STUDIES OF SOME EFFECTS OF HOT CLIMATIC CONDITIONS ON THE PERFORMANCE OF FRIESIAN AND SAHIWAL X FRIESIAN HEIFERS.

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ABSTRACT

Two Friesian heifers and two Sahiwal x Friesian (F1) heifer calves were subjected to 33°C air temperature in a climate chamber for 12 weeks. Another two pairs of calves were kept in a 'control' room maintained at 15.5°C ambient temperature. All heifers were fed hay during the first 6 weeks of the trial. A concentrate diet was fed the following 6 weeks. In each period, records were taken during the last four weeks only.

The measurements taken twice daily included, the voluntary intake of water (VWI) and feed (DMI); the rates of sweating (SWR) and respiration (RR); and the rectal temperature (TR)of each animal. Liveweight gain and growth rate of the hair coat were calculated from measurements taken at the beginning and at the end of each period.

The experiment was repeated using the same calves, but exchanged between temperatures. Concentrate feeding was carried out during the first half of Trial 2. Hay was then fed for the following 6 weeks.

The data were analysed using the multivariate analysis of variance technique for repeated measurements. The results indicated that high ambient temperatures increased significantly the rectal temperature, respiration rate and the voluntary intake of water by all calves. Intake of DM and DE were significantly reduced($P < 0.05$) by the exposure of calves to a hot environment. The rate of liveweight gain was reduced from 0.67kg/day at 15.5°C to 0.39kg/day at 33°C.($P < 0.05$)

The Sahiwal x Friesian heifers were less affected by hot conditions than were Friesians. They had significantly lower TR ($P< 0.05$) and drank comparatively less water than did the Friesian heifers on exposure to 33°C ambient temperature. Their RR was lower than that of the Friesians, however the interaction between the effects of ambient temperature and breed on RR, was not significant.

The greater heat tolerance of the Sahiwal x Friesian heifers as compared with that of their Friesian counterparts was associated with their faster rates of sweating. Greater rates of sweating were suggested to facilitate faster evaporative loss of heat from the body.

Of all the variables, DEI showed the greatest response to diet treatment factor. The heifers consumed more digestible energy, under concentrate feeding than when hay was fed. As a result, faster rates of LWG were achieved during concentrate feeding than during hay feeding. Further analysis demonstrated that the declines in DEI were responsible for the slow rates of LWG, achived on exposure of animals to high ambient temperatures.

The analysis of the growth rate of the hair coat indicated that exposures to cool conditions resulted in faster rates of growth of hair, than observed under hot conditions. The effect was probably associated with intake of dry matter. It was found, however, difficult to justify this suggestion because of the confounded effects of photoperiodicity.

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CHAPTER ONE

LITERATURE REVIEW

1.1 INTRODUCTION:

1.1.1 Effects of high ambient temperatures on the productivity of animals.

The effects of high ambient temperatures on the performance of animals have been reviewed in many papers. Many experiments, in both field and controlled environments, suggest that high ambient temperatures affect productivity of animals directly through effects on the physiology and metabolism of the animals (see reviews by Thompson 1973; Bianca, 1965; and Holmes, 1979). Of particular interest here are the changes in the intake and the metabolism of food energy, proteins and body fats which occur during exposure to hot conditions. Changes in the intake and metabolism of water have also been reported (Winchester and Morris, 1956). Production processes such as lactation, reproduction, growth and even survival of animals, have been reported to be threatened by exposure of animals to hot environments. Consequently, production of animals in the hot tropics is likely to be lower than achieved in the temperate climates,due to the effects of hot ambient temperatures.

The hot ambient temperatures often reported in the tropics also affect livestock productivity indirectly through their influence on the production and availability of quality pastures. Growth of pastures in the hot tropics is highly seasonal, with rapid growth rates during the rainy seasons. During the dry seasons, high ambient temperatures encourage lignification and maturation of the pasture crop. The standing herbage becomes fibrous and unpalatable; and often deficient in digestible energy,digestible proteins(Russel, 1966) and key minerals, particularly phosphorus nitrogen and sulphur (Brumby, 1974;Kemp,1978). The digestibility of this dry-season pasture declines rapidly, and makes it impossible for the animals to digest enough nutrients to maintain their body weight. The end results are that net production is affected. To avert these effects, pasture improvement in the tropics may be necessary to improve the productivity of animals in these regions.

Another indirect means through which hot climates affect the productivity of livestock is disease; particularly those associated with parasitic infestation. Parasites of major interest in the hot tropics, are the tick and the tse-tse fly which have made livestock production uneconomical or impossible in some areas in Africa. Finelle(1974) has for example, estimated that about 7 million square kilometers of (the 15 million km^2) land suitable for grazing in Africa ,is not utilised because of tse-tse fly infestation. Finelle (1974) observes that deforestration to control tse-tse flies alone, costs Nigeria about $4,200 per km^2 per year. The flies are carrier agents for trypanosomes responsible for 'Nagana' in the tropical Africa.

Ticks are, like tse-tse flies, responsible for great losses of animal products in the tropics. They contribute to unthriftiness and anaemia by exsanguination of animals. They cause damage to the hides, but most important of all, they harbour and transmit disease agents responsible for bovine anaplasmosis, babesioses, theilarioses and heart water. These diseases are widely spread in the hot tropics (see Bram, 1975). Springell (1974) suggests that tick diseases cause a loss of U.S. $8.50 per beast annually in the Australian economy. In the U.S.A., losses amounting to $98 would be achieved for every $1.00 less spent on tick control.(Bram and Gray, 1979).

The above effects associated with feed production and parasite population, suggest that the effects of hot ambient temperatures on the productivity of animals, are not simply of a direct cause and effect relationship. Hence improvement of animal productivity in the tropics needs consideration of the effects of hot ambient temperatures on the nutrition as well as the health of the animals.

1.1.2 Improvement of Productivity of Animals in Hot Environments.

Research workers have tried in different ways to improve the productivity of animals in the hot conditions. The techniques adopted have been

(1) to modify the thermal environment of the animal
(2) improve the quality of feed
(3) to improve productivity through cross-breeding

Reduction of heat load on animals in the tropics may be achieved by modification of the microenvironment, so that the effective ambient temperature is lowered. Provision of shades, use of water sprinklers, or wallows have been tried to reduce heat loads on animals, and hence improve production (Bond and Laster, 1975). Clipping of coats of animals has also been tried (Turner, 1962), however its practical value has not been rated. Provision of an adequate supply of water is an important aspect of livestock production in the hot climates. The success of the above techniques depends upon the financial costs, and are unlikely to be adopted in the tropics.Most farmers cannot afford to provide sufficiently clean drinking water to their animals.

To improve the quality of available feed, improvement of pastures may be necessary. Brumby,(1974) and Thomas (1973) have discussed measures of improvement of tropical pastures. It seems likely that the use of protein concentrates to improve the N content of daily rations may be necessary under these tropical conditions. These will not only improve the digestibility of feeds eaten but may also alleviate the effects associated with heat increments of the diets. The financial costs of concentrate feeding may retard the adoption of this technique in the most developing countries.

The third alternative to improve productivity of animals in hot environments is by crossbreeding. These results are likely to be adopted in the tropics, since they involve permanent changes in the genetical constitution of the animal. Crossbreeding in the tropics has had the objective of combining the qualities of heat tolerance of Bos indicus and the higher productive potential of Bos taurus. In tse-tse and tick areas, breeding and selection for tolerance to trypanosomes (Murray et al, 1979)and also to tick borne diseases (Hayman, 1974) have been tried. Successful programmes, have been reported in Kenya, and also in Australia.

Although success has been reported, very few papers have attempted to describe the physiological bases of heat tolerance or the disease tolerance of the tropical animals. Controversies have been noted where comparisons were made between performance of the two breeds of cattle (Turner, 1975).

1.1.3 Objectives:

The objectives of the present experimental study were therefore:-

a. to review the literature and discuss some physiological factors that may contribute to the heat tolerance of the Bos indicus animals.

   An experiment was carried out to compare some characteristics such as sweating rate, coat weight, and respiratory responses of Bos taurus and Bos indicus x Bos taurus crossbred heifers exposed to hot environment.

b. to study the effects of hot ambient temperatures on intake of dry matter by cattle of the two breeds. The responses in liveweight gain and water intake were also studied.

c. To study the effects of feeding concentrates instead of hay to animals exposed to hot environments. The purpose here was to compare responses to heat stress by animals fed hay or concentrate rations.

1.2 DRY MATTER INTAKE

1.2.1 Effects of hot conditions on intake of Dry matter.

1.2.1 1. Introduction

The effects of exposure to temperature above and below the comfort zone for animals have been discussed in many review papers (Balch, 1976; Baile and Forbes,1974; Thompson, 1973; Bianca, 1965). The most common and direct effect reported is the increase in the intake of food by animals in cold conditions and conversely, a decrease in the intake of food by animals in hot environments.

'Hot' and 'cold' are, however, relative terms with reference to the zone of thermal comfort for an individual. Consequently differences within and between classes, breeds and even species of animals are likely to be encountered. Some differences between animals in dry matter intake will be associated with feed characteristics; while some will depend upon the physiology and state of production of the animal.

The following review discusses some of these factors in relation with exposures of animals to hot conditions.

1.2.1. 2. Experimental evidence with Cattle.

Studies with cows (MacDonald and Bell, 1958), heifers (Colditz Kellaway, 1972; Kellaway and Colditz, 1975) and with steers (King, 1978) have demonstrated that feed intake decreases with increases in the ambient temperature.

Ragsdale *et al.*,(1948) studied the influence of increases in ambient temperature from 4^{o}C to 40^{o}C on feed intake by lactating cows and heifers. They observed that the animals exhibited some depression in appetite at 24^{o}C and a marked decline at 30^{o}C. Although some breed differences were noted, all animals virtually stopped eating at 40^{o}C. Johnson et al.,(1967) also reported similar results.

Table 1.2.1 summarizes some data reported in experiments in which feed intake by animals exposed to different temperature conditions were compared

TABLE 1.2.1: Dry matter intake by cattle under hot conditions.

Author	Class of Animal	Temperatures	DMI*	Temperatures	DMI*
Johnson et al., 1967	Holstein cows - lactating	15^{o}C	21.4	29.0^{o}C	15.6
Johnson et al., 1963	Holstein cows - lactating	18^{o}C	9.3	32.0^{o}C	6.3
Ragsdale et al.,1948	Holstein cows - lactating	15^{o}C	14.0	37.0^{o}C	0.5
Ragsdale et al.,1948	Holstein cows - lactating	15^{o}C	13.0	40.0^{o}C	1.0
Kellaway and Colditz 1975	Holstein heifers	20^{o}C	8.6	38.0^{o}C	3.5
King 1978	Friesian steers	16.9^{o}C	3.9	34.5^{o}C	2.6
Ragsdale et al.,1948	Jersey cows - lactating	15^{o}C	9.0	37.0^{o}C	1.0
Ragsdale et al.,1948	Jersey cows - lactating	15^{o}C	9.0	40.0^{o}C	2.0
Kellaway and Colditz 1975	Brahman X Friesian heifers	20^{o}C	8.1	38.0^{o}C	6.0
King 1978	Brahman X Friesian steers	16.9^{o}C	4.9	34.5^{o}C	4.1

1.2.1 3. Experimental evidence with Pigs - Other Species

The effects of ambient temperature on dry matter intake by pigs have been well demonstrated in reports by Heitman and Hughes,(1949); Fuller, (1965) and recently by Close and Mount, (1978); Close, (1978) and Close et al., (1978).

Heitman and Hughes, (1949) observed that feed consumption by pigs decreased as the air temperature was increased from 4^{o}C to 38^{o}C.

The decrease was more rapid (per unit of ^{o}C increase) at higher temperatures than at lower temperatures. Close and Mount, 1978, reported that intake of feed by pigs decreases with increases of temperature from 167.5g of food DM/kg$^{0.75}$per day at 10^{o}C, to only 103.9g of DM/kg$^{0.75}$per day at 30^{o}C. Close (1978), later demonstrated a significant quadratic relation between maintenance energy requirements and ambient temperature. This suggested that dry matter intake and maintenance energy requirements by pigs decreased with increases in the ambient temperature.

1.2.1. 4. Experimental evidence with Rats

Hamilton (1963) used male Sprague-Dawley rats to study the relationship between food intake, body temperature and ambient temperature. Food intake decreased as the ambient temperature was increased from 7^{o}C to 35^{o}C. The decrease in food intake per unit increase in the ambient temperature was greatest at temperature above 32^{o}C; (see Fig.1.1), and at 35^{o}C food intake was almost reduced to zero.

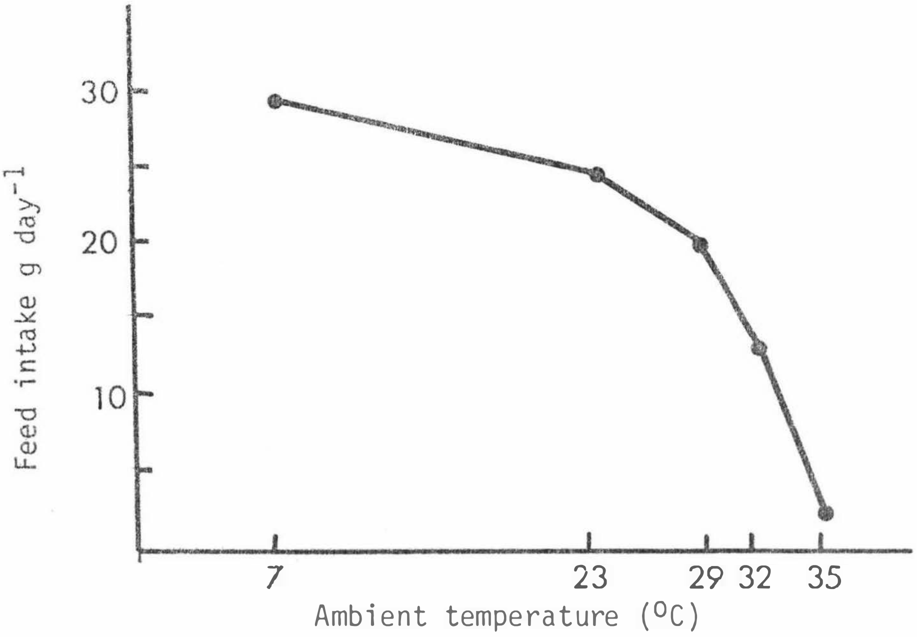

Figure 1.1: Food intake as a function of environmental temperature (Hamilton 1963)

1.2.1 5. Discussion of Effects

Most of the literature available (see review by Baile and Forbes, 1974) tend to suggest that elevation in the ambient temperature influences the intake of feed through systems which regulate energy balance in the animal.

When energy is ingested as food, at least part of it will be converted into heat as a result of the inefficiency of the metabolic processes - which occur when food is digested, or when the absorbed metabolites are converted into other biochemical compounds essential for the well-being or growth of the animal.

In cold conditions animals are forced to increase the rate of heat production by shivering or by non-shivering thermo-genesis (Holmes, 1979). In hot conditions, however, animals may find it difficult to dissipate all the heat produced in the body. Thus any additional input of energy through dietary consumption would further increase the heat load on the animal. In response, therefore, the animals decrease their intake of feed when exposed to stressful hot conditions.

In prolonged exposures, however, animals may develop some ability to preserve homeothermy and increase their feed intake. Early work reported by Johnson et al., (1967), clearly demonstrates this effect on dry Holsteins exposed to 29°C temperature conditions. Feed intake by these animals declined markedly (See Table 1.2.2) after exposure to 29°C. The least value of intake was reached during the second week of exposure. There was a gradual increase in intake thereafter, and a maximum stable value of intake was attained during the fourth and fifth week of exposure. The latter value of intake was however still lower than expected at 18°C.

TABLE 1.2.2 Average difference from expected values of intake at 18^{o}C for 10 lactating and 2 dry cows during heat exposure.(Johnson et al., 1967)

	Feed intake Kg/day for	
Weeks	Lactating	Dry
1	-5.4	-2.0
2	-4.9	-4.6
3	-3.1	-2.8
4	-2.3	-1.3
5	-0.8	-1.0
6	-1.4	-1.4
7	-2.5	-0.4
8	-2.1	-0.2
9	-2.4	-0.5

The results of these experiments, and of those reported by Hamilton, (1963) on rats, suggest that a period of at least 4 weeks may be required to establish the dry matter intake of an animal under heat stress.

The influence of hot day temperatures on the intake of dry matter by a grazing animal, may not be easily recognised over a period of time. Cowan (1975) demonstrated that on hot days, grazing cattle ate less dry matter than they did on cold days. Ehrenriech and Bjugstad, (1966) also showed a similar effect with cattle grazing tropical pastures. Mugerwa et al.,(1973),suggest that the effects of hot day temperatures on intake of dry matter and production by the animals are not often detectable because they compensate for the reduced day grazing by increased grazing at night. If animals were not allowed to graze at night, the effects of hot day temperatures could be severe.

1.2.2. Other factors which may influence the response in intake of food by animals exposed to hot conditions.

1.2.2. 1. Animal Factors.

1.2.2. 1.1. Breed:

Differences between breeds in dry matter intake at high ambient temperatures have been reported in early work by Ragsdale *et al*., (1950 , 1951) and recently by Kellaway and Colditz, (1975). The latter authors reported that feed intake by Friesians and Brahman X Friesian heifers were similar at 20°C, with successive increases in temperature (Table 1.2.3.) the feed intake and liveweight gain of Friesians were significantly reduced. The depression in intake associated with the increase in ambient temperature from 20°C to 38°C was much greater for the Friesian than for the Brahman, cross Friesian heifers which were used in this experiment.

TABLE 1.2.3 Responses of Friesian and Brahman X Friesian heifers to heat (Kellaway and Colditz, 1975)

Genotype	Friesian			Brahman X Friesian		
Temperature	20°C	30°C	38°C	20°C	30°C	38°C
Feed intake kg/100 KgBWT	2.9	2.4	1.9	2.7	2.6	2.2
Livewt.gain/day (g)	1180	730	280	1190	900	820
Water intake ml/KgBWT	86	244	252	68	138	174
Rectal temperature (°C)	38.6	39.8	40.3	38.4	38.9	39.3

King (1978) working with Friesian and Brahman X Friesian steers also observed significant reduction in dry matter intake from 4.28 kg/day per animal at 16.9°C to 3.00kg/day per animal at 34.5°C. Contrary to work reported by Kellaway and Colditz (1975), the interaction effects of temperature X Breed on intake in King's experiment did not reach significant levels; although the results did suggest higher intakes of dry matter by Brahman X Friesian than by the Friesian steers at 34.5°C.

King did not explain this discrepancy. It may, however, be suggested from Sauwa's work (Sauwa, 1978) that the Friesians accommodated a comparatively high dry matter intake at the expense of their body heat load. They exhibited higher rectal temperatures in the hot room than did the crossbred steers. The interaction of the effects of breed and air temperature on rectal temperature were in this case reported to be significant. ($P < 0.05$)

There is also a belief that Bos indicus cattle have a more efficient digestive system than Bos taurus animals. This stems from the observation reported by Howes *et al.*, (1963), that on low protein diets Brahman digested more protein and consumed more dry matter than Herefords.

Recent studies, (Vercoe, 1967; Colditz and Kellaway, 1972) have recorded no differences in the digestive efficiencies of these animals. In fact, after adjusting for the differences in intake, Kellaway and Colditz (1975) observed that the DM digestibility was similar for all breeds at different temperatures. Consequently differences between breeds in dry matter intake at high ambient temperature cannot be explained by the differences noted in dry matter digestibility.

O'Kelly (1973), reported an experiment in which cattle of different breeds showed no difference in DMI when their rectal temperature had been increased by the same amount. However, in order to get increases, for example, of 1.3°C in rectal temperature, it was necessary to raise the ambient temperature from 21°C to 33°C for Friesians, and from 21°C to 38°C for B.indicus counterparts

This suggests that it is the heat load in the body that limits further consumption of dry matter by animals exposed to hot conditions. The differences between breeds in dry matter intake which occur in response to exposures to hot conditions may probably be due to the genetic differences in mechanisms for heat dissipation.These differences are discussed in 1.5.2.

1.2.2. 1.2 Age and Weight of Animals:

Voluntary intake of feed dry matter is known to increase as the animal grows and gains weight. This concept stems from the fact that growth is associated with increases in body size, and hence increases in the metabolic requirements. McDonald et al., (1966) have suggested that energy required for maintenance, for example, increases linearly with increases in liveweight$^{0.73}$. To relate energy intake to bodyweight at different rates of weight gain, they developed a general equation that

$$I = aW^{0.73} + bG$$

where I is energy intake
W is liveweight
G is liveweight gain
a & b are coefficients for estimating the quantities of food energy used for maintenance (a) and for gain (b)

For a given diet, I increases with amount of feed eaten. The above equation suggests therefore, that, although the amount of dry matter consumed increases as the animal grows, it does not do so in a direct proportion to bodyweight or age. The above exponential relation is often met in literature; (Pickard et al.,1969) Bines et al., 1969). Normally the exponent is written as LW$^{0.75}$ for mathematical simplicity (McDonald et al., 1966).

There has been a considerable discussion about the actual value of the exponent to be used under different conditions of feeding, or for different classes of livestock. Holmes et al.,(1961),for example, observed that the dry matter intake by growing animals was linearly related to BW$^{0.62}$, rather than BW$^{0.73}$. Hodgson and Wilkinson (1967) reported a value of 0.61 for grazing heifers. Rogerson et al., (1968) reported that a value of 0.50 for the exponent could be used for Hereford cattle; but failed to show any linear relationship between liveweight$^{0.50}$ and dry matter intake by zebu cattle. Both Blaxter (1960) and Brierem (1960) have expressed their view that for growing ruminants, voluntary intake of dry matter increases with liveweight$^{0.60}$ rather than liveweight$^{0.73}$.

Recent work appears to suggest greater values for the exponent. Graham (1972) suggested that $BW^{0.90}$ was a more suitable unit of metabolic body size than either 0.73 or 0.75. Experiments reported by Playne (1978) have also indicated that intake of hay by both cattle and sheep was more closely related to $BW^{0.9}$ than with $BW^{0.75}$. Thus using the exponent 0.90 for liveweight, reduced species differences in dry matter intake than did the exponent 0.75.

It is suggested that the use of 0.73 exponent for weight should not be a dogma for comparison of intake between animals of different classes or species - unless it brings the least error in estimating intake by animals. The best relationship should be derived and tested for lack of bias for each class of cattle under study.

The effects of age on dry matter intake by animals have been discussed in the work reported by Langlands, (1968); Langlands and Hamilton (1969) and by Saubidet and Verde (1976).

Langlands (1968) estimated the voluntary intake of pasture dry matter by ewes ranging in age from 11 to 71 months. He observed a significant allometric relationship between intake and age of sheep.

i.e. $DOM/_{KgLW} = 0.246X + 0.00161X^2$

where X is the age in months.

Although the above work demonstrated breed differences, the influence of weight was not excluded from the equation. Subsequent work with cattle (Saubidet and Verde, 1976) indicated that DMI was more reliably estimated from age than liveweight of an animal. At the same age, liveweight differences, in this experiment, accounted for 43% of the variation in DMI. On the other hand; age differences accounted for 65% of variation in DMI by animals of the same weight. The equations were:

$$YW = -7.6095 + 0.1095W - 0.000161W^2 \text{ for weight}$$

and

$$YA = 19.8271 + 0.0990A - 0.00677A^2 \text{ for age}$$

Where

YW = DMI kg/day corrected for Liveweight

YA = DMI kg/day corrected for Age in weeks.

It is interesting to note that at a constant age, animals of the same breed and sex, but differing in liveweights consumed the same amount of feed per unit metabolic bodyweight. The lighter animals were suggested to have a more favourable energy balance than the heavier ones, owing to their lower maintenance requirements.

Levels of production and environmental demand for energy play an important role in determining intake of dry matter by mature animals. The influence of age on DMI by mature cattle is almost negligible (Journett and Remond, 1976).

1.2.2 1.3 Effects of Body Condition:

Intake of dry matter is related to body size as well as to body condition. The effects of body condition on intake of dry matter are probably well demonstrated under grazing conditions where dramatic changes in the body condition of cattle are likely to occur.

Work in laboratory conditions (Bines _et al_., 1970) has demonstrated that thin cows of low body condition scores consume more dry matter per unit of the body weight than do fat cows with high condition scores. Bines _et al_.,(1970) noted in an experiment that thin cows consumed 76% more hay and 52% more concentrates given per unit of metabolic body weight, than did fat cows consuming similar diets. The observations reported are summarised in Table 1.2.4.

In a previous work, Bines et al (1969), had suggested that the thin cows might have had higher rates of DMI, because of the greater rate of utilisation of the digestion products, particularly the lipogenic substrates, to replenish body fat in the thin cows. Bines (1970), later suggested that extensive fat deposition within the abdominal cavity (eg.mesenteric and omental fat) reduced the effective capacity of the cavity, and thus might have reduced roughage intake by the animals.

TABLE 1.2.4: Mean daily intake of Straw,hay and hay and concentrates by six cows when fat and when thin(Bines et al 1969)

Diet	Total daily intake of dry matter (kg)			Total daily intake of dry matter (g/kgBW$^{0.75}$)		
	Fat	Thin	Difference	Fat	Thin	Difference
Straw	3.6	3.4	-0.2	30.8	38.1	7.3
Hay	6.3	8.2	1.9**	50.9	89.7	38.8**
Hay + Conc	9.5	11.7	2.2**	74.1	112.6	38.5**

** The difference is significant $P < 0.01$.

The difference in intake of dry matter by animals differing in body conditions are likely to increase on exposure of the animals to hot conditions. This is due to the fact that both lipostatic and thermostatic mechanisms of control of intake will be operative in the fat animals. Having higher levels of body fat as well as energy balance, the animals in the fat condition will suffer the effects of heat stress more than will those in low body conditions. Body fat, particularly at subcutaneous level, acts as an insulator against heat exchanges; (1.5.6.1) and hence becomes a burden in hot environments.

1.2.2. 1.4 State of Production:

a. Pregnancy:

Pregnancy influences intake of dry matter by animals probably through its effects on the hormonal system and by reduction of the effective volume of the gut.

Penzhorn and Meintjes (1972), for instance, studied the dry matter intake of Africander heifers and cows and noted that feed intake increased from about the 32nd week precalving to the 8th week before calving. The DMI fell from then on. The lowest value for intake was recorded during the two week period before calving. After calving intake increased.

The increases in dry matter intake during the period between the 32nd & 8th week precalving, could be explained by the increased demand of nutrients for maintenance and growth of the foetus.

