahman F_1. The measured coat weights were significantly lighter ($P<0.05$) than the Friesians (Table XVII). Previous research findings (Dowling, 1959; Hutchinson, Brown and Allen, 1973; and Yeates, 1977) have shown that the lighter coats are also more medullated, shallower and have low scores. Such coats have been said to be Zebu type and have the advantage of greater openness to ventilation thereby increasing convective heat transfer. And according to Bennett (1964) sensible heat loss is correlated to coat score, and the significance of the coat increases with increasing air circulation (Blaxter and Wainman, 1964). It is therefore possible that the small breeze (0.36 km/hr air circulation) could have increased the convective heat loss of the Brahman X (F_1) more than that of the Friesians.

The most probable cause of the variation in heat storage between the two genotypes was the difference in cutaneous evaporative heat loss. Sweating rate measurements suggested that on average Brahman calves were losing 250% more moisture than the Friesian calves. Using the estimated specific heat of vaporization (0.6 kcal/g) given by Carlson and Hsieh (1970) Brahman cross calves were losing about 55 kcal/m^2 hr more than the Friesians during the radiation hours. This represents a very significant extra heat loss in comparison to the total gain from radiation, and indeed of the estimated average heat production when on growth (90 kcal/m^2 hr, Holmes, Hughes and Christensen, in press).

Previous workers (Kibler and Yeck, 1959) found little difference in cutaneous evaporative heat loss between Brahmans and Shorthorns at 25°C, but at 40°C ambient the Brahmans were evidently losing more heat through evaporation of moisture at the skin. And using lactating cows Kibler and Brody (1954) observed similar effects for radiation. The authors reported that radiation caused significantly greater increase in both respiration rate and rectal temperature in Holsteins and Jerseys than in Brahmans.

CHAPTER SIX

CONCLUSIONS

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The main findings of this study have been that heat stress as indicated by elevated rectal temperature and respiration rate is associated with significant decreases in voluntary food intake and liveweight gain (King, 1978). That Brahman X calves were more tolerant to the hot conditions than the Friesians. It was also indicated that feeds of lower digestibility cause a greater heat burden than feeds of higher digestibility. However, only F_1 calves fed on the concentrate diet consumed significantly more dry matter and grew faster than hay fed calves. It is therefore possible that the productivity of *B. indicus* cattle under warm conditions could be improved by supplementing or substituting roughage feeds with grain and other feeds of higher digestibility. Such systems, if adopted, would increase the caloric density of the feed to compensate for reduced consumption during the critical periods of environmental heat stress.

Although coat weight was positively correlated with rectal temperature at the high air temperature, clipping of the calves' coats did not reduce the animals' heat stress (rectal temperature) or increase their food intake. This suggested that coat weight is the result of rather than a cause of heat stress; and therefore heat tolerance is hereditary. Further, it was indicated that the most important factor contributing to the differences in heat tolerance between the genotypes was a difference in sweating ability.

It is therefore possible that these hereditary characters could be useful in the selection of cattle for warm climates. Coat cover could be used as a visual aid to assess the relative heat tolerance of individuals and for initial selection of herds; sweating rate measurements could could be used to identify more heat tolerant cattle within the *B. taurus* genotype from which individuals can be selected and adopted in a crossbreeding programme in warm countries.

It was also pointed out in the discussion that respiration rate count is possibly not a very accurate indicator of heat stress. Like sweating rate, respiration rate does not describe the heat status of a body, but the relative rates of heat loss. Moreover, they can be activated by external stimuli even though body temperature may be normal. It is therefore concluded that rectal temperature represents a more accurate measurement of heat stress and whenever possible it should be used in preference to respiration rate.

It was found that radiant heat caused a significant ($P<0.05$) increase in body temperature after 8 hours of exposure to artificial radiation. But, there were no corresponding decreases in DMI and liveweight gain. It is therefore suggested that further studies should be conducted before any valid conclusion can be made. Such studies should consider among other things the effect of radiation on carcase quality.

REFERENCES

REFERENCES

ALLEN, T.E. (1962) Responses of Zebu, Jersey, and Zebu x Jersey crossbred heifers to rising temperature, with particular reference to sweating. *Aust. J. Agric. Res. 13(1):* 165.

ALLEN, T.E. and DONEGAN, S.M. (1974) *Bos indicus* and *Bos taurus* crossbred dairy cattle in Australia. III: Climate room test of heat tolerance used in the selection of young sires for progeny testing. *Aust. J. Agric. Res. 25:* 1023.

ALLEN, T.E., PAN, Y.S. and HAYMAN, R.M. (1963) The effect of feeding on evaporative heat loss and body temperature in Zebu and Jersey heifers. *Aust. J. Agric. Res. 14:* 580.

AMES, D.R. and INSLEY, L.W. (1975) Wind-chill effect for cattle and sheep. *J. Anim. Sci. 40:* 161.

ANDERSON, B., EKMAN, L., GALE, C.C. and SUNDSTON, J.W. (1963) Control of thyrotrophic hormone (TSH) secretion by the 'Heat Loss Centre'. *Acta Physiol. Scand. 59:* 12.

ANDERSON, B. and LARSON, B. (1961) Influence of local temperature changes in the preoptic area and rostral hypothalamus on the regulation of food and water intake. *Acta Physiol. Scand. 52:* 45.

ATTERBERY, J.T. and JOHNSON, H.D. (1969) Effect of environmental temperature, controlled feeding and fasting on rumen motility. *J. Anim. Sci. 29:* 734.

BALDWIN, B.A. and INGRAM, D.C. (1967) The effect of heating and cooling the hypothalamus on behavioural thermoregulation in the pig. *J. Physiol. (London) 191:* 375.

BALDWIN, B.A. and INGRAM, D.C. (1968) The role of behaviour in the regulation of body temperature. *Vet. Ann. 1968.*

BERMAN, A. (1967) Diurnal and seasonal changes in bovine respiratory function in a subtropical climate. *Aust. J. Agr. Res. 18:* 849.

BERMAN, A. (1971) Thermoregulation in intensively lactating cows in near-natural conditions. *J. Physiol. 215:* 477.

BERMAN, A. and KIBLER, H.H. (1959) Effect of clipping the coat on the thermoregulatory reactions of dairy heifers. *Nature 183:* 606.

BERMAN, A. and MORAG, M. (1971) Nychthermeral patterns of thermoregulation in high yielding dairy cows in a hot dry near natural climate. *Aust. J. Agric. Res. 22:* 671.

BERMAN, A. and ZAMSKY, J. (1971) Thermoregulatory control in cattle exposed to the natural climate. *J. Dairy Sci. 54:* 1216.

BIANCA, W. (1959) The effect of clipping the coat on various reactions of calves to heat. *J. Agric. Sci. 52:* 380.

BIANCA, W. (1959a) Acclimatization of calves to a hot dry environment. *J. Agric. Sci. 52:* 296.

BIANCA, W. (1959b) Acclimatization of calves to a hot humid environment. *J. Agric. Sci. 52:* 305.

BIANCA, W. (1963) Rectal temperature and respiration rate as indicators of heat tolerance in cattle. *J. Agric. Sci. 60:* 113.

BIANCA, W. (1965) Cattle in hot environments. *J. Dairy Res. 32:* 291.

BIANCA, W. and HALES, J.R.S. (1970) Sweating, panting and body temperature of newborn and one-year-old calves at high environmental temperatures. *Br. Vet. J. 126:* 45.

