SOME EFFECTS OF HOT CLIMATIC CONDITIONS ON BRAHMAN X FRIESIAN AND FRIESIAN CALVES FED HIGH AND LOW ROUGHAGE RATIONS

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ABSTRACT

The experiment consists of two parts: the Main trial and Radiant heat stress trial.

1. Main Trial. The effects of temperature, breed type, diet types and their interactions on feed intake, digestibility, liveweight gain (LWG) and Water intake were examined in the Main trial. Eight Friesian (F) and eight Brahman x Friesian (BF) castrated male calves (6 months old) were allocated to be fed on the High ration (pellets ad lib. + 10% of the total feed dry matter as hay) and the Low ration (hay ad lib. + 10% of the total feed dry matter as pellets), and to be kept in a hot room (34.5°C, 45% RH) OR a cool room (16.9°C, 86% RH) for a period of 59 days. There were eight individual treatments, with two animals on each treatment.

The calves in the hot room had a significantly lower dry matter intake (DMI), digestible energy intake (DEI) and LWG than those in the cool room. The calves fed on the High ration had a significantly higher DMI, DEI and LWG than those fed on the Low ration. BF calves had a significantly higher DMI, DEI and LWG than F calves when fed the High ration in both the hot and cool rooms, but the two breeds had very similar feed intakes and LWG when fed the Low ration.

In the hot room, there was a slight but significant increase in dry matter and energy digestibilities, but not apparent nitrogen digestibility.

The Water intake was significantly higher in the hot room than in the cool room. The water intake by BF calves fed the High ration was significantly higher than other treatments due to their higher DMI. The calves fed the High ration had a significantly higher water intake than those fed on the Low ration in the hot room and this was also mainly a reflection of the higher DMI by calves fed the High ration.

2. Radiant Heat Stress Trial. The effects of exposure to simulated sunshine on feed and water intakes were investigated in this trial. Six animals (4 BF, 2 F) from the hot rooms in the Main Trial were exposed to a radiant heat load for 8h daily during a period of two weeks, followed or preceded by a period of two weeks in the absence of a radiant heat load in a hot environment (30.0 - 33.1^{o}C) and fed on a high roughage diet (500g pellets + hay ad lib.).

There was no significant reduction in DMI or increase in water intake when the calves were exposed to the radiant heat load in a hot environment.

In both the Main and Radiant Heat Stress Trials, the rectal temperature as heat stress indicator did not correlate well with the DMI and LWG of BF and F calves under heat stress.

I N T R O D U C T I O N

There is no doubt that beef production in tropical countries could be substantially increased. However, during the last twenty years, production increases have been mainly due to greater numbers of cattle and buffaloes. There has been no increase in meat production per head of cattle (Jasiorowoki, 1976). The main reasons for this are:-

a. Unfavourable climate. The tropical areas are characterized by climates which are basically unsuited to livestock. Temperature and radiation are high, rainfall is excessive or sparse and usually badly distributed in relation to the needs of pasture.

b. Poor nutrition. Most of the beef is produced on natural grasslands, the productivity and nutritive value of which are low.

c. Low genetic potential. The potential growth rate of tropical cattle is lower than temperate-type cattle, and there has been practically no attempt to improve the economic characteristics of cattle in the tropical countries.

d. Diseases, insects and parasites. These are also important limiting factors to beef production in the tropics.

e. Social constraints. Religious and social taboos make technological advancement of livestock production difficult to implement even when expertise exists, which in itself is a rarity.

It is often assumed that B. taurus are best suited to

conditions of good nutrition, the absence of climatic stress and good management whereas B. indicus perform better in poor nutritional circumstances and under conditions of considerable stress. The objectives of the present experiment were to study the performance of Brahman x Friesian (F1) and Friesian calves when fed (i) two types of diets in a hot and a cool environment; (ii) a high roughage diet in an environment with or without radiant heat load.

The experiment consists of two parts. The main experiment was designed to examine the effects of temperature, breed type, and diet type on feed intake, digestibility, liveweight gain and water intake in Brahman x Friesian (BF) and Friesian (F) calves fed high and low roughage diets in a hot and a cool environment. Of major interest is the possible interaction between the effects of the breed and heat stress, in order to assess whether BF calves have a productive advantage over F calves under heat stress in term of voluntary feed and water intakes, digestibility and growth rate. As tropical cattle feeds are mainly of the high roughage type, it is also of great interest to find out whether BF calves can make a better utilization of high roughage diets in heat stress than F calves, i.e. breed x diet x temperature intereactions.

In the tropical grazing conditions, radiant heat represents an important part of the total heat stress. Thus, radiant heat load was simulated in the second part of the experiment, to assess the effects of radiant heat on voluntary feed and water intakes in the heat-acclimatized BF and F calves fed a high roughage diet.

CHAPTER ONE

REVIEW OF LITERATURE

The emphasis of the literature review is on the effect of hot climatic conditions (high air temperature and radiation) on voluntary feed and water intake, digestibility and growth of cattle in relation to breed and diet. As there are many other factors which affect these parameters, they are also briefly reviewed. A knowledge of the mechanisms involved in the control of feed and water intake is essential to the understanding of the various effects on these measurements, thus, they are also included.

The format taken in an attempt to cover all these aspects is shown in the content.

I VOLUNTARY FEED INTAKE IN CATTLE

Profitable animal production almost always requires an efficient conversion of feed into animal products. Much research effort has been devoted to attempts to improve conversion rates. Most efficient feed conversion is achieved when the animal is able to obtain from the feed consumed a maximum amount of nutrients for productive purpose over the inevitable losses during metabolism (Balch, 1976). The simplest method of increasing the proportion of a diet devoted to productive purposes is to increase the amount of feed intake. The main factor determining the rate of growth of ruminants is their intake of digested nutrients (Osbourn, 1976).

1. The Control of Voluntary Feed Intake

The balance between feed intake and energy expenditure, which can be maintained in most animals over long periods, despite considerable variations in the nature of diet and the level of energy demand indicates the existence of mechanisms controlling feed intake (Hervey, 1969).

According to Mayer (1967), voluntary feed intake is regulated broadly between 'summit metabolism' and 'basal metabolism'. Within these large 'biometric margins', additional regulations are necessary. These additional regulations involve the short-term, generally day to day, regulation of energy intake which adjusts intake to requirement; and in the long term, there is the regulation of body reserves. It corrects the errors of the short-term mechanism involving either excessive or deficit intakes.

The errors of adjustment in the control of feed intake over a short period of time can be large, but the correlation between input and output improves if a longer period is considered (McCane, 1972).

1.1 The Central Nervous System and Voluntary Feed Intake

There are many good reviews on this subject: Davey (1973), Baile and Forbes (1974), Baumgardt (1969), Anand (1961), Brobeck (1960), Mayer (1967) and Grossman (1967).