The decline in intake in the late pregnancy has also been reported in sheep (Forbes, 1968; Forbes, 1969). It seems logical to suggest that the effective gut volume may be reduced by the increased bulk of abdominal fat and uterine volume. No quantitative evidence has been provided for cattle to support this claim.

Moreover, Hunter et al.,(1970)have reported tenfold increases in urinary excretion of oestrogens as pregnancy progresses in animals.

Early work by Tarttelin (1968) and by Forbes and Rook (1970) demonstrated in goats that high levels of oestrogen content in blood depressed dry matter intake. O'Brien et al., (1968) and Bloss et al., (1966) also reported increased dry matter intake by oestrus heifers when their oestrogen secretion was suppressed by application of Melengesterol acetate (MGA).

It is apparent, therefore that the decline in intake in the late pregnancy may result from changes in the hormonal balance as well as from changes in the effective volume of the gut. The significance of these changes when oestrus or pregnant animals are exposed to heat has not been explored. The influence of oestrogens on intake of food by heat stressed animals are likely to be very small since oestrogen production is suppressed during heat stress (Abilay et al., 1975a).

b. Lactation:

Feed intake has often been observed to increase after parturition. Several workers (Curan and Holmes, 1970; Curan et al.,1970; Monteiro, 1972), have demonstrated significant relations between milk yield and energy intake. There is often a delay in the response of feed intake to the increased energy demand for lactation. While the maximum milk yield is reached is reached 5-8 weeks after calving, daily feed intake may reach its maximum value 8-18 weeks after calving. An average difference between peaks of seven weeks has been quoted for cattle.(Broster, 1972).

After the peak intake of feed is reached during a lactation, most data indicate a progressive decline in intake as lactation proceeds. (Gibb and Treacher, 1978). While these changes may be a result of reduced demand for lactation; under conditions of grazing changes in the quality of feed may also result in a reduced intake of feed by lactating animals.

1.2.2. 2. Feed Factors

1.2.2. 2.1 The Physical Form of Feed:

The properties used to describe the physical form of feed include the size of feed particles and rates of dilution in case of slurries. Forage can be supplied as fresh green feed or in the form of dried grass, hay, chopped, ground or pelleted.

Recent studies (Osuji et al., 1975; Thomson and Cammel, 1979) have demonstrated that chopping, grinding and pelleting of forage feeds improve the dry matter intake by animals. Osuji et al., (1975), for instance, measured the dry matter intake by sheep offered an equal amount (by weight) of forage of different particle sizes. (Table 1.2.5.) Intake was highest in sheep fed on dried and pelleted grass. It was observed that the high intake of pelleted feed was mainly due to its faster rates of consumption by sheep.

TABLE 1.2.5 Dry matter intake by sheep fed on different forms of forage. (Osuji et al., 1975)

Physical Form	Amount offered (g)	Intake DMI (g)	Rate of eating (g/min)	Chewing time % Total	Rumination time % Total
1. Fresh grass	860	240	4.4	7	12
2. Chopped and dried grass	860	848	10.5	18	24
3. Chopped,dried and Pelleted	860	884	33.5	7	16
4. Dried and ground	860	837	-	-	-

Alteration in the particles size not only changes the bite size but also changes the rates of passage of digesta from the rumen. Feed particles must be broken down (eg. by chewing and rumination) to sizes sufficiently small to pass through the orifices between compartments in the gut. The finer the particles the faster is the rate of passage.

Grinding and chopping help reduce the sizes of feed particles prior to consumption. Both processes reduce the time required for chewing and rumination,and also the amount of heat produced during eating (Osuji et al.,1975). These effects are of particular importance in hot environments where consumption of food is known to be limited by the level of heat being produced in the body.

1.2.2. 2.2 Nutritive Value of Feed

a. Digestibility of Dry Matter:

There is a lot of evidence which indicates that feed intake by animals increases as digestibility increases. Work reported by Blaxter et al., (1961) on sheep, and by Conrad et al., (1964) on lactating cows have demonstrated that feed intake is closely related to its apparent digestibility. Conrad et al., (1964) for example,showed in an experiment that intake of dry matter by cows (fed rations varying in digestibility from 52% ro 80%) increased linearly with increases in the percentage of the dry matter digested. After adjusting for the differences in the metabolic body weight they noted that DMI increased from 10kg/day at 52% to a maximum of 14.5kg/day at 66.7% digestibility. For rations with digestibility higher than 66.7% DMI corrected for the metabolic body size did not respond to increases in the digestibility. Conrad et al., (1964), suggested that up to about 66% DMD; the rate of passage from, and the amount of undigested material in the digestive tract determined feed intake. For digestibilites above 66% intake was thought to be determined by some factors of products and appetite of the animal rather than the physical limits of the gastro intestinal tract.

Stehr and Kirchgessner (1976) worked with cows grazing on pasture and reported a constant increase in intake over a range of digestibility from 64 to 84%. Their animals were estimated to have increased their herbage intake by 0.55kg DM for each increase of 1% in DMD. Hodgson (1968) also reported a linear relationship between digestibility and intake of pasture DM by calves over the range between 62% and 82% DMD. These observations suggest that the factors suggested by Conrad et al (1964),as above were not obvious under grazing conditions.

The relationship between DMD and DMI are further complicated by the observation that even plant fractions with the same digestibility may show differences in intake by animals. Osborn (1967), having analysed the digestible fraction of two strains of Timothy grass which were of the same digestibility, suggested that the difference in intake between the two strains was related to differences in their pepsin soluble carbohydrate content. Tilley et al., (1964) suggested that differences in intake of plant material with similar DMD could arise from the levels to which they reduce the rumen pH. More recently Kaufman (1976) studied the relation between the rumen pH and the DMD of feeds and observed a close relationship between pH and crude fibre (CF) % in the ration. The lower the CF % in the ration the lower was the rumen pH, and higher was the DMD.

It was therefore suggested that feeds with high DMD (eg. above 68%) will reduce the rumen pH to low levels (eg. 5.4-6.4 range), which may be suitable for starch degradation and subsequent production of propionic acid in the forestomach. Accumulation of this acid is associated with depressions in the intake of quality feeds by animals. Little advantage is therefore achieved in terms of intake by increasing the digestibility of feeds beyond 68%.

On the other hand, high roughage diets with low digestibility percent require much longer time for mastication and rumination. In the process, feed is well mixed with saliva; and an increase in the rumen of pH occurs as a result of reactions between saliva and the rumen acids. The value of the pH reached, varies between 6.0 and 6.8. This range is however optimal for cellulolytic bacteria activity. Therefore increases in the intake of dry matter are achieved on increasing the digestibility of high roughage diets. These increases will be noted as long as the activity of these bacteria is not affected (Kaufman,1976).

b. Digestible energy content

Dinius and Baumgardt (1970) draw attention to the significance of the relation between dry matter intake and energy concentration of feeds. The general observation reported (Baumgardt,1970) is that feed intake is increased with increases in digestible energy concentration to 2.5kcal/g for non lactating and growing animals;

and to about 2.7 kcal/g for lactating dairy cows.

Beyond these energy concentrations, DMI tends to decrease with increases in the digestible energy (DE) concentration of feed; the total digestible energy intake (DEI) being maintained at almost a constant level (Fig.1.2).

The influence of high ambient temperatures on these relations has not received much attention. Available data indicates significant depression in DMI, and hence gross energy intake by animals exposed to hot conditions. Recently King (1978) reported significant declines in DEI by animals exposed to 34°C;and early work (Kibler et al., 1966) had also reported that the digestibility percent of energy consumed is not changed by exposure of animals to high ambient temperatures. Vohnout and Bateman (1972) observed no significant interaction between diet and temperature, and therefore suggested that DMI and DEI by animals could be increased by proportionally increasing the caloric density of the ration.

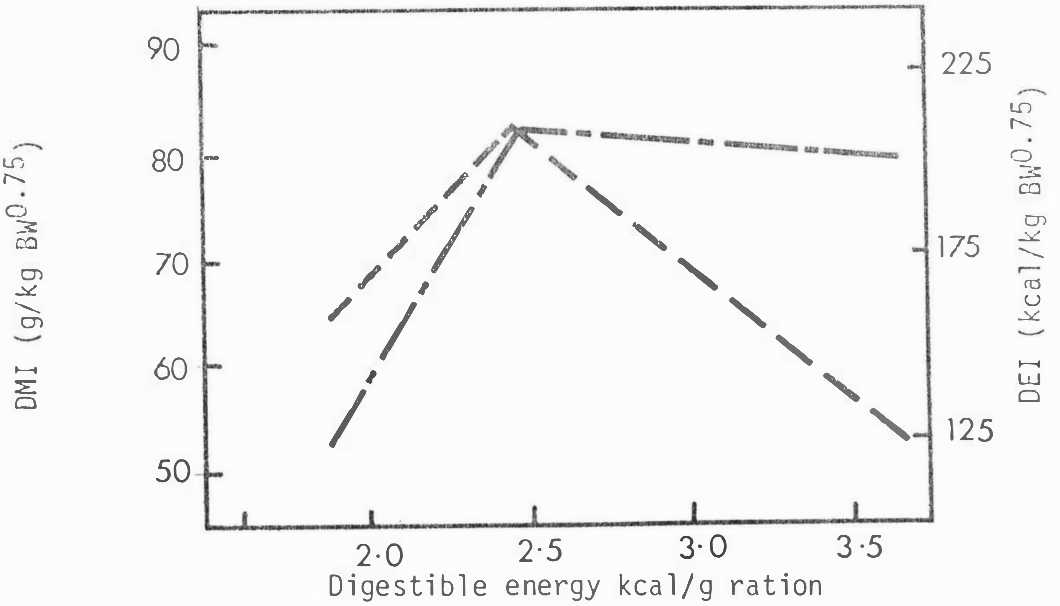

Fig 1.2 Dry matter intake (DMI) and Digestible Energy Intake (DEI) response of sheep when fed rations composed of basal concentrate mixture diluted from 5 to 50 percent at 5% increments with oak sawdust in 3% kaolin clay From:Dinius and Baumgardt(1970

This suggestion may be true for feeds with energy concentration less than 2.5kcal/g.(See Fig 1.2). It is unlikely that similar increases in DMI will be noted for feeds with caloric densities (DE) higher than 2.5kcal/g; since the total DEI is maintained at a constant value so that increases in DE concentration have an effect of decreasing the voluntary intake of feed. In fact both the inflection point and the slopes of the DMI and DEI indicated in Fig.1.2 might change on exposure of animals to hot conditions.

Thus, the relation between the caloric density of a ration and DMI by animals exposed to hot conditions requires intensive studies to determine caloric density at which DMI becomes limited by the energy concentration and not the physical limitations in the animal.

c. Nutrient Deficiencies in the diet:

The effects of imbalance or deficiencies in amino acids on intake of feed by non-ruminants have been studied extensively (Harper et al., 1970). Experimental work with sheep (Elliott, 1976b) have indicated that animals eat less of diets deficient in protein.

Feed intake has also been known to be depressed in ruminants fed diets deficient in calcium, (NRC 1963), potassium (Telle et al., 1964) sodium chloride, copper, cobalt and zinc (NRC 1963). Excess amounts of arsenic, molybdenum, zinc and Selenium are also known to depress intake possibly through their toxic effects on metabolic functions of the animal (Raymond, 1969). Similarly excessive levels of urea (eg. more than 45% of the ingested Nitrogen;Karue et al., 1973) and high levels of pasture fertilisation with N (Fernando and Carter, 1970) have been reported to reduce feed DMI.

It is difficult to determine the physiological importance of high N concentration in feed, as far as the depression in intake is concerned. It could involve low dry matter concentrations (Arnold, 1962) or changes in the palatability of herbage produced (Raymond and Spedding, 1965). It could also involve effects of high concentration of toxic nitrogenous compounds (Butler,1959) or the effects of low concentration of soluble carbohydrates in the forage matter (Bland and Dent, 1964).

Furthermore, there are cases where no significant depression of DMI by cattle could be obtained by high levels of fertilisation of pastures with N (Hight <u>et al</u>., 1968; Marten and Donker, 1964). Therefore no conclusive suggestion can be made about the effects of high levels of N in feed on its intake by a ruminant animal.

1.2.2. 2.3 Supplementation:

The poor roughages (straws and low quality hays) apart from their low digestibility values, are also usually deficient in protein. Supplementation of such diets with high protein concentrates will improve the DMI (Crabtree and Williams, 1971) through improved bacterial and protozoal cellulolysis in the rumen (Campling <u>et al</u>., 1962; Kaufman, 1976). The increased intake may be noted until the crude protein reaches 6-8% (Broster, 1973).

Supplementation of good quality forages with cereal-protein based concentrates will reduce intake of herbage (Langlands, 1970; Taparia and Davey, (1970).

For instance, Langlands (1969) studied feed intake by sheep supplemented with varying quantities of wheat. He noted that the . intake of dry matter by sheep increased with increases in the amount of supplement offered. The intake of organic matter from herbage was however noted to decrease. When the stocking rate was held at about 7 sheep ha^{-1}, herbage intake was reduced at a rate of 1.42 kg per kg of supplement offered. At a stocking rate of 58 sheep ha^{-1}, 2.86 kg of herbage were reduced per kg of supplement offered.

With dairy cattle, Taparia and Davey (1970) observed substitution rates of 0.6 to 0.7kg of herbage dry matter reduced per 1 kg of additional concentrate offered.

It is of interest to note that when concentrate feed is given ad libitum; animals will still eat the poor quality forage. Bines (1976) suggested that animals could voluntarily consume poor hay up to about 20% of their total DMI; when fed concentrates ad lib . Remond and Journett (1971) observed that cattle fed concentrates ad lib, still consumed the poor roughage which contributed up to 13% of their daily intake of dry matter. Thus 100% substitution of poor roughage by supplementation seems unlikely under grazing conditions.

1.2.2. 2.4 Interactions between the effects of type of animal and diet:

These have been recently studied by King (1978) who observed significant interactions between the effects of animal breed and feed type on DMI. The Brahman X Friesian calves used in this experiment had significantly higher DMI than the Friesian counterparts when fed on the concentrate ration and not when fed on hay alone. Although the DMD% and DE% did not show significant animal breed X diet interaction, the Brahman X Friesian calves had lower digestibilities than the Friesians when concentrates were offered. Thus the Friesians might have compensated for the DEI by improved digestibilities.

Arnold (1966) also found that weaner sheep ate (5.5g/kg) more DOM than adult sheep on pastures producing 55-80% digestible dry matter. The difference in actual DOMI of old sheep compared with young sheep decreased from 46% on a highly digestible pasture to only 3% on pastures of low digestibility. Arnold explained the relation between intake and digestibility differences to be associated with "growth surge" or "competence". No other physiological differences were thought to be associated with this drop in DOMI.

With respect to comparisons between sheep and cattle, (Playne,1978a) it has been suggested that the interaction (Animal X diet) could be associated with differences in ability to recycle nutrients to the rumen; and hence rumen microbial activity. Playne (1970) had reported that cattle digest low digestibility roughages better than do sheep, however with concentrate rations sheep seem to show superior digestive ability than cattle. Cipolloni et al., (1951) found significant animals species X feed interaction for the digestibility of crude protein in the case of dry roughages (i.e. cattle digest crude protein in some feeds significantly better than do sheep).

Jordan and Staples also compared the digestibility of hays by steers or lambs and noted that steers had higher DMD coefficients than sheep. Depending on the quality of pasture, the superiority ranged between 0.3% in early cut hay to 2.5% (medium) and 2.9% on late cut hay the differences were not significant. Similarly Harkess (1963) and Thomas and Campling (1977) failed to detect any real differences in digestibility of hays between sheep and calves. The latter (authors) suggested that, any differences, if noted, could be related to the differences in rumination behaviour between these species. However little is known about a possible physiological explanation for the difference between cattle and sheep. Due to the fact that sometimes one of these two species of ruminants is superior; and sometimes the other, Cipolloni et al., (1951)were convinced that their digestion coefficients could not be used interchangeably.

More recently Playne (1978b) examined the relationship between cattle and sheep in their ability to digest feeds with DMD below 60%. He observed that for these feeds the DMD(Y) by cattle was given by

$$Y = 0.673X + 20.3 \quad SE(b) = \pm 0.111$$
$$r = 0.843$$
$$Sy.x = \pm 3.41$$

where

Y = DMD % of hay when fed to cattle

X = DMD % of hay when fed to sheep

For feeds with DMD greater than 60% the following equation was recommended

$$Y = X + 2$$

where

Y is the digestibility estimate for cattle and

X is digestibility determined using sheep

Therefore the digestibility of a feed by cattle can be predicted from measurements of its digestibility by sheep, however hot conditions may affect the reliability of such predictions. Lippke (1975) for example, recently reported an increase in hay dry matter digestibility (DMD) by steers from 62.2% at 21°C to 67.5% at 32°C under similar conditions of treatment, sheep increased their DMD for hay from 62.7% to 62.8%. The increases within species were not significant.

1.2.3 Effects of high ambient temperatures on the metabolism of animals.

1. The contribution of the Gastro intestinal tract:

Metabolism in the gastro intestinal tract (GIT) is affected by high ambient temperature, through changes in the motility of the rumen. Exposures of cattle to 38°C for 5 days resulted in a significant decrease in the frequency and amplitude of rumen contractions (Atterbery and Johnson (1969). Atterbery and Johnson (1969) observed that the decrease in the rumen motility was not mediated indirectly by the level of intake since feed intake was kept constant by force feeding.

Although no evidence is given, Thompson (1973) has suggested that rumen motility may cease in hyperthermic animals. The ultimate effect however is a reduction in the transfer of digesta between compartments in the G.I.T. This impairs further consumption of dry matter.

It is suggested that changes in the pancreatic secretion (Aliev and Ashirov,1965)and thyroid activity (Miller *et al.*,1974) may be responsible for the reduction of rumen contractions in animals exposed to heat. Levin (1969) has suggested that the activity of both the pancreas and the thyroid affect movements of the G.I.T.

There is also some evidence indicating that rumen metabolism may also be affected by high ambient temperatures through changes in the rumen pH and ferementation process. Weldy et al., (1964) and recently Martz et al., (1971) reported significant decreases in the concentration of Volatile Fatty Acids, especially acetic acid, in the rumen liquor, Since acetic plays an important role in energy metabolism in ruminants (Baile and Forbes 1974); decreases of its concentration in the rumen are of physiological importance to the animals.

The proportion of acetic acid to propionic acid also changes in the rumen on exposure of cattle to high ambient temperatures (Kelly et al., (1967). Such a change has been reported to affect the fat content and composition of milk (Jorgensen et al., 1965). Mishra et al., (1970) have reported decreases in the pH of the rumen fluid of heat stressed cattle. This change in the pH was associated with increased levels of lactic acid in the rumen. Maintenance of a suitable pH is essential for the activity of micro organisms in the rumen. Brosberg (1957)for example, reported a complete abolition of the ability of the rumen content to consume oxygen with acidification below 7. This indicates that oxidation-reduction potential of the rumen may be reduced by exposure of animals to hot environments. This may consequently lead to a depression in intake of dry matter.

It seems, therefore, that high ambient temperatures affect dry matter intake by cattle through effects on rumen motility and on the fermentation process in the gut.

1.2.3. 2 Cellular Metabolism:

High ambient temperature conditions may depress intake indirectly through the influence of these conditions on the uptake and utilisation of metabolites by tissue cells. Tissues of major interest, as far as heat production and energy metabolism are concerned are the muscle cells, the adipose tissue and the liver.

Bell and Thompson (1976) showed increased uptake and oxidation of circulating energy substrates, notably free fatty acids, acetate and glucose, in the hind leg of an ox exposed to (0-4.5°C) cold condition. On exposure to hot condition, there is a general relaxation of the muscle. This may result in less consumption of oxygen and consequently a depression in substrate utilisation by muscle cells.

Increased uptake of gluconeogenic precursors and subsequent increase in the output of glucose by liver cells has been reported under severe cold conditions (Thompson and Bell, 1975). These increased rates of gluconeogenesis under cold conditions probably involve pyruvate carboxylase which is known to be activated by increased levels of CO-A derivatives of acetic, propionic and butyric acids (Keech and Utter, 1963). The production of these acids has been suggested in some experiments (eg. Kelley et al., 1967) to be depressed on exposure of animals to hot conditions. Thus the depression in the rates of glucose synthesis by body tissues may result as a response to the reduced activation of the pyruvate carboxylase.

The metabolism of the adipose tissue may also be severely affected by exposure of animals to hot conditions. Noble et al., (1973) for example, have reported that the metabolism of cholesterol may be severely reduced through depression of the activity of lypolitic enzymes required for cholesterol metabolism.

Heat stress may result in serious and irreparable damage to some tissues on animals exposed to severe heat. Hanneman et al., (1977) noted, in dogs exposed to 54.4°C for 30 minutes, some fragmentation of the myocardium. Acute necrosis of the kidney and marked degenerative changes in the cerebellum and cerebral cortex were also noted. The damages done to the brain were serious and considered irreversible.

Holmes, (1979) also reported a case of inco-ordination and a severe depression of appetite in a calf exposed to 42^{o}C for a few hours. Kellaway and Colditz (1975),also reported an apparent increase in muscle catabolism by heifers exposed to 38^{o}C temperature condition.

Other manifestation of the effects of hot conditions on the metabolism of animals mentioned in the literature include:

1. Changes in the RNA synthesis (Kellaway and Colditz, 1975).
2. Changes in the clotting properties of blood and the synthesis of albumin (Oratz _et al_., 1963)
3. Increased rate of excretion of nitrogen in the form of creatine and as urinary nitrogen (Ames and Brink, 1977; Kellaway and Colditz, 1975).
4. Increased excretion of Calcium and Potassium in the urine of animals exposed to hot conditions (Holmes and Grace, 1975), indicating affected mineral metabolism.

Many of these physiological and metabolic changes may be associated with disturbances of the endocrine systems, in response to changes in the temperature conditions of the environment. It is possible that these changes in metabolism may have an influence on food intake under hot conditions.

1.2.4 CONCLUSION

High ambient temperatures depress the voluntary intake of dry matter by animals. The effects are mainly associated with the need to control heat production, under these hot conditions. They generally involve a depression of hormone secretion, and under severe heats, degeneration of body tissues may be noticed.

The effects of temperature on dry matter intake may interact with the effects of animal or feed factors to cause variation in the intake of dry matter by animals. These factors have also been discussed in the review.

1.3 THE EFFECTS OF HOT ENVIRONMENTS ON INTAKE AND METABOLISM OF WATER

1.3.1 Introduction:

Water is an essential metabolite required for the maintenance of osmotic homeostasis of the body fluids. It offers a medium for biological transport and for biochemical reactions that are necessary for the survival of animals. Water helps in excretion of faecal residue and is of particular significance in evaporative cooling of the skin, or respiratory tract, when animals are exposed to hot environments.

Shebaita and Johnson (1972) measured the amount of water in cattle, and noted that body water represented about 73.5 ± 2.0% of the lean body mass. Roubicek (1969) also reported the same range in his review.

Body water arises from the intake in food, the catabolic processes at cellular level, and free water which is voluntarily ingested by animals.

Water losses from the body include

(a) Obligatory water loss from the respiratory tract and through the skin.
(b) Solvent water excreted in urine and faeces.
(c) Evaporative losses of water from sweat glands.
(d) Water lost in milk production.

Thus the mechanisms of body water control will involve mechanisms co-ordinating intake and output of water. The general aspects of compensatory drinking and body water control mechanisms have been exhaustively discussed in reviews by Anderson (1978), and Fitzsimons (1971,1972,1975).

The effects of hot ambient temperatures on the voluntary intake of water by animals have been discussed by Holmes (1979); Blaxter et al., (1959);Winchester and Morris (1956) and by Siebert and MacFarlane (1969). These authors report that, voluntary water intake by animals generally increases in hot environments.

1.3.2. Effects of hot conditions on intake of water:

1.3.2. 1.Evidence with Cattle

On exposure to high ambient temperatures animals increase their voluntary intake of water. Harbin et al., (1958) studied the influence of ambient temperature on the voluntary intake of water (VWI) by dairy cows. They observed that lactating cows increased their VWI by 0.58kg/100kgBW per unit°C rise in the ambient temperature between 10°C and 31°C. For the same range of temperatures, the dry cows increased their VWI by about 0.41kg/100kgBW per unit °C rise in ambient temperature. Kellaway and Colditz (1975) also reported that voluntary intake of water by heifers increased with increases in ambient temperature. Their results are presented in Table 1.3.1.

Cattle exposed to conditions of rising temperature may develop the habit of spilling water and sprinkling it over their body. (Ragsdale et al., 1951). This may result in falsely high figures for water consumption. Hence allowances must be made for spillage if this habit develops.

TABLE 1.3.1 Voluntary intake of water* by heifers exposed to 20°, 30°, and 38°C. temperature conditions.

	Temperature		
Breed	20°	30°	38°
Brahman x Friesian	68	138	174
Friesians	86	244	252

* VWI in ml/kgBW day

Source Kellaway and Colditz (1975)

1.3.2. 2 Other Species:

Mount et al., (1971) studied the effects of ambient temperature on VWI by young pigs (21 to 73kgBW) kept in chambers at various temperatures between 7° and 33°C. They observed little difference in water intake between 7° and 22°C; however the intake was considerably increased at 30°C and 33°C (ie. from 2.2 l/kg feed at 20°C to 5.0 l/kg feed at 30°C). Holmes (1973) also reported that pigs drank more water at 34°C (11.7kg/day)than at 25°C (6.3kg/day). Apparently this difference was not statistically significant.

Carlisle (1973) reported a direct linear relationship between water intake and ambient temperature in fasted rats exposed to temperature conditions varying between 5°C and 30°. For temperatures above 30°C an inverse relation was noted. Such a change in the effects of ambient temperature seems to be peculiar to this species of animals. Fitzsimons (1972) suggests in a review that rats do not replace their losses of body fluid in the heat unless food is available. This implies that food intake is a necessary factor for exhibition of thirst in some animals.

Discussion of the Effects

Three major points emerge from the experiments reported:

1. Voluntary intake of water by animals increases with increases in ambient temperature.
2. The increases are considerable at high ambient temperatures. (ie. higher than thermoneutral zone for a given class of animals).
3. The responses are greater when dry matter intake is increased.

It may therefore be summarised that the increases in the consumption of water by animals exposed to hot conditions depend upon the severity of heat load, and the amount of dry matter consumed.