BLAXTER, K.L. (1962) The energy metabolism of ruminants. *Hutchinson, London.*

BLAXTER, K.L. and WAINMAN, F.W. (1961) Environmental temperature and the energy metabolism and heat emission of steers. *J. Agric. Sci. 56:* 81.

BLAXTER, K.L. and WAINMAN, F.W. (1964) The effect of increased air movement on the heat production and emission of steers. *J. Agric. Sci. 62:* 207.

BLAXTER, K.L. (1967) *The Energy Metabolism of Ruminants.* 2nd Edition. Charles C. Thomas, Springfield, Illinois, U.S.A.

BLIGH, J. (1961) The synchronous discharge of apocrine glands of the Welsh Mountain sheep. *Nature (London) 189:* 582.

BLIGH, J. (1967) A thesis concerning the process of secretion and discharge of sweat. *Environ. Res. 1:* 28.

BLIGH, J. (1973) *Temperature regulation in mammals and other vertebrates.* North Holland Publishing Company, London.

BOND, T.F., KELLY, C.F., MORRISON, S.R. and PEREIRA, N. (1967) Solar atmospheric and terrestrial radiation received by shaded and unshaded animals. *Trans. Ame. Soc. Agric. Eng. 20:* 622.

BONSMA, J.C. (1949) Breeding cattle for increased adaptability to tropical and sub-tropical environments. *J. Agric. Sci. 39:* 204

BROCKWAY, J.M., McDONALD, J.D. and PULLAR, J.D. (1965) Evaporative heat loss mechanisms in sheep. *J. Physiol. 179:* 554.

BRODY, S. (1956) Influence of radiation intensity on evaporative cooling and heat production in Brahman and Ayrshire cows. *J. Dairy Sci. 39:* 204.

CABANAC, M. (1974) *Thermoregulatory behaviour in environmental physiology.* Ed. by Robertshaw, Butterworths University Park Press, Baltimore.

CALVERT, D.T., FINDLAY, J.D. and McLEAN, J.A. (1972) Quantitative thermoregulatory response of the ox to anterior hypothalamic warming. *Biometro. 5:* 40

CARLISLE, H.J. and INGRAM, D.L. (1973) The influence of body core temperature and peripheral temperatures on oxygen consumption in the pig. *J. Physiol. 231:* 341.

CARLSON, L.D. and HSIEH, A.C.L. (1970) *Control of Energy Exchange.* Collier-Macmillan Limited, London.

CARTER, H.B. and DOWLING, D.F. (1954) The hair follicle and apocrine gland population of cattle skin. *Aust. J. Agric. Res. 5:* 745.

CARTWRIGHT, T.C. (1955) Responses of beef cattle to high ambient temperatures. *J. Anim. Sci. 14:* 350.

CHAUHAN, P.S., VERMA, P.S., ARORA, C.K., ARORA, R.B. and DATTA, A.G. (1969) Acceleration of C^{14} phenylalamine incorporation into proteins of the liver cell fractions in response to cold exposure. *Life Sci. 8:* 415.

CHRISTISON, D.T. and JOHNSON, H.D. (1972) Cortisol turnover in heat-stressed cows. *J. Anim. Sci. 35:* 1005.

CHRISTOPHERSON, R.J. (1976) Effects of prolonged cold and the outdoor winter environment on apparent digestibility in sheep and cattle. *Can. J. Anim. Sci. 56:* 201.

COCHRAN, W.G. and COX, G.M. (1950) *Experimental Designs.* John Wiley and Sons Inc., New York.

COCKREM, F. and SUTCLIFFE, P.J. (1968) Sources of variation in body temperature in relation to its measurement in the New Zealand Romney sheep. *N.Z. J. Agric. Res. 11(4):* 911.

COLDITZ, P.J. and KELLAWAY, R.C. (1972) The effect of diet and heat stress on feed intake, growth and nitrogen metabolism in Friesian, Brahman x Friesian heifers. *Aust. J. Agric. Res. 23:* 717.

COLLINS, K.J. and WEINER, J.S. (1968) Endocrinology aspects of exposure to high environmental temperatures. *Physiol. Rev. 48(4):* 785.

CUNNINGHAM, D.J.C. and O'RIORDAN, J.L.H. (1957) The effect of a rise in the temperature of the body on the respiratory responses to carbon dioxide at rest. *Quart. J. Exp. Physiol. 42:* 329.

DOWLING, D.F. (1955) The hair follicle and apocrine gland population of Zebu *(Bos indicus)* and Shorthorn *(Bos taurus)* L. cattle skin. *Aust. J. Agric. Res. 6:* 645.

DOWLING, D.F. (1956) An experimental study of heat tolerance of cattle. *Aust. J. Agric. Res. 7:* 469.

DOWLING, D.F. (1958) Seasonal changes in coat characters in cattle. *Proc. Aust. Soc. Anim. Prod. 2:* 69.

DOWLING, D.F. (1959a) The medullation characteristics of the hair coat as a factor in heat tolerance of cattle. *Aust. J. Agric. Res. 10:* 736.

DOWLING, D.F. (1959b) The significance of the coat in heat tolerance of cattle. *Aust. J. Agric. Res. 10:* 744.

DOWLING, D.F. (1960) The significance of the coat in heat tolerance of cattle. II. Effect of solar radiation on body temperatures. *Aust. J. Agric. Res. 11:* 871.

ENDERSTROM, H.E. (1954) Blood flow changes in the dog during hyperthermia. *Amer. J. Physiol. 176:* 347.

FERGUSON, K.A. and DOWLING, D.F. (1955) The functions of cattle sweat glands. *Aust. J. Agric. Res. 6:* 640.

FINCH, V.A. (1972) Thermoregulation and heat balance of the East African eland and hartebeest. *Amer. J. Physiol. 222:* 1374.

FINCH, V.A. (1976) An assessment of the energy budget of Boran cattle. *Thermal Biology 2:* 1.

FINDLAY, J.D. and HALES, J.R.S. (1969) Hypothalamic temperature and regulation of respiration of the ox exposed to severe heat. *J. Physiol. (London) 203:* 651.

FINDLAY, J.D. and INGRAM, D.L. (1961) Brain temperature as a factor in the control of thermal polypnoea in the ox *(Bos taurus)*. *J. Physiol. (London) 155:* 72.

FINDLAY, J.D. and JENKINSON, D. McE. (1964) Sweat gland function in the Ayrshire calf. *Res. Vet. Sci. 5:* 109.

FINDLAY, J.D. and ROBERTSHAW, D. (1965) The role of the sympato-adrenal system in the control of sweating in the ox *(Bos taurus)*. *J. Physiol. (London) 179:* 285.

FINDLAY, J.D. and WHITTOW, G.C. (1966) The role of arterial oxygen tension in the respiratory response to localised heating of the hypothalamus and to hyperthermia. *J. Physiol. (London) 186:* 333.

FINDLAY, J.D. and YANG, S.H. (1950) The sweat glands of Ayrshire cattle. *J. Agric. Sci. Camb. 40:* 126.

FINELLE, P. (1973) African animal trypanosomiasis, Part 1. *World Anim. Rev. (F.A.O.) 7:* 1.

FINELLE, P. (1973) African animal trypanosomiasis, Part 4. *World Anim. Rev. (F.A.O.) 16:* 15.

GALE, C.C., MATHEWS, M. and YOUNG, J. (1970) Behavioural thermoregulatory responses to hypothalamic cooling and warming in baboons. *Physiol. Behav. 5:* 1.