Ultimately, the brain is the prime controller of feeding. The basic control systems involving the central nervous system (CNS) have facilatory and inhibitory mechanisms stemming from the higher nervous

levels which are superimposed on reflex actions operating through lower levels in a hierarchal organisation.

At the lowest levels are the spinal cord and brain stem which take part in such feeding responses as chewing, salivating and swallowing, etc., and also in rejection of unacceptable objects (Brobeck, 1960). These responses are probably reflex in nature. Food serves as a stimulus for these reflexes and awareness of food brought about through any sensory means initiates the feeding reflexes.

The next level involves the hypothalamus, which is directly involved in the regulation of feed intake and energy balance. Regulation of food is brought about by the two main "centres" in the hypothalamus: satiety centre in the ventromedial areas and feeding centre in the lateral area of the hypothalamus. The feeding centre facilitates and the satiety centre inhibits the feeding reflexes.

At the highest levels, the limbic system and neocortex are involved in feed intake control. These cerebral structures are involved in feeding behaviour, prejudices, selectivity and other complex integrations which finally determine what and how much an animal will eat (Baumgardt, 1969). However, conclusive information is not available to permit a clear-cut description of the exact mechanisms.

1.2 Signals to the Regulating System

A change in the energy balance or status of an animal produces a feed-back signal which ultimately is integrated in the hypothalamus (Baumgardt, 1969). A long and continuing search for such signals has

led to the conclusion that there are a variety of signals, any one of which may predominate at a given time. Brobeck (1960) has summed up the various factors which have been suggested by different workers. The important ones are:

(i) Physical signals

(ii) Chemostatic theory
(iii) Lipostatic theory
(iv) Thermostatic theory
} 'metabolic signals'

(v) Water concentration in cells - i.e. correlated with water intake

They can be divided into two classes: physical and metabolic signals. The 'physical signals' are not literally physical as they also have a neural basis (Davey, 1973); they refer to signals that are triggered by distension. "Metabolic signals' refer to signals that are triggered as a result of metabolism or events closely related to metabolism.

Rations that are low in nutritive value (due to either low digestibility or high bulkiness) are consumed at a low level because the physical capacity of the digestive tract imposes a limit to further intake before the limit imposed by metabolic signals has been achieved, i.e. physical signals inhibit further intake. As the nutritive value of the ration is increased, both feed and energy intake increase until energy intake reaches the point set by the physiological demands of the particular animal. Further increases in the nutritive value of the ration are accompanied by a decrease in feed intake of a magnitude to allow approximately stable energy intake, i.e. metabolic signals inhibit further intake. This dual control of

feed intake as discussed by Davey (1973); Forbes (1970, 1977); Conrad et al. (1964); Montgomery and Baumgardt (1965); Baumgardt (1969) and illustrated in Figure 1.

1.2.1 Physical Signals

There is sufficient evidence in ruminant animals reviewed by Baumgardt (1970) and Baile and Forbes (1974) to suggest that metering of feed in the mouth, pharynx or oesophagus is not an important signal in normal regulation of feed intake.

It is unlikely therefore that exhaustion of the salivary glands, or fatigue of the jaw muscles limits or acts as a control of feed intake. Also there is no evidence that a quantitative monitoring of the volume of feed swallowed might influence feeding (Baumgardt, 1969).

Gastric distension, on the other hand, is known to be an important satiety signal under some feeding conditions. Many experiments have been carried out to investigate the change in feed intake in response to rumen filling. In the case of ruminants being fed high-roughage rations, distension is the primary signal inhibiting feed intake. This subject has been reviewed by Baile and Forbes (1974); Forbes (1970) and Davey (1973).

Distension and tension receptors are localized in the gastro-intestinal tract, and distension in these areas increases the electrical activity in the vagus nerve and in the satiety centre in proportion to the amount of distension imposed (Baumgardt, 1970).

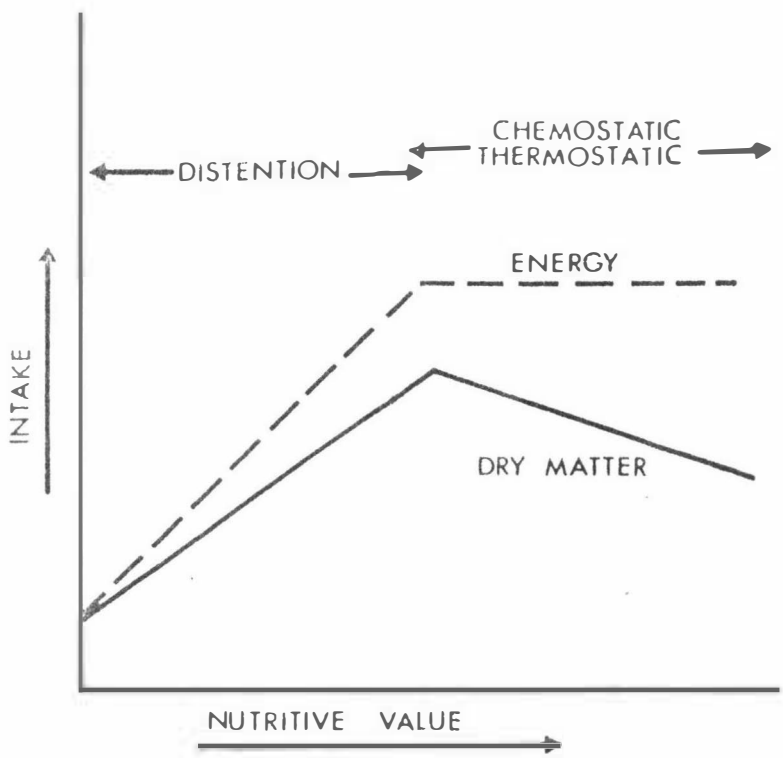


FIGURE 1 Probable relationships between energy and food intake and controlling mechanisms. From Montgomery and Baumgardt (1965d)

Factors which affect the physical limit of feed intake are the size and capacity of the reticulorumen, and the rate of disappearance of the digesta. The latter is a function of the rate of digestion (microbial digestion and mechanical disintegration), rate of passage of food residues and the motibility of alimentary organs (Campling, 1970). Various physiological processes such as growth, gestation, lactation and the nutrient status of the animal can modify the capacity of the reticulorumen and possibly the factors responsible for the breakdown and removal of digesta from the rumen. These will be discussed in section I.2.1.2.

It is evident that physical factors alone are not solely responsible for regulating the feed intake of ruminants under all conditions although they are limiting with certain roughage diets. It is pointed out by Campling (1970) that while it is convenient to separate physical from metabolic factors controlling intake, it should be realized that these are not necessarily independent and that it is unlikely that any one factor (or groups of factors) will be universally responsible for regulating voluntary intake.