The effects of heat load probably act through changes in the hypothalamic temperature. Andersson and Larson (1961) observed that local warming of the preoptic region and rostral hypothalamus caused a replete goat to drink, and prevented a hungry animal from eating. Local cooling of these areas caused reverse effects. Andersson and Larson therefore suggested that there are thermosensitive neurons in this area which activate the hypothalamic mechanisms concerned with regulation of water intake. Other work have indicated that sudden increases in the hypothalamic temperature activates vasodilation and panting in dogs (Hellstrom and Hammel, 1967). Sweating is also activated on warming the hypothalamus (Andersson et al., 1967) Thus increases in the intake of water on warming the diencephalon, probably occur to complement other mechanisms for heat dissipation. An increase in skin temperature may have similar effects on intake of water by animals. Grace and Stevenson (1971) noted that drinking in response to hot conditions, occurred before appreciable changes were noticed in the rectal temperature and in the state of dehydration of rats. It seems likely, therefore, that a change in the skin temperature, or stimulation of other thermosensitive regions in the body may cause increases in water intake by animals. Cattle are not exempted from these effects.

Increases in body temperature may also be associated with increased rates of evaporative water loss and respiratory activity (Blaxter et al., 1959). Increases in water turnover rates have also been demonstrated in sheep (Hopkins et al., 1978), and also in cattle and buffaloes (Siebert and MacFarlane, 1969). The latter authors also indicated that body water content of animals increased concomitantly with water turnover rates, as the ambient temperature was increased from 23^{o} to 38^{o}C. These changes in the balance of body water may impose a demand for increased intake of water. However, direct associations have rarely been reported between the increases in intake and losses of water from the body of 'hot' animals (McLean et al., 1971)

Hence, it is not justifiable to make general conclusions that losses of water, eg. by sweating, will result in direct increases in water intake.

An efficient thirst mechanism is however essential to ensure that water intake keeps pace with water loss from the body. Other authors (Wolf, 1968, Andersson and Larson, 1966), suggest that increased intake of water may also be stimulated by local dryness of the oral-pharyngeal membranes, changes in the volume of the vascular system, changes in the osmolarity of body fluids, and also the emotional state of the animal. Thus thermal stimulation is not the only way by which thirst mechanism may be activated.

1.3.3. Other factors which may influence intake of water by animals exposed to hot conditions.

1.3.3.1 Animal Factors

1.3.3.1.1. Species Differences:

In a study of species differences in the usage of water, Moran et al., (1979) observed that Brahman cross cattle drank 4.57 l/kgDM eaten, when the corresponding figures for the water buffaloes the banteng, and the Short horn cattle were 5.34; 4.75 and 5.17 l/kgDMI respectively. Although evaporative water loss was the same for all species, the bantengs had a significantly lower urine output than other species on exposure to hot environments. Differences between species in voluntary intake of water under hot conditions may involve their differences in their metabolic body size. Recent work on sheep (Degen, 1977); and camels (Schmidt-Nielsen et al., 1956) however, suggest that the differences between species in water intake are related to their genetic resistance to changes in the plasma volume.

In general animals adapted to hot desert conditions have lower water turnover rates than the more water dependent species. The latter, therefore show greater increases in VWI on exposure to hot conditions (MacFarlane and Howard, 1970).

1.3.3. 1.2 Differences between Breeds:

In studies with different breeds of cattle (Winchester and Morris, 1956 ; Kellaway and Colditz,1975; Siebert and MacFarlane,1969) it has been shown that the Bos indicus animals or their crossbreds have a lower consumption of water per unit of dry matter eaten than the B.taurus counterparts under similar conditions of ambient temperature. Winchester and Morris (1956) observed that intake of water (in kg/kgDMI) by both B.taurus and B.indicus cattle remained at a constant level between -12^{o}C, and 4^{o}C. Between 4 and 38^{o}C the intake increased at an accelerated rate. (Figure 1.3).) Under all conditions of temperature the B.indicus cattle drank less water per kg of dry matter consumed that the B.taurus.

The lower intake of water by the Bos indicus animals may be associated with their lower requirements for water when exposed to hot conditions. Phillips (1960) reported that water requirements for Zebu cattle was significantly less than for the grade Herefords.

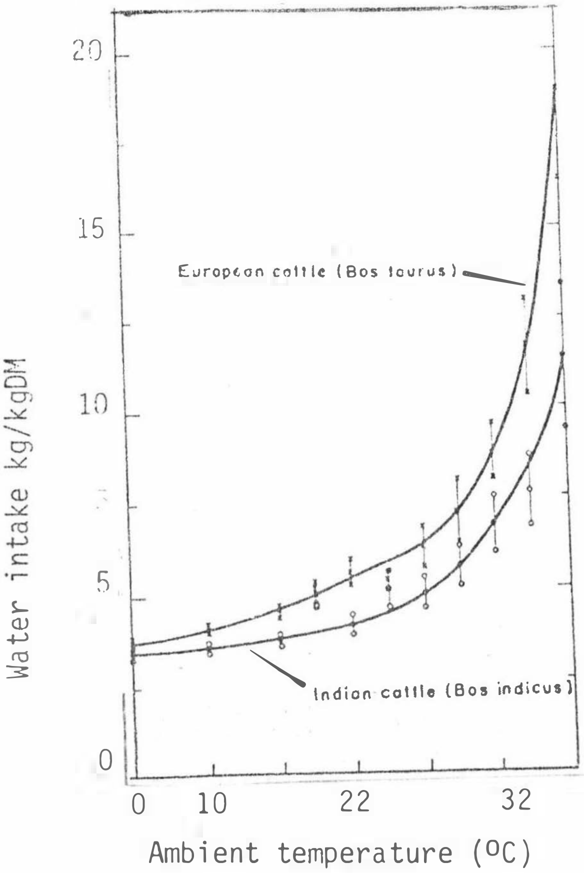

Fig 2: Water intake expressed as a function of dry matter & temperature Winchester and Morris, 1956.

McDowell (1972) suggested that heat tolerance differences between breeds of cattle may be involved in the variation in VWI by animals of different breeds. Thus the greater the heat tolerance, the smaller is the increase in VWI with increases in ambient temperature. In absence of heat stress no significant differences in intake of water is expected between cattle of different breeds, (Rogerson _et al_., 1968; Ledger _et al_., 1970).

1.3.3. 1.3 Body Size:

The voluntary consumption of water by animals also depends upon their metabolic body sizes.

Richmond et al., (1962) have suggested the use of $BW^{0.82}$, to describe the relation of most aspects of water metabolism to BW. This exponent is adopted in most literature reviewed, (MacFarlane and Howard , 1970; Springell, 1968). For the purposes of relating VWI to metabolic body size of cattle, this exponent will be used in this book.

Recent estimates made by Devendra (1976) indicate that most animals consume between 5 and 8% of their empty body weights of water. This estimate may be used in determining the least amount of water that should be offered to a non-lactating and non-pregnant animal under cool conditions.

1.3.3. 1.4 Lactation:

Lactating animals will have an increased demand for water intake to cater for milk production. An extra consumption of.87kg of water may be required for production of each kg of milk by animals (ARC 1965). Consequently, lactating animals will show higher intakes of water than non-lactating animals of similar metabolic body size (Little _et al_., 1976; Owen _et al_., 1968; Johnson _et al_., 1967).

Although there is a need to increase water intake by animals during lactation, available data indicate that milk production accounts for only a small part of the increases in water intake. Owen et al., (1968) demonstrated in an experiment that increases of water intake by lactating animals are primarily associated with the increased intake of dry matter. DMI accounted for over 50% of the variation in intake of water by animals while the influence of milk yield was associated with only 12% of the variations in VWI. On exposure to hot conditions, lactating animals have a tendency to increase VWI so long as their rectal temperature is maintained at a constant level. When their rectal temperature rises, gradual decreases in total water consumption may be noted. Johnson et al., (1963) suggested that this decrease in VWI by animals exposed to ambient temperatures high enough to cause a rise in the rectal temperature may be associated with decreases in milk synthesis by these animals.

Since milk synthesis and hence production are depressed at much lower temperatures than required to cause significant reduction in voluntary DMI by animals (Stanley, et al.,1975), it is suggested that depression in water required for milk synthesis may be noted, even before any significant changes in DMI are observed.

1.3.3. 1.5 Growth:

The process of growth requires a continuous supply of water in the body. Available data indicate that animals require about 5.4 to 7.5kg of water per kgDM eaten, during growth; but as the animal matures the ratio is reduced to about 3.5g/kgDMI.(Smith et al., 1965). Growing animals may show higher rates of metabolic activity hence higher rates of intake of water per unit of body weight may be required for the elimination of the metabolic waste products.

1.3.3. 1.6 Pregnancy:

Pregnancy may also affect water intake by animals. An increase in intake of water may be required to cater for the increases in the uterine liquid volume and for the growth and metabolic processes of the foetus.

An increase in VWI in pregnant animals becomes prominent during the last few months of pregnancy. Forbes (1968) reported that ewes carrying single or twin lambs had significantly higher intake of water than had the non-pregnant ewes in the 16th to 20th week period of pregnancy. At no time was there any significant differences in VWI between different litter sizes.

Forbes suggested that the greater water need of the pregnant ewes was due to greater heat production resulting from increased metabolic activity, and to greater urinary excretion.

1.3.3. 1.7 Activity:

Increased activity, both physiological and physical,raises the rate of heat production in the body. Not only is more water needed for dissipation of heat from the body, but also for the elimination of metabolic waste products which increase under these conditions.

1.3.3.2 Feed Factors:

1.3.3.2.1 Dry Matter Intake of Feed:

In studies with rats, Haack et al., (1975) demonstrated that water intake increased directly with increases in total dry matter consumed by the animals. In both normal and those with hereditary hypothalamic diabetus inspidus, it was shown that about 50% of the variation in VWI were associated with the quantity of feed eaten. Forbes (1968) also reported significant linear relationship between VWI and dry matter intake by non-pregnant ewes.

The work reported by Owen et al., (1968) on cattle suggested that about 50% of the variations in VWI by lactating cows was accounted for by variations in dry matter intake.

Available data indicate that farm animals require between 2.7kg to 3.6kg of water per kg of dry matter consumed under cool conditions. Krishna et al., (1976) reported that Zebu cattle consumed about 3.3 (range 3.01-3.63) kg of water per kg of dry matter consumed. Owen et al., (1968) had reported 3kg of VWI per kg of dry matter eaten by lactating cows. Devendra (1978) worked with sheep and reported rates of VWI ranging between 2.7 and 3.6kg per kgDM; a ratio of 1:3 of water to dry matter. A similar ratio was reported for growing pigs.
(Alcantara and Arganosa, 1975).

On exposure to hot conditions, the ratio increases at an accelerating rate. Winchester and Morris (1956) demonstrated the relation graphically (Fig.2). The increases in VWI under these conditions are probably due to the increased demand for heat dissipation.

1.3.3. 2.2 Crude protein Content of Feed:

Payne (1963) reported that increases in protein content of feed caused increases in VWI by cattle. Ritzman and Benedict (1924, cited by Bianca, 1965) also reported an experiment in which animals fed on high protein rations drank 26% more water than animals fed on low protein diets.

Recent work reported on sheep (Devendra, 1976) and on cattle (Krishna et al., 1976) suggest that decreases in water intake associated with lower levels of crude protein in the diet are small, and, in most cases, insignificant. This casts doubt about the influence of CP% of feed on the intake of water by animals. The increases are probably through increases in dry matter intake, rather than a direct effect of CP.

1.3.3. 2.3 Mineral Content of Feed and Water:

Increases in water salinity, (Wilson, 1975),dietary sodium chloride content (Morris and Gartner, 1971), or ruminal infusion with common salt solutions,(Ternouth and Beattie, 1971), have been shown to increase the voluntary intake of water by animals.

Studies with rats (Fisher and Buggy, 1975) indicate that higher salt intakes induce cellular dehydration which result in preference shifts towards water rather than further intake of salt solutions. Roubicek (1969) suggested that cattle may drink an additional 230 to 440ml of water per gram of salt ingested in feed containing 1-2% common salt.

1.3.3. 2.4 The Water Content of Feed:

Water in feed and the precipitation on forage may constitute from as low as 5-7% by weight of hay, to as high as 80% or more in young lush pastures. On consumption of feeds, therefore animals consume dietary water in amounts which depend mainly upon the percent content of water in the feed. This variable depends among many other factors upon the physical form of feed, plant part, seasons and the climatic regions in which the herbage is grown. For instance, it is estimated that a 350kg heifer consuming 8.75kg of dry matter from lush green pasture containing over 85% water, consumes about 50kg of water daily in the diet. This would suffice to cater for the daily requirement of water by this heifer had the requirements been based on figures presented by Waldo _et al_., (1965), and by Winchester and Morris (1956) for animals in environmental conditions with less than 21^{o}C. If , however, the forage had been made into hay, consumption of some free water would have been necessary to satisfy the demands of these animals since hay has less dietary water.

The importance of the effects of dietary water on the voluntary intake of water by animals have been demonstrated by Wilson (1962) and later on by Taylor (1968). Wilson noted that cattle grazing wet tropical pastures consumed less than 15% of their daily requirements as free water. During the dry season, the intake of free water was increased to about 58% of the total intake.

MacFarlane and Howard, (1970), also reported that sheep satisfied their daily requirements of water on grazing pastures containing 85% moisture. However, grazing had to be restricted to the cooler part of the day, or at night only. Thus declines in the voluntary intake of water are expected on consumption of feed with greater moisture content.

1.3.4. CONCLUSION

Free water intake by animals seems to be a factor of cellular dehydration, which may be caused by intake of hypertonic solutions or by excessive water loss associated with changes in the ambient temperature. Voluntary intake of water by animals may be increased in response to increased demand for production; however, the influence of dry matter intake by animals on their VWI appears to overshadow the demands for production; particularly when animals are exposed to hot conditions.

1.4 EFFECTS OF EXPOSURE TO HOT ENVIRONMENTS ON GROWTH OF ANIMALS

1.4.1 Introduction:

The increase in body weight over time tends to follow a characteristic ʃ shaped (sigmoid) curve pattern (De Torre and Rankin 1978). However the course of growth of an individual may be different from that observed in another due to their differences in genetical constitution, environment and management conditions provided. Of the environmental factors, several climatic conditions are known to affect growth and development of young animals indirectly through their influence on energy exchange and utilisation in the animal body. The direct effect of thermal conditions on growth may be due to their influence on the synthesis and production of growth hormone. Other effects may be associated with changes in the rates of biochemical reactions concerned with body building.

Many experiments conducted in controlled temperature conditions have demonstrated decreases in growth rate of animals exposed to high ambient temperatures. Foetal dwarfing, involving disproportionate growth of skeleton and other organs have been reported in heat stressed sheep (Alexander and Williams, 1971). Delays in physiological maturity, and reduced growth performance of sex cells, have been reported in heat stressed cattle (d'Alba and Riera, 1966; Bond and McDowell, 1972). The majority of experiments reported in literature have paid a lot of attention to the changes in liveweight gain by animals on exposure to hot conditions. All authors seem to come to a conclusion that liveweight gain increases as the ambient temperature is increased below the thermoneutral zone, but decreases with increases in the ambient temperature above the thermoneutral zone of a given animal.

1.4.2. Effects of high ambient temperatures on liveweight gain

1.4.2.1 Evidence with cattle:

The effects of exposure to hot conditions on the liveweight gain of calves have been illustrated in experiments carried out by Vohnout and Bateman (1972), Colditz and Kellaway (1972) and by Kamal and Johnson (1971). The results (summarised in Table 1.4.1) indicate that exposures in cattle from cool (15-20°C) to hot (33-40°C) conditions have an effect of decreasing liveweight gain of growing cattle.

Bonsma (1949) showed, in South Africa, that calves born to British breeds after pregnancy in summer had lower weights than of those born after winter pregnancies. This effect was not recorded in the local Africander cattle which were more heat tolerant than the British breeds. These observations suggest that hot conditions may reduce liveweight gain by cattle.

1.4.2.2. Evidence with other species:

Work on sheep (Brink and Ames 1975; Ames and Brink, 1977) and on pigs Heitman and Hughes, 1949) demonstrated decreases in liveweight gain of these animals when exposed to high ambient temperatures. Ames and Brink (1975) analysed some data involving 36 observations with lambs grown in a controlled environment. The mean temperatures ranged between -5°C and 35°C. They observed that the average daily gain (ADG) of lambs was related to temperature by a quadratic equation:

$$\text{ADG (g)} = 123.926 + 9.259T - 0.322T^2$$

where

T is ambient temperature in °C.

they observed that the quadratic relation was maintained when the analysis was carried out on data involving animals exposed to hot

TABLE 1.4.1 Liveweight gain (g/day) of calves exposed to Cool (15°-20°C) and to Hot (33-40°C) temperature conditions.

Animal	Feed	Cool(15-20°C)	Hot(33-40°C)	Reference
Friesian heifers	concentrate pellets	1180	280	1
Brahman x Friesian heifers	"	1190	820	1
Friesian steers	"	965	410	2
Friesian steers	hay	710	205	2
Brahman X Friesian steers	concentrate pellets	1200	905	2
Brahman X Friesian steers	hay	705	365	2
Friesian heifers	concentrate pellets	1180	590	3
Brahman X Friesian heifers	"	1060	670	3
Brahman heifers	"	960	670	3
Jersey bull calves	concentrates 2.7 Mcal/kgDM	520*	300*	4
	2.0 Mcal/kgDM	600*	360*	4

* Weight gain in g/100kg Body Weight

References:

1. Kellaway and Colditz (1975)
2. King (1978)
3. Colditz and Kellaway (1972)
4. Vohnout and Bateman (1972)

conditions (15-35°C) only. The new equation was

$$ADG(g) = 213.159 + 3.748T - 0.243T^2$$

For animals raised in the cooler conditions, the relationship was linear. In this case, the relation was described by

$$ADG(g) = 112.118 + 6.991T$$

Similar relationships were demonstrated in an experiment with pigs. Heitman and Hughes,(1949) maintained groups of pigs which had previously been acclimatised to 21°C in temperature controlled rooms, with ambient temperatures varying between 5°C and 40°C. The animals were fed ad libitum during the seven days of exposure. The results illustrated in figure 1.4,demonstrate clearly that there is a critical value of ambient temperature below which increases in ambient temperature are associated with increases in the liveweight gain of animals. Above this point, however, increases in the ambient temperature reduce liveweight gain of animals. It is therefore, suggested that increases of ambient temperature are likely to reduce liveweight gain if animals are exposed to temperatures higher than the upper critical temperature they need for maximum energy conversion efficiency (see 1.4.2.3)

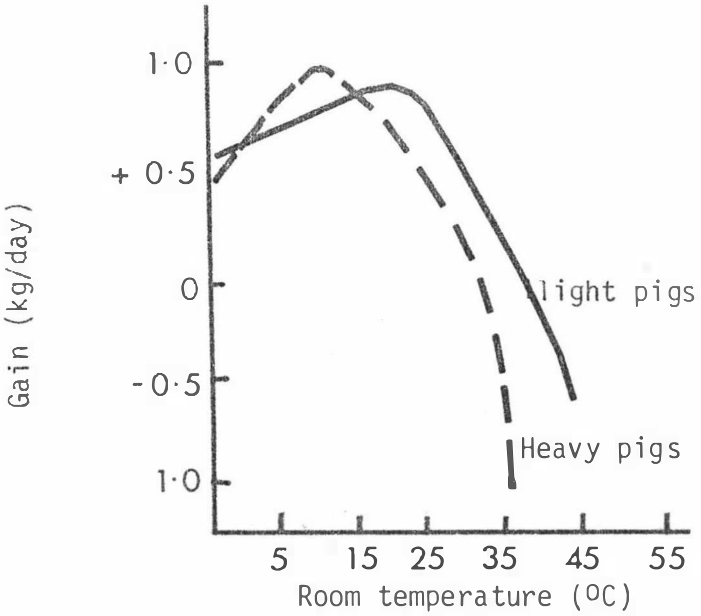

Figure 1.4: The effects of air temperature on weight gain of pigs. (From Heitman and Hughes, 1949)

1.4.2. 3 Discussion of the Effects:

The effects of hot conditions on growth of animals have been suggested by many authors (Bianca, 1965, Thompson 1973, Holmes, 1979) to include:

a) Changes associated with dry matter intake:
b) Changes in the metabolism of food nutrients, and also in metabolism of muscle and body fats:
c) Changes in the activity of the endocrine system.

a) Dry matter intake:

On exposure to hot conditions animals reduce their voluntary intake of dry matter and consequently decrease the amount of nutrients metabolised. These declines in the consumption of dry matter have been associated with the declines in LWG of animals exposed to hot conditions (Mendel et al., 1971; Holmes et al., 1980; King 1978).

Mendel et al., (1971) for example, reported an experiment in which growth rate was related to the average daily temperature to which cattle were exposed. Daily weight gain decreased linearly at a rate of 30g per $1^{o}C$ rise in the ambient temperature between $23^{o}C$ and $33^{o}C$. The dry matter intake declined at about $0.03kg/^{o}C$ rise in the ambient temperature. The authors suggested that changes in the DMI were responsible for the declines in the rate of liveweight gain.

To support this theory, Holmes et al., (1980), carried out an experiment with Brahman x Friesian, and Friesian steers. They noted that the two breeds had a similar intake of dry matter at $17^{o}C$. On exposure to $34^{o}C$ the Friesian steers consumed less feed; than did the Brahman x Friesians. The LWG of the two Friesian steers was observed to be lower than that of Brahman x Friesians at $34^{o}C$. On correcting for the differences in intake of DM, the difference noted in LWG between the two breeds disappeared. It was therefore suggested that the declines in the intake of dry matter were responsible for most of the declines reported for LWG on exposure of the two steers to 34^{O}C from 17^{O}C.

Other experiments have demonstrated that declines in the LWG on exposure of animals to hot conditions are not simply a consequence of reduction in DMI. Significant declines in LWG were reported in an experiment in which no appreciable decline in DMI had been observed by exposing heifers from 20^{O}C to an environment of 32^{O}C.(McDowell 1968). Since there was no change in the digestibility of DM, McDowall (1968) concluded that a portion of energy available for growth was used for combating the effects of heat stress at 32^{O}C.

Recent work such as those reported by Ames and Brink (1977), Fuller and Boyne (1971), Kellaway and Colditz (1975) and by Vercoe and Frisch (1970) have demonstrated that there are changes in the metabolism of food nutrients on exposure of animals to hot conditions. These changes are suggested to affect LWG so that on equivalent consumption of dry matter heat stressed animals may still show lower weight gains than will be observed in a thermoneutral environment.

b) Changes in the metabolism of Nutrients:

The effects of high ambient temperatures on liveweight gain of animals has been suggested above to be associated with changes in the metabolism of nutrients. The changes which have been reported, include, energy metabolism, nitrogen metabolism, metabolism of fatty acids, and metabolism of water. As will be seen later, these effects are also associated with changes in the activity of the endocrine system.

Available data (Vercoe and Frisch, 1970; Vercoe 1969; Colditz and Kellaway, 1972) suggest that LWG may be affected by high ambient temperatures through a disturbance in the metabolism and retention of nitrogen in the body. Vercoe and Frisch (1970) reported increased urinary excretion of N in heat stressed heifers. In an earlier paper, Vercoe (1969) had demonstrated that the urinary losses of N occurred even when food intake was controlled. This indicated, therefore, that the increased urinary excretion was not due to the declines in energy intake (Broster,1973; Crampton 1964). The observation reported later by Colditz and Kellaway (1972) that both urinary excretion and plasma concentration of creatinine were increased on exposure of animals to hot conditions, suggested that muscle catabolism was involved.

Kellaway and Colditz (1975) demonstrated in another work that the concentration of RNA in the muscle was also reduced by exposing cattle to 38^{o}C. This suggested that the synthesis of proteins in the body is also affected by exposure of animals to hot conditions.

It seems therefore that hot conditions may affect LWG through their effects on consumption and retention of dietary nitrogen, and also through decreased synthesis of proteins in the body. Since proteins are essential metabolites for lean mass production, the depression of their synthesis or utilisation by the body may result in a reduced growth and development of young animals.

Weight losses have been reported even in cases where positive balance in N had been recorded (Shebaita and Kamal 1975; Kamal and Johnson, 1971). The latter authors demonstrated that body fat was also destroyed, so that declines in liveweight gain may still be noted even if no appreciable changes are noted in Nitrogen status of heat stressed animals.

Prolonged exposure of cattle to ambient temperatures high enough to cause increases in the rectal temperature has been associated with marked changes in total fatty acids (Noble, <u>et al.</u>, 1970) and lipid constituents of plasma. (O'Kelly 1973b). There is a general decrease in the concentration of total cholesterol and phospholipids; decreases in the alkaline phosphatase action; but increases in the ratio of free to total cholesterol. Non esterified fats and glucose levels seem to be unaffected by exposures of animals to hot conditions (Vercoe 1976; Noble et al., 1976).

O'Kelly (1973a) also reported increased excretion of fatty acids in the faeces of heat stressed calves, indicating reduced retention of fatty acids in the body. There is also some evidence indicating that cattle exposed to high ambient temperatures show decreased rumen activity (Atterbury and Johnson, 1969) and a decreased production of total volatile fatty acids (Weldy et al., 1964). The acids function as a readily available source of energy required by the animals for production (Noble,1978). These changes may affect the availability of energy and hence cause serious declines in the liveweight gain of growing or fattening cattle. The indirect significance of reduced levels of some of these components should also be mentioned. High cholesterol levels are important for the bulk supply of metabolically active cholesterol required for the production of steroid hormones. Of particular interest here are the progesterones which are essential for the development of gonadal ducts, the secondary sex characters and the maturation of reproductive cells.(Gordon,1972). Thus the effects of hot conditions on animals are not only important for weight changes, but also for the physiological maturation of an animal.

c) The Endocrine System:

Growth, like many other physiological processes in the body is subject to the influence of the endocrine system. The activity of the endocrine system is however greatly affected by hot conditions. Therefore, the declines in the growth rate, or the declines in the rates of converting food to body weight in heat stressed animals may in part be attributed to disturbances in the hormonal system. The direct effects could be through production and utilisation of growth hormones; while the indirect effects would be those associated with other hormones essential for animal metabolism.

Growth hormone

During prolonged exposure to hot conditions cattle have been observed to decrease the rate of secretion and utilisation of growth hormone. Mitra et al., (1972) for example, reported that growth hormone secretion by cattle was reduced from 16mg per day per animal at 18°C to .9mg per day per animal at 35°C. Yousef and Johnson (1970) suggested that declines in the secretion of Growth Hormone affect growth through its effects on energy metabolism and protein synthesis in the body.

Other hormones

Hot conditions may affect growth through the effects of these conditions on the synthesis, secretion, or degradation of other hormones by the body. Of particular interest are thyroid hormones and the steroids produced by the gonads and the adrenal medulla.