GAUDIO, R. and ABRAMSON, N. (1968) Heat-induced hyperventilation. *J. Appl. Physiol. 25:* 742.

GOMES da SILVA, R. (1973) Improving tropical beef cattle by simultaneous selection for weight and heat tolerance. Heritabilities and correlations of the traits. *J. Anim. Sci. 37(3):* 637.

GUETHER, W.C. (1964) *Analysis of Variance.* Prentice-Hall Inc., Englewood Cliffs, N.J.

HAFEZ, E.S.E., BADRELDIN, A.L. and SHAFEI, M.M. (1955) The hair coat in bovines. *Emp. J. Exp. Agric. 23:* 24.

HALES, J.R.S. (1967) The partition of respiratory ventilation of the panting ox. *J. Physiol. (London) 188:* 45.

HALES, J.R.S. (1969) Changes in respiratory activity and body temperature of the severely heat-stressed ox and sheep. *Camb. Biochem. Physiol. 31:* 975.

HALES, J.R.S. (1970) Hypothalamic control of heat loss mechanisms in the ox. *Proc. Aust. Physiol. Pharmacol. Soc. 1:* 42.

HALES, J.R.S. (1974) *Physiological Responses to Heat.* in Environmental Physiology. Physiology Series One Vol.7. Ed. D. Robertshaw p.107.

HALES, J.R.S. and FINDLAY, J.D. (1968a) The oxygen cost of thermally-induced and CO_2 induced hyperventilation in the ox. *Resp. Physiol. 4:* 353.

HALES, J.R.S. and FINDLAY, J.D. (1968b) Respiration in the ox, normal values and the effects of exposure to hot environments. *Resp. Physiol. 4:* 333.

HALES, J.R.S., FINDLAY, J.D. and ROBERTSHAW, D. (1968) Evaporative heat loss mechanism of the newborn calf, *Bos taurus.* *Br. Vet. J. 124:* 83.

HALES, J.R.S. and HUTCHINSON, J.C.D. (1971) Metabolic, respiratory and vasomotor responses to heating the scrotum of the ram. *J. Physiol. (London) 212:* 353.

HALES, J.R.S. and JESSEN, C. (1969) Increase of cutaneous moisture loss caused by local heating of the spinal cord in the ox. *J. Physiol. (London) 204:* 40.

HALHORN, H.T. (1966) *The Application of Control Theory to Physiological Systems.* W.B. Saunders Company, London.

HAMMEL, H.T. (1968) Regulation of internal body temperature. *Ann. Rev. Physiol. 30:* 641.

HAMMEL, H.T. (1972) The 'set point' in temperature regulation analogy or reality in Esseys on temperature regulation. Ed. J. Bligh and R.E. Moore. North-Holland Publ. Co. London.

HAMMEL, H.T., WYNDHAM, C.H. and HARDY, J.D. (1958) Heat production and heat loss in the dog at 8-36°C environmental temperature *Amer. J. Physiol. 194:* 99.

HARDY, J.D. (1961) Physiology of temperature regulation. *Physiol. Rev. 41:* 521.

HAYMAN, R.H. and NAY, T. (1958) Sweat glands in Zebu *(Bos indicus L.)* and European *(Bos taurus L.)* cattle. II. Effects of season and exercise on sweat gland volume. *Aust. Agric. Res. 9(3):* 385

HOLMES, C.W. and McLEAN, N.A. (1975) Effect of air temperature and air movement on the heat produced by young Friesian and Jersey calves with some measurements of the effects of artificial rain. *N.Z. J. Agric. Res. 18:* 277.

HOPKINS, P.S. (1976) Effect of tropical climate on the health of cattle. In: Beef Cattle Production in Developing Countries, ed. A.J. Smith, University of Edinburgh.

HORST, Vander, C. and STEENKAMP, J.D.G. (1975) Effect of breed and nutrition on the heat tolerance of cattle. *Rhod. Agr. J. 72(3).*

HUTCHINSON, J.C.D. (1962) Adaptation of domestic animals to the tropics. Biometrology. Ed. S.W. Tromp, Oxford, Pergamon.

HUTCHINSON, J.C.D. and BROWN, G.D. (1969) Penetrance of cattle coats by radiation. *J. Appl. Physiol. 26:* 454.

HUTCHINSON, J.C.D., BROWN, G.B. and ALLEN, T.E. (1973) Effect of the coat on the heat dissipation of cattle in a radiant environment. *C.S.I.R.O. First Australian Conference on heat and mass transfer at Monash University, Melbourne, Australia, May 1973.*

INGRAM, D.L. (1965) Evaporative cooling in the pig. *Nature (London) 207:* 415.

INGRAM, D.L. and LEGGE, K.F. (1972a) The influence of deep-body temperature and skin temperatures on respiratory frequency in the pig. *J. Physiol. 220:* 283.

INGRAM, D.L. and LEGGE, K.F. (1972b) Influence of deep-body and skin temperatures on thermoregulatory responses to heating of the scrotum in pigs. *J. Physiol. 224:* 477.

INGRAM, D.L. and MOUNT, L.E. (1975) *Man and Animals in Hot Environments.* Springer - Ver Lag, Berlin.

ISABIYRE, J.K. and ROBERTSHAW, D. (1972) The sweat gland response to solar radiation in domestic animals. *Biometeorology 5:* 67.

JASIOROWSKI, H.A. (1973) Twenty years with no progress? *World Anim. Rev. 5:* 1.

JASIOROWSKI, H.A. (1976) The developing world as a source of beef for world markets. In: Beet Cattle Production in Developing Countries, Ed. J. Smith, Speedspools, Edinburgh.

JENKINSON, D. McE. and MABON, R.M. (1973) The effect of temperature and humidity on skin surface pH and the ion composition of skin secretions in Ayrshire cattle. *Br. Vet. J. 129:* 282.

JESSEN, C., McLEAN, J.A., CALVERT, D.T. and FINDLAY, J.D. (1972) Balance and unbalanced temperature signals generated in spinal cord of the ox. *Am. J. Physiol. 222:* 1343.

JOHNSON, K.G. (1970) Sweating rate and the electrolyte content of skin secretions of *Bos taurus* and *Bos indicus* cross-bred cows. *J. Agric. Sci. (Cambridge) 75:* 397.

JOHNSON, H.D. and KAMAL, T.H. (1958) Effects of raising environmental temperature (35°-90°F) on thyroxine $[^{131}]$utilization of young dairy calves. *J. Anim. Sci. 17:* 1228.

JOHNSON, H.D. and KIBLER, H.H. (1963) Temperature-humidity effects on thyroxine $[^{131}]$disappearance rate in cattle. *J. Appl. Physiol. 18:* 73.

JOHNSON, H.D., KIBLER, H.H. RAGSDALE, A.C., BERRY I.L. and SHANKLIN, M.D. (1961) The role of heat tolerance and production level in responses of lactating Holsteins to different conditions of temperature and humidity. *J. Dairy Sci. 44:* 1191 *Abstract.*

JOHNSON, M.K. and LIEBERT, R.M. (1977) *Statistics, Tool of the Behavioural Sciences.* Prentice-Hall Inc., Englewood Cliffs, New Jersey.