1.2.2 Metabolic Signals

Anabolism and catabolism (which make up metabolism) result in changes of metabolite levels and heat production, which may act as feedback signals for voluntary feed intake. There are three main theories proposed in an attempt to identify the signals involved. These are: Chemostatic, Lipostatic and Thermostatic Theories.

1.2.2.1 Chemostatic Theory

The fact that appetite in man and non-ruminants responded to the rate of glucose utilization led Mayer (1955) to identify a glucose signal as one component in the regulation of feed intake referred to as the Glucostatic Theory.

Available evidence indicates that the glucostatic system applies only to monogastrics and is not operative in ruminants. Neither the intravenous infusion of glucose nor intraperitoneal infusion to resemble absorption from the digestive tract, produces satiety in cattle and sheep (Manning et al., 1959). This can be related to the comparatively low blood glucose level of ruminants and to their increased dependence on volatile fatty acids (VFA) as energy sources when compared with non-ruminants.

The VFA's are an important energy source for ruminants and have characteristics that make them possible factors for control of feeding, namely (Baile and Mayer, 1970): (1) they are produced in the forestomachs and are mostly absorbed prior to passage into the abomassum, (2) their rates of production and absorption are closely related to feeding behaviour and, (3) the intraruminal injection of VFA decreases feed intake of cattle.

Feeding responses to administration of the three major VFA differ. These are reviewed by Baile and Mayer (1970); Baile and Forbes (1974); Davey (1973) and Preston and Willis (1975). Acetate has received more attention as a possible satiety signal than the other VFA because it is produced and absorbed in greatest quantities in ruminants.

Though the exact mechanism by which the VFA's regulate feed intake has not been elucidated, it is probable that acetate and propionate do play a part in the role of hunger-satiety signal system in ruminants. Butyrate probably has a less important role in feed control signalling.

The amount of VFA's produced influences the rumen pH; the effects of these changes in rumen fluid pH on feed intake are unclear. It is likely that feed intake is depressed when rumen pH falls below 5.5 because of the rumen stasis that results (Dirksen, 1970). Baile and Forbes (1974) after reviewing the subject conclude that rumen pH is unlikely to act as a physiological controller of intake, although under pathological conditions it may be a principal cause of an accompanying hypophagia.

1.2.2.2 Lipostatic Theory

Kennedy (1953) had proposed a 'lipostatic' theory which postulated that "in the long run, the hypothalamus modifies the general level of feed intake and bodily activity in response to changes in body fat". Mayer (1955) contends that although the short-term regulation is "chemostatic", the long-term regulation of body reserves is "lipostatic".

The amount of body fat provides an integrated record of the energy balance and no other physiological quantity could act in the same way (Hervey, 1971). Fat is continuously being mobilized from fat depots for use as an important energy source. It is released from the fat tissue as free fatty acids (FFA) bound to albumin. The metabolite or perhaps the hormones involved may serve as the feed-back signal.

There are some experiments which showed that FFA changes or the associated hormones in lipid metabolism are related to the regulation of voluntary feed intake (Kennedy, 1966; Simkins et al., 1965a; Thye et al., 1970; Trekle and Kuhlemeier, 1966). Davey (1973) also mentioned that Schinekel (1960) with sheep, and Hutton (1963) with non-lactating cattle provided indirect evidence for the long-term control of feed intake and changes in the set-point of reference of input. However, little information is available to show that FFA are a cause rather than an effect of changes in feeding (see Baile and Forbes, 1974).

1.2.2.3 Thermostatic Theory

The negative relationship of environmental temperature and feed intake led Brobeck (1960) to put forward his Thermostatic Theory of feed intake control. Brobeck and his collegues have tried to establish his hypothesis in a number of ways. In sum, it can be stated that a fall in hypothalamic temperature stimulates, and a rise inhibits the hypothalamic phagic centre. The heat (external origin or from SDA) causes the rostral cooling centre to stimulate the medial satiety centre and inhibit the lateral appetite centre. The result is decreased feed consumption.

There are paradoxes in this theory just as there are in others, in attempting to predict food intake from the single parameter of heat, which in itself is very complex. The arguments against this theory are reviewed by Hamilton (1967); Baile and Forbes (1974) and Anand (1961). Baile and Forbes (1974) concluded that "there seems to be little evidence that temperature per se acts under most conditions as a signal for the

hunger-satiety system. Although temperature changes during a meal do not apparently have a role in hunger-satiety system, changes of environmental temperature may affect feeding."

Although a precise relationship between heat production during feeding and feed intake regulation cannot be argued, there is no doubt that thermoregulation and feed intake regulation are interrelated. Information brought by the visceral afferent systems originates in the peripheral receptors for temperature, vascular volume, osmotic pressure and other receptors for various conditions in the gastro-intestinal tract. This information, with that from the central receptors, appears to be integrated in the hypothalamus (Stevenson, 1967). The information of water, energy and thermoregulatory needs are then available for integration into the total behaviour of the animal. Feed and water intakes are regarded as the behavioural thermoregulatory responses. Furthermore, hormonal control of feed intake and thermoregulation are closely related. Adrenalin, noradrenalin, corticosteroids involved in thermoregulatory thermogenesis are connected to feed intake regulation which will be discussed in Section I.1.2.4.

Hamilton (1967) suggests that when conditions exist that call forth heat retention mechanisms (thermogenesis, vasocontriction, piloerection, etc.) feeding is enhanced. When heat loss responses (sweating, panting, vasodilation, etc.) are appropriate to circumstances, feeding is depressed. Obviously, in a hot environment, a point may be reached when the body temperature becomes so elevated that feed intake sufficient to maintain body weight would embarass the heat regulating

mechanisms. On the other hand, at low temperature, increased energy demands will result in increased food intake, perhaps in response to temperature through metabolic signals.

Although the thermostatic theory cannot be the only mechanism in feed and water regulations, thermoregulation certainly plays a part in the integrated control of feed and water intake.

1.2.3 Correlation of Food and Water Intake

Animals consume less feed during period of water deprivation (see Section II.2.3.2) and reduce their water intake when feed intake is reduced (Forbes, 1968; Calder et al., 1964). This close relationship of dry matter and water intakes led to the speculation that their regulation mechanisms are correlated.

From this relationship, some workers had done further quantitative and more detailed studies on feed intake in response to water concentration in body fluids. Changes in the osmolarity of body fluids may influence feeding of ruminants (see Baile and Forbes, 1974). Jacob (1964) suggested that osmotic stimuli which signal water intake may also do so in feed intake regulation.

Anand and Dua (1958); Montemurro and Steveson (1956); Larsson and Stroma (1957) had carried out studies to determine whether changes in feed and water intakes after lateral hypothalamic leisons are interdependent or independent. Anand (1961) after reviewing their work concluded that the hypothalamic mechanisms controlling water and feed intakes in the lateral hypothalamus although physically

situated at the same region, act independently. Nevertheless, there is still doubt in the minds of some that water and feed regulations act totally separately (e.g. Stevenson, 1964).