The hormones produced by the thyroids are important for all differentiation during growth, and also have a calorigenic action essential for the regulation of body temperature (Gordon 1972). Therefore, factors affecting production or utilisation of these hormones will ultimately affect growth and development of a young animal.

Declines in the production of thyroxine have been associated with declines in intake of dry matter ; however, even when the intake of feed is controlled, declines in the secretion and rate of degradation of this hormone may still be observed in heat stressed cattle (Johnson and Yousef, 1966). These declines in the level of thyroxine may therefore be responsible for some of the declines reported in the LWG of heat stressed cattle.

Androgen administration to male castrates has been reported to increase RNA formation and muscle weight in guinea pigs (Kochakian _et al_., 1964) and in intact rabbits (Grigsby,Bergen and Merkel, 1976). These experiments support an observation by Preston and Willis (1970),that heifers had lower LWG (cf bulls) because of their higher intake levels of oestrogens.Increased production of progesterones have been reported in heat stressed cows (Stot _et al_.,1967).These do cause delays in the oestrus of heifers as well as affect their growth rate.(Thompson _et al_., 1963).

Glucocorticoids and noradrenaline are known to affect growth through their catabolic effects on the adipose tissue in the body. Alvarez and Johnson (1970) and Thompson _et al_., (1963) reported increased excretion of these hormones in exposure of cows and heifers(respectively) to hot conditions. Although Thompson et al., (1963) did not show any relations between changes in weight gain and rates of secretion of corticosteroids, it is possible that some of the declines reported in LWG were due to the increased levels of corticosteroids.

Insulin production is important for the suppression of the catabolic effects of these hormones (Winegrad 1962).Kamal _et al_.,(1970) have indicated reduced plasma insulin concentration in dry cows exposed to high ambient temperatures. This suggests that the antilypolitic function of this hormone is reduced on exposure of cattle to hot conditions. The results are increased catabolism of body fats and hence a decline in mean LWG of growing or fattening animals.

In summary it is concluded that hot conditions affect LWG of cattle through the effects of these conditions on intake and metabolism of food. Growth may also be affected by high ambient temperatures through an influence on the endocrine system.

It should, however, be remembered that changes in LWG on exposure of animals to hot conditions may sometimes be difficult to detect since body water increases under these conditions (Kamal and Johnson,1971). It is therefore, likely that greater changes than normally reported occur; however, due to the associated increases in body water,only small changes may be observed.

1.4.3 Other Factors which may influence LWG of Animals in hot conditions.

Cattle may show differences in their LWG responses to hot conditions. These differences may be associated with genetic or physiological characteristics of animals. Of major importance to weight gain are differences associated with the breed, age, weight and sex of the animals exposed to hot environments.

1. Breed:

Mason, (1971) has given an extensive review of literature on growth of large cattle breeds in their relative and absolute growth rates at a given age or weight (Table 1.4.2). Moran (1973) has also reported significant differences between growth rates of Brahman, the Banteng, Short-horns (representing 3 species of Bovidae) when exposed to similar conditions of management.

TABLE 1.4.2 Growth rate of Steers of Various breeds in an Experimental farm at Omatjenne.(S.W.Africa) (From Mason 1971,)

Breed	WEIGHT /kg		
	8 months of Age	18 months	Estimated daily gain (kg)
Angus	150 kg	225 kg	0.25
Shorthorn	160 kg	235 kg	0.25
Sussex	175 kg	275 kg	0.33
Southdown	200 kg	300 kg	0.33
Brown Swiss	220 kg	330 kg	0.38
Simmental	225 kg	340 kg	0.38

On exposure of animals of different breeds to high ambient temperatures, significant differences in growth response may be noted. Some of these differences are illustrated in Table 1.4.1.In general, the growth rate of cattle which are well adapted to hot conditions, particularly those tropical in origin or their cross-breds, appear to be less affected than the temperate animals (Winks, *et al*., 1979) However, the absolute growth rate of these tropical animals (*B.indicus* mainly) may remain at a lower level than that recorded in the temperate (*B.taurus*) animals when exposed to similar conditions of ambient temperature (Frisch and Vercoe, 1978; Frisch 1976).

Colditz and Kellaway, (1972) compared the growth rate of Brahman, Brahman X Friesian and Friesian heifers when exposed to either 17°C or 38°C in psychometric chambers. They reported a 50% decrease in the growth rate of Friesians; and only about 30% for the Brahman heifers (Table 1.4.1).The difference was significant ($P < 0.05$). The cross-bred animals grew faster than any of the parent genotypes on exposure to 38°C.

Willis and Preston (1969) in Cuba, and Rudder *et al*., (1975) in Queensland, also demonstrated some superiority in growth performance of the cross-bred, *B.taurus* x *B.indicus* animal over the parental genotypes..

The superior performance of the cross-bred animals over their parental genotypes is probably associated with heterosis effects on growth. However,the relatively small decreases in the rates of growth of *B.indicus*, as compared with *B.taurus* has been explained by their differences in heat tolerance (Phillips, 1948; McDowell *et al.*, 1955; Rhoad, 1944). These authors, have demonstrated that *B.indicus* animals show higher heat tolerance than do *B.taurus*. The *B.indicus* X *B. taurus* cross-breds had intermediate heat tolerance coefficients, although some heterosis effects on tolerance have been demonstrated (Lee, 1965).

The success of *B.indicus* cattle in the harsh tropical climates has also been attributed to their resistance to tropical diseases. (Dally and Hall, 1955; Francis and Little,1964). Recently,Frisch (1976) has suggested that the difference between *B.taurus* and *B. indicus*, in their ability to cope with fluctuation in food supply may explain part of this superiority. He observed in a study that resistances to helminth infection, pink-eye, heat and fluctuations in feed supply; respectively accounted for 30%,20%,15% and 10% of the differences in growth performance. Thus low growth rates of *B.taurus* cattle when exposed to hot tropical conditions cannot be explained entirely by their low heat tolerance ability.

1.4.3. 1.2 Age and Weight:

Growth rates of animals is known to vary with age, (de Torre and Rankin, 1978; Brown *et al*., 1976) as well as with the weight of the animal. Brody, (1945) (cited by de Torre and Rankin, 1978) suggested an asymptotic curve such as demonstrated in Fig.1.5 The growth curve equation suggested was

$$W = A\{1-3^{-k}\,(t-t^{x})\}$$

where W is the Weight at age and t and t^x is the Origin of the curve.
A and k are constants, respectively describing the mature weight and rate of maturation of the animal

The growth rate$(\frac{\delta w}{\delta t})$ of the animal, therefore decays exponentially to zero as the weight matures exponentially to an assymptotic mature weight A.

On exposure to heat both the mature weight (A) and the rate of maturation (k) are depressed probably through the effects heat stress has on the metabolism of the animal. Bianca (1965),has reviewed study cases in which puberty was delayed by exposures to heat. Alba and Riera (1966) also reported significant depression in weight at puberty (A) of young bulls reared in hot conditions (35°C-36°C)vs (19°C-27°C). The animals in the hot conditions attained puberty when they were 6 weeks older and 11kg lighter than those in the warm conditions.

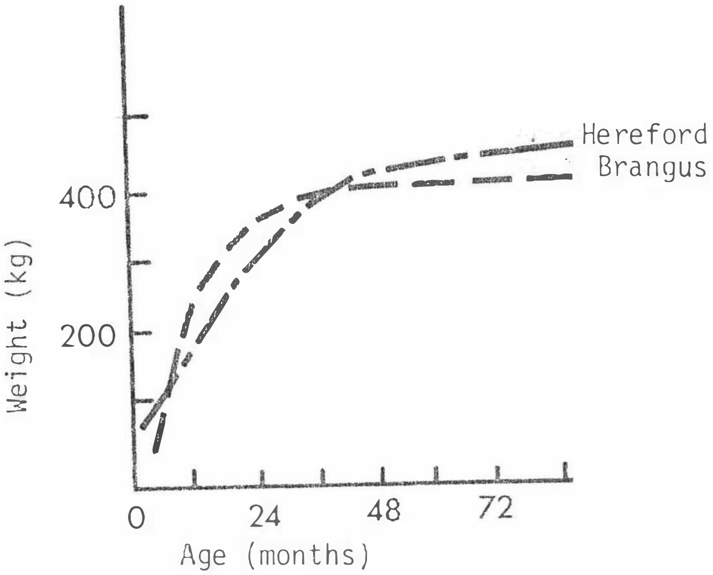

Figure 1.5 Growth curves of Hereford and Brangus heifers in New Mexico -Range environment (From Lopez de Torre,G.and Rankin,(1978).

1.4.3 1.3. Sex:

Bull calves appear to have much higher growth rates than heifers (Winks, et al., 1978) In some cases it has also been indicated that heritability of weights, weight gain and feed conversion efficiency are comparatively higher in bulls than when determined from records on heifers (Green and Carmon, 1977).

In an experiment where the effects of genotype and environment on variation in post weaning growth rate of Brahman calves were studied (Plasse and Verde, 1976), it was indicated that between 12 and 24 months of age, bull calves were superior to heifers in growth rate. Preston and Willis (1974) suggest little difference in the growth rate of calves of different sexes before weaning. Castration of animals decrease their growth rate. However, castrates still grow at a faster rate than heifers of the same age (Winks et al., 1978).

Galbraith <u>et al</u>., (1978) for example, compared growth rate of bulls and steers, and reported significantly higher feed conversion efficiencies, faster growth rates, higher levels of serum growth hormone and prolactin in bulls than in steers. This suggests that castration probably changes the availability of some growth promoting factors, which apparently very low in heifers. Androgens are probably involved.

1.4.4. CONCLUSION:

It is indicated that cattle may show differences in their LWG responses to changes in the ambient temperature. Within species, differences associated with breed, sex and age have been reported and discussed.

Hot conditions have been reported to have a general effect of decreasing LWG of animals. The effects have been associated with reductions in DMI, and also with changes in the activity of the endocrine system.

1.5. THERMOREGULATORY RESPONSES TO HEAT BY Bos Taurus AND Bos indicus CATTLE.

1.5.1. Introduction.

On exposure to heat animals react in such a manner as to increase the rate of heat loss from the body. The immediate responses are normally physiological. If, however, these fail to restore the thermal balance of the animal, behavioral mechanisms may be employed to regulate the rates of heat production in the body, and heat loss from the body. The following section of the review, compares B.taurus with B.indicus cattle with respect to their responses to thermal stress.

1.5.2. Changes in the Cardiovascular activity in response to thermal stress:

One of the most important mechanisms by which thermoregulation is achieved in the homeotherms is by variation in the activity of the cardiovascular system. This system, transfers heat from deep to the superficial tissues. Its success as a means of heat exchange, depends upon the volume of blood flowing through the peripheral tissues, and also thermal conductivity of the tissues between the blood vessels and the body surface.

The amount of blood flowing into the cutaneous capillaries have been demonstrated to increase in sheep (Hales, 1973) and also in man (Hellon, 1963) during exposure to heat. Whittow (1965, 1970, 1971) has also demonstrated these changes in several experiments with cattle. Fox and Eldhom (1970) suggested that these changes occur in response to thermal stimulation of the nervous system and thus bear a close relationship with body temperature. Since Bos indicus exhibit lower rectal temperatures than Bos taurus cattle on exposure to hot environments (figure 1.6) it is suggested that they may similarly show cardiovascular responses of less magnitude than Bos taurus cattle on exposure to hot conditions. Other changes which occur in the system on exposure of animals to hot conditions are summarised in Table 1.5.1 .

TABLE 1.5.1 Effects of a hot environment on body temperature, respiratory rate and systemic circulation (means of six steers) From Whittow, 1965.

	Environmental temperature (°C)	
	15°C	40°C
Rectal temperature (°C)	39.0	41.5
Respiratory rate (respirations/min.)	26	185
Cardiac output (1.mm)	25.3	48.6
Heart rate (beats/min.)	67	137
Mean arterial B.Pressure (mm.Hg.)	136	141
Total Peripheral resistance (dynes sec. cm^{-5})	450	298.

1.5.3 Sweating:

Cutaneous moisture loss may occur as a result of insensible perspiration (a simple transudation of water through skin) or as a result of glandular activity associated with expulsion of body water to the surface (sweating). The loss of water from the skin surface is by evaporation; a process which absorbs heat of evaporation and consequently cools the surface from which evaporation occurs.

Bos indicus and their crossbreds have been shown to exhibit faster sweat rates than Bos taurus (Taneja, 1959a,Pan, 1963; Nay and Hayman, (1956). Literature (Nay and Hayman, 1956;Pan et al., 1969), indicates that Bos indicus has bigger and comparatively more sweat glands than has Bos taurus.Pan et al., (1969) have also indicated that Bos taurus has shorter and more convoluted sweat glands than those found on Bos indicus. Some of these comparisons are presented in table 1.5.2. Their sweating responses on exposure to hot conditions are compared in Figure 1.7.

TABLE 1.5.2. Sweat gland density and volumes reported in literature

Characteristic	B.taurus	Bos taurus x Bos indicus	B.indicus
a.Density (glands per cm^2	1128*[1]		1197[1]
-mean			
-Rump (area)"	888[2]	887[2]	682[1]
- mean "	1776[5]		1584[5]
b.Volume			
- Total ($X10^6 x\mu^3/cm^2$)	8.02[1]	9.37[2]	33.23[1]
- Individual (10^6 $x\mu^3$)	7.34[1]	10.66	30.47[1]
mean	10.46[5]		3.06[5]
- Individual (Rump) (10^6 $x\mu^3$)	8.57		30.51
c.Sweat Rate			
at (38°C) gm/m^{2}hr	43.9[3]	46.74[3]	
(42°C)	43.0[6]	650	
(34°C) gm/m/hr	60.00[4]	157.5[4]	

* References

1. Pan (1963)
2. Pan et al (1969)
3. Taneja (1959)
4. Sauwa (1978)
5. Amakiri (1974) used N'dama and White Fulani data
6. McDowell et al., 1961)

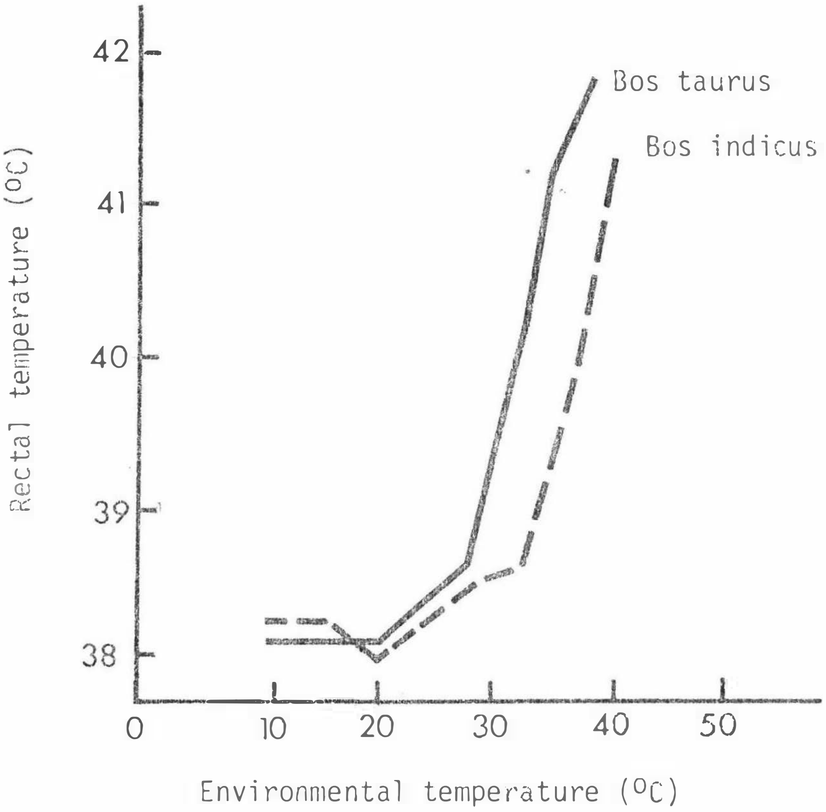

Figure 1.6 Rectal temperature of lactating European and Indian cattle as a function of environmental temperature. (Adapted from Mount, 1979)

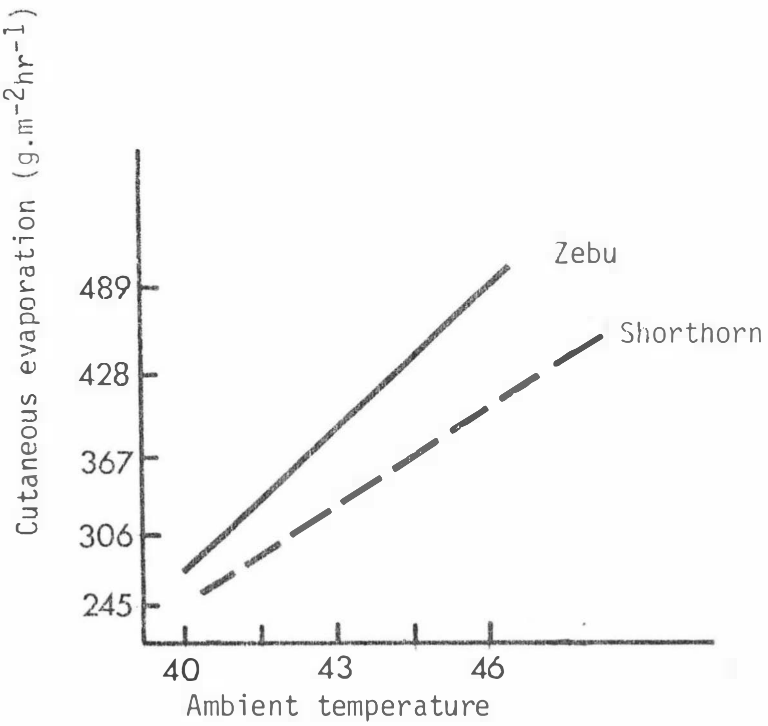

Figure 1.7 Cutaneous evaporation from the belly area of Zebu cross and Shorthorn cattle exposed to an air temperature 39°C being gradually raised to 46°C in the same day. Adapted from Taneja, 1959.

Despite some contradictory observations (Amakiri, 1974,1979); most authors conclude that Bos indicus cattle have a superior sweating capacity,and hence more effective surface cooling than have Bos taurus due to the greater volume of their sweat glands.

1.5.4. Respiratory Ventilation:

Increases in heat loss from animals may also be achieved by increasing the respiratory ventilation in the animal. In this case heat loss is through evaporation of moisture from the respiratory tract. This effect has been demonstrated in the ox, by a fall in temperature of blood in the external jugular vein (Ingram and Whittow, 1962; Hales, 1969) which is magnified or attenuated with opening or closing of the mouth respectively, (Hales, 1969).

In thermoneutral environments cattle appear to have a respiratory rate of about 18 to 22 breaths per min. The volume of expired air under these conditions varies between 40 and 64 litres, depending upon the size of the animal.

On exposure to heat, animals increase their respiration rates concomitantly with increases in the rectal temperature. Whittow and Findlay (1969) observed and later confirmed with Jersey steers, (Whittow, 1971) that the respiratory rate of cattle increased with increases in both the ambient and rectal temperatures. The maximum respiratory rate of about 180 breaths was achieved when the rectal temperature had increased to 40.7°C. Further increases in the rectal temperature were associated with a decline in the respiratory rate. Some of the changes in respiratory ventilation reported (Hales and Findlay, 1968) for Ayrshire cattle exposed to hot conditions for 3 hours are summarised in Table 1.5.3.

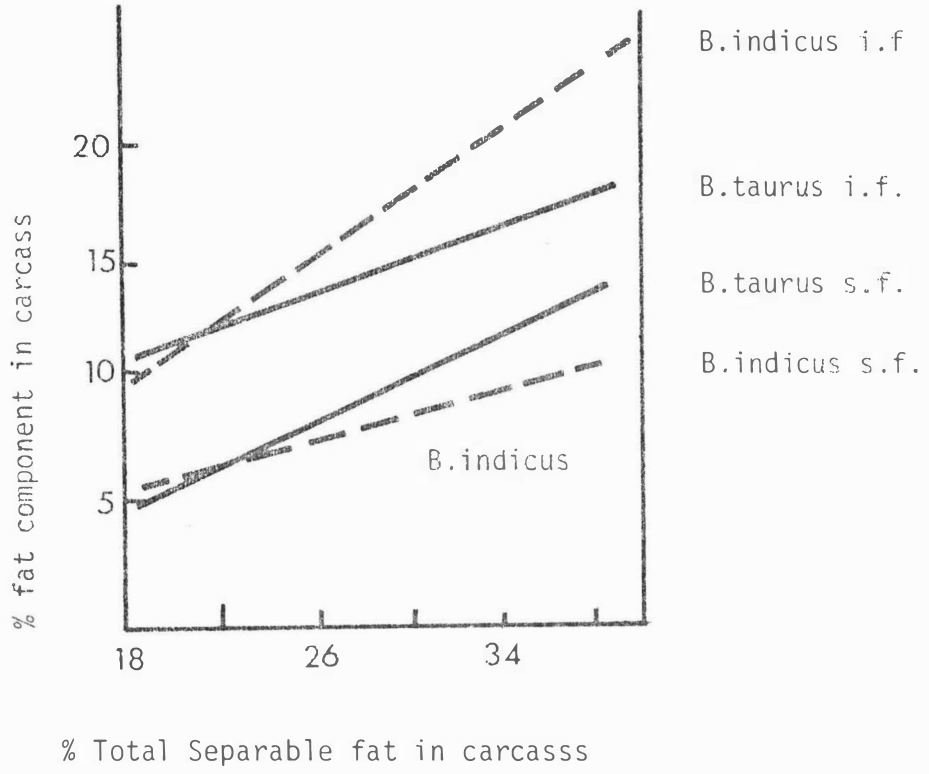

Figure 1.8 Comparison of subcutaneous (s.f.) and intermuscular (i.f.) fat deposition of Bos taurus and Bos indicus (Ledger, 1959)

TABLE 1.5.3: The effect of exposure to severe heat (40/38^{o}C)* on the respiratory ventilation and blood pH of eight oxen. (Hales and Findlay, 1968).

Parameter	Control (14-20^{o}C)	40/38^{o}C Peak rate of Shallow panting	40/38^{o}C Slower deeper panting
Rectal temperature	38.7	40.2	41.7
Respiratory rate (breaths/min)	17	177	123
Tidal volume (l)	2.05	1.16	2.16
Respiratory minute volume (l/mm)	35.9	195	225.4
Dead space ventilation (l/mm)	22.4	167.7	200.9
pH of Arterial blood	7.40	6.52	7.63

* dry bulb and wet bulb temperature reading.

Differences between breeds of cattle in respiratory responses to heat exposures have been studied by Sauwa, (1978). McDowell (1972) has reviewed some earlier work, and suggested that at any one temperature condition, <u>B.indicus</u> animals have slower respiratory rate than <u>B.taurus</u> (Table 1.5.4)

Sauwa (1978) reported that on exposure to a hot environment (34^{o}C), Brahman - Friesian cross steers increased their respiration rate from 31 at 15^{o}C to 93 breaths per min.at 34^{o}C. With a smilar change in the ambient temperature, Friesian steers increased their respiratory rates from 46 to 100 breaths per min. The respiratory rates at 34^{o}C were significantly ($P <0.01$) different between the two breeds.

The contribution of respiratory ventilation as a means of thermoregulation has been studied in sheep, (Alexander and Williams, 1962;Brook and Short, 1960), and in cattle (McLean, 1963; McLean and Calvert,1972). In both species a complementary action of sweating and respiratory activity in thermoregulation is noted. Both are increased with increases in the ambient temperature, however, the relative contribution of each varies with ambient temperature.

TABLE 1.5.4. Respiratory rate of Zebu and Friesian cattle exposed to various ambient temperatures (McDowell, 1972)

	Breaths/min		% Total evaporation through respiration	
Air temperature ^{o}C	Zebu	Friesian	Zebu	Friesian
10	17	27	23	40
16*	31*	46	--	--
21	15	30	29	42
27	14	41	27	36
32	14	45	16	23
35	22	49	17	25
35*	93*	100	--	--

* Brahman x Friesian Cross from Sauwa, 1978.

At 15°C heat loss by evaporation accounted for only 18% of the total heat loss by cattle, (McLean and Calvert, 1972), whereas at 35°C it accounted for 84% of the total heat loss. Respiratory losses accounted for 54% at 15°C, and only 38% at 35°C of the total heat lost by evaporation. This indicates that as the ambient temperatures rises the relative contribution of respiratory activity as a means of evaporative heat loss declines, while cutaneous losses become more prominent.

This suggests therefore that faster evaporative cooling of animals exposed to hot conditions is achieved mainly by a greater sweating capacity than by higher respiratory rates. Thus animals (cattle) which depend mainly upon sweating will show faster cooling rates and lower body temperatures than those in which panting plays a relatively bigger role of evaporative cooling. In these,panting may have an obvious advantage over sweating for preferential cooling of the brain (Ingram and Whittow, 1962).

On exposure to hot conditions, B.taurus depends upon respiratory ventilation for evaporative cooling more than does B.indicus. This is suggested in the work reported by Kellaway and Colditz (1975) and also the work reported in Table 1.5.4. Thus at the same rate of panting, B.indicus animals will have greater sweat rate than B.taurus will have. Effectively then, B.indicus will show faster rates of heat loss because of the associated greater effect of evaporative cooling of the skin.

Both sweating and respiratory ventilation have some disadvantages to the animal. Both may be associated with dehydration of the body unless drinking water is supplied. Sweating also involves losses of body electrolytes including Na, Ca, K, Mg, Ca, (Jenkinson and Mabon, 1973) and metabolites e.g Urea, Proteins, Non-protein N, sugars and lactic acid (Johnson, 1970).

Respiratory ventilation could be advantageous in that it preferentially cools blood going into the brain. Hyperventilation may however develop respiratory alkalosis (an excessive washout of CO_2 from blood); which raises the pH of blood; hence causing changes in the metabolic functions of blood in the body. These lead to carpopedal spasms, convulsions and death of a hyperthermic animal.

1.5.5. Changes in Endocrine functions:

An air temperature above 30^{o}C seems to have a marked influence on the functions of adrenal glands, (Johnson and Morris, 1960.) Thyroid activity, pituitary as well as gonadal hormone production are affected by increased ambient temperatures. Weiner and Collins (1968) have provided an exhaustive review concerning the influence of high ambient temperatures on the endocrine functions in cattle and other animals.

Available data indicates a greater depression of endocrine activity in B.taurus than in B indicus.Blincoe (1958), for example demonstrated that high ambient temperatures severely depressed thyroid activity of cattle of European origin (B.taurus) but had little effect on Brahman (B.indicus) cattle . Post(1963) also demonstrated these effects using protein bound iodine (P.B.I.) indicator(Table 1.5.5).