JOHNSON, H.D. and RAGSDALE, A.C. (1960) Temperature effects on thyroid $[^{131}]$release rate of dairy calves. *Univ. Mo. Agric. Exp. Res. Bull. 709.*

JOHNSON, H.D., RAGSDALE, A.C. and YECK, R.G. (1958) Environmental physiology and shelter engineering, XLIX. Effects of constant temperatures of 50°F and 80°F on the feed and water consumption of Brahman, Santa Gertrudis and Shorthorn calves during growth. *Univ. Mo. Agric. Exp. Sta. Res. Bull 684:* 1.

JOHNSON, H.D. and YOUSEF, M.K. (1966) Effect of short-term fasting on thyroid activity of cattle at various environmental temperatures. *J. Anim. Sci. 25:* 1069.

JOHNSON, K.G. and WEBSTER, M.E.D. (1967) Extremity skin temperature in British and Zebu cross cattle. *J. Agric. Sci. Camb. 69:* 1.

JOHNSTON, J.E. (1965) Physiological responses of cattle to tropical environment. *Cornell Latin American Year Conference on the Potential of the Hot Tropics in Latin America. Cornell University, Ithaca, N.Y.*

JOSHI, B.C., McDOWELL, R.E. and SADHU, D.R. (1968) Surface evaporation from the normal body surface and with sweat glands activated in Indian cattle. *J. Dairy Sci. 51:* 916.

JOSHI, B.C., JOSHI, H.B., McDOWELL, R.E. and SADHU, D.P. (1968) Composition of skin secretion from three Indian breeds of cattle under thermal stress. *J. Dairy Sci. 51:* 917.

JOYCE, J.D. and BLAXTER, K.L. (1964) Effect of air movement, air temperature and infrared radiation on the energy requirement of sheep. *Br. J. Nutri. 18:* 5.

JOYCE, J.P., BLAXTER, K.L. and PARK, C. (1966) The effect of natural outdoor environments on the energy requirement of sheep. *Res. Vet. Sci. 7:* 342.

KAMAL, T.H. and JOHNSON, H.D. (1973). Total body solids loss as a measure of short-term heat stress in cattle. *J. Anim. Sci. 32:* 306.

KELLAWAY, R.C. and COLDITZ, P.J. (1975) The effect of heat stress on growth and nitrogen metabolism in Friesian and F_1 Brahman x Friesian heifers. *Aust. J. Agric. Res. 26:* 615.

KIBLER, H.H. (1957) Environmental physiology and shelter engineering. XLIII. Energy metabolism and cardiorespiratory activities in Shorthorn, Santa Gertrudis and Brahman heifers during growth at 50°F and 80°F temperatures. *Univ. Mo. Agric. Exp. Sta. Res. Bull. 643:* 1.

KIBLER, H.H. and BRODY, S. (1949) Environmental physiology with special reference to domestic animals. VIII. Influence of ambient temperature °C to 105°F on insensible weight loss and moisture vaporization in Holstein and Jersey cattle. *Res. Bull Mo. Agric. Exp. Sta. 451:* 19.

KIBLER, H.H. and BRODY, S. (1952) Relative efficiency of surface evaporative respiratory moisture loss in Jersey, Holstein, Brown Swiss and Brahman cattle. *Res. Bull. Mo. Agric. Exp. Sta. 497:* 51.

KIBLER, H.H. and BRODY, S. (1953) Influence of humidity on heat exchange and body temperature regulation in Jersey, Holstein, Brahman and Brown Swiss cattle. *Res. Bull. Mo. Agric. Exp. Sta. No.522.*

KIBLER, H.H. and BRODY, S. (1954) Influence of radiation intensity on evaporative cooling heat production and cardiorespiratory activities in Jersey, Holstein and Brahman cows. *Mo. Agric. Exp. Sta. Res. Bull. 574.*

KIBLER, H.H. and YECK, R.G. (1959) Vaporization rates and heat tolerance of growing Shorthorn, Brahman and Santa Gertrudis calves raised at constant 50° and 80°F temperature. *Res. Bull. Mo. Agric. Exp. Sta. 701:* 32.

KLUSSMANN, F.W. and PIERAN, Fr K. (1972) Extrahypothalamic deep body thermosensitivity. In Essays on temperature regulation, Eds J. Bligh and R. Moore, North Holland Publishing Company, London.

KOROXEMIDIS, G.T., SHEPHERD, J.T. and MARSHALL, R.J. (1961) Cardiovascular response to acute heat stress. *J. Appl. Physiol. 16:* 869.

LEDGER, H.P. (1959) A possible explanation for part of the difference in heat tolerance exhibited by *Bos taurus* and *Bos indicus* beef cattle. *Nature 184:* 1405.

LINDSAY, D.R. (1969) Sexual activity and semen production of rams at high temperatures. *J. Reprod. Fert. 18:* 1.

MARTZ, F.A., MISHRA, M., CAMPBELL, J.R., DANIELS, L.B. and HILDERBRAND, E. (1971) Relation of ambient temperature and time postfeeding on ruminal, arterial and venous volatile fatty acids and lactic acid in Holstein steers. *J. Dairy Sci. 54:* 520.

MASON, I.L. (1976) Factors influencing the world distribution of cattle. In: Beef Cattle Production in Developing Countries, ed. J. Smith, Speedspools, Edinburgh.

McDOWELL, R.E. (1958) Physiological approaches to animal climatology. *J. Heredity 49:* 52.

McDOWELL, R.E. (1968) Climate versus man and his animals. *Nature, London 218:* 641.

McDOWELL, R.E. (1972) *Improvement of Livestock Production in Warm Climates.* Freeman and Company, San Francisco.

McDOWELL, R.E., McDANIEL, B.T., BARRADA, M.S. and LEE, D.H.K. (1961). Rate of sufrace evaporation from the normal body surface and with sweat glands inactivated under heat conditions. *J. Anim. Sci. 20:* 380.

McDOWELL, R.E., MOODY, E.G., VAN SOEST, P.J., LEHMANN, R.P. and FORD, G.L. (1969) Effect of heat stress on energy and water utilization of lactating cows. *J. Dairy Sci. 52(2):* 188.

McLEAN, J.A. (1963a) The partition of insensible losses of body weight and heat from cattle under various climate conditions. *J. Physiol. (London) 167:* 427.

McLEAN, J.A. (1963b) The regional distribution of cutaneous moisture vaporization in the Ayrshire calf. *J. Agric. Sci. 61:* 275.

McLEAN, J.A. (1963c) Measurement of cutaneous moisture vaporization from cattle by ventilated capsules. *J. Physiol. (London) 167:* 417.

McLEAN, J.A. and CALVERT, D.T. (1972) Influence of air humidity on the partition of heat exchange of cattle. *J. Agric. Sci. 78:* 303.

McLEAN, J.A., HALES, J.R.S., JESSEN, C. and CALVERT, D.T. (1970) Influence of spinal cord temperature on heat exchange of the ox. *Proc. Austr. Physiol. Phamacol. Soc. 1:* 2, 32.

MISHRA, M., MARTZ, F.A., STANLEY, R.W., JOHNSON, H.D., CAMPBELL, J.R. and HILDERBRAND, E. (1970) Effect of diet and ambient temperature-humidity on ruminal pH, oxidation reduction potential, ammonia and lactic acid in lactating cows. *J. Anim. Sci. 30:* 1023.

MITRA, R. and JOHNSON, H.D. (1972) Growth hormone response to acute thermal exposure in cattle. *Proc. Soc. Exp. Biol. Med. 139:* 1086.