Water and feed intakes are related physiologically in many ways. At a higher level of feed intake, there will be an increase in water loss through faeces, more water used in metabolism, followed by the need to excrete more waste products via the kidneys.

Water and food intakes do not always show a positive correlation and they do not always show that they are of equal importance (Jacob, 1964). In many cases of 'conflict' between energy and water balance, the former seems to have priority. Jacob (1964) reckons that this is physiologically logical as the wide limits of excess hydration in animals with normal kidney functions allows the priority of energy balance without threat to water balance.

Apparently, the actual influence of dry matter and feed intake on water intake is counfounded with that of temperature, forage quality and digestibility.

1.2.4 Roles of Hormones in Regulation of Feed Intake

Recognizing the importance of metabolic factors in influencing feed control, one would assume that hormonal secretions may also affect this regulation. So far, no direct convincing proof exists to support this assumption. However, certain suggestive evidence is available.

1.2.4.1 Corticosteroids

Hervey (1969) suggested that adrenal glucocorticoids may provide communication between adipose tissue and the CNS. Glucocorticoids caused increased feed intake in sheep when injected intramuscularly over periods of several weeks (Basset, 1963; Superlock and Clegg, 1962). However, Bassett (1963) claimed that intake was increased only when sheep were temporarily hypophagic. Baile and Martin (1971) found no effect of hydrocortisone (one type of glucocorticoids) injected intravenously during spontaneous meals on feed intake of sheep. It is likely that corticosteroids act indirectly on feed intake via their effect on energy metabolism (Baile and Forbes, 1974).

1.2.4.2 Insulin, Growth Hormone and Glucagon

Kennedy (1966) suggested roles for insulin and Growth Hormone (GH) in an integrated scheme for Lipostatic Theory. It may be that the hypothalamus receives a postmeal signal of satiety associated with lipogenesis (or insulin) followed later by a hunger signal of Lipolysis (or GH). Anand (1961) reported some experiments indirectly relating insulin to feed intake control, but Baile and Martin (1971) showed that when injected into the sheep during spontaneous feeding, neither insulin nor GH affected daily feed intake.

Insulin and Glucagon have been integrated with the Glucostatic Theory. Insulin enhances glucose utilization and lower blood sugar thus may stimulate feed intake. Glucagon, on the other hand, stimulating breakdown of glycogen in the liver, may inhibit feed intake. The proof concerning insulin has been discussed. Again, there is no definite proof that Glucagon is a signal for feed regulation, but

Baumgardt (1969) reported that the administration of Glucagon usually results in an inhibition of feed intake.

1.2.4.3 Epinephrine (Adrenalin) and Norepinephrine

Epinephrine and norepinephrine are involved in energy metabolism and may also influence feed regulation; but both depressed feed intake only when injected at near lethal doses (Baile and Martin, 1971).

In conclusion, the exact role of these hormones in feed intake regulation - whether they act directly on nervous centres or indirectly through changes in metabolism - is not yet known.

Conclusion - Voluntary Feed Intake Control Mechanisms

Though the control of voluntary feed intake is discussed separately as 'physical' and 'metabolic' means, they are not independent as noted before. A statement by Egan (1970) may best sum up the highly complex integrated system of voluntary feed control - "That a complex of intereacting physical and metabolic factors may be involved throughout the whole range of diets utilized by ruminants, and that there is not simply a switch-over to metabolic regulation at a point where disposal of indigestible bulk is no longer an embarrassment or a limitation to the total digestible energy intake."

2. Factors Affecting Voluntary Feed Intake (VFI)

Extensive reviews in recent years have analysed the factors affecting regulation of feed intake in ruminants (Balch and Campling, 1962; Baumgardt, 1969; Arnold, 1970; Forbes, 1970; Baile and Forbes, 1974; Journet and Remond, 1976; Bines, 1976; Forbes, 1977).

Factors influencing intake in cattle can be broadly categorized as being due to characteristics of the animals, the food and the environment. All these factors may act as "signals" to influence the feed intake regulation.

2.1 Animal Factors

These include genetic factors (breed) and others (physiological state, sex, growth and health of the animal).

2.1.1 Genetic Factors

There are breed differences in voluntary feed intake in cattle (Warnick and Cobb, 1976; A.M.R.C., 1975; Bines, 1976). In several studies, Frisch and Vercoe (1969), Rogerson et al. (1968); Ledger et al. (1970); Colditz and Kellaway (1972) it has been found that Zebu and Zebu-British crossbred cattle had lower feed intakes than British breeds at comparable weights on high-quality forage rations or high-concentrate rations when all are maintained in the absence of major environmental stresses. The voluntary intake of Zebu cross is probably intermediate between their parent breeds (Vercoe and Frisch, 1974). The increased appetite or food capacity of the British breeds is regarded as the key to the higher potential productivity of British breeds, and the most important attribute that the British breed parents contribute to Zebu-British crosses (A.M.R.C., 1975).

Gross efficiency of feed conversion (the amount of feed needed to product unit gain in liveweight) is related to the amount of feed consumed relative to maintenance requirements. Regardless of the efficiency of maintenance, gross efficiency of feed conversion improves as the ratio of feed intake to maintenance requirements increases.

The absolute difference between voluntary intake and maintenance requirement is bigger in British breeds, and gives them a higher potential growth rate per head. However, this potential advantage is distorted when stresses differentially alter feed intake in Zebu and temperate breeds. For example, on a low-quality forage ration, Zebu type cattle have usually been observed to have a higher voluntary intake (Colditz and Kellaway, 1972; Karue et al. 1972; Howes et al., 1963). Also, at the same ambient temperature, Zebu and Zebu crossbreds usually have higher voluntary feed intakes (Colditz and Kellaway, 1972; Kellaway and Colditz, 1975). Olbrich et al. (1973) found that the breed-temperature-ration interaction for voluntary feed intake was significant. Thus, genetically determined differences between Zebu and temperate breeds in feed intake are dependent in their expression upon type of feed and environmental conditions such as ambient temperature.

Inheritance. The extent to which appetite may be inherited within a breed is not definitely clear but work done so far revealed that there are some consistent variations in appetite between animals of similar liveweights, at least during the growth phase. The estimated heritability (h^2) of feed consumption varies greatly depending on the type of rations, the type of cattle and the length of feeding period.

For example, Swiger et al. (1961) found that h^2 ranged from 0.07 to 0.97 depending on the length of feeding. Overall, genetic differences in voluntary feed intake apparently are of a magnitude that makes selection rather effective (Warnick and Cobb, 1976).

2.1.2 Other Animal Factors Affecting Voluntary Feed Intake

2.1.2.1 Physiological State

The physiological state of the animal will influence the amount of energy it can utilize and this, in turn, will tend to affect its demand for food. Any effect of the physiological state on abdominal capacity will affect intake, particularly when the energy concentration of the ration is low.