TABLE 1.5.5 Plasma PBI (μg) of cattle during summer and winter months. (From Post, 1963).

Breed	Summer	Winter	gain PBI
B.taurus (Hereford x Shorthorns)	2.57	3.49	0.92
F_1 Zebu x B.taurus(Africander x Shorthorns)	3.12	3.68	0.56
F_2 Zebu x B.taurus (Africander x Shorthorns)	4.02	3.76	- 0.64
Zebu	3.96	-	-

This may be taken to show that the poor performance of B.taurus in tropical climates are partly due to their low ability to maintain hormonal balance under hot tropical conditions.(Howes et al, 1962) also came to this conclusion.

1.5.6. Changes in the Use of Body water:

Within the thermoneutral zone, the major avenues of water loss from the body are, in decreasing order of importance, through faeces, urine, respiration and evaporation from the skin surface (McDowell, 1972). On exposure to high ambient temperatures this order is virtually reversed; and an extra avenue, loss by salivation, may be brought into use.

South African studies (Fourie, et al, 1964b) demonstrated that B.indicus cattle reduced their faecal and urinary excretion of water by about 39%, while B.taurus only by 20% when animals of both breeds were exposed to 33.8^{o}C from 17.2^{o}C conditions. Bos indicus also exhibited greater increases in the extra cellulose volume of water than did B.taurus (Fourie, 1964a)

Available data indicate these differences may be of importance to evaporative cooling of the body. They are also important for metabolism of nitrogen in the body. Vercoe,(1971) found that increased intake of water depressed plasma urea N, and increased urinary urea N excretion. Vercoe (1967) had also reported that Brahman x Hereford steers drank less water than the Hereford counterparts; high water intakes being closely associated with high urinary loss of N, creatine, urea uric acid, consequently low plasma urea N and low Nitrogen balance of these animals.

Thus greater intake and relatively greater urinary output of water by the B.taurus influence the metabolism of nitrogen so that their growth performances are affected more than they are in B.indicus.

1.5.7 Anatomical Adaptation in response to prolonged exposures to heat:

1.5.7.1. Surface area:

Surface area is conventionally used as a basis on which to express heat transfer from animals. The greater the surface area per unit metabolic weight, the faster is the transfer of body heat expected to be.Greater surface area to body mass ratio of the B.indicus (cf.B.taurus) has been thought to explain the greater heat tolerance ability of these animals. However, physiological studies do not agree with this claim. (eg. McDowell, 1958).

The appendages such as the dewlap, the hump, the large vulvas and prepuce folds add a lot to the surface area of B.indicus, but because they are poorly supplied with blood, they are unlikely to be an effective means of heat dissipation to bring about the superiority of the B.indicus in terms of heat tolerance. Surgical removal of the dewlap and the hump of Red Sindhi bulls, for example, does not significantly change their responses to heat (McDowell, 1958). The role played by these appendages remains unclear, and their contribution to heat loss seems to be small. Thus the superior performance in B.indicus in the tropical environment is unliekly to be associated with the presence of the hump or large dewlap in these animals.

1.5.7.2. Difference in fat deposition:

Ledger, (1959) working with Boran (B.indicus) and a group of European beef breeds of cattle (B.taurus) observed that the differences between levels of subcutaneous fat and intermuscular fat tend to decrease as fattening proceeds in B.taurus but increases in B.indicus (Figure 1.8). The proportion of body fat laid down under the skin increased at a faster rate in the B.taurus than in the B.indicus with a similar change in the total separable fat. Ledger suggested that the differences in the rates and methods of laying down fat at the subcutaneous level may account for some of the differences in heat tolerance between B. taurus and B.indicus animals. This stems from the fact that subcutaneous layer of fat acts as an insulator against heat loss (Ingram, 1964) so that heat lost by conduction is less in animals with thicker subcutaneous layers of fat.

On exposure to hot environments, then B.taurus cattle with proportionately more subcutaneous fat may experience greater heat stress than will B.indicus which deposits lower proportions of their body fat under the skin. Conflicting observations have recently been reported by Thornton et al., (1974) and Butterfield (1965) indicating that at the same total carcass fat (%) Brahman (B.indicus) have higher % of subcutaneous fat than the Angus (B.taurus). Thus the insulation effect of subcutaneous fat is unlikely to explain the differences in heat tolerance between these two breeds of cattle, but may be of physiological importance in the cold when wasoconstriction occurs and blood flow is restricted to deeper vessels (Mount, 1979).

1.5.7.3. Differences in hair coat characteristics:

Dowling (1958) presented evidence indicating that the marked seasonal alteration in the appearance of the coat in cattle was due to morphological variation in fibre characteristics. Dowling (1958) reported seasonal changes in coat weight, mean diameter of fibre, mean length of hair and medulation characteristics of the hair coat. (Table 1.5.6.)

TABLE 1.5.6.: Seasonal Variation of hair characteristics of 30 Hereford Steers.(Dowling 1958).

	Mean wt.	Mean diameter	Mean	Medulation		Felting
Season	mg/cm^2	U	length cm	continuous fibres %	discontinuous fibres %	Grade
Summer	16.65	38.5	.80	45	42	0
Winter	48.60	43.6	2.04	15.2	8.4	5

The changes suggest that the coat in cattle varies from insulating (Winter) type coat, with hair fibres which are longer but of more variable length and less medulated to non-insulating (Summer) type of coat characterised by shorter, and medulated fibres. The important thermal property for the prevention of heat loss from the body is the capacity of the winter hair covering to stabilise an insulating layer of air; whereas the summer coats with short and flat lying hair are conducive to minimising insulation.

Bos indicus cattle are known to have shorter and highly medulated hair fibres; denser and more compact coats than have *B.taurus*(Dowling, 1956, 1959a, and 1959b). It is therefore possible that the greater heat tolerance of *B. indicus* cattle as compared with *B.taurus* is partly due to the faster rates of conduction of heat through their coats.

Cena (1974) has suggested that at a given value of therm absorption coefficient, animals with shorter coats show faster heat exchanges by radiation than those with long hairs in the coat. This suggests that *B.indicus* cattle will lose heat faster by radiation than will *B.taurus*.

1.5.8 Conclusion:

A general conclusion is made suggesting that *Bos indicus* breeds of cattle are superior to *B.taurus* in heat tolerance and hence are less affected on exposure to hot conditions. The above comparative study associates this superiority with:

1. The differences in sweat rates and in evaporative water loss by these animals.
2. The differences in heat conductance characteristics of the coats of these animals.

Bos taurus cattle tend to have hair coats with better insulation properties than do B.indicus. animals. They also have lower sweat rates than the B. indicus when exposed to hot environments. Consequently, heat loss by evaporation, conduction radiation and convection are all impeded in B.taurus when exposed to high ambient temperature conditions.

CHAPTER TWO

EXPERIMENTAL REPORT

2.1 Experimental Design:

The effects on animal performance of two ambient temperatures and two breed types were investigated in a 2 x 2 factorial experiment. Eight heifers, four from each breed were allocated randomly to the two temperature levels.

Two diets were fed *ad libitum* during the experiment. A diet of hay was fed during the first and last experimental periods, while a diet of concentrate plus 0.5kg hay was fed during the second and third periods.

The following measurements were recorded:

1. Daily intake of dry matter per animal.
2. Daily intake of water per animal.
3. Respiration rate.
4. Rectal temperature.
5. Changes in liveweight
6. Changes in hair coat cover.
7. Cutaneous water loss - (sweat rate).

The experiment was run over a total of four experimental periods; each of 28 days duration. A fourteen day re-adjustment period was allowed between consecutive experimental periods . The plan of the experiment is laid out in Table 2.1.

TABLE 2.1 Plan of Experiment.

				TEMPERATURE	
TRIAL	DAY	PERIOD	DIET	HOT(33°C)	COOL (15.5°C)
1	1-28	1	HAY	^{x}SF 1, 3 F 2, 4	SF 5, 7 F 6, 8
	29-43		DIET CHANGE		
	44-71	2	CONCENTRATE + HAY	SF 1, 3 F 2, 4	SF 5, 7 F 6, 8
	72-79		ANIMAL CHANGED BETWEEN TEMPERATURES		
2	80-108	3	CONCENTRATE + HAY	SF 5, 7 F 6, 8	SF 1, 3 F 2, 4
	109-123		DIET CHANGE		
	124-152	4	HAY	SF 5, 7 F 6, 8	SF 1, 3 F 2, 4

x

SF = Sahiwal x Friesian Nos 1,3,5, and 7

F = Friesian Nos 2,4,6, and 8

2.2 Materials:

2.2 1 Animals:

Eight heifers whose average age was 8 months at the start of the experiment were used. Four were Friesians which came from No.1 Dairy Farm, Massey University, and four were Sahiwal-Friesian crosses, which came from 2 farms in the Manawatu region.

2.2 2 Housing:

The four animals from each breed were allocated randomly to one of the two temperature treatments; in the hot treatment nominally 33°C average temperature was imposed - in a climatic chamber (10-10m^2) fitted with thermostatic control equipment. The cool treatment; nominally 15.5°C, was imposed in a chamber (10 x 10m^2) fitted with heating and ventilation equipment. Air temperature in this chamber varied between 12°C and 18°C.

Relative humidity was not controlled directly, the average values were respectively 40.0% and 86.9% for the hot and cool rooms.

2.2.3 Feeds:

Two diets were fed ad libitum
(a) Hay
(b) Concentrate + 0.5kg Hay.

Table 2.2 gives some of the components of each diet, as determined in our laboratory, or as described by the manufacturers in the case of concentrate in the form of pellets.

TABLE 2.2 Composition and Chemical Analysis of feed used:

CONCENTRATES		HAY
Ingredients as described by concentrate manufacturer. Maize meal, Bran, Barley meal, Brewers grain molasses, and crushed linseed.		
- Minimum Crude Protein =	12.0%	
- Maximum fat %	4.25%	
- Maximum fibre	9.0%	
- Salt	1.0%	
Chemical Analysis- (experimental)		
Crude protein	13.05%	13.72%
Gross energy (MJ/g dry matter)	18.49	17.69
Energy digestibility*	74.61%	62.26%
Dry matter digestibility*	77.19%	61.66%
Apparent Nitrogen digestibility *	65.97%	68.60%

* Determined with (6) sheep

A commercial mineral mixture was used to supplement for mineral requirements of the animals in the concentrate. The mineral mix contained -

Vitamins A,D, and E;
Manganese
Magnesium
Iron
Zinc
molybdenum
Copper
Cobalt
Iodine

Common salt was provided *ad libitum* during periods 1 and 4 when hay was fed.

2.2. 4 Water:

Fresh water was provided ad libitum in cans placed beside the feed troughs.

2.3 Method:

2.3.1 Weighing of Animals:

All animals were fasted overnight (24 hrs) and weighed at the beginning and at the end of each experimental period. The first fasted weight was taken 14 days before the commencement of the experiment. Other weights were taken on day 1, 29, 44, 72, 80, 109, 124, and 153 of the experiment.

Table 2.3 gives the weight and age in weeks of each calf, 14 days prior to the commencement of period 1.

TABLE 2.3: Weight and age of heifers used for experiment.

Heifer number	Breed	Date of Birth	Age in Wks. at start of Experiment	Fasted Weight at start of Experiment.
1	Sahiwal x Friesian	16.8.1978	35	122.0kg
2	Friesian	3.8.1978	38	148.2kg
3	Sahiwal x Friesian	30.7.1978	39	118.8kg
4	Friesian	17.7.1978	40	149.3kg
5	Sahiwal x Friesian	30.7.1978	39	128.5kg
6	Friesian	10.7.1978	41	182.5kg
7	Sahiwal x Friesian	11.8.1978	36	103.0kg
8	Friesian	30.7.1978	39	155.4kg

The gain in weight over each experimental period was obtained by subtracting the fasted weight of each animal at the beginning of each experiment, from the fasted weight measurements obtained at the end of the experimental period.

2.3 2 Feeding procedure:

Sufficient feed was offered to each animal so that at least 15% of the amount offered was left uneaten. Fresh feed was given at 08.30 and at 15.30 hours. The residual feed was removed before fresh feed was offered and these refusals were collected in separate sacks for each animal. Two samples of feed were taken each day; one was oven dried at 70°C for 24 hours to determine the dry matter concentration. The other stored at -10°C for subsequent determination of energy and nitrogen concentrations.

At intervals of one week, during each experimental period, the refused feed was weighed, mixed and samples taken to be oven dried for the determination of dry matter concentration.

Subsequently the total weekly intake of dry matter (DMI) by each animal could be calculated as the difference between DM offered and the DM refused. Daily intake of DM was estimated as the difference between DM offered daily and the average daily refusal during the week of collection.

2.3 3 Determination of the digestibility of dry matter:

The digestibility of dry matter was determined in a balance trial with 6 sheep. The main assumption made here was that the digestibility of a feed by cattle was linearly related to its digestibility by sheep. This assumption was based on observations reported by Playne (1977); Bird (1974), and Cipolloni et al., (1951).

The linear relations adopted for the present experiment were those reported by Playne (1978b):-

$y = 0.673 + 20.3$ for hay

and

$y = \quad x + 2$ for concentrates

where

y is the digestibility (%) estimated for cattle

x is the digestibility determined with sheep.

2.3. 4 Chemical analysis of feed and faeces:

The Macro Kjedahl method was used to determine the nitrogen content of the samples of feed and faeces. The energy content of the samples were determined in an adiabatic bomb calorimeter. (Gallenkamp and Co.)

2.3. 5 Estimation of Water Consumption:

Ad libitum supply of water was offered prior to feeding in graduated 25 litre cans. The amount of water which had not been drunk before the next feeding was measured, and this was subtracted from the amount offered to get the 'apparent' voluntary intake by each animal.

2.3. 6 The ambient temperature and Relative humidity measurements:

Air temperature was measured with a mercury-in-glass thermometer. A whirling hygrometer was used to determine the relative humidity of air in each room. These measurements were made at 08.00 and 14.30 hrs each day in both the hot and cool room.

2.3.7 Other parameters on the animals:

2.3.7.1 Rectal Temperature:

Rectal temperature was measured with mercury in glass clinical thermometer. The thermometers were inserted into the rectum and kept in position by a clip attached to the hair on the animal. Three minutes or more were allowed for the thermometer readings to reach a constant level on each animal.

2.3.7.2. Respiration rate:

Respiration rate was determined by counting the number of cycles each heifer breathed in and out in a period of one minute. Counting was preferably done when the animals were lying down.

2.3 7.3 The rate of growth of hair and the net change in weight of hair coat:

An area of about $128 cm^2$ fixed by a length of high tensile wire bent into a rectangular shape, was clipped off the hip area of the animals. The hair so clipped was collected,dried and weighed. After 28 days of treatment, the regrowth of hair on the same area was clipped off, dried and weighed. This effectively gave the rate of regrowth of hair during the experimental period.

Another area adjacent to the previously clipped area, was clipped at the end of each experimental period. (See figure 2.1). The difference between the latter reading and that obtained at the beginning of each period,gave the net change in the weight of hair coat.

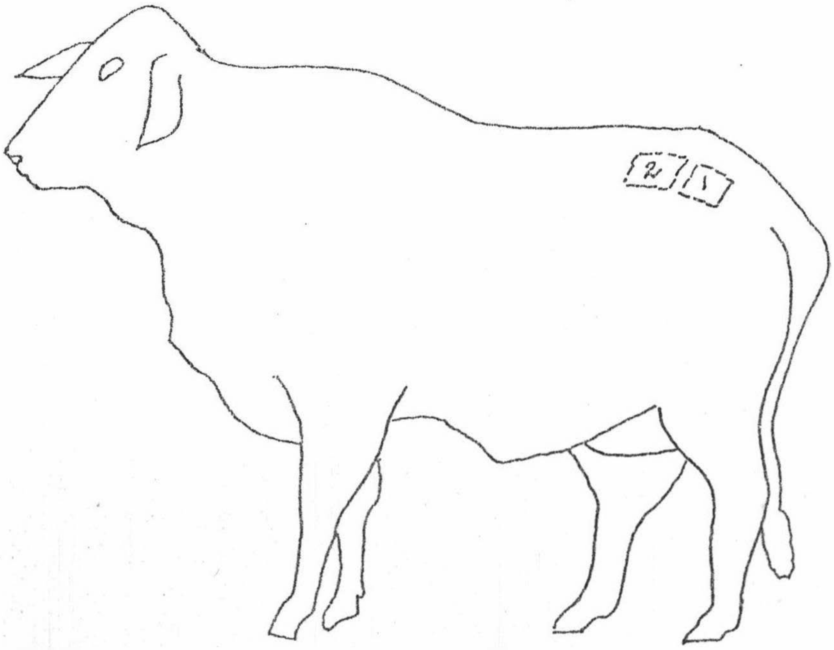

Figure 2.1: The rump area clipped for the determination of changes in the weight of the hair coat.

2.3 7.4 Sweating rate measurement:

The direct absorption method was used to determine the cutaneous water loss of the animals.

Calcium chloride granules were put in a plastic petri dish, and then covered with a filter paper (Figure 2.2). The filter paper was held in position by a perforated petri dish (2). Both dish (1) and (2) were glued in position by a band of an adhesive tape such as shown in Figure 2.2. When the capsule was not being used a third petri dish (3) was used to protect the system from absorbing moisture from the surroundings.

To prevent further absorption of moisture the covered capsules were always kept in a dessicator half full of calcium chloride granules.

The capsules were uncovered (by removal of dish 3), inverted and rapidly applied over the clipped area, on the rump of each animal for a period of 5 minutes.

The difference between the weight of the capsule prior to and after application was assumed to be all due to the absorption of cutaneous moisture (sweat) from the covered patches by the calcium chloride.

Sweating rate measurements were taken daily at 08.00 and 14.30 hrs for the last 14 days of each experimental period.

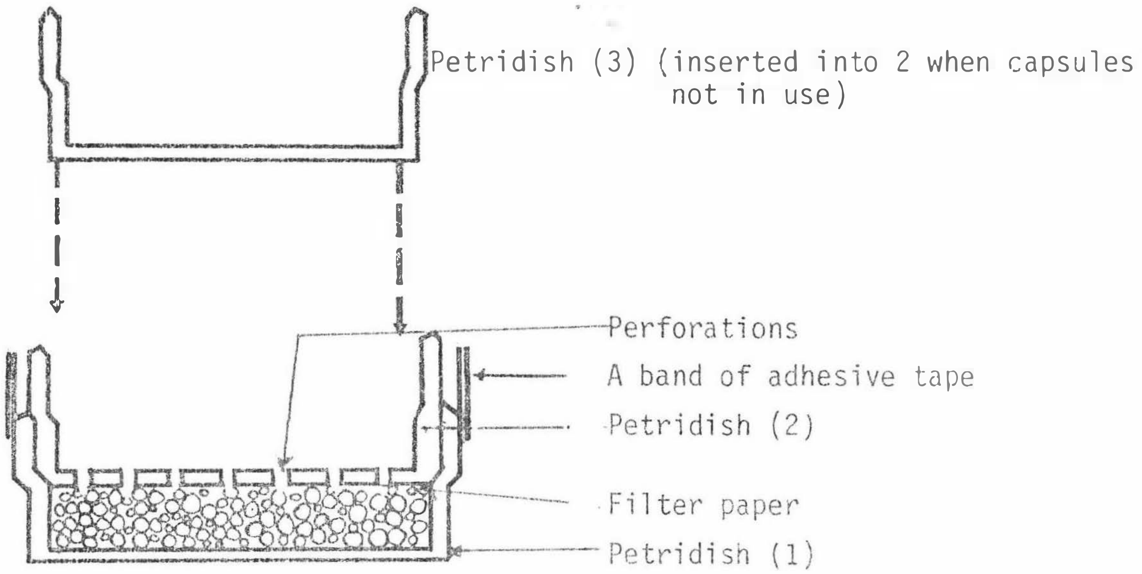

Figure 2.2 The sweating capsule: Cutaneous water was recovered in the absorbent calcium chloride in the capsule.

2.3.8 Statistical Analyses:

The statistical analysis techniques used included

1. Analysis of Covariance
2. Multivariate analysis of variance
3. Product-moment correlation analysis.

Several statistical techniques were required because of the complex nature of the experimental design; (see 2.1). The factors which make the analysis of data in this experiment difficult are:

1. The low number of experimental units; resulting in a few degrees of freedom for significance tests.
2. The likelihood of correlations between periods and between measurements on the same animals.
3. Treatments were re-randomised between trials; this made it necessary to treat the experiment as two separate trials.
4. The confounding of diet with periods in each trial.

1. Analysis of Covariance:

The procedure used is that explained by Snedecor and Cochran (1967). The objective was to adjust for extraneous variation in the observed treatment effects. For example, if dry matter intake is observed to be correlated with the weight of an animal, prior to the commencement of trial, then the observed values of DMI should be adjusted for the variations which are due to linear association between DMI and LW.

The linear model used in each trial was

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + bX_{ijk} + e_{ijk} \quad \text{-----------(1)}$$

$i = 1,2$
$j = 1,2$
$k = 1,2$

where

Y_{ijk} = the observation on the K^{th} animal of the j^{th} breed exposed to i^{th} temperature.

μ = a general mean
α_i = the fixed effect of the i^{th} temperature
β_j = the fixed effect of the j^{th} breed
$(\alpha\beta)_{ij}$ = the interaction effect between the i^{th} temperature and the j^{th} breed.
b = the regression coefficient of Y_{ijk} on the concomitant variable X_{ijk}
X_{ijk} = the measurement on the concomitant variable deviated from the mean of all animals in the trial.
e_{ijk} = a residual error effect unique to the observation Yijk. Residual effects were assumed to be independently and identically distributed with mean zero, and variance σ^2e.
For purposes of testing hypotheses residual effects were also assumed to be Normally distributed.

The observations (Y_{ijk}) in the different analyses included (1) dry matter intake (2) liveweight gain (3) voluntary intake of water and (4) the growth rate of the hair coat after clipping. The concomitant variables (X_{ijk}) measured at the beginning of the trial included age, liveweight and the weight of hair clipped from a selected area of the coat.

The advantages of this analysis of covariance technique are:

1. Bias in the observations may be eliminated.
2. It aids in detection of treatment similarities or differences free of the obscuring influence of the concomitant variable.

3. It gives an indication of the nature of the relation existing between the observed values of the dependent variable (Y_{ijk}) and the independent variable (X_{ijk}) in an experiment.

2. The multivariate analysis of variance:

The technique adopted was that described by Morrison (1976) for analysing repeated measurements on the same experimental subject. The essential feature of this analysis is that it takes account of the correlation between random residual errors pertaining to repeated observations recorded on a single animal. Gill and Hafs (1971) demonstrated that the technique should be used in animal experiments, particularly when the correlation is expected to be large.

The model used was

$$Y_{ijk} = \mu h + \alpha_{hi} + \beta_{hj} + (\alpha\beta)_{hij} + e_{hijk} \text{ ------------------(2)}$$

$h = 1, 2$
$i = 1, 2$
$j = 1, 2$
$k = 1, 2$

where

Y_{hijk} = the observation on the kth animal of the jth breed, exposed to the ith temperature during period h

μ_h = a general mean for the period

α_{hi} = the fixed effect of the ith temperature in period h

β_{hj} = the fixed effect of the jth breed in period h

$(\alpha\beta)_{hij}$ = the interaction effect between jth breed and ith temperature in period h.

e_{hijk} = a residual error effect unique to the observation Y_{hijk}

Within the period h, the residual effects e_{hijk} were assumed to be independently and identically distributed according to a Normal distribution with mean zero and variance

$$\sigma^2_h$$

Residual error effects pertaining to observations on the same animal, but obtained in two different periods, were assumed to be distributed according to a Bi-variate Normal distribution as follows:

$$\{ e_{hijk}, e'_{hijk} \} \sim \text{Biv.Normal} \quad \mu_h = 0 \quad \mu'_h = 0 \ ; \ \sigma^2_h \quad \sigma^2_{h'} \quad \rho$$

where ρ is the correlation coefficient between the residual error effects e_{hijk} and e'_{hijk}.

Period and dietary effects were completely confounded in that all animals were fed hay in period 1, and then concentrate in period 2. In a subsequent trial, the order of hay and concentrate feeding was reversed.

Within a trial, the null hypothesis of no temperature-by-breed-by-period (diet) interaction was tested as follows:

$$Y_{hijk} = \mu_{hijk} + e_{hijk} \qquad \text{-----------------------------------(3)}$$

$h = 1, 2$

$i = 1, 2$

$j = 1, 2$

$k = 1,2$

where

μ_{hij} = the mean of the ith temperature and jth breed treatment combination in period h.

e_{hijk} = a random residual error effect pertaining to the kth animal in the (ijth) treatment sub-class in period h. Assumptions have been given in model (2)

In matrix terminology, the model is equivalently

$$\underset{\sim}{Y} = \underset{\sim}{A}\,\underset{\sim}{U} + \underset{\sim}{e} \text{ ------------------------------------(4)}$$

where

$\underset{\sim}{Y}$ = an N x2 matrix of observations,

$\underset{\sim}{A}$ = an N x 4 design matrix,

$\underset{\sim}{U}$ = a 4 x 2 matrix of unknowns (ijth) treatment combination means in 2 periods

$|\mu_{hij}|$ $h = 1,2$
$i = 1,2$
$j = 1,2$

and

$\underset{\sim}{e}$ an N x 2 matrix of residual error effects.