MITRA, R., CHRISTISON, G.I. and JOHNSON, H.D. (1972) Effect of prolonged thermal exposure on growth hormone secretions in cattle. *J. Anim. Sci. 34:* 776.

MOLYNEUX, G.S. (1965) Observations on the structure, distribution and significance of arterio-venous anastomoses in sheep skin. In: Biology of the Skin and Hair Growth, 591 (Ed. A.G. Lyne and B.F. Short) Sydney: Angus and Robertson.

MONTEITH, J.L. (1973) *Principles of Environmental Physics.* Edward Arnold, London.

MOODY, E.G., VAN SOEST, P.J., McDOWELL, R.E. and FORD, G.L. (1967) Effects of high temperature and dietary fat on performance of lactating cows. *J. Dairy Sci. 50:* 1909.

MORAN, J.B. (1970) Brahman cattle in a temperate environment. I. Live-weight gains and carcass characteristics. *J. Agric. Sci. Camb. 74:* 315.

MORAN, J.B. (1970) Brahman cattle in temperate environment. II. Adaptability and grazing behaviour. *J. Agric. Sci. Camb. 74:* 323.

MORAN, J.B. (1973) Heat tolerance of Brahaman cross, Buffalo, Bantang and Shorthorn steers during exposure to sun and as a result of exercise. *Aust. J. Agric. Res. 24:* 775.

MOUNT, L.E. (1968) *The climatic physiology of the pig.* Edward Arnold (Publishers) Ltd, London.

MOUNT, L.E. and INGRAM, D.L. (1965) The effects of ambient temperature and air movement on localized sensible heat loss from the pig. *Res. Vet. Sci. 6:* 84.

MUNRO, H.N. (1964) In "Mammalian Protein Metabolism" p.381. Academic Press, New York.

MURRAY, D.M. (1966) A comparison of cutaneous evaporation rates in cattle exposed to heat in a climate laboratory and in the field. *J. Agric. Sci. 66:* 175.

NAY, T. (1959) Sweat glands in cattle: histology, morphology and evolutionary trends. *Aust. J. Agric. Res. 10:* 121.

NAY, T. and DOWLING, D.F. (1957) Size of sweat glands in Shorthorn strains and Zebu x Shorthorn crossbred cattle. *Aust. J. Agric. Res. 8:* 4.

NAY, T. and HAYMAN, R.H. (1956) Sweat glands in Zebu *(Bos indicus L.)* and European *(Bos taurus L.)* cattle. I. Size of individual glands, the denseness of their population and their depth below the skin surface. *Aust. J. Agric. Res. 7:* 482.

OLBRICH, S.E., MARTZ, F.A., JOHNSON, H.D., PHILLIPS, S.W., LIPPINCOTT, A.C. and HILDERBRAND, E.S. (1972) Effect of constant ambient temperature of 10°C and 31°C on runimal responses of cold tolerant and heat tolerant cattle. *J. Anim. Sci. 34:* 64.

PATCHELL, M.R. (1954) Direct effects of climate on cattle. I. Some observations on the skin temperature, body temperature, respiration rate and pulse rate of dairy stock under normal temperature conditions. *N.Z. J. Sci. Tech. 36(1):* 1.

PATCHELL, M.R. (1954) Direct effects of climate on cattle. II. Measurements of skin temperature in cattle. *N.Z. J. Sci. Tech 36(1):* 10.

PATCHELL, M.R. (1954) Direct effects of climate on cattle. III. The diurnal trend in body temperature, respiration rate and pulse rate. *N.Z. J. Sci. Tech. 36(2):* 94.

PAYNE, W.J.A. and HANCOCK, J. (1957) The direct effect of tropical climate on the performance of European type cattle. II. Production. *Emp. J. Exp. Agric. 25:* 321.

PHILLIPS, G.D. (1960) The relationship between water and food intakes of European and Zebu type steers. *J. Agric. Sci. 54:* 231.

PHILLIPS, G.D. and RAGHAVAN, G.V. (1970) Responses of unshorn and shorn sheep to thermal stress. *J. Physiol. (London) 208:* 317.

PRESTON, T.R. and WILLIS, M.B. (1974) *Intensive Beef Production.* Pergamon Press Ltd, London.

QUARTERMAN, J., PHILLIPS, G.D. and LAMPKIN, G.H. (1957) A difference in the physiology of the large intestine between European and indigenous cattle in the tropics. *Nature 180:* 552.

QUARTERMAIN, A.R. (1960) Some physiological effects of shading dairy cattle. *N.Z. J. Agric. Res. 3:* 454.

RHOAD, A.O. (1940) A method of assaying genetic differences in the adaptability of cattle to tropical and sub-tropical climates. *Emp. J. Exp. Agric. 8:* 190.

RICHARDS, S.A. (1973) *Temperature regulation.* Wykeman Publications (London) Ltd, University for London.

ROBERTSHAW, D. (1968) The pattern and control of sweating in the sheep and the goat. *J. Physiol. (London) 198:* 531.

ROBERTSHAW, D. and FINCH, V. (1976) The effect of climate on the productivity of beef cattle. In: Beef Cattle Production in Developing Countries, ed. A.J. Smith, University of Edinburgh.

ROBERTSHAW, D. and TAYLOR, C.R. (1969) A comparison of sweat gland activity in eight species of East African bovids. *J. Physiol. (London) 203:* 135.

RHOAD, A.O. (1944) The Iberian Heat Tolerance Test for cattle. *Trop. Agric. 21:* 162.

SCHEFFE, H. (1959) *The Analysis of Variance.* John Wiley, New York.

SCHLEGER, A.V. (1967) Relationship of coat type and colour to milk production in Australian Illawarra Shorthorn dairy cattle. *Aust. J. Agric. Res. 18:* 539.

SCHLEGER, A.V. and TURNER, H.G. (1965) Sweating of cattle rates in the field and their reaction to diurnal and seasonal changes. *Aust. J. Agric. Res. 16:* 92.

SKINNER, J.D. and LOUW, G.N. (1966) Heat stress and spermatogenesis in *B. indicus* and *B. taurus* cattle. *J. Appl. Physiol. 21:* 1704.

SNEDCOR, G.W. (1962) *Statistical Methods Applied to Experiments in Agriculture and Biology.* The Iowa State University Press, Ames, Iowa, U.S.A.

SPRINGELL, P.H. (1974) The cattle tick in relation to animal production in Australia. *World Anim. Rev. (F.A.O.) 10:* 19.

TANEJA, G.C. (1958) Cutaneous evaporative losses. *J. Agric. Sci. 50:* 73

TANEJA, G.C. (1959) Cutaneous evaporative losses. *J. Agric. Sci. 52:* 50

TAYLOR, C.R. (1970) Dehydration and heat: effects on temperature regulation of E. African ungulates. *Amer. J. Physiol. 219:* 1136.

TAYLOR, C.R., ROBERTSHAW, D. and HAFMANN, R. (1969) Thermal panting: a comparison of wildebeest and Zebu cattle. *Amer. J. Physiol. 217(3):* 907.

THOMPSON, G.E. (1973) Review of the progress of dairy science climatic physiology of cattle. *J. Dairy Res. 40:* 441.

THOMPSON, G.E. (1976) Principles of climatic physiology. In: Beef Cattle Production in Developing Countries, ed. A.J. Smith, University of Edinburgh, Edinburgh.

THOMPSON, R.D., JOHNSTON, J.E., BREIDENSTEIN, C.P., GUIDRY, A.J., BANERJEE, M.R. and BURNETT, W.T. (1963) Effect of hot condition on adrenal, cortical, thyroid and other metabolic responses of dairy heifers. *J. Dairy Sci. 46:* 227.