Fatness. There is abundant evidence that fatness may reduce intake in cattle (see Bines, 1976, 1976b), and that this effect may be both physical and metabolic in origin. The thin cattle have a 'requirement' for nutrients for fat synthesis, which is reduced in or absent from the fat cow (Bines, 1971). Moreover, where high roughage diets are offered, the fat depot may compete for space, causing a reduction in the effective volume of the cavity into which the rumen can expand during feeding (Journet and Remond, 1976).

Pregnancy. It affects VFI and the effects vary with the stage of pregnancy. If one divides pregnancy in cow into three parts: early, mid- and late pregnancy, early and mid-pregnancy produces a measurable increase in appetite (see Forbes, 1970; Bines, 1971; Journet and Remond, 1976). It is clear that this is an attempt to increase their

energy intake to meet the higher energy requirement of the developing foetus. The volume occupied by the foetus in early and mid-pregnancy do not seem to play a role in the variation of VFI with dairy cows.

In the late pregnancy, VFI decreases. Despite the increase in girth in late pregnancy, the volume of the uterus is so great that the capacity of the rumen is decreased. This is often enough to depress the voluntary intake of roughage diets. With diets whose intake is not thought to be limited physically, some metabolic factor might cause the decline in intake. Forbes (1970) supposed that ovarian hormones could influence VFI; progesterone levels can stimulate intake during mid-pregnancy, but the increase of oestrogen can have a depressing effect on intake at the end of pregnancy, near to calving.

Lactation. The available literature relating VFI to lactation is very extensive, no attempt is made to survey it completely.

In general, the lactating cow may be expected to consume more than an otherwise similar non-lactating cow and a high-producing cow may be expected to eat more than a low-producing cow. This is because the greater the animal's energy requirement, the greater will its energy intake.

There is a distinct lag in the response of feed intake to the increased energy demand of lactation. The increase in VFI that occurs after parturition lags behind the increase of milk yield, i.e., peak intake is not usually achieved until milk yield is declining, several weeks after peak milk production (Forbes, 1970).

It is not clear why VFI in early lactation increases slowly in relation to the energy output in milk. It is possible that lactation, in which energy expenditure in high-producing dairy cows raises to about three times the maintenance requirement, is a situation in which it is not always possible for the animal to adjust its energy intake to its energy demands in short-term but does succeed in doing so over a period of several months (Baile and Forbes, 1974).

2.1.2.2 Growth

As the animal grows bigger in size the maintenance requirements increase, the abdominal cavity will also increase in capacity thereby allowing a higher intake of a given ration; other things being equal, this results in two consequences: (1) older cattle (e.g. steer) will have a greater appetite than young cattle (calf); (2) higher VFI in fast growing than slow growing cattle.

However, the increase in intake of a given diet during growth of an animal is not linear, but probably varies in proportion to the metabolic weight of the animal (Bines, 1976) i.e. VFI/$kg^{0.75}$ remains constant.

2.1.2.3 Sex and Health

Males are capable of a greater growth than females and this is reflected in a greater intake of food (Bines, 1976).

Loss of appetite is a characteristic of many disease, both metabolic (Acetonaemia, Ketosis, bloat and lactic acidosis) and infectious or parasitic in origin (Gastro-intestinal disorders, mastitis) all result in marked reduction in VFI (see Bines, 1976).

2.2 Food Factors Affecting VFI

These factors are types of food and others include nutrient imbalance, palatibility of feed and the availability of feed.

2.2.1 Types of Diet

The general relationship between types of diet and VFI has been described briefly in Section I.1.2 and reviewed by Bines (1976); Forbes (1970) and described by Conrad et al. (1964).

In ruminants with high-quality diets, VFI is thought to be regulated according to nutrient requirements. However, the usual type of diet offered to ruminants, especially in the tropics, has a low concentration of digestible energy, with the result that physical factors can impose limits to further intake before the metabolic limits have been reached.

The limits within which physical regulation occurs are not yet clearly defined. With roughage diets containing at least 10% crude protein, control of VFI by physical factors in the adult animals appears to cease at about the range 65-70% digestibility (Campling, 1970). However, the physical form of the diet offered will alter the threshold of digestibility at which physical limitations cease to be important (Bines, 1976; Montgomery and Baumgardt, 1965).

Physical Form of Diet

For roughages, grinding improves VFI. With long or chopped roughages, the most important physical limitation to intake is likely to be the slow microbial digestion and mechanical disintegration

(Campling, 1970). Grinding will give a large improvement in intake of straw, but much smaller increase in intake of good quality dried grasses (Campling and Freer, 1966). Thus, for roughage, the general relationship may be that the magnitude of the effect of grinding on intake is inversely related to the quality of the forage. These effects probably result from the increased rate of digestion (microbial and mechanical) and increased rate of passage.

Mixed Rations

The majority of the published findings on the interaction of constituents in mixed rations on VFI reflect these trends:

(a) Addition of concentrate to all roughage diet

Addition of concentrate to the diets of ruminants offered roughage ad libitum often alters the VFI of the roughage. The type and extent of change seems to depend largely on the quality of the roughage and the extent of concentrate addition.

(i) With poor quality roughage.

With roughages containing small amounts of nitrogen such as cereal straws, significant increase in VFI occurred when nitrogeneous supplements were given (e.g. Campling et al., 1962; Combie and Tribe, 1963; Hemsley and Moir, 1963; Campling and Murdoch, 1966). The stimulation of intake of poor quality roughages by small amounts of concentrates is probably due to the additional nitrogen supplied by the concentrate which enhances digestion and an accelerated rate of disappearance of digesta from the reticulorumen (Campling et al., 1962; Coombie and Tribe, 1963; Hemsley and Moir, 1963; Campling and Murdoch, 1966).

(ii) With better quality roughage.

When the concentrate is given in small amounts to better quality roughage (e.g. hay, silage) fed ad libitum, there was little effect on VFI of the roughage. But, the addition of large amounts of concentrates to the diets offered better-quality roughage ad libitum, a depression in voluntary intake of the roughage has often been observed (Holmes et al., 1960; Blaxter and Wilson, 1963; Campling and Murdoch, 1966; Campling, 1966; Bath et al., 1974; Taparia and Davey, 1970).

The relationship between the weight of concentrate added and the decrease in intake of roughage is unknown. For example, more than 6 kg of concentrate fed daily reduced hay intake by about 0.3 kg dry matter per kg concentrate dry matter given in non-lactating cows (Campling and Murdoch, 1966). And lactating cows stall-fed on high quality fresh pasture reduced pasture dry matter intake by 0.6-0.7 kg per kg supplemental concentrate given (Taparia and Davey, 1970).

When concentrates are given to cattle, the rate of decline in intake of hay tended to be greatest with the hay of highest digestibility (Campling and Murdoch, 1966).