The null hypothesis of no period by temperature by breed interaction is

$H_0 = \underset{\sim}{C}_1 \; \underset{\sim}{U} \; \underset{\sim}{M}_1 = \underset{\sim}{0}$,

i.e.

$$H_0 \underset{\underset{\sim}{C}_1}{\begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 1 & -1 & 0 \\ 0 & 0 & 1 & -1 \end{bmatrix}} \underset{\underset{\sim}{U}}{\begin{bmatrix} \mu_{111} & \mu_{211} \\ \mu_{112} & \mu_{212} \\ \mu_{121} & \mu_{221} \\ \mu_{122} & \mu_{222} \end{bmatrix}} \underset{\underset{\sim}{M}}{\begin{bmatrix} 1 \\ -1 \end{bmatrix}} = \underset{\sim}{0} \quad \text{-------(5)}$$

Observe that the constancy of the between period difference across treatment combinations (temperature and breed) is what this null hypothesis is testing. In order to test the null hypothesis,the following matrices (scalers in this example) are required.

$$\underset{\sim}{H} = \underset{\sim}{M}_1' \; \underset{\sim}{X} \; \underset{\sim}{A} \; (\underset{\sim}{A}'\underset{\sim}{A})^{-1} \; \underset{\sim}{C}_1' \; \{\underset{\sim}{C}_1(\underset{\sim}{A}'\underset{\sim}{A})^{-1}\underset{\sim}{C}'\}^{-1}\underset{\sim}{C}_1 \; (\underset{\sim}{A}'\underset{\sim}{A})^{-1} \; \underset{\sim}{A}' \; \underset{\sim}{X}\underset{\sim}{M}_1 \text{ --(6)}$$

and

$$\underset{\sim}{E} = \underset{\sim}{M}_1' \; \underset{\sim}{X} \; \{I - \underset{\sim}{A} \; (\underset{\sim}{A}'\underset{\sim}{A})^{-1} \; \underset{\sim}{A}' \} \; \underset{\sim}{X} \; \underset{\sim}{M}_1 \text{ --------------------------(7)}$$

Neverthless, it is easily shown that in this case the matrix

$$(\underset{\sim}{A}'\underset{\sim}{A})^{-1}\underset{\sim}{C}_1' \ \{ \underset{\sim}{C}_1 (\underset{\sim}{A}'\underset{\sim}{A})^{-1}\underset{\sim}{C}_1' \}^{-1} \ \underset{\sim}{C}_1 (\underset{\sim}{A}'\underset{\sim}{A})$$

is simply the matrix

$$\tfrac{1}{2} (\underset{\sim}{I} - \tfrac{1}{4} \underset{\sim}{J})$$

where

$\underset{\sim}{I}$ is an identity matrix and $\underset{\sim}{J}$ is a 4 x 4 matrix of all ones.

With further algebraic simplification it can be shown that $\underset{\sim}{H}$ and $\underset{\sim}{E}$ are the interaction and residual sums of squares, respectively in an ordinary 2-way crossed classification analysis of variance of within animal differences between observations taken in 2 different periods.

Following Morrison (1976, sec.5.6) the statistic

$$\frac{4}{3} \ \mathrm{tr}(\underset{\sim}{H},\underset{\sim}{E}^{-1})$$

is, under the null hypothesis, distributed according to an F distribution with 3 and 4 degrees of freedom.

Given that the breed-by-temperature-by-period interaction was not significant, observations on the same animal were added together, giving a variable which was then analysed according to a 2-way crossed classification fixed-effect analysis of variance. That is in the equations equivalent to equation (5) the vector $\underset{\sim}{M}_1$, was a unit vector and the $\underset{\sim}{C}_1$ matrix was

(1) Testing No breed effect: $\underset{\sim}{C}_1 = \{1 \ -1 \ \ 1 \ -1\}$
(2) Testing No temperature : $\underset{\sim}{C}_1 = \{1 \ \ 1 \ -1 \ -1\}$
(3) Testing No breed x temperature : $\underset{\sim}{C}_1 = \{1 \ -1 \ -1 \ \ 1\}$

It is trivial to show that the matrix approach detailed here leads to the usual sums of squares in a 2-way crossed classification with fixed effects, on the sums of observations made.

Response Effects:

The kind of diet and response effects were completely confounded in this experiment. The null hypothesis of equal reponse effect is:

H_0: $\underset{\sim}{C}_2\ \underset{\sim}{U}\ \underset{\sim}{M}_1 = \underset{\sim}{0}$

ie:

$$H_o: \quad \{1 \quad 1 \quad 1 \quad 1\} \left| \begin{matrix} \mu_{111} & \mu_{211} \\ \mu_{112} & \mu_{212} \\ \mu_{121} & \mu_{221} \\ \mu_{122} & \mu_{222} \end{matrix} \right| \left| \begin{matrix} 1 \\ -1 \end{matrix} \right| = 0$$

Following Morrison's work, the statistic T^2 is, under the null hypothesis, distributed according to F distribution with 1 and 4 degrees of freedom.

where

$$T^2 = N\ \underset{\sim}{\bar{X}}^1\ \underset{\sim}{M}_1\ (\underset{\sim}{M}_1'\ \underset{\sim}{S}\ \underset{\sim}{M}_1)^{-1}\ M'\ \underset{\sim}{\bar{X}} \text{ ---------------------------}(8)$$

and

$S = \frac{1}{4}\ \underset{\sim}{E}$ note $\underset{\sim}{E}$ has the same value as obtained in (7)

In this example, it is observed that equation (8) gives the F value needed for testing the hypothesis of equal response effect.

CHAPTER THREE

RESULTS

3.1 Treatment Factors:

3.1.1 Environmental conditions:

The mean values for air temperature and relative humidity in the two rooms are shown in Table 3.1. The records taken in the cool room showed greater variation since the room was not equipped with a refrigeration unit to control its ambient temperature.

TABLE 3.1: Ambient conditions in the cool room (COOL) and in the hot room (HOT).

Trial	Climatic condition	COOL	HOT
1	Period 1	17.06	33.06
	Period 2	15.77	32.88
	Period 3	14.15	33.09
2	Period 4	15.12	32.97
	Mean ambient temperature (%)	15.52 ± 0.61	33.00 ± 0.04
	Mean Relative humidity %	87.0 ± 1.8	40.0 ± 0

3.1.2 Animals:

The animals remained healthy throughout the experiment. Although one of the Friesians developed warts on the neck, these disappeared after treatment.

3.2 Responses to Heat Stress:

3.2.1 Heat Stress Indices:

3.2.1.1 Rectal Temperature:

The mean values for rectal temperature and the results of multivariate analysis of variance are presented in Table 3.2. Values for individual animals during each period of the experiment are appended (Appendix 3.2).

The overall mean values for rectal temperature were 38.8°C and 39.9°C in the cool and hot rooms respectively. Of the main treatments, only the effects of environmental temperature were significant ($P< 0.005$). There was a significant ($P <0.05$) interaction between the effects of temperature and the effects of breed-for both trials ie., the increase in the rectal temperature of Friesian heifers being significantly greater ($P< 0.05$) than observed in the Sahiwal Friesian heifers when the ambient temperature was raised from 15.5°C to 33°C for both breeds.

3.2.1 Respiration Rate:

The mean value for the respiration rate and the results of multivariate analysis of variance are presented in Table 3.3 The respiratory frequency of individual animals in different period of the experiment are presented in Appendix. .3.3.

The overall mean values were 37 and 100 breaths per minute in the cool and hot rooms respectively. The effects of ambient temperature were significant in both trials ($P< 0.005$). The effects of Breed were also significant ($P< 0.01$ in Trial 1, and $P <0.05$ during Trial 2). Responses to the change in diet were significant ($P< 0.01$) in Trial 1 but not Trial 2.

TABLE 3.2a: Mean rectal temperatures (°C) of Sahiwal x Friesian (SF) and Friesian (F) heifers fed hay (HAY) or concentrates (CONC) at 15.5°C (COOL) or at 33°C (HOT) ambient temperature conditions:

Source of variation		Trial 1		Trial 2		MEAN ± SEM
Temperature	Breed	Period 1 HAY	Period 2 CONC	Period 3 CONC	Period 4 HAY	
HOT	SF	40.03	39.95	39.21	39.36	39.64 ± 0.21
	F	40.47	40.27	39.84	39.93	40.13 ± 0.11
COOL	SF	38.90	38.50	38.81	38.75	38.74 ± 0.09
	F	38.96	38.73	38.71	38.50	38.73 ± 0.09
Period means		39.59	39.41	39.14	39.14	

TABLE 3.2b: Mean Rectal temperatures (°C) and treatment effects

		Trial 1			Trial 2		
TREATMENT		Mean (°C)	SEM	F Test#	Mean (°C)	SEM	F.Test #
Temperature	Hot	40.13	±0.15	***	39.58	±0.26	***
	Cool	38.87	±0.08		38.69	± 0.10	
Breed	SF	39.39	±0.25	NS	39.03	± 0.21	NS
	F	39.60	±0.35		39.24	± 0.47	
Diet	Hay	39.59	±0.48	NS	39.14	± 0.40	NS
	Conc	39.41	±0.46		39.14	± 0.34	
Breed x temperature interactions				*			*

F Test, level of significance on multivariate analysis of variance where

NS = Not significant

* = P <0.05

** = P <0.01

***= P <0.005

Similar notations are used in all other analyses carried out

TABLE 3.3a: Respiration rates of Sahiwal x Friesian (SF) and Friesian (F) heifers fed hay (HAY) or concentrates (CONC) at 15.5^{o}C (COOL) or at 33.0^{o}C(HOT) ambient temperature conditions:

Source of variation		TRIAL 1		TRIAL 2		MEAN ± SEM
Temperature	Breed	Period 1 HAY	Period 2 CONC	Period 3 CONC	Period 4 HAY	
HOT	SF	101.1	81.6	65.5	91.6	84.95 ± 9.7
	F	129.4	112.6	103.9	113.8	114.93 ± 6.5
COOL	SF	50.5	27.0	20.9	19.3	29.35 ± 8.9
	F	64.5	47.9	38.0	24.9	43.83 ± 10.2
Period Means		86.4	67.3	57.1	62.3	

TABLE 3.3b: Mean Respiration[a] rates and treatment effects:

TREATMENT		TRIAL 1			TRIAL 2		
		Mean	± SEM	F test#	Mean	± SEM	F Test
Temperature	Hot	106.18	± 12.75	***	93.70	± 10.1	***
	Cool	47.48	± 9.98		25.75	± 5.7	
Breed	SF	65.04	± 20.3	**	49.32	± 22.12	**
	F	88.62	± 23.9		70.13	± 28.14	
Diet	HAY	86.38	± 22.0	**	62.32	± 24.3	
	CONC	67.28	± 23.4		56.7	± 27.4	NS
Breed x temperature interactions				NS			NS

[a] Respiration rates in breaths per minute

F Test : level of significance on multivariate analysis of variance

For notations refer Table 3.2b:

TABLE 3.4a: Sweat rate (g $m^{-2}hr^{-1}$) of Sahiwal x Friesian (SF) and Friesian (F) heifers fed hay (HAY) or concentrates (CONC) at 15.5°C(COOL) or at 33°C (HOT) ambient temperature conditions.

Source of Variation		TRIAL 1		TRIAL 2		MEAN ± SEM
Temperature	Breed	Period 1 HAY	Period 2 CONC.	Period 3 CONC.	Period 4 HAY	
HOT	SF	24.57	75.28	129.48	54.78	71.03± 19
	F	21.99	61.15	103.07	33.26	54.87± 22
COOL	SF	32.33	40.98	70.05	34.27	44.41± 10
	F	35.33	67.81	82.67	31.42	52.28± 14
Period Means		28.56	61.31	94.82	38.56	

TABLE 3.4b : Mean sweat rate and treatment effects.

TREATMENT		TRIAL 1			TRIAL 2		
		Mean	± SEM	F Test#	Mean	± SEM	F Test#
Temperature	Hot	45.75	± 10.1	NS	80.15	±26.9	NS
	Cool	44.11	± 9.9		54.73	±15.6	
Breed	SF	43.29	± 13.6	NS	72.15	±25.1	NS
	F	46.57	± 13.2		62.73	±21.9	
Diet	Hay	28.56	± 4.8	NS	38.56	± 7.5	**
	Conc.	61. 31	± 23.4		96.32	±22.4	
Breed x temperature interactions				NS			NS

F, notations refer Table 3.2b

3.2.1.3 Sweat Rate:

The mean values for sweat rate and the results of multivariate analysis of variance for sweat rate are presented in Table 3.4a and 3.4b respectively. The mean sweat rate of heifers in the cool room was 4.9 $g.m^{-2}hr^{-1}$. Calves in the hot room had an average sweat rate of 63. $g.m^{-2}hr^{-1}$. The effects of temperature, breed and the interaction between these effects, did not reach significant levels. The effects of diet were significant in Trial 2 ($P< 0.01$) but not in Trial 1.

3.2.2 Relations between heat stress indices:

The pooled data indicate that respiration rate (RR) of these heifers was linearly related to their rectal temperature (TR). The regression equation for the relationship was:

$$TR = 38.36 + 0.0139\ RR \quad (r = 0.8705\ df\ 30)$$

where

TR is rectal temperature (°C)
RR is respiration rate (breaths per minute)

Coefficients of regression and correlation describing the association between these variables under different treatments are summarised in Table 3.5.

Sweat rate was generally negatively related to rectal temperature. Although the pooled did not show any significant association, the sweat rate of heifers in the hot room was significantly ($P <0.05$) associated with the rectal temperatures of the heifers (Table 3.6) Each 1°C fall in their TR was associated with an increase of about 150g in the sweat rate.

There was no close association between sweat rate and respiration rate of calves in all treatment combinations (ie.pooled data).The correlation coefficients relating these variables became significant (Appendix 3.4) when the data analysed involved animals in the hot room; or more specifically, when the data analysed were from Sahiwal x Friesian heifers in the hot room.

TABLE 3.5 : The relationship[a] between TR (^{o}C) and RR (breaths per minute of heifers under different treatment combinations.

		Temperature		Breed		Diet	
		Hot	Cool	SF	F	CONC	HAY
correlation coeff.	Hot	0.60*	-	0.37	0.02	0.35	0.81*
	Cool		0.51*	0.52	0.91**	0.10	0.77*
	SF			0.82**	-	0.74*	0.30
	F				0.71**	0.89**	0.97***
	Conc					0.83***	-
	Hay						0.64**
regression coeff.	Hot	0.0155					
	Cool	-	0.00				
	SF	0.0158	0.004	0.0116			
	F	0.0002	0.0128	-	0.0122		
	Conc.	0.0096	0.0014	0.0093	0.0176	0.0136	
	Hay	0.0207	0.0079	0.0044	0.0180	-	0.0162

TABLE 3.6: The relationship[a] between TR(^{o}C) and SWR ($g.m^{-2}hr^{-1}$) of heifers under different treatment combinations.

		Temperature		Breed		Diet	
		Hot	Cool	SF	F	CONC	HAY
correlation coeff.	Hot	-0.65*	-	-0.76*	-0.57	-0.78*	-0.69
	Cool		0.22	0.18	0.26	0.20	0.27
	SF			-0.15	-	-0.03	-0.33
	F				0.13	0.01	-0.56
	Conc					0.004	-
	Hay						-0.13
regression coeff.	Hot	-0.0066					
	Cool	-	0.0015				
	SF	-0.0056	0.0008	-0.0016			
	F	-0.0053	0.0024	-	0.0032		
	Conc.	-0.0081	0.0014	-0.0002	0.0032	0.0006	
	Hay	-0.01608	0.0130	-0.0105	-0.0366	-	-0.0057

[a] all diagonal values have 14 degrees of freedom.The offset co efficients have 6 degrees of freedom

* significant at $P < 0.05$ ** significant at $P < 0.01$ ***significant at $P < 0.00$

3.2.3 Dry matter intake:

Both the dry matter intake (DMI) and digestible energy intake (DEI) were positively associated with the weight of calves at the beginning of the experiment. None of these associations reached significant levels on the analysis of covariance. Therefore, the data were presented (Table 3.7 and 3.8) without adjustments.

Calves in the hot room consumed a mean of 3.71 kgDM/day each. In the cool room, the mean intake was 4.46 kgDM/day. The effect of temperature was significant. ($P < 0.05$) during Trial 1 but not in Trial 2.

Although the calves consumed apparently more concentrate diet than they did the hay, the difference did not reach significant values for either trial.

3.2.4 Digestible energy intake:

The mean values for the daily intake of digestible energy by calves under different treatment conditions are presented in Table 3.8a. A summary of the results of multivariate analysis of variances for the digestible energy intake has also been presented in Table 3.8b.

The overall mean values for digestible energy (DE) consumed were 1.37 ± 0.09 MJ/kgBW$^{0.75}$/day for calves in the hot room and 1.62 ± 0.08 MJ/kgBW$^{0.75}$/day for calves in the cool room.

The effect of temperature was significant ($P < 0.05$) for both trials. None of the other sources of variation had significant influence on DE intake except the response to diet which became significant ($P < 0.05$) during Trial 2.

TABLE 3.7a: Daily dry matter intake (kg/calf) by Sahiwal x Friesian (SF) and Friesian (F) heifers fed hay (HAY) or concentrates (CONC) at 15.5°C (COOL) or at 33°C (HOT) ambient temperature conditions .

Source of Variation		TRIAL 1		TRIAL 2		MEAN ± SEM
Temperature	Breed	Period 1 HAY	Period 2 CONC.	Period 3 CONC.	Period 4 HAY	
HOT	SF	3.22	3.40	4.60	3.72	3.74 ± 0.53
	F	2.78	3.68	4.79	3.50	3.68 ± 0.72
COOL	SF	4.09	3.79	4.32	4.13	4.08 ± 0.29
	F	3.58	5.23	5.59	4.46	4.71 ± 0.77
Period Means		3.41	4.03	4.83	3.95	

TABLE 3.7b: Mean dry matter intake and treatment effects.

TREATMENT		TRIAL 1			TRIAL 2		
		Mean	± SEM	F Test#	Mean	± SEM	F Test#
Temperature	Hot	3.27	±0.39	*	4.15	±0.46	NS
	Cool	4.19	±0.53		4.62	±0.66	
Breed	SF	3.62	±0.38	NS	4.19	±0.59	NS
	F	3.81	±0.69		4.59	±0.70	
Diet	Hay	3.41	±0.39	NS	3.95	±0.29	NS
	Conc.	4.02	±0.62		4.83	±0.65	
Breed x temperature interactions				NS			NS

F, notations refer Table 3.2b

TABLE 3.8a: Daily intake of Digestible energy ($MJ/kgBW^{0.75}$) by Sahiwal x Friesian (SF) and Friesian (F) heifers fed hay (HAY) or concentrates (CONC) at $15.5^{o}C$(COOL) or at $33^{o}C$ (HOT) ambient temperature conditions.

Source of Variation		TRIAL 1		TRIAL 2		MEAN ± SEM
Temperature	Breed	Period 1 HAY	Period 2 CONC.	Period 3 CONC.	Period 4 HAY	
HOT	SF	1.38	1.46	1.76	1.26	1.47 ±0.18
	F	1.04	1.42	1.49	1.03	1.25 ±0.21
COOL	SF	1.75	1.60	1.69	1.45	1.62 ±0.11
	F	1.28	1.82	1.98	1.40	1.62 ±0.28
Period Means		1.36	1.58	1.73	1.29	

TABLE 3.8b: Mean consumption of digestible energy and treatment effects.

TREATMENT		TRIAL 1			TRIAL 2		
		Mean	± SEM	F Test#	Mean	± SEM	F Test#
Temperature	Hot	1.32	± 0.16	*	1.38	± 0.21	*
	Cool	1.61	± 0.17		1.63	± 0.23	
Breed	SF	1.55	± 0.15	NS	1.54	± 0.23	NS
	F	1.39	± 0.22		1.47	± 0.24	
Diet	Hay	1.36	± 0.19	NS	1.28	± 0.12	*
	Conc.	1.57	± 0.18		1.73	± 0.23	
Breed x temperature interactions				NS			NS

F notations refer Table 3.2b

3.2.5 Voluntary Water Intake:

The mean values of water intake by calves, and the results of multivariate analysis of their variance are presented in Table 3.9.

Heifers in the cool room each drank 19.3kg of water daily, while those in the hot room each drank an average of 41.0kg of water daily.

The effect of both temperature, and breed, were significant ($P < 0.005$) for both trials. Although the calves consumed more water when fed on hay than when fed on concentrate, the difference was significant during Trial 1 only.

The exponent of 0.82 for body weight was adopted to study variations in water consumption that might have been associated with differences in the metabolic body sizes. (MacFarlane and Howard, 1970).

Table 3.10a gives the mean values of water consumed by calves per unit of their metabolic body weight ($BW^{0.82}$). The treatment means and their respective standard errors are presented in Table 3.10b.

The overall mean values for water intake by calves in the hot and in the cool rooms were respectively 0.57 and 0.27kg of water per $kgBW^{0.82}day^{-1}$. Unlike the daily water intake per calf measurements (Table 3.9), water intake per unit of metabolic body weight did not show significant effects of diet, and, of the interaction between the effects of breed and temperature.

3.2.6 Liveweight Gain:

Weight gain during the two trials was not affected significantly by either age or weight of the animals at the beginning of the experiment.

TABLE 3.9a: Daily intake of water (kg calf^{-1}day^{-1}) by Sahiwal x Friesian (SF and Friesian(F) heifers fed hay (HAY) or concentrates (CONC) at 15.5^{o}C (COOL) or at 33^{o}C (HOT) ambient temperature conditions.

Source of Variation		TRIAL 1		TRIAL 2		MEAN ± SEM
Temperature	Breed	Period 1 HAY	Period 2 CONC.	Period 3 CONC.	Period 4 HAY	
HOT	SF	36.61	20.57	22.34	31.18	27.68 ± 14.5
	F	51.39	53.92	60.69	56.25	55.56 ± 3.4
COOL	SF	22.62	12.00	14.18	18.32	16.78 ± 12.5
	F	27.81	21.00	21.34	22.64	23.20 ± 2.7
Period Means		34.53	26.87	29.64	32.10	

TABLE 3.9b: Mean daily consumption of water (kg day^{-1}calf^{-1}) and treatment effects.

TREATMENT		TRIAL 1			TRIAL 2		
		Mean	± SEM	F Test#	Mean	± SEM	F Test#
Temperature	Hot	40.62	14.3	***	42.62	17.1	***
	Cool	20.79	6.2		19.12	4.1	
Breed	SF	22.95	9.3	***	21.03	7.1	***
	F	38.47	15.2		40.23	19.0	
Diet	Hay	34.54	11.5	*	32.10	15.3	NS
	Conc.	26.87	16.6		29.64	18.7	
Breed x temperature interactions				NS			*

F notations refer Table 3.2b

TABLE 3.10a: Daily intake of water (kg/BW$^{-0.82}$) by Sahiwal x Friesian (SF)and Friesian (F) heifers fed hay (HAY) or concentrates (CONC) at 15.5°C(COOL) or at 33°C(HOT) ambient temperatur conditions.

Source of Variation		TRIAL 1		TRIAL 2		MEAN ± SEM
Temperature	Breed	Period 1 HAY	Period 2 CONC.	Period 3 CONC.	Period 4 HAY	
HOT	SF	0.63	0.34	0.32	0.42	0.43±0.1
	F	0.76	0.78	0.70	0.64	0.72±0.1
COOL	SF	0.38	0.20	0.21	0.26	0.26±0.05
	F	0.39	0.27	0.28	0.28	0.31±0.05
Period Means		0.54	0.40	0.38	0.40	

TABLE 3.10b: Mean daily consumption of water (kg/BW$^{0.82}$) and treatment effects.

TREATMENT		TRIAL 1			TRIAL 2		
		Mean	± SEM	F Test#	Mean	± SEM	F Test#
Temperature	Hot	0.62	0.07	***	0.52	0.06	***
	Cool	0.31	0.03		0.26	0.02	
Breed	SF	0.38	0.07	**	0.30	0.04	***
	F	0.55	0.08		0.47	0.07	
Diet	Hay	0.54	0.06	NS	0.40	0.06	NS
	Conc.	0.40	0.09		0.38	0.07	
Breed x temperature interactions				NS			NS

F notations refer Table 3.2b

TABLE 3.11a: Daily liveweight gain (kg $calf^{-1}day^{-1}$) of Sahiwal x Friesian (SF) and Friesian (F) heifers fed hay (HAY) or concentrates (CONC) at 15.5°C (COOL) or at 33°C (HOT) ambient temperature conditions.

Source of Variation		TRIAL 1		TRIAL 2		MEAN ± SEM
Temperature	Breed	Period 1 HAY	Period 2 CONC.	Period 3 CONC.	Period 4 HAY	
HOT	SF	-0.06	0.33	1.08	0.29	0.41 ± 0.4
	F	0.08	0.23	0.90	- 0.33	0.22 ± 0.4
COOL	SF	0.37	0.56	0.92	0.54	0.60 ± 0.2
	F	-0.08	1.36	1.29	0.39	0.74 ± 0.6
Period Means		0.08	0.62	1.05	0.22	

TABLE 3.11b: Mean liveweight gain ($kg.calf^{-1}day^{-1}$) and treatment effects.

TREATMENT		TRIAL 1			TRIAL 2		
		Mean	± SEM	F Test#	Mean	± SEM	F Test#
Temperature	Hot	0.14	0.22	**	0.48	0.6	**
	Cool	0.55	0.54		0.78	0.4	
Breed	SF	0.30	0.30	NS	0.71	0.4	NS
	F	0.40	0.58		0.57	0.6	
Diet	Hay	0.08	0.2	*	0.22	0.4	**
	Conc.	0.62	0.5		1.05	0.3	
Breed x temperature interactions				NS			*

\# F notations refer Table 3.2b

The mean values for the liveweight gain by calves during each period are presented in Table 3.11a. A summary of the results of the multivariate analysis of variance carried out are also presented (Table 3.11b).

Over the whole experiment animals in the cool room gained more weight (0.67kg/day) than those in the hot room (0.39kg/day).

The effect of temperature was highly significant in both trials. The interaction between the effects of temperature and breed was significant only during the second trial. Breed differences were not significant for both trials.

3.2.7 Relations between, DMI, DEI, VWI,TR AND LWG

The pooled data indicate that the voluntary intake of water (VWI) by calves was positively associated with their rectal temperature (TR). Both the intake of dry matter (DMI) and digestible energy(DEI) were negatively associated with TR. The rate of Liveweight gain (LWG) also decreased with increased in the TR. The coefficients for these relations are presented in Table 3.12

TABLE 3.12 Coefficients of correlation[a] between TR,DMI,DEI,VWI and LWG.[b]

	TR	DMI	DEI	VWI	LWG
TR	1	-0.5057**	-0.4935**	0.8400***	-0.4628**
DMI		1	0.8533**	-0.2984	0.8107***
DEI			1	-0.3870*	0.8101***
VWI				1	0.4351*
LWG					1

a all at 30 degrees of freedom
* r is significant $P < 0.05$
** " " $P < 0.01$
*** " " $P < 0.001$

b TR = °C
DMI = kg/day
DEI = MJ/day
VWI = kg/day
LWG = kg/day

The rate of LWG was mainly affected by the intake of dry matter and digestible energy. The relationship between DEI and LWG for different treatment combinations are presented in Table 3.13.