THOMPSON, H.J., YECK, R.G., WORSTELL, D.M. and BRODY, S. (1954) The effect of wind on evaporative cooling and surface temperature in dairy cattle. *Res. Bull. Mo. Agric. Exp. Sta. No.548.*

TURNER, H.G. (1962) Effect of clipping the coat of performance of calves in the field. *Aust. J. Agric. Res. 13:* 180.

TURNER, H.G. and SCHLEGER, A.V. (1958) Field observations on associations between coat type and performance in cattle. *Proc. Aust. Soc. Anim. Prod. 2:* 112.

TURNER, H.G. and SCHLEGER, A.V. (1960) The significance of coat type in cattle. *Aust. J. Agric. Res. 11:* 645.

ULBERG, L.C. and BURFENING, P.J. (1967) Embryo death resulting from adverse environment on spermatozoa or ova. *J. Anim. Sci. 26:* 571.

VERCOE, J.E. (1970) The fasting metabolism of Brahman, Africander and Hereford x Shorthorn cattle. *Br. J. Nutr. 24:* 599.

VERCOE, J.E. and FRISCH, J.E. (1970) The effect of increased rectal temperature on notrigen metabolism in Brahman cross and Shorthorn x Hereford steers fed on a low nitrogen roughage. *Aust. J. Agric. Res. 21:* 857.

VERCOE, J.E. and FRISCH, J.E. (1972) Apparent digestibility, nitrogen utilization, water metabolism and heat tolerance of Brahman cross Africander cross and Shorthorn x Hereford steers. *J. Agric. Sci. Camb. 79:* 71.

VOHNOUT, K. and BATEMAN, J.V. (1972) Effects of crude fibre upon feeding efficiency of cattle in 'warm' environments. *J. Agric. Sci. Camb. 78:* 413.

VON EULER, C., HERRERO, F. and WEXLER, I. (1970) Control mechanisms determining rate and depth of respiratory movements. *Resp. Physiol. 10:* 93.

WAITES, G.M. (1962) The effect of heating the scrotum of the ram or respiration and body temperature. *C.S.I.R.O. Quarterly J. Exp. Physiol. 47:* 314.

WAITES, G.M.H. and MOULE, G.R. (1963) Relation of vascular heat exchange to temperature regulation in the testis of the ram. *J. Rep. Fert. 2:* 213.

WAITES, G.M.H. and VOGLMAYR, J.K. (1962) Apocrine sweat glands of the scrotum of the ram. *Nature, London 196:* 965.

WALKER, C.A. (1957a) The skin thickness of cattle in Northern Rhodesia. *J. Agric. Sci. 49:* 211.

WALKER, C.A. (1957b) Studies of the cattle of Northern Rhodesia. II. The apocrine gland population of skin of NOrthern Rhodesian cattle and its connexion with the heat toleration co-efficient. *J. Agric. Sci. 49:* 401.

WALKER, C.A. (1960) The population morphology and evolutionary trends of apocrine glands of African indigenous cattle. *J. Agric. Sci. Camb. 55:* 123.

WARREN, W.P., MARTZ, F.A., ASAY, K.H., HILDERBRAND, E.S., PAYNE, C.G. and VOGT, J.R. (1974) Digestibility and rate of passage by steers fed tall fescue, alfalfa and orchard grass hay in 18^{o} and 32^{o}C ambient temperatures. *J. Anim. Sci. 39:* 93.

WEBSTER, A.J.F., CHLUMECKY, J. and YOUNG, B.A. (1970) Effect of cold environments on the energy exchanges of young beef cattle. *Can. J. Anim. Sci. 50:* 89.

WEBSTER, A.J.F., and PARCK, C. (1967) The effect of jute coats on the heat losses of two breeds of sheep exposed to different environments. *Anim. Prod. 9:* 483.

WEINER, J.S. and HELLMAN, K. (1960) The sweat glands. *Biol. Rev. 35:* 141.

WHITTOW, G.C. (1962) The significance of the extremities of the ox *(Bos taurus)* in thermoregulation. *J. Agric. Sci. 58:* 109.

WHITTOW, G.C. (1965) The effect of hyperthermia on the systemic and pulmonary circulation in the ox *(Bos taurus)* *Quart. J. Exp. Physiol. 50:* 300.

WHITTOW, G.C. (1970) *Comparative Physiology of Thermoregulation 1.* New York Academic Press.

WHITTOW, G.C. (1971) Cardio-acceleration in the ox *(Bos taurus)* during hyperthermia. *Res. Vet. Sci. 12:* 495.

WHITTOW, G.C. and FINDLAY, J.D. (1968) Oxygen cost of thermal panting. *Amer. J. Physiol. 214:* 94.

WILLIAMS, J.S., SHRODE, R.R., LEIGHTON, R.E. and RUPEL, I.W. (1960) A study of the influence of solar radiation on physiological responses of dairy cattle. *J. Dairy Sci. 43:* 1245.

WORSTELL, D.M. and BRODY, S. (1953) Clmparative physiological reactions of European and Ihdian cattle to changing temperature. *Res. Bull. Mo. Agric. Exp. Sta. NO.515.*

YASSEN, A.M. (1977) Respiratory responses of N'Dama and Boran cattle to climatic conditions in Nigeria. *World Rev. Anim. Prod. 8(2):* 33.

YEATES, N.T.M. (1955) Seasonal changes in coat character and their importance in heat regulation. *Aust. J. Agric. Res. 6:* 891.

YEATES, N.T.M. (1958) Observations on the role of nutrition in coat shedding in cattle. *J. Agric. Sci. Camb. 50:* 110.

YEATES, N.T.M. (1965) *Modern Aspects of Animal Production.* Butterworths, London.

YEATES, N.T.M. (1977) The coat and heat retention in cattle: studies in the tropical maritime climate of Fiji. *J. Agric. Sci. Camb. 88:* 223.

YEATES, N.T.M., EDEY, T.N. and HILL, M.K. (1975) *Animal Science, Reproduction, Climate, Meat, Wool.* Pergamon Press, London.

YEATES, N.T.M. and SOUTHCOTT, W.H. (1958) Coat type in relation to cold adaptation of cattle. *Proc. Aust. Soc. Anim. Prod. 2:* 102.

YOUNG, B.A. (1975) Effects of winter acclimatization on resting metabolism of beef cows. *Can. J. Anim. Sci. 55:* 619.

YOUNG, B.A. (1975) Temperature-induced changes in metabolism and body weight of cattle *(Bos taurus)*. *Can. J. Physiol. Pharmacol. 53:* 947.

YOUSEF, M.K. and JOHNSON, H.D. (1966a) Blood thyroxine degradation rate of cattle as influenced by temperature and feed intake. *Life Sciences 5:* 1349.

YOUSEF, M.K. and JOHNSON, H.D. (1966b) Calorigenesis of dairy cattle as influenced by thyroxine and environmental temperature. *J. Anim. Sci. 25:* 150.

YOUSEF, M.K. and JOHNSON, H.D. (1966c) Calorigenesis of cattle as influenced by growth hormone and environmental temperature. *J. Anim. Sci. 25:* 1076.

YOUSEF, M.K. and JOHNSON, H.D. (1967) Calorigenesis of cattle as influenced by hydrocortiso and environmental temperature. *J. Anim. Sci. 26:* 1087.