As noted before, it has been shown that the VFI of roughages by ruminants is determined mainly by the amount of digesta in, and its rate of disappearance from the reticulorumen. Both factors are likely to be associated with the decreased intake of better-quality roughage caused by the addition of large amounts of concentrates.

The amount of digesta. At the end of a meal the amount of digesta in the reticulorumen of the cows offered ad lib. hay with restricted amounts of concentrates was about the same as that found when offered hay ad lib. as the only feed (Campling, 1966). This might explain the fact that there is little effect in hay intake when restricted amount of concentrate is added to good quality roughage. However, there was a tendency for the amount of digesta in the reticulorumen immediately after a meal to be lower with higher levels of concentrates addition (Freer and Campling, 1963). Presumably giving the cattle greater amounts of concentrates would give rise to a situation where the animal would stop eating hay before their reticulorumen contained an amount of digesta equal to that found with hay alone.

Effects of rate of disappearance of digesta. The addition of concentrates in large amounts to all roughage diets decreased the rate of disappearance from the digestive tract of the digesta derived from roughage. This is due to marked decrease in the digestion of the crude fibre of the roughage and increased time the cattle spent ruminating the roughage (Campling, 1966). The effect of supplements of carbohydrates in depressing the digestibility of the crude fibre of hay is known (Head, 1953; Hamilton, 1942). The lowered digestibility of crude fibre was due to a reduction in the cellulolytic activity of the rumen micro-organisms, probably caused by competition between the cellulolytic and amylolytic groups of bacteria for nutrients (El-Shazly et al., 1961).

The cause of considerable variation between animals in their response in intake of roughage to addition of concentrate is not known.

It may have been due to differences between animals in the extent to which the rate of disappearance of digesta from the digestive tract was altered by the addition of concentrate.

Addition of roughage to all-concentrate diet

The general observation on the addition of a small amount of roughage to all-concentrate diet is that it increases intake of the basal ration (Bines, 1976; Wise et al., 1961, 1965). The reason for the increased intake is probably due to the fact that when cattle are fed all-concentrate diet, they usually limit their intake to the animal's energy requirement ('metabolic control') and not the physical limit of the reticulo-rumen.

The addition of small amounts of roughage in all-concentrate diet can either have no effect on the performance of calves (Wise et al., 1965) or may even improve body weight gain (Wise et al., 1961).

McMullough (1969) suggested that the relationship between VFI and ratio of hay to concentrate is not constant and it varies with the liveweight of the animal. This may be expected as age (liveweight) is likely to be one of the factors affecting VFI.

2.2.2 Other Food Factors Affecting VFI

2.2.2.1 Nutrient Imbalance

Many deficiencies of major and minor nutrients are known to influence the feeding of cattle, but the mechanisms involved are not clear.

Regulation of energy intake appears to be in some instances independent and in some instances closely related to regulation of protein and amino-acid intake (Harper, 1967). The effects of excessive or deficient protein content and amino-acid imbalance have been discussed in detail by Harper (1967). When the protein level of the feed is very low, it has been clearly shown to reduce VFI and this can be corrected by addition of protein and urea (see Bines, 1976; Harper, 1967). Excessive levels of urea (more than 45% of ingested nitrogen) may also cause a depression in intake (Karue et al., 1973); if the diet is deficient in one of the indispensable animo-acids, VFI is also depressed (Frazier et al., 1947).

Schmidt and Widdowson (1967) had found that in rats kept on the low protein diet at 21°C lost weight, while those on the same diet at 5°C lost only a little weight. This was due to an increased feed intake in the cool temperature, which compensated some of the protein deficiency in the diet. Thus, there is an indication that at low temperatures the animal may be able to maintain weight on low-protein diets by consuming more, but not at high temperature.

Reduced VFI due to protein deficiency may be due to a reduction in bacterial and protozoal cellulolysis in the rumen (Campling et al., 1962) or to a decreased ability of the animal to handle the end-products of digestion (Egan, 1965).

Deficiencies of vitamins A, D and B_{12} reduce feed intake in ruminants, though B_{12} may be synthesized in the rumen if adequate cobalt is supplied (Bines, 1976). Other minerals shown to be

necessary in adequate amounts to avoid depression of intake include calcium, manganese, potassium, phosphorus, copper, zinc and sodium chloride (Baile and Forbes, 1974).

2.2.2.2 "Palatability" of Feed

Sensory appraisal of feed quality by cattle has not been emphasized in research work. Apparently, the feed intake of grazing ruminants can be modified by gustatory and olfactory factors but does not depend to any extent on sight (see Baile and Forbes, 1974). Sheep and cattle are thought to be colour blind. The effect of odour is of only limited importance in grazing animals (Tribe, 1949), although animals may avoid pasture contaminated with faeces. Ruminants are sensitive to the basic tastes (bitter, sour, sweet and salty) according to Goatcher and Church (1970), and cattle are more sensitive than sheep.

The sensory appraisal of food quality may play a role in initiating a meal (Baile and Forbes, 1974). Ruminants show preferences for certain foods such as specific species of grasses, and straw is apparently not as "palatable" as hay (Greenhalgh and Reid, 1967).

2.2.2.3 Availability of Food

The influence of the availability of food on VFI is of greatest importance when animals are in competition for it (Bines, 1976), for example when grazing or when a group is fed indoors.

The effect of frequency of feeding of feed is closely related to the type of ration given. Increases in the time of access to food

daily, causes increased intake to a greater extent in concentrates than in hay (Freer and Campling, 1963).

2.3 Environmental Factors and VFI

2.3.1 High Temperature and VFI

It is clear that feed consumption of cattle is influenced by high and low temperatures, At high temperature which leads to heat stress, feed intake is reduced; and at low temperature causing cold stress, feed intake is increased.

There are many workers who have showed that hot environments depress VFI: Vercoe and Frisch (1970); Vercoe et al. (1972); Wayman et al. (1962); Olbrich et al. (1972, 1973); Vohnout and Bateman (1972); Kellaway and Colditz (1975); Moody et al. (1967); Martz et al. (1971); Allen et al. (1963) and the earlier studies are reviewed by Bianca (1965).

Brobeck (1960) indicates that eating increases heat in three ways, though they may not be distinctly separable. The first is the specific dynamic action (SDA). The second is the increase in metabolic rate with increased level of nutrition, and the third is the increased heat production observed as body weight increases. In the hot environment, thus, the animal might have to depress their VFI lest it should embarrass the heat-dissipating mechanisms. Reduced feed intake in a hot environment inevitably leads to a fall in metabolic rate or heat production (Webster, 1976).

Worstell and Brody (1953) found that the decrease in voluntary intake with increasing temperature coincides with the beginning of the rise in body temperature. As may be expected the temperature thresholds for a decline in feed consumption are not the same in the field as in climatic room studies because of the modifying effects of other climatic factors that operate outdoors, especially radiation. In the outdoor situation, peripheral temperature instead of deep body temperature may be the more important factor which influences feed intake (Robertshaw and Finch, 1976).