TABLE 3.13: The relationship between DEI (MJ/day) and LWG (kg/day)

		Temperature		Breed		Diet	
		Hot	Cool	SF	F	Hay	Conc
correlation coeff.	Hot	0.8443[a]***	-	0.9384***	0.7972*	0.1381	0.8275*
	Cool		0.9089***	0.7803*	0.9670***	0.6680	0.8673**
	SF			0.8689***		0.7689*	0.8438**
	F				0.9147***	-0.2021	0.8817**
	HAY					0.6015*	
	CONC						0.8568***
regression coeff.	Hot	0.0275[a]					
	Cool		0.0280				
	SF	0.0307	0.0197	0.0261			
	F	0.0249	0.0332		0.0311		
	HAY	0.0079	0.0365	0.0389	-0.0078	0.0293	
	CONC	0.0292	0.0234	0.0244	0.0347		0.0273

For all treatment combinations

LWG = -0.9920 + 0.02874 DEI $\quad r = 0.8880$***

df = 30

[a] All diagonal values have 14df. The offset values have 6 df.

3.2.8 The Hair Coat:

The mean weight of the hair coat of individual calves at the beginning of experiment are presented in Table 3.4a. They indicate that the Friesian heifers had heavier coats than had the Sahiwal x Friesian heifers prior to the commencement of the experiment.

Tbe analysis of covariance did not show significant association between the original weights of hair coat, and their regrowth after clipping. The observed rates of growth of the hair coat were, therefore, accepted for analysis.

THe mean growth rates of hair coats of heifers under different treatments are presented in Table 3.14b, and a summary of the multivariate analysis of their variance is presented in Table 3.14c.

The effects of both ambient temperature and breed were not significant in the two trials. Feeding hay resulted in significantly faster rates of growth of the hair coat than concentrate feeding. During hay feeding, the calves had a mean rate of hair coat growth of 3.17 g $m^{-2}day^{-1}$, where as under concentrate feeding they had a mean hair growth rate of 1.19 g $m^{-2}day^{-1}$.

TABLE 3.14a: Weight(g m^{-2}) of hair coat of individual calves at the beginning of the experiment.

Heifer number	Breed	Weight of Hair coat(g m^{-2})	Breed Means
1	Sahiwal x Friesian	211	
3	Sahiwal x Friesian	211	217
5	Sahiwal x Friesian	233	
7	Sahiwal x Friesian	214	
2	Friesian	368	
4	Friesian	458	325
6	Friesian	262	
8	Friesian	211	

TABLE 3.14b: Mean rates of growth*of hair coat of Sahiwal x Friesian (SF) and Friesian (F) heifers fed hay (HAY) or concentrates (CONC) at $15.5^{\circ}C$ or at $33^{\circ}C$ (HOT) ambient temperature conditions.

Source of Variation		TRIAL 1		TRIAL 2		MEAN ± SEM
Temperature	Breed	Period 1 HAY	Period 2 CONC.	Period 3 CONC.	Period 4 HAY	
HOT	SF	2.31	1.35	1.45	3.42	2.05± 1.06
	F	3.23	0.92	1.21	2.30	1.93± 1.04
COOL	SF	2.13	1.45	1.21	2.70	1.87± 0.82
	F	7.65	1.06	1.16	1.61	2.87± 2.90
Period Means		3.83	1.19	1.18	2.52	

* Weight of hair in g m^{-2}day

TABLE 3.14c: Mean hair growth* rates and treatment effects

TREATMENT		TRIAL 1			TRIAL 2		
		Mean	± SEM	F Test#	Mean	± SEM	F Test#
Temperature	Hot	1.95	1.08	NS	1.67	0.67	NS
	Cool	3.07	2.84		2.03	1.03	
Breed	SF	1.81	0.88	NS	2.12	0.99	NS
	F	3.21	2.85		1.59	0.67	
Diet	Hay	3.83	2.48	**	2.52	0.78	**
	Conc.	1.19	0.50		1.18	0.28	
Breed x temperature interactions				NS			NS

F notations ref Table 3.2b

CHAPTER FOUR
DISCUSSION

4.1 Rectal temperature (TR)

4.1.1 Effects of ambient temperature:

The mean rectal temperature of all heifers was significantly $(P < 0.005)$ higher in the hot room (39.9°C) than in the cool room (38.8°C). Similar increases in rectal temperature have been reported in previous experiments. (Table 4.1)

TABLE 4.1: The effects of ambient temperature on Rectal temperature

	Ambient temperature (°C)		Rectal temperature (°C)	
Author	Cool	Hot	Cool	Hot
Olbrich *et al*; (1972)	10	31	38.5	39.8
Kellaway and Colditz (1972)	17	38	38.6	39.3
Sauwa (1978)	17	34.5	39.00	40.15
O'Kelly (1973)	2.3	33.0	38.4	39.5
Present data	15,5	33.0	38.5	39.5

Kerslake (1972) suggested that under thermo-neutral conditions body temperature is relatively constant and independent of the changes in the ambient temperature. Monteith (1974) also suggested that the net metabolic heat production, and the net exchanges of heat between the animal and its environment are minimal in a thermo-neutral environment. The exchanges of heat between the animal and its environment may be low mainly because of the low temperature gradient between the body and the environment. The skin surface temperature increases on exposure of animals to hot conditions; this may be accompanied by an increase in the amount of heat energy gained from the environment. If the body 'heat content' is to be maintained constant in hot conditions, then the animals must increase the rate of dissipation of heat from the body to the environment by the evaporative or non-evaporative means.

It seems therefore that the core temperature rises so as to maintain a temperature gradient, and hence a continuous exchange of heat with the environment. Increases in TR above normal in animals exposed to hot conditions are indicative of heat stress, (Kerslake,1972). Therefore, the higher rectal temperatures recorded in heifers subjected to the hot conditions indicate that the ambient temperature maintained in the hot room was higher than the thermo-neutral range of these heifers.

4.1.2. Effects of breed:

The mean rectal temperature of Friesian heifers was higher than that of the Sahiwal x Friesian heifers in both trials. There was no significant ($P > 0.05$) difference between the rectal temperatures of the two breeds at 15.5°C, while at 33°C, the Friesian heifers had significantly ($P < 0.05$) higher rectal temperatures than had the Sahiwal x Friesian heifers. The effects are discussed below under temperature x breed interactions.

4.1.3 Temperature x Breed interactions:

The interaction between the effects of temperature and breed on TR was signficant ($P < 0.05$). The Friesian heifers exhibited higher values for TR than did the Sahiwal x Friesian heifers when exposed to (33°C) hot ambient temperature.

The results are in agreement with previous studies reported by Rhoad, (1938); Kibler and Brody,(1951); Kellaway and Colditz, (1975), and by Sauwa, (1978). These authors found that in hot conditions TR did not increase in Bos indicus cattle and their cross breds, as much as it did in Bos taurus cattle.

The explanation for this difference in response to hot conditions seems to involve genetical differences in the way these two breeds utilise body water for evaporative cooling.(Olbrich et al.,(1972), Sauwa, (1978) and Vercoe et al.,(1972) suggested that Bos indicus cattle relied more heavily on skin surface evaporative cooling than did Bos taurus cattle. The latter breed was observed to have higher respiration rates, and hence it was assumed that at high ambient temperatures, Bos taurus cattle depended upon the respiratory system for evaporative cooling. Since this system is not as effective as skin surface evaporative cooling of hot animals (McLean, 1963), it was suggested that the Bos taurus cattle had higher TR than had the Bos indicus cattle at 31°C, because of their differences in the rates of evaporative dissipation of heat from the skin.

It is therefore suggested that the Sahiwal x Friesian heifers were able to maintain lower rectal temperatures than did the Friesian heifers on exposure to 33°C because of the advantage they had in sweating and hence greater evaporative cooling at the skin level (see section 4.3).

4.1.4 Responses to diet:

Heifers exposed to hot conditions had a mean TR of 39.81°C when fed on concentrates but a mean of 39.95°C when hay was fed; the difference (0.14°C) was not significant. Previous work reported by Webster et al., (1976), and Osuji et al., (1975), indicated that animals consuming unpelleted forages of low digestibilities show greater heat production than those eating pelleted and highly digested diets. Webster et al., (1976) for example, concluded that the heat increment from a fixed amount of food is inversely related to the digestibility of the diet. It was therefore expected that at a constant value of DMI, animals consuming hay would have shown higher rectal temperatues than those eating concentrates.

The data adjusted to a common value for DM, (Table 4.2) did not indicate significant differences between diets.

TABLE 4.2: Mean Rectal temperatures (^{o}C)* of heifers fed hay (HAY) and concentrates (CONC) at 15.5^{o}C (COOL) and 33^{o}C (HOT) ambient temperature conditions.

	AMBIENT TEMPERATURE	
DIET	COOL	HOT
HAY	38.75	39.96
CONC	38.79	39.75
difference	-0.04	- 0.21

* rectal temperature adjusted for the mean intake of DM of 4.04 DM/calf/day.

Similar results have been reported by Colditz and Kellaway (1972) who found significant diet influence on the TR of cattle consuming high quality diet (rolled barley and soy bean meal) as opposed to low quality diet (oaten chaff and soy bean meal).Sauwa (1978), with a very similar pattern of feeding as maintained in the present experiment also reported no significant difference between the rectal temperature measurements of animals consuming hay and those fed on concentrates. This may be taken to indicate that there is little advantage in TR, on feeding concentrates instead of hay at 33^{o}C. The advantage is however notable when DEI is considered.(sec.4.4).

4.2. Respiration Rate:

4.2.1. The Effects of Ambient temperature:

The heifers subjected to 33^{o}C ambient temperature had a mean respiratory rate (RR) of 100 breaths min^{-1} while those in the cool room maintained a mean RR of 37 breaths min^{-1}. The difference between the rates of respirations at the two temperature conditions was highly significant (P <0.01.)

When cattle are exposed to hot conditions their respiratory frequencies increase in association with the increases in rectal temperature. These increases in the respiratory ventilation are adopted to facilitate heat loss by evaporation from the upper respiratory tract (Ingram and Whittow, 1962). Work reported previously by Hales and Findlay, (1968); Colditz and Kellaway, (1972), and recently by Sauwa (1978), have deomonstrated these effects (increases in RR) on cattle exposed to hot conditions (see 1.5.4.)

With the pooled data it was established in the present experiment that the heifers increased their respiration rates by about 72 breaths per 1°C rise in the rectal temperature. Using this relationship it can be shown that the maximum frequency of about 180 breaths per minute at which cattle enter the second phase breathing would have been achieved at 40.86°C (TR). This estimate is in a good agreement with Hales and Findlay's (1968) experiment in which oxen exposed to a severe heat stress achieved a maximum respiratory frequency of 180 breaths per minute when their rectal temperature was 40.7 ± 0.1°C. Second phase breathing was not observed in the present experiment.

4.2.2 Effects of Breed:

The results of this experiment, like those reviewed by McDowell (1972), suggest that Bos indicus cross bred animals exhibit lower respiratory frequencies than Bos taurus when animals of both breeds are exposed to hot conditions.

In this experiment the Sahiwal x Friesian heifers had a mean respiration rate of 84.6 breaths min. Whereas the Friesian heifers had a mean of 115 breaths per minute on exposure to 33°C. The difference in RR between the two breeds in the hot room conditions was about twice as large as the difference recorded at 17°C.

Sauwa, (1978) also observed significant differences in respiration rate of cattle of different breeds when exposed to 34.5°C.Sauwa's Friesian steers had a mean respiratory frequency of 100 breaths min^{-1} while Brahman x Friesian steers had a mean RR of 93 breaths min^{-1}. Data reported in other experiments are summarised in Table 1.5.4.

With a series of regression equations, Sauwa (1978) demonstrated that RR, was positively related with TR. Similar relations were obtained in the present experiment (Table 3.5). It is therefore suggested that the Friesian heifers had higher RR than had the Sahiwal x Friesian heifers, because of their higher rectal temperatures, which is supported by the experiment reported by O'Kelly (1973a), in which cattle of different breeds attained similar RR when they had their TR raised by the same amount.

4.2.3 Responses to diet:

The effect of diet on RR was significant ($P< 0.01$) in the first trial but not in the second trial. In both cases, however, heifers exhibited higher respiratory frequencies during hay feeding than when concentrates were fed. These results contradict those reported by Colditz and Kellaway (1972) who noted that heifers eating rolled barley with about 15% CP, had similar respiration rates (55vs 56 breaths min^{-1}) to those fed on oaten chaff with about 9.8% CP. Sauwa (1978) also reported significant dietary influence on the RR of steers consuming diets similar to those used in the present experiment; in Sauwa's experiment however, faster RR were noted in animals consuming concentrates rather than hay.

It seems therefore that the influence of diet on the rate of breathing by animals is not simply an effect associated with feed quality. It is probable that amounts of energy (DE) consumed from different diets, total intake of dry matter and the effects of increases in body heat, all contribute to the increases in the RR of cattle. Sauwa, (1978) demonstrated these effects in his experiment with cattle, while Heisey et al., (1971) demonstrated them with goats.

It is concluded that, on exposure to high ambient temperature cattle increase their respiration rate to facilitate evaporated heat loss from the body. Hay feeding resulted in higher respiratory frequencies than did the concentrate diet. No direct physical explanation is available for this dietary effect. It is however suggested that the differences in heat production when the two diets are consumed may be involved, since the hay fed calves also showed higher TR than concentrate fed calves.

4.3. Sweating:

4.3.1 The effects of breed and temperature:

The results of this experiment (Table 3.4) indicated that heifers subjected to 33°C exhibited higher sweat rates than those at 15.5°C The difference was however not statistically significant. The effects of breed were also not significant, although Sahiwal x Friesian heiferes exhibited slightly faster sweat rates than did the Friesian heifers on exposure to the hot condition.

The mean sweat rate of 71g.$m^{-2}hr^{-1}$observed in Sahiwal x Friesian heifers in the hot room are lower than those reported previously in experiments by Sauwa (1978) and by Findlay and Robertshaw (1965). Sauwa reported a sweat rate of 150g.$m^{-2}hr^{-1}$ for Brahman x Friesian steers exposed to 32.4°C. While the Friesian heifers in the present experiment had a mean sweat rate (SWR) of about 55g.$m^{-2}hr^{-1}$ Findlay and Robertshaw's (1965) Ayrshire calves had a mean sweat rate of 130g.$m^{-2}hr^{-1}$ on exposure to 35°C (Fig 4.1). Schleger and Turner (1965) have demonstrated that variations in SWR, between animals within breed can sometimes be very large.

The small differences noted in this experiment between SWR of the two breeds of heifers, should not be considered extraordinary for this experiment. Taneja (1959a) indicated that the differences between SWR of cattle of different breeds may not be very obvious under mild heat stress conditions. He noted that at 34°C Zebu cross cattle and Shorthorn cattle had a similar sweat rate (about 150g.$m^{-2}hr$). As the ambient temperature increased above 39°C, SWR increased at a faster rate for Zebu cattle than for the Shorthorns (Fig.1.7). Pan et al., (1969), also reported cases in which Red Sindhix Jersey had sweat rates which were similar to those of pure Jersey animals on exposure to 38°C.

One possible explanation of this similarity in the SWR of cattle of different breeds may be associated with sweating characteristics of the areas of skin on which observations were made. Pan et al., (1969) suggested that Bos taurus cattle may have a few sweat glands which are active enough the secrete as much sweat as would the small but numerous sweat glands of the rump of Bos indicus cattle.

4.3.2. Responses to diet:

The results of this experiment (Table 3.4) demonstrated that concentrate feeding resulted in significantly ($P < 0.01$) greater sweat rates than those observed when hay was fed despite the fact that TR was higher when hay was fed than when concentrates were fed.

Further analyses (Figure 4.2) demonstrated that SWR was negatively associated ($P < 0.05$) with TR of cattle subjected to 33°C. This suggests that greater SWR of heifers during concentrate feeding might have been responsible for the lower TR exhibited by these animals. The question which remains unanswered is why should animals with similar TR exhibit different rates of sweating when fed the two types of feed ; eg; Figure 4.2 indicates that at a TR of 39.5°C, the heifers had a sweat rate of 60 $g.m^{-2}hr^{-1}$ if fed hay, but 120$g.m^{-2}hr^{-1}$, if fed on concentrates.

The results indicated a much closer association between SWR and DEI ($r = 0.66$) than between SWR and TR ($r = -0.37$). It is possible that higher energy intakes in the hot room required a greater cooling than was needed when the intake was low. This is in accordance with the suggestion by Alvarez et al., (1970) that an increase in heat production resulting from consumption of food may raise the hypothalamic temperature and ultimately increase sweat gland secretory activitiy. Thus consumption of concentrates resulted in a faster sweat rate than did hay feeding. Further studies are invited to identify other nutritional factors which might affect sweat rate of animals under hot environments.

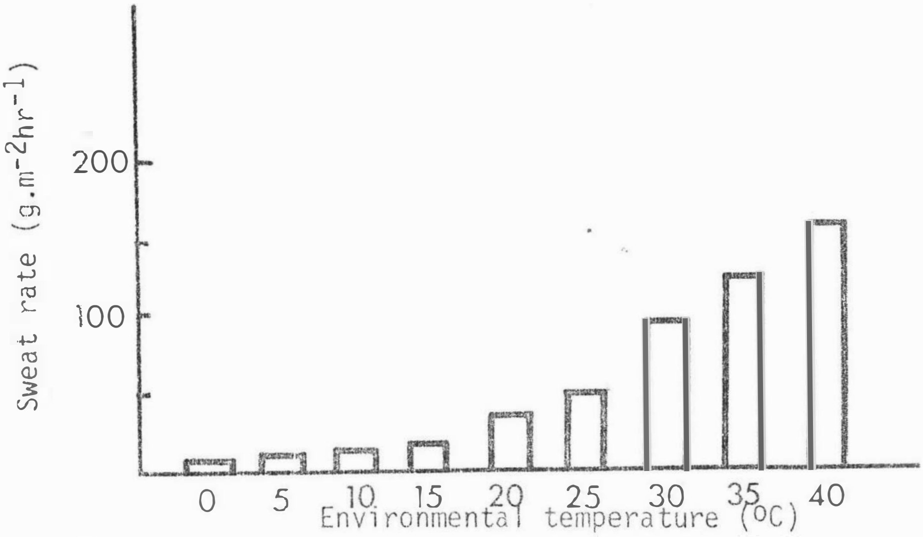

Figure 4.1: Cutaneous moisture loss from Ayrshire calves measured at various ambient temperatures. From Findlay and Robertshaw

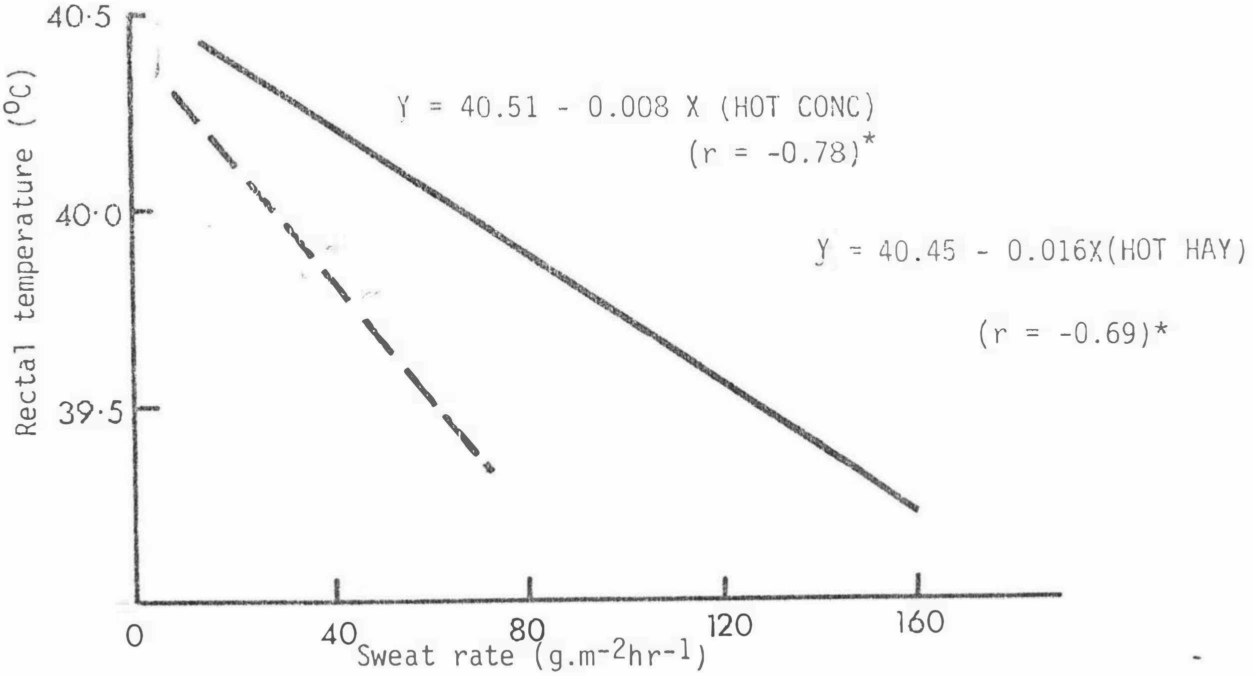

Figure 4.2: The relationship between sweat rate and rectal temperature of cattle fed concentrates or hay at 33°C.
r significant at P <0.05.

4.3.3 The relationship between sweating and respiration:

Respiratory activity has been mentioned to be augmented by sweating in animals to facilitate evaporative heat loss from the body. Studies of the relationship between respiratory frequency changes and sweat rate of animals have been reviewed by Hales (1974);and McLean (1963b) has demonstrated that at low ambient temperatures (eg. between 15-20^{o}C), heat loss by evaporation of moisture from the skin surface is almost equal to that lost by respiration. At high temperatures cutaneous evaporation increases, and becomes the major source of heat loss from the body. At 35^{o}C for example McLean's calves lost about 45g.hr^{-1} of water through respiration, but about 230g.hr^{-1} by cutaneous evaporation. These results are demonstrated in Figure 4.3.2.

The present experiment, like Mclean's observations, has indicated that RR is positively associated with SWR, when the ambient temperature is increased. At a constant high ambient temperature, however, sweat rate is negatively associated with respiration rates. (see Appendix 3.4). The closest association was obtained with Sahiwal x Friesian calves in the hot chamber and for these a depression of RR by one unit was achieved in association with and increase in sweat rate of 2.4g.m^{-2}hr^{-1}.

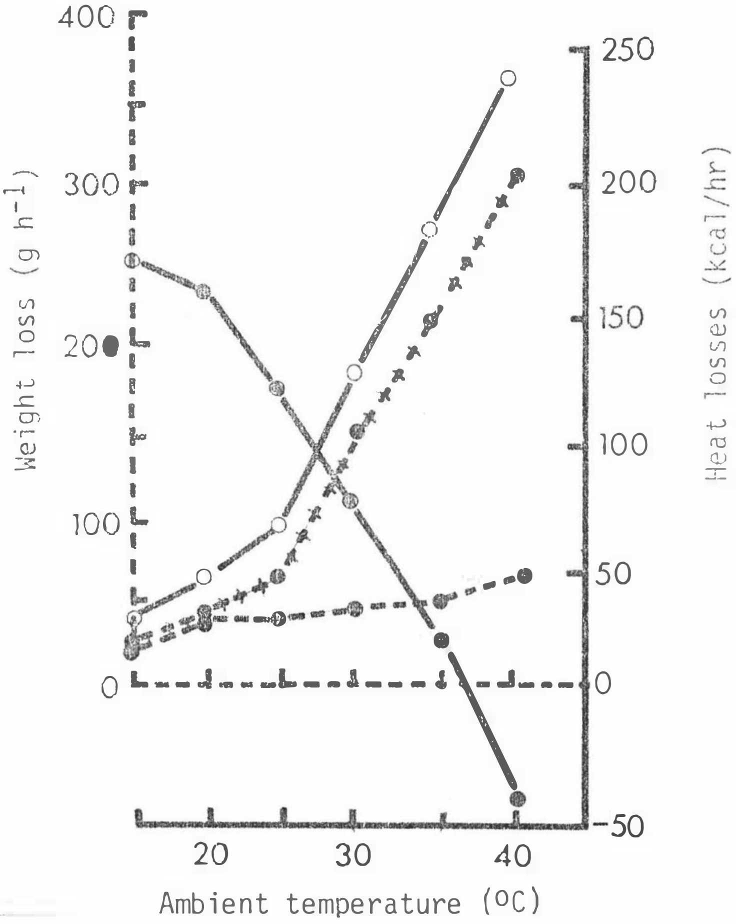

Figure 4.3: The effects of environmental temperature on moisture losses by respiratory (●------●) and cutaneous (●+●) evaporation. Superimposed are the associated total evaporative heat loss (o-o) and non-evaporative heat loss(●-●) from Ayrshire calves.

Experiments reported previously by Bligh (1957) and by Findlay and Ingram (1961) suggested that increases in the RR of calves are almost entirely attributable to peripheral thermal stimulation when TR is less than 40°C. The mean TR of hot calves in the present experiment was 39.86°C. Thus the heifers had a TR which was within the range suggested by Findlay and Ingram (1961) in which RR is mainly dependent upon peripheral stimulation. It is therefore suggested that increases in SWR affected the RR of hot animals through the cooling effects achieved on evaporation of moisture from the skin surface.

In conclusion it is suggested that increasing the ambient temperature may result in increases of both sweat rate and respiratory frequency of cattle. At a constant high ambient temperature, increases in sweat rate are associated with decreases in both respiration rate and rectal temperatures. Therefore, the greater sweat rate of the Sahiwal x Friesian heifers is suggested to be responsible for the comparatively lower TR and RR recorded in these heifers than in the Friesians.

4.4 Dry Matter and Energy Intake:

4.4.1 Effects of Ambient temperature:

Exposure of animals to hot environments is known to cause decreases in their voluntary intake of feed and energy (Bianca, 1965) and the results of this experiment agree with those of other experiments, (Colditz and Kellaway, 1972; Allen *et al*., 1963; Vercoe *et al*., 1972; Kellaway and Colditz, 1975) in which increases in the ambient temperature were associated with decreases in the intake of dry matter. The animals subjected to 33°C in the present experiment consumed only 3.71kg of dry matter per day, while those at 17°C consumed a mean of 4.46kg. These results may be compared with those reported by King (1978) in which a decrease in DMI by about 30% (ie. from 4.26kg at 17°C to 3.0kg/day at 34.5°C) were observed on exposure of steers to a hot environment. It is difficult to compare the results of the present experiment with those reported in other experiments because of the differences in the diets used in each case.

The difference noted between the DEI by the "hot" heifers and "cool" heifers is associated with the above differences in their intake of dry matter. The observation that DEI was also significantly related with rectal temperature, voluntary intake of water and liveweight gain, (Table 3.1.2a) suggest a possibility that part of the difference could be ascribed to the effects which high ambient temperature had on these variables. The negative association between TR and intake of digestible energy may be a factor of thermostatic control of body heat (Brobeck, 1960). On the other hand, reduction of dry matter intake and consequently the DEI, might have been necessary to allow for an increase in the intake of free water under hot conditions. This may explain the negative correlations observed between DEI and VWI by calves at 33°C. In the cool condition, the two variables were positively correlated, which agrees with other work reported in literature (eg. Ternouth and Beatie, 1971).