YOUSEF, M.K. and JOHNSON, H.D. (1967) A rapid method for estimation of thyroxine secretion rate of cattle. *J. Anim. Sci. 26:* 1108.

YOUSEF, M.K., ROBBERTSON, W.D., JOHNSON, H.D. and LAHN, L. (1968) Effect of ruminal heating on thyroid function and heat production of cattle. *J. Anim. Sci. 27:* 677.

OTHER REFERENCES

BENNETT, J.W. (1964) Thermal insulation of cattle coats. *Proc. Aust. Soc. Anim. Prod. 5:* 160.

BENNETT, J.W. and HUTCHINSON, J.C.D. (1964) Thermal insulation of short lengths of Merino fleece. *Aust. J. Agric. Res. 15:* 427.

BIANCA, W. (1962) Tolerance to severe heat and the integument of respiratory minute volume in cattle. *Nature (London) 195:* 1208.

BIANCA, W. (1966) The impact of the atmospheric environment on the integument of domestic animals. *Proceedings of the 14th Biomet. Congress, Rutgers University 83.*

DOWLING, D.F. (1955b) The thickness of cattle skin. *Aust. J. Agric. Res. 6:* 776.

DOWLING, D.F. (1958a) The significance of sweating in heat tolerance of cattle. *Aust. J. Agric. Res. 9:* 579.

BRODY, S. (1945) *Bioenergetics and Growth.* New York: Reinhold Publishing Corporation.

FINELLE, P. (1974) African animal trypanosomiasis, Part 4. *World Anim. Rev. (F.A.O.) 16:* 15.

FOURINE, P.C. (1964) The influence of ambient temperature on serum and extracellular fluid volumes in Africander and Shorthorn cattle. *Pro. S. Afric. Anim. Prod. 3:* 146.

GAGGE, A.P., STOLWIJK, J.A.J. and NISHI, Y. (1971) An effective temperature scale based on a simple model of human physiological regulatory response. *Ashrae Transactions 77:* 247.

JOHNSTON, L.A.Y. (1969) The effect of cattle tick *Boophilus microplus* on production of Brahman cross and British breed cattle in Northern Australia. *Aust. vet. J. 45:* 175.

JOHNSTON, J.E., HAMBLIN, F.B. and SCHRADER, G.T. (1958) Factors concerned in the comparative heat tolerance of Jersey, Holstein and Red Sindhi-Holstein F_1 cattle. *J. Anim. Sci. 17:* 473.

KAMAL, T.H. (1964) Physiological reactions of cows to hot environmental conditions. *In*: Radioisotopes in animal nutrition and physiology. Symp. FAO. IAEA Prague 23.

KERSLAKE, D. McK. (1972) *The stress of hot environment.* University Press, Cambridge.

KING, C.T. (1978) Thesis for Degree of M.Agr.Sc., Massey University, Palmerston North.

LEVIN, R.J. (1969) Review. The effects of hormones on the absorptive, metabolic and digestive functions of small intestine. *J. Endocr. 45:* 315.

MONTEITH, J.L. and MOUNT, L.E. (1974) *Heat loss from animals and man. Assessment and control.* Butterworths, London.

MURRAY, D.M. (1964) A field study of coat shedding in cattle under conditions of equal day-length but different temperatures. *J. Agric. Sci., Camb. 65:* 295.

OLBRICH, S.E., MARTZ, F.A. and HILDERBRAND, E.S. (1973) Ambient temperature and ration effects on nutritional and physiological parameters of heat and cold tolerant cattle. *J. Anim. Sci. 33:* 655.

PAYNE, W.J.A. (1955) Some effects of improved management on dairy cattle in the tropics. *Anim. Breed. Abstr. 23:* 1.

PAYNE, W.J.A. (1969) *Problems of the nutrition of ruminants in the tropics: Nutrition of animals of agricultural importance. Part 2.* Ed. Sir David Cutherbertson, Pergamon Press Ltd, London.

TANEJA, G.C. (1960) Sweating in cattle. VI. Density of sweat glands and its relationship with cutaneous evaporation. *J. Agric. Sci., Camb. 55:* 109.

TAYLOR, C.R., SPINAGE and LYMAN, C.P. (1969) Water relations of waterbuck an East African antelope. *Am. J. Physiol. 217:* 630.

TURNER, H.G. (1975) Breeding of beef cattle for tropical Australia. *Aust. Meat Res. Rev. 24.*

TURNER, H.G., NAY, T. and FRENCH, G.T. (1962) The hair follicle population of cattle in relation to breed and body weight. *Aust. J. Agric. Res. 13:* 960.

TURNER, H.G. and SHORT, A.J. (1972) Effects of field infestation of gastrointestinal helminths and of the cattle tick *Boophilus microplus* on growth of three breeds of cattle. *Aust. J. Agric. Res. 23:* 177.

VACCARO, L.P. de (1973) Some aspects of the performance of purebred and crossbred dairy cattle in the tropics. I. Reproductive efficiency in females. *Anim. Breed. Abstr. 41:* 571.

VACCARO, L.P. de (1974) Some aspects of the performance of European purebred and crossbred dairy cattle in the tropics. II. Mortality and culling rates. *Anim. Breed. Abstr. 42:* 93.

VACCARO, L.P. de (1975) Some aspects of the performance of European purebred and crossbred dairy cattle in the tropics. III. Growth, size and age at calving in Holstein-Friesians and other crosses. *Anim. Breed. Abstr. 43:* 493.

VERCOE, J.E. (1969) The effect of increased rectal temperature on nitrogen metabolism in Brahman cross and Shorthorn cross Hereford steers fed on lucerne chaff. *Aust. J. Agric. Res. 20:* 607.

WEBSTER, A.J.F. (1976) The influence of the climatic environment on metabolism in cattle. *In* Principles of cattle production Eds. Swan, H. and Broster, W.H., Butterworths, London.

WETTEMANN, R.P., WELLS, M.E., OMTREDT, I.T., POPE, C.E. and TURMAN, E.J. (1976) Influence of elevated ambient temperature on reproductive performance of boars. *J. Anim. Sci. 42:* 664.

YOUSEF, M.K., HAHN, L. and JOHNSON, H.D. (1968) Adaptation of cattle. *In* Adaptation of Domestic Animals Ed. E.S.E. Hafez, Lea and Febiger, Philadelphia.

YOUSEF, M.K., KIBLER, H.H. and JOHNSON, H.D. (1967) Thyroid activity and heat production in cattle following sudden ambient temperature changes. *J. Anim. Sci. 26:* 142.

Appendix 1

A general model for the analysis of variance for
a three-factor completely randomized design
(Fixed effects) After Guenther, 1964.