2.3.1.1 Breeds

The environmental temperature at which VFI is reduced is not always the same. It varies with the breed of the cattle. The experimental data suggest that temperate breeds are depressed at a lower ambient temperature than that of tropical breeds (Vercoe and Frisch, 1970; Vercoe et al., 1972; Colditz and Kellaway, 1972; Kellaway and Colditz, 1975; Allen et al., 1963; see also Payne, 1966). It takes a higher environmental temperature to stress a Zebu than temperate cattle (Vercoe and Frisch, 1970; Vercoe et al., 1972; Wayman et al., 1962). Thus, it may be expected that the ambient temperature at which VFI falls with Zebu breeds is higher than B. taurus cattle.

2.3.1.2 Diets

In some reports, it is found that the effects of heat stress on VFI is less on low-fibre diets than high-fibre diets (Wayman et al., 1962; Olbrich et al., 1973). The intake of digestible energy and dry matter by the animal in a hot environment may be increased if it is

fed a diet low in fibre (Vohnout and Bateman, 1972). This may be of practical importance in the tropics to decrease the heat load in the critical period of production.

The heat increment resulting from a fixed quantity of feed (KJ per 100 KJ ME) is inversely related to the digestibility or nutritive value of that feed (Webster, 1976). Thus, the poorer the quality, the higher the heat increment. The high increment of low quality (high fibre) diets can be attributed with reasonable confidence principally to the high proportion of acetate to propionate produced during their fermentation in the rumen (Armstrong and Blaxter, 1962; Blaxter, 1967) and higher activities of eating. One would expect that cattle offered high-quality diets during exposure to heat stress would show a smaller reduction in feed intake than if low-quality diets were given. There is also evidence to show that in a hot environment, a ration with a low-fibre content has a beneficial effect on the animal's thermal balance and hence on its production (Stott and Moody, 1960; Leighton and Rupel, 1960).

2.3.1.3 Protein Content

Foodstuffs have different SDA values - fat the lowest and protein the highest. However the limited experimental evidence about the effect of increasing the protein content of the diet on the ruminants' "heat tolerance" suggests that it is of no significant importance (see Payne, 1966).

2.3.1.4 Feeding Behaviour

In tropical conditions, the animals will try to programme their

meals so as to assume adequate nutrition without taxing the heat-dissipating systems beyond limit. It is common that cattle alter their feeding habits in very hot weather. In the heat of the day feeding slows or stops; and there is a shift towards eating more food during the cooler part of the evening (see Bianca, 1965; Payne, 1966). There was some evidence of a positive relationship between grazing time and milk yield (Cowan, 1975). Animals that are penned at night either because of theft or predators would have their normal grazing hours limited by such a management and may affect production.

Hamilton (1967) mentioned that alterations in the pattern of feeding by increasing the number of meals and at the same time decreasing the size of each meal, would be a device whereby the SDA load of any one meal would be decreased. This has been shown in sheep by Rakes et al. (1961). It is likely that the reduction in heat production with more frequent feeding may be due to a more uniform rate of absorption of nutrients and the spreading of the total heat increment over a much longer period of time so that the heat-dissipating mechanisms of the animal are not over-loaded at any time (Payne, 1966).

2.3.2 Diurnal Variations and VFI

Grazing domesticated ruminants show different diurnal patterns of feeding depending on the quantity and species of herbage available. Grazing time can vary widely but most of the grazing is during the daylight hours (Arnold, 1970; McClymont, 1967). For ruminants kept in feedlots about 75% of the time spent in feeding occurred between 6 a.m. - 6 p.m. When light cycles were reversed or length of light periods

was varied, cattle were at the feeder more during light periods irrespective of time of the day (see Baile and Forbes, 1974). Continuous lighting eliminated most of the diurnal pattern. Light is probably not essential for the activity of eating as cattle adapted to partial or nearly complete darkness maintained similar rates of gain (Baile and Forbes, 1974).

The type of ration does not change the diurnal feeding pattern (Putnam and Davis, 1963). The diurnal variations of VFI in relation to heat stress has been discussed (Section 2.3.1.4).

Thus, ruminants show diurnal variation in feeding, but this behaviour is easily modified.

II VOLUNTARY WATER INTAKE IN CATTLE (VWI)

Water is important in all essential body functions. Water makes up about 70-75% of total body weight (Roubicek, 1969). Thus, to deprive the body of water is second in seriousness only to depriving it of oxygen.

Regulation of the volume of water in the body depends on the balance between water intake and output. Most water enters the body orally, either as liquid or combined in feeds. Only a small portion of the body water comes from metabolic sources. Water is lost through urine, faeces, respiration, perspiration, and in lactating females, through milk production.

Whereas water requirements in temperate climates mainly stem from metabolic demands, in tropical climates they arise primarily from thermoregulatory demands (Bianca et al., 1965).

1. Control Mechanisms of Water Balance

Since the body water content of the animals is maintained within narrow limits, accomplished by a dynamic balance between gains and losses, it is reasonable to look for some mechanisms that regulate water balance. Reviews on this subject include: Roubicek (1969); Andersson and Olsson (1970); Wagner (1964); Wolf (1958); Stevenson (1967) and Grossman (1967).

The homeostatic control of body water content is dependent on (a) a regulated release of antidiuretic hormone (ADH) to regulate renal water loss and (b) on an efficient thirst mechanism which ensures that

the water intake keeps pace with the water loss. Brain mechanisms are involved in all these facets of the control of water balance. However, the mandatory output of water in urine for solute excretion and the evaporative loss of water for temperature regulation cannot be controlled by the CNS in response only to the body's general need for water (Stevenson, 1967).

1.1 Regulation of Renal Output

In water regulation, the part played by ADH is quite clear. In the presence of a regulated release of ADH from the neurohypophysis, body water content can be maintained quite constant despite fluctuating intake. An excessive water intake inhibits the release of ADH which results in a positive renal clearance of free water. During dehydration, on the other hand, ADH is released in amounts sufficient to induce optimal renal absorption of water. A deficiency of ADH results in diabetus insipidus (abnormally high water turnover) or a rapid depletion of body fluids if no water is ingested.

ADH secretion involves synthesis of ADH in the hypothalamic neurosecretory cells, transport to the pituitary and a neurally-controlled release of the hormone into the circulation. The supraoptico-neurohypophyseal tract is the final pathway for ADH release from the pituitary. The cells in this region of the pituitary may be subjected to excitory and inhibitory influences from the periphery and from other parts of the brain (Andersson and Olsson, 1970). Thus, many factors may influence the ADH-release acting directly or indirectly on the supraoptic-neurohypophyseal system. Dehydration and a rise in plasma osmolarity are well-known stimuli (or

signals) to release ADH (Wolf, 1958; Andersson and Olsson, 1970; Roubicek, 1969).

There is another hormone, aldosterone, secreted by the adrenal cortex, which influences water excretion by the kidneys. Aldosterone is chiefly concerned with electrolyte homeostasis, which in turn is closely associated with water balance. Aldosterone production is stimulated by high potassium and low sodium electrolyte levels (Andersson and Olsson, 1970). It acts to resorb sodium from the urine, and to maintain proper electrolyte balance and osmotic pressure.

Other hormones, including oxytocin and epinephrine act with ADH or aldosterone in controlling water balance under particular physiological conditions (Roubicek, 1969).

1.2 Regulation of Water Intake (Drinking)

When there is a lowering of water level in body tissues, either because of too great loss or a limited intake, a sensation of 'thirst' is conveyed to the hypothalamus.

The parts of hypothalamus that are involved in water regulation are described in detail by Stevenson (1964, 1967) and Grossman (1964). In sum, the suggestion is that water intake regulation involves similar regions in the hypothalamus as feed intake regulation. For example, the hypothalamic 'drinking centre' seems to be all but coexistent anatomically with neural mechanisms which participate in the regulation of feed intake. And it appears that the well-known interaction between the effects of feed and water deprivation may be

due to this intimate central relationship rather than purely peripheral factors (Grossman, 1964). But, as noted before, it is clear that feed and water intake are regulated with a degree of independence which appears surprising in view of the close anatomical relationship of the hypothalamic mechanisms.

The signals for 'thirst' are many, but osmotic and thermal signals seem to be of paramount importance.

1.2.1 Osmotic Signals

Evidence for an osmotic stimulus for 'thirst' is given in detail by Wolf (1958). The change in osmolarity stimulates the 'osmoreceptors' and the impulse is conveyed to the hypothalamus. This influences drinking as well as the secretion of ADH. Osmoreceptors are found in many parts of the CNS, including hypothalamus itself (Stevenson, 1964); and in oral, gastric parts, bladder and vascular system.

1.2.2 Thermal Signals

Water is essential for thermoregulation due to its role in evaporative cooling and vascular response. One of the important controls of water intake originated in the central mechanisms of the thermoregulatory system as noted before. Studies with bilateral leisions show that an important pathway runs from the anterior thermoregulatory region caudally past the ventromedial region to the lateral hypothalamus which is involved in the regulation of feed as well as water intake. These pathways may be essential to the effects of body and environmental temperatures on feed and water intakes (Stevenson et al., 1964).

1.2.3 Other Signals

Against this background of osmotic and thermal regulations in the hypothalamus, other facilitatory and inhibitory systems modify their influence. Among these, some recognised ones are oral and gastric metering, including the important satiety signals of distension, the dryness of the mouth and perhaps, the osmotic state of other peripheral sensors, volume receptors in the vascular system, the physiological state of the animals and the emotional state of the animal and his present relation to the external environment in terms of priority of activities (Stevenson, 1964; Adolph, 1964; Towbin, 1964).

The precise stimuli will vary under different conditions and in different species, but all or most of the signals funnel through the hypothalamus to produce an integrated signal which determines the act of drinking and its inhibition.

2. Factors Affecting VWI

As in VFI, the factors affecting VWI can be divided into animal factors, food and environmental factors.

2.1 Animal Factors

These include genetic factors (breed) and others (pregnancy, lactation, age, activity).

2.1.1 Breed Differences in VWI

Winchester and Morris (1956) showed that water consumption per unit of dry matter intake by the Bos indicus is always lower than the B. taurus for any given temperature. Phillips (1960) reported a lower

water requirement for Zebus than for Grade Herefords and a significantly smaller water intake per dry matter intake for Zebus. Thus, there is evidence to suggest that B. indicus and B. taurus have different water consumption and water requirement.

Under thermal heat stress. It is clear that Zebus drink less water per unit of dry matter intake in heat stress (Section 2.3) which presumably reflects lower water requirements too. Natural selection of Zebu cattle in the semi-arid conditions in many parts of the Tropics might have produced physiological adaptions which allow them to conserve water more efficiently than temperate breeds under heat stress. Zebu cattle are known to have better ability to concentrate urine and faeces under water deprivation (Payne, 1963; Kirkbride, 1973; Quarterman et al., 1957) and thus to conserve more water.

With the absence of heat stress. Rogerson et al. (1968) and Ledger et al. (1970) noted that the water requirements of Zebu and temperate cattle are not significantly different. The concluded that without heat stress the frequently inferred lower water requirement of Zebus may more truely reflect a lower dry matter intake by the Zebus.

2.1.2 Other Animal Factors Affecting VWI

Pregnancy. An increase in VWI in late pregnancy have been reported in ewes (Leitch and Thomson, 1944; Head, 1953; Forbes, 1968) and in cows (Lenkeit et al., 1966; Winchester and Morris, 1956). The extra water intake is only partly accounted for by accumulation in the uterus; the increase in heat production and excretion as pregnancy progresses probably accounts for most of the increment in water intake during pregnancy (Forbes, 1970).

However, an increase in VWI does not always accompany pregnancy, as shown by Campling (1966b) and Owen et al. (1968). There is no apparent explanation for these differences in the effect of pregnancy on water intake in these experiments (Forbes, 1970).

Lactation. Lactating cows drink more water than their dry counterparts (Campling, 1966; Owen et al., 1968). The production of milk obviously increases requirements of water. In addition to the water of milk, there is an increased need for water to meet the requirements of higher feed consumption and heat production.

Age. In general, young animals require more water per unit body weight than older animals under the same conditions. Bodies of young animals contain relatively more water per unit weight than those of adults. In addition, young animals are generally more metabolically active than are older animals. This necessitates increased urine excretion to remove waste products of metabolism (Kirkbride. 1973).

Activity. Increased activity, both physical and metabolic, raises the amount of water which must be removed by way of the urine in order to eliminate metabolic waste products. Working and growing animals have greater water requirements than do less active and mature animals (Kirkbride, 1973).

2.2 Food Factors Affecting VWI

The VWI is greatly affected by food factors. The close correlation between VFI and VWI has been discussed (Section I.1.2.3).

2.2.1 Type of Diet

An outstanding characteristic of feed that affects VWI is the water content of the feed. Dry matter content of the forage has been shown to be closely related to water intake. When cattle have access to feed which contains considerable amount of water, their need for drinking is reduced. For example, dry cows fed only hay consumed 42 kg of water per day; when they were fed hay and silage, they consumed only 34 kg a day (Atkerson and Warren, reported by Sykes, 1955). Wilson et al. (1962) found that water consumption of cows grazing in Trinidad was inversely related to the water content of the grass.

The protein content of the diet also has an effect on VWI. Cattle drink more water when fed on a high-protein than on lower protein diet (Payne