Slight increases in the digestibility of dry matter by cattle in hot conditions have been reported in some experiments.(Vercoe and Frisch 1970; Vercoe et al., 1972; O'Kelly, 1973a).Vercoe et al., (1972) noted that, when Brahman cross cattle were exposed to conditions hot enough to raise their rectal temperatures by 1.4°C, the digestibility of dry matter they consumed increased from 60% to 62.8%. Olbrich et al., (1973) observed that the increases are often very small, and are therefore unlikely to have caused any significant influence on the DEI values recorded in the present experiment.

4.4.2 Effects of Breed:

Several experiments show that hot conditions depress DM and DE intakes to a greater extent in B.taurus than in B.indicus (Kellaway and Colditz, 1975; Ragsdale et al., 1951). The present set of trials have demonstrated these effects; however, the interaction between the effects of temperature and breed were not significant. Using diets similar to those used in the present experiment, King (1978) also did not obtain any significant temperature x Breed interactions.

It appears that conditions hotter than that maintained in the present experiment are required to show significant Breed x temperature interactions. Kellaway and Colditz (1975) work (Table 1.2.3) demonstrates this fact.

4.4.3 Response to diet:

The multivariate analysis of variance suggested no significant linear diet-response function for the intake of dry matter by heifers in the two trials. However, whereas the consumption of concentrate diet was not significantly affected by ambient temperature in both trials, significantly less of the hay diet was eaten at the hot temperature than at the cooler temperature. The intake of digestible energy gave a much clear picture of the influence of diet on the performance of animals than does DMI. Significantly ($P < 0.05$) more DE was consumed when concentrates were fed than when hay was fed.

Feed factors which may have led to a significant difference in the DEI and in the total intake of dry matter were probably the differences in the digestibilities and the physical forms in which the two feeds were fed. The estimates of digestibility provided in Table 2.2 indicate that hay ration was less readily digested than was the concentrate diet. According to Blaxter, Wainman and Wilson (1961) intake of food is closely related to its apparent digestibility. This observation was confirmed in an experiment with sheep (Minson et al., 1964) and in another experiment with cattle (Conrad et al., 1964). The latter authors indicated that intake of feeds with digestibilities lower than 67% was limited by its digestibility and the rate of passage in the gut. For diets with digestibilities higher than 67% intake was thought to be controlled by factors other than the physical form of the diet. Further experiments,(Nocek and Kesler 1980) have demonstrated cattle consume more feed DM when the diet is fed in the pelleted form than compared with other forms such as long hay.

The digestibility of hay in the present experiment falls within the range of digestibilities proposed by Conrad et al., (1964) where DMI is mainly influenced by the apparent digestibility of the ration. It is therefore suggested that the intake of hay dry matter may have been low due to its lower digestibility, and also due to its physical (unchopped) form.

The results of this experiment have demonstrated that dry matter intake is reduced significantly by hot conditions when hay is fed, but not when the concentrate diet is fed to hot animals. This advantage should be made use of particularly in the hot tropics where livestock production is limited by low intakes of digestible organic matter (McDowell, 1972). Therefore feeding concentrate diets is recommended under hot conditions.

4.5 Voluntary Intake of Water:

4.5.1 Effects of Ambient Temperature:

The results presented in Table 3.9a and 3.9b indicated significant ($P < 0.005$) increases in the daily intake of water by heifers on exposure of the animals to hot environments. In absolute terms the amount of water the heifers consumed at 33°C was just over twice the amount drunk at 15°C. The heifers consumed 19.3kg of water per head per day in the cool room.

These results are comparable with those which had been reported by Winchester and Morris (1956); O'Kelly (1973a) and recently by King (1978).(Table 4.3).

TABLE 4.3: The Voluntary intake of water(kg/kgDM) by cattle exposed to hot or cool conditions.

AUTHOR	BREED	COOL (15-17^{o}C)	HOT (33-35^{o}C)
1. Winchester & Morris 1956	B.taurus	4.5	10
2. King 1978	Brahman x Friesian	3.4	9.0
	Friesians	3.8	10.6
3. O'Kelly 1979a	Shorthorn x Hereford	7.5*	21.6
	Africander X	6.5*	20.1**
4. Present data	Sahiwal x Friesian	4.3	6.0
5. Present data	Friesian	5.6	14.3

* Values recorded at 23^{o}C

**Values recorded at 38^{o}C

Two possible sources of variation in the voluntary intake of water between temperatures in this experiment were the dietary content of water and the influence of evaporative losses of eater from the body.

On dry matter analysis it was observed that the animals obtained only 0.5kg of water daily from the feed they consumed in the cool room. This was less than 3% of the 19.3kg of water drunk at 15.5^{o}C. Under heat stress the animals consumed less feed and more free water; consequently the dietary water constituted a very small proportion of the mean daily intake of water at 33^{o}C. Thus the variation in intake of dietary water between the two temperatures could not have significantly affected the VWI by these animals. Hot conditions are known to cause increase in intake of water directly through stimulation of thirst centres (Grace and Stevenson, 1971) and indirectly through increased cellular dehydration (Carlisle, 1971). It is suggested that these effects were responsible for the increased intake of water by 'hot' heifers in the present experiment.

4.5.2 Effects of breed:

Although no significant differences were noted between the voluntary intake of feed by the two breeds, the Friesian group was noted to drink significantly more water ($P< 0.005$)than did the Sahiwal x Friesian heifers. These differences existed even after water intake had been adjusted for differences in metabolic body sizes of the animals. (Table 3.10a).

The results of this experiment agree with other observations reported by French (1956) and by Winchester and Morris (1956) in which evidence was provided indicating that Bos indicus cattle drank less water than did Bos taurus. The differences in the voluntary intake of water are mainly noted under conditions of heat stress (Ledger et al., 1970; Rogerson et al., 1968). In the cool conditions, differences in VWI by different breeds or animals within a breed may be associated with metabolic demands for maintenance, growth and production (Winchester and Morris, 1956). Water intake is also influenced by intake of dry matter (Haack et al., 1975).

It has been shown (Table 3.12) that TR had significant linear association ($r = 0.84$, $P< 0.01$) with VWI, and that the Friesian heifers had higher TR than had Sahiwal x Friesian heifers at $38^{O}C$. It is therefore suggested that the differences noted in the VWI between the two breeds in the hot room were associated with the severity of heat stress experienced by these heifers.

Similar effects were reported by O'Kelly (1973a). This author observed that at $33^{O}C$ B.taurus calves consumed more water than did B.indicus, but when B.indicus cattle were exposed to $38^{O}C$ their rectal temperature and VWI increased to be equal to those of B.taurus cattle exposed to $33^{O}C$.

4.5.3 Responses to diet:

The animals consumed more water during hay feeding than during concentrate feeding (Table 3.9b). The effect of diet was however significant ($P < 0.05$) in Trial 1 only.

Similar observations have been reported in other experiments (Waldo et al., 1965) in which the VWI by heifers eating hay silage or concentrates were compared. Church et al., (1972) associate these effects with the form of feed.

The effects noted in the present experiment were probably associated with the heat stress imposed on the calves on consumption of the two diets. This stems from the observation made earlier that water intake increased with increases in the rectal temperature. It has been demonstrated in Table 3.2a that the animals exhibited higher rectal temperature during hay feeding than under concentrate feeding. Thus the higher rates of intake of water could have partly been explained by the heat stress condition developed.

Other factors of dietary origin which could have caused differences in the intake of water by the calves have been outlined in 1.3.3 Since most of these factors were not measured it is not justified to discuss their effects in the present experiment.

It is concluded therefore that exposures of the animals to 33°C increased their VWI through effects on heat balance in the body. Friesian heifers consumed more water than did the Sahiwal x Friesian heifers because they were experiencing greater heat stress than did the crossbred heifers.

4.6 Liveweight Gain:

4.6.1 Effects of Ambient temperature:

Previous experiments, such as those reported by Kamal and Johnson (1971); Vohnout and Bateman (1972) and Shebaita and Kamal (1975) showed that the liveweight gain (LWG) of animals exposed to hot conditions is lower than of those exposed to thermo-neutral conditions. Results of a number of experiments indicating similar effects have been summarised in Table 1.4.1.

The present experiment also indicated significant ($P < 0.01$) reduction of the rate of LWG on exposure of animals to hot (33°C) compared with cooler (15.5°C) conditions.

These decreases in the rate of LWG on exposure of animals to high ambient temperature may be a result of either the direct influence of increases in body temperature (O'Kelly, 1973b), or the indirect influence of reduced intake of dry matter (Kamal and Seif, 1969) or both factors may have an influence. The analysis provided in Table 3.12 demonstrates that there was a significant linear association between the LWG and TR ($P< 0.01$) and also between LWG and DEI ($P< 0.001$). For pooled data, increases in TR were associated with 21% of the variation in LWG; while increases in DEI were assocated with 66% of the variations in the rate of LWG. Data from the animals in the hot room indicated that changes in TR accounted for only 25% of the variations in LWG. Under similar conditions DEI was associated with 71% of the variations in LWG.

A multiple regression equation developed to describe the combined effects of TR, and DEI on LWG is:

$$\text{LWG} = 1.2820 + 1.257618\ \text{DEI} - 0.06759\ \text{TR}$$

where

$\text{LWG} = \text{kg/day}$

$\text{DEI} = \text{MJ/kgBW}^{0.75}$

$\text{TR} = {}^{\circ}\text{C}$

and

$r_{\text{LWG.DEI}} = 0.8101,^{***}\text{df} = 30$

$r_{\text{LWG.TR}} = -0.4628^{**}\quad \text{df} = 30$

At a constant rectal temperature, LWG was linearly related with DEI. The partial correlation coefficient between LWG and DEI at a constant TR was 0.7545***. The relationship between LWG and TR was not significant ($r = -0.228$), when DEI was held constant. King (1978) also reported results similar to these, indicating that once the effects of DMI are removed, temperature accounts for a minute proportion of the declines in the rate of LWG.

It is therefore suggested that declines in the rates of LWG on exposure of animals to hot conditions are mainly due to decreases in DEI. Nevertheless, the small negative association reported between TR and LWG may be of biological significance (see Yousef and Johnson, 1966).

4.6.2 Effects of breed:

A number of experiments have indicated that the rate of LWG of a crossbred between Friesian and Bos indicus cattle is the same as that of a pure Friesian in a thermally neutral environment, but in a hot environment the crossbred gains weight faster than the Friesian counterpart. Colditz and Kellaway (1972) reported that an increase in ambient temperature from 17°C to 38°C reduced the LWG of Friesians from 1.18kg.day^{-1} to 0.59kg.day^{-1} whereas the corresponding values for Brahman x Friesians were 1.06 kg day^{-1} at 17°C and 1.10kg.day^{-1} at 38°C.

The present experiment did not show a significant difference betweeen the mean liveweight gains of the two breeds (Table 3.11a) However,in agreement with Colditz and Kellaway's (1972) results the present experiment has indicated that the crossbred animals gained weight faster than did the Friesians in the hot room. In the cool room however, the Friesian heifers gained weight faster than did the Sahiwal x Friesian heifers. The interaction between the effects of temperature and breed was significant ($P < 0.05$) only in Trial 2.

The difference between the rates of LWG of the two breeds under hot conditions may be associated with their differences in energy consumption. Table 3.8a shows that the Sahiwal x Friesian heifers consumed more digestible energy than did the Friesian heifers in the hot chamber. It has also been indicated (4.6.1) that DEI was positively associated with LWG. Therefore it is suggested that the Friesian heifers had lower rates of LWG at 33°C than had the Sahiwal x Friesians because of their comparatively lower intakes of digestible energy.

It is interesting to note that at 15.5°C both breeds consumed the same amount of DE; but differed in LWG. The Friesian heifers gained LW at the rate of 3.3kg,per 100MJ of DE consumed in the cool room. Under similar conditions the Sahiwal x Friesian heifers gained weight at the rate of 2.0kg per 100MJ of DEI. This suggests that the Friesian heifers converted energy to body weight more efficiently than did the crossbred animals. Similar observations were reported in Kenya by Ledger *et al*., (1970). These authors noted that *Bos indicus* cattle and their crossbreds converted feed to body weight less efficiently than did the *Bos taurus* cattle on the same level of feeding. This difference may be associated with maintenance requirements which were included in the present estimates (see also Great Britain, 1975).

4.6.3 Responses to diet:

The effects of diet on the rate of liveweight gain were highly significant ($P < 0.01$). The heifers gained weight at the rate of 0.23kg per day when fed hay, whereas when fed on concentrates, they gained 0.83kg per day. An experiment with results similar to these was reported by Colditz and Kellaway (1972). These authors noted that heifers gained weight more rapidly when a high quality diet (rolled barley) was fed than when a lower quality diet (Oaten chaff) was fed to the animals. The mean rate of weight gain they reported were 1.09 and 0.80kg per day on the high and low quality diets respectively ($P < 0.01$).

Holmes et al., (1980) also reported recently that Friesian and Brahman x Friesian steers gained weight more rapidly when fed concentrates than when fed unchopped hay. Holmes et al., (1980) attributed these dietary effects on LWG to differences associated with intake of dry matter when the two diets were consumed. This was verified by the adjustments for DMI, which removed the effects of diet on LWG.

The differences noted in the present experiment could have been associated partly with the direct effects of heat stress and partly with differences in energy intake when the two diets were consumed. The first suggestion may be disregarded since no significant differences were observed between the TR measurements of animals consuming the two diets. The amounts of DE consumed were however different (Table 3.7b). Therefore the main effect of type of diet on the rates of LWG was due to effects on DEI. This is verified by the observation that the relationship between DEI and the rate of liveweight gain (Table 3.13) was positive, ($P < 0.001$) so that higher intakes of digestible energy were associated with faster rates of liveweight gain.

In conclusion it is suggested that high ambient temperatures affect liveweight gain mainly through reduction of DEI. Feeding diets of high digestibilities may improve the consumption of DE and hence the rate of liveweight gain by animals. The use of such diets is recommended particularly for hot tropical conditions.

4.7 The Hair Coat:

4.7.1. Differences between the two breeds in weight of hair coat:

The weights of hair coat measured at the beginning of the experiment (Table 3.12a) indicate that the Sahiwal x Friesian heifers had considerably lighter hair coats than had the Friesian heifers. The Sahiwal x Friesian heifers had hair coats with a mean of 220g.m^{-2} whereas that of Friesians weighed 300g.m^{-2}. The weights of hair coat reported in this experiment are comparable to those reported in experiments by Turner and Schleger (1960); Holmes et al., (1978) and Sauwa (1978). These authors reported hair coat weights varying between 130 and 470g.m^{-2} for cattle. The present experiment as well as those reported by Dowling (1958) and Sauwa (1978) indicate that Bos indicus crossbred cattle have lighter coats than do Bos taurus. Dowling (1955) suggested that these differences are associated with rates of medulation of hair in the coat. Bos indicus cattle have shorter and more medulated hairs than B.taurus cattle.

The differences in coat weight between individual animals may be of importance to heat loss characteristics of these animals on exposure to hot environments. Heavy coats are known to offer better thermal insulation than the lighter coats (Bennett, 1964). The present experiment showed significantly close ($P < 0.05$) association between RR and weight of the hair coat ($r = 0.4081$ df=30) however the relationship between TR and the weight of hair coat ($r = 0.006$ df= 30) was not significant. It is therefore possible that part of the differences noted in heat stress between animals in different temperature conditions were associated with the indirect effects of coat weight.

4.7.2. Growth of hair coat after clipping:

The effects of temperature and breed were not significant in either trials. However in both ambient temperature conditions the growth rate of hair coats of Friesian heifers was higher than that of Sahiwal x Friesians , and heifers in the cool room appeared to have faster rates of growth of hair coat than had those in the hot room.

No comparable studies were found in literature to relate the growth rate of hair coats in cattle with ambient temperature.

The few relevant experiments, carried out on wool, (Thwaites, 1968; Cartwright and Thwaites, 1976) suggest that growth of hair is depressed by high ambient temperatures through decreased dry matter consumption. The differences we noted in the growth rate of clipped hair coats of heifers under different thermal environments may have been associated with intake of dry matter. However consumption of hay resulted in significantly faster growth rates of hair coat than observed during concentrate feeding. ($P < 0.01$). If DMI had been the main cause of variation in hair growth rates, then faster growth rates would have been measured during concentrate feeding. It is therefore suggested that there were other factors responsible for the differences in the growth rate of hair coats of calves when the two diets were fed.

Turner and Schleger (1970) have reported the occurrence of photo periodicity in growth of hair coats in cattle. These authors demonstrated in Australia that growth of hair coat of cattle is most rapid in February-early May period. During this time the number of actively growing follicles increase to cause the build-up of a long, dense winter coat. Between May and July, the coat ceases growth and the mature hairs are not shed until August when a new cycle of growth starts. This seasonal pattern of growth and replacement cycles of hair has been reported in some breeds of sheep (Hutchinson, 1965). Hutchinson (1976), and Nagorcka (1979) associated the effects with changes in photoperiod rather than seasonal changes in the ambient temperature.

It is possible that this factor was responsible for the effects noted between the growth rate of the hair coat of heifers when the two diets were fed. Hay feeding was done during periods of fastest growth rates of the hair coat (April - May , and August September), while concentrate feeding was done during periods of least growth (June-July and July-August); as was reported by Turner and Schleger (1970).

A conclusion is therefore reached that the effects of treatments on hair growth were not clear due to the associated effects of photoperiodicity. A similar conclusion was reached by Dowling (1958).

5. CONCLUSION:

5.1 The effects of Ambient temperature:

The general effects of exposure of the heifers to 33^{0}C when compared with 15.5^{0}C ambient temperature were:-

1. To increase the mean rectal temperature from 38.78^{0}C to a mean of 39.86^{0}C. The difference was highly significant ($P< 0.01.$) Friesian heifers exhibited significantly ($P< 0.05$) greater increases in the rectal temperature than did the Sahiwal x Friesian heifers.

2. To cause a marked increase in RR and a small increase in sweat rate. At 33^{0}C, the Friesian heifers exhibited greater respiration rates(115 breaths per minute) than did the Sahiwal x Friesian heifers which had a mean respiratory frequency of 84.6 breaths per minute. On the other hand, the Sahiwal x Friesian heifers exhibited comparatively greater sweat rates ($70g.m^{-2}hr^{-1}$) than did the Friesian heifers ($55g.m^{-2}hr^{-1}$) . The difference was however not statistically signficant.

3. To increase water intake of all animals from a mean of 19.3 kg per calf per day to 40.01kg per calf per day. The difference was significant ($P < 0.005$). The Friesian heifers exhibited significantly ($P < 0.05$) greater increases in their voluntary consumption of water than did the Sahiwal x Friesian heifers on exposure to hot conditions. It was observed that VWI was positively related with TR measurements, but negatively related with dry matter consumption in the hot room. Neither

respiration rate nor sweat rate was linearly related with VWI. It was therefore suggested that greater consumption of water on exposure of animals to the hot environment was associated mainly with the increases in the body temperature, rather than with changes in the sweat rate or respiratory frequency.

4. To cause significant ($P < 0.05$) declines in the amount of dry matter consumed by the heifers, from a daily mean of 4.46kg $calf^{-1}$ in the cool room to 3.71 kg $calf^{-1}$ in the hot room condition. The effects of hot ambient temperatures on DMI were largely responsible for the declines in energy intake and consequently the declines in the liveweight gain(LWG) of animals.

The faster rates of LWG recorded in the cool room (cf hot) were explained by the greater consumption of digestible energy in this cool environment. It was estimated that the differences in DEI, between animals in the two temperature conditions accounted for 64% of the differences noted in LWG. Only 21% of the variations in LWG were associated with changes in the TR measurements. It is therefore suggested that low LWG in hot environments are mainly a result of decreases in the DEI observed on exposure of animals to these hot conditions. Increased TR was associated with a decline of DEI by animals. Factors which increase DEI, without an appreciable change in TR in hot environments would therefore be of a great help to improvement of LW production in hot micro climates.

Feeding concentrates in the hot room resulted in slightly lower rectal temperatures, but significantly ($P< 0.05$) greater DEI, when compared with the feeding of hay.

It is therefore recommended that, where possible, highly digestible diets should be used to improve LWG of animals growing in hot climates.

5.2 The effects of breed:

The results of this experiment have indicated that at 33^{o}C Friesian heifers were heat stressed to a greater extent than were the Sahiwal x Friesian heifers. For example, the Friesian heifers had a mean rectal temperature of 40.13^{o}C in the hot room, while the Sahiwal x Friesians had a mean rectal temperature of 39.64^{o}C in the same room. Other differences were noted in, respiration rates, dry matter intake, digestible energy intake, water intake, and also in liveweight gain. All the effects reported indicated that the Friesian heifers suffered from heat stress more than the Sahiwal x Friesian heifers on exposure to the hot room. THe only variable for which Sahiwal x Friesian heifers had a greater response than observed in the Friesian heifers was in sweat rate.

Bos indicus cross animals have been reported in many papers to be less reponsive to increases in the ambient temperature than are B.taurus animals, (Sauwa, 1978; Kellaway and Colditz, 1975). Recently, Amakiri (1979) and Sauwa, (1978) suggested that the greater heat tolerance of B indicus cattle or their crossbred with B taurus is attributable to their sweating capacity, which is often greater than exhibited by pure B taurus cattle. Like the work reported by Sauwa (1978) this experiment has demonstrated a negative association between sweat rate and rectal temperature measurements under hot conditions which suggested that faster sweating resulted in lower rectal temperatures in animals exposed to the hot room condition. It is therefore suggested that the greater sweat rate of Sahiwal x Friesian heifers is responsible for the higher heat tolerance of these animals.

5.3. The effects of diet:

The effects of the change in diets from hay to concentrates was to lower the effects of heat stress on both breeds. The animals exhibited slightly lower rectal temperatures (39.82^{o}C) when fed concentrates than when fed hay (39.95^{o}C) in the hot room. Both respiratory frequency and VWI were significantly reduced ($P< 0.05$)

by feeding concentrates instead of hay. Daily LWG as well as DMI were significantly increased ($P< 0.05$). These effects indicate that the animals were less heat stressed during concentrate feeding than when hay was fed. Consequently, it is suggested that feeding concentrates should be adopted where heat stress is known to depress productive performance of animals.

The rate of growth of the clipped hair coat was noted to be significantly decreased ($P< 0.05$) when the diet was changed from hay to concentrate. The effect was suggested to be confounded with the influence of photoperiodicity.

Sweat rate was significantly ($P< 0.01$) increased from $33.7g.m^{-2}hr^{-1}$, when hay was fed to a mean of $78.4g.m^{-2}hr^{-1}$ during concentrate feeding. It was observed that sweat rate was linearly related with DEI. So that greater sweat rates noted when concentrates were fed were associated with the greater intake of digestible energy when concentrate diet was fed. The physiological basis of the relationship between sweating and energy intakes when different diets are fed, is not known. The author therefore invites further experiments to explore sweating behaviour of animals when fed different diets.

It is concluded that the change of diet fed from hay to concentrate has the benefit of increasing DEI and hence LWG by animals exposed to hot environments. Feeding of highly digestible concentrate diets or supplement is recommended to improve producivity of animals in hot environments. Supplementation with concentrates is highly recommended for animals grazing mature tropical pastures, which are often deficient in DE and essential minerals.

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APPENDIX 3.2

Rectal temperature

(^{o}C)

Mean values for individual animals during different periods

Breed	Heifer	Trial 1		Trial 2	
	Number	Period 1	Period 2	Period 3	Period 4
		(HAY)	(CONC)	(CONC)	(HAY)
Sahiwal Friesian Cross	1	39.99	40.01	38.73	38.80
Friesian	2	40.48	40.19	38.83	38.58
Sahiwal Friesian Cross	3	40.07	39.48	38.88	38.69
Friesian	4	40.45	40.35	38.58	38.41
Sahiwal Friesian Cross	5	38.95	38.80	39.35	39.14
Friesian	6	38.97	38.97	40.13	39.92
Sahiwal Friesian Cross	7	38.84	39.00	39.06	39.57
Friesian	8	38.95	38.49	39.55	39.93

APPENDIX 3.3

Respiration rate, (breaths per minute) for individual animals during different periods of the experiment.

Breed	Heifer	Trial 1		Trial 2	
	Number	Period 1	Period 2	Period 3	Period 4
		(HAY)	(CONC)	(CONC	(HAY)
Sahiwal Friesian Cross	1	103.87	88.80	19.01	19.59
Friesian	2	133.90	115.22	44.02	24.78
Sahiwal Friesian Cross	3	98.34	74.36	22.75	18.43
Friesian	4	124.99	109.98	31.90	24.95
Sahiwal Friesian Cross	5	52.48	26.84	51.31	86.52
Friesian	6	66.62	56.32	101.75	101.04
Sahiwal Friesian Cross	7	48.48	27.18	76.72	96.74
Friesian	8	62.39	39.50	106.02	126.56

APPENDIX 3.4

Relationship between Sweat rate (Y $gm^{-2}hr^{-1}$) and respiratory rate (X breaths per minute)

		Temperature		Breed		Diet	
		Hot	Cool	SF	F	HAY	CONC
correlation coeff.	Hot	-0.59*	-	-0.72*	0.30	-0.52	-0.44
	Cool		0.04	-0.26	0.09	0.14	0.40
	SF			-0.05	-	0.13	0.33
	F				0.20	-0.35	0.60
	Conc						0.22
	Hay					-0.08	
regression coeff.	Hot	-1.2550*	-	-2.4145*	0.2528	-0.4499	-0.9604
	Cool		0.0530	-0.4568	0.1408	0.0291	0.8515
	SF			-0.465	-	0.0440	0.4078
	F				0.1369	-0.0567	0.4983
	Conc.						0.2484
	Hay					-0.0849	

For all animals

$Y = 57.3776 - 0.0203X_i$ (4 = 0.0210095)

APPENDIX 3.5

Growth rate* of the hair coat of individual heifers after clipping:

	Heifer number							
Period	1	2	3	4	5	6	7	8
1	1.20	3.61	3.41	2.85	2.88	6.07	1.37	9.22
2	1.42	1.22	1.27	0.61	2.21	1.43	0.68	0.68
3	0.84	1.44	1.57	0.88	0.97	1.49	1.32	0.93
4	2.71	1.92	2.69	1.30	3.42	1.57	3.42	3.15

* growth rate in g $m^{-2}day^{-1}$