Source	SS	d.f.	MS	EMS	F value
Treat-ments					
A	SS_A	a-1	MS_A	$\sigma^2 + bcn \dfrac{\sum_{i=1}^{a} \alpha_i^2}{a-1}$	$\dfrac{MS_A}{MS_E}$
B	SS_B	b-1	MS_B	$\sigma^2 + acn \sum_{j=1}^{b} \dfrac{\beta^2}{b-1}$	$\dfrac{MS_B}{MS_E}$
C	SS_C	c-1	MS_C	$\sigma^2 + abn \sum_{k=1}^{c} \dfrac{\gamma_k^2}{c-1}$	$\dfrac{MS_C}{MS_E}$
AB	SS_{AB}	(a-1)(b-1)	MS_{AB}	$\sigma^2 + cn \dfrac{\sum_{i=1}^{a} \sum_{j=1}^{b} (\alpha\beta)_{ij}^2}{(a-1)(b-1)}$	$\dfrac{MS_{AB}}{MS_E}$
AC	SS_{AC}	(a-1)(c-1)	MS_{AC}	$\sigma^2 + bn \dfrac{\sum_{i=1}^{a} \sum_{k=1}^{c} (\alpha\gamma)_{ik}^2}{(a-1)(c-1)}$	$\dfrac{MS_{AC}}{MS_E}$
BC	SS_{BC}	(b-1)(c-1)	MS_{BC}	$\sigma^2 + an \dfrac{\sum_{j=1}^{b} \sum_{k=1}^{c} (\beta\gamma)_{jk}^2}{(b-1)(c-1)}$	$\dfrac{MS_{BC}}{MS_E}$
ABC	SS_{ABC}	(a-1)(b-1)(c-1)	MS_{ABC}	$+ n \dfrac{\sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{c} (\alpha\beta\gamma)_{ijk}^2}{(a-1)(b-1)(c-1)}$	$\dfrac{MS_{ABC}}{MS_E}$
Error	SS_E	abc(n-1)	MS_E	σ^2	
Total	SS_T	abcn-1			

Appendix I-a: Table of analyses of variance for location and height ambient temperature differences

Source of variation	d.f.	M.S.	F value
Location	4	4.62	14.00 *
Height	1	4.22	12.79 *
Error	4	0.33	
Total	9		

Appendix I-b: Analyses of variance for rectal temperature and respiration rate - Trial I-a

		Rectal Temperature		Respiration Rate	
Source of variation	d.f.	M.S.	F value	M.S.	F value
Breed	1	0.588	10.970 *	515.29	13.74 **
Temperature	1	5.290	98.694 **	13386.49	356.83 ***
Diet	1	0.009	0.175 NS	357.21	9.52 *
Breed x Temperature	1	0.423	7.892 *	72.25	1.96 NS
Breed x Diet	1	0.033	0.621 NS	29.16	0.78 NS
Temperature x Diet	1	0.070	1.306 NS	77.44	2.06 NS
Breed x Temp. x Diet	1	0.087	1.626 NS	5.76	0.15 NS
Error	8	0.054		37.52	
Total	15				

* $P<0.05$

** $P<0.01$

*** $P<0.005$

Appendix I-b$_1$: Analyses of variance for rectal temperature over the three periods during Trial I-a

Source of variation	d.f.	PERIOD I		PERIOD II		PERIOD III	
		M.S.	F value	M.S.	F value	M.S.	F value
Breed	1	0.85	31.48 **	0.54	8.31 *	0.32	5.33 *
Temperature	1	4.04	149.63 **	5.98	92.00 **	5.85	95.43 **
Diet	1	0.09	3.33 NS	0.08	1.23 NS	0.06	0.98 NS
Breed x Temperature	1	0.67	24.81 **	0.42	6.46 *	0.17	2.77 NS
Breed x Diet	1	0.01	0.37 NS	0.06	0.92 NS	0.08	1.31 NS
Temperature x Diet	1	0.003	0.11 NS	0.09	1.38 NS	0.23	3.75 NS
Breed x Temp. x Diet	1	0.07	2.59 NS	0.10	1.60 NS	0.16	2.61 NS
Error	8	0.027		0.065		0.06	
Total	15						

Appendix I-b_2: Analyses of variance for respiration rate over the three periods during Trial I-a

Source of variation	d.f.	PERIOD I		PERIOD II		PERIOD III	
		M.S.	F value	M.S.	F value	M.S.	F value
Breed	1	944.03	12.78 **	246.49	4.46 NS	419.23	6.88 *
Temperature	1	17802.23	241.06 **	13432.81	242.85 **	10490.88	172.11 **
Diet	1	865.10	11.56 **	443.10	8.01 *	91.68	1.50 NS
Breed x Temperature	1	2.03	0.027NS	108.16	1.95 NS	269.78	4.43 NS
Breed x Diet	1	32.20	0.44 NS	22.56	0.41 NS	33.35	0.55 NS
Temperature x Diet	1	18.71	0.25 NS	211.71	3.83 NS	222.76	3.65 NS
Breed x Temp. x Diet	1	47.27	0.64 NS	3.06	0.05 NS	2.64	0.04 NS
Error	8	73.85		55.31		60.96	
Total	15						

Appendix I-c: Comparative daily mean rectal temperature (°C) estimates

Calf No	Mean of 12 two-hour interval measurements	Mean of 2 measurements at 8 a.m. and 2 p.m.
F8	38.88	38.88
F1	38.95	38.82
F5	38.68	38.85
F3	38.89	38.92
B6	39.04	39.12
B2	38.88	38.80
B3	39.04	38.90
B4	38.99	38.92
B7	40.71	40.35
B1	40.40	40.20
B8	39.78	39.62
B5	39.18	39.05
F7	39.97	39.85
F4	40.90	40.72
F6	40.69	40.87
F2	40.58	40.22

Appendix I-d: Table of analyses of variance for coat cover weights

Source of variation	d.f.	M.S.	F value
Breed	1	5513.07	8.65 *
Temperature	1	2943.07	4.62 NS
Diet	1	9653.06	15.14 **
Breed x Temperature	1	2730.05	4.28 NS
Breed x Diet	1	637.56	0.99 NS
Temperature x Diet	1	473.06	0.74 NS
Breed x Temp. x Diet	1	95.07	0.15 NS
Error	8	637.69	
Total	15		

Appendix I-e: Analyses of variance for the clipping trial

		Rectal Temperature		Respiration Rate	
Source of variation	d.f.	M.S.	F value	M.S.	F value
Breed	1	0.002	0.027 NS	20.801	0.383 NS
Clipping	1	0.011	0.135 NS	11.801	0.216 NS
Breed x Clipping	1	0.015	0.197 NS	33.014	0.607 NS
Error	4	0.078		54.381	
Total	7				

* P<0.05

** P<0.01

Appendix II-a: Analyses of variance for the effect of radiant heat load

Source of variation	d.f.	Rectal Temperature		Respiration Rate	
		M.S.	F value	M.S.	F value
Radiation	1	5.0183	9.364 *	4110.70	7.476 *
Breed	1	3.7857	7.057 *	3629.64	6.600 *
Radiation x Breed	1	0.1496	0.279 NS	64.868	0.118
Error	8	0.5365		549.86	
Total	11				

* $P<0.05$

** $P<0.01$

Appendix II-b: Individual sweating rate (g/m^2 hr) and rectal temperature (°C) measured simultaneously under radiant heat load

Pair	RH %	Brahman X		Friesian	
		Sweating Rate	TR	Sweating Rate	TR
Pair One	40	184	38.95	58	40.60
	40	154	39.00	78	40.55
	52	155	39.23	63	41.10
	44	189	39.90	141	42.20
	55	172	38.98	93	40.95
	54	168	39.65	116	41.50
Pair Two	46	129	38.80	18	40.25
	46	145	40.20	22	41.25
	55	145	39.20	22	40.75
	45	130	39.88	25	41.50
	52	141	38.90	31	40.50
	46	144	39.50	26	41.25
	46	136	39.20	46	41.00
	50	126	39.32	37	41.45
Mean	48	151.3 ±5	39.33	55.4 (10)	41.06

±5

't' = 8.23 $P<0.005$ (d.f. 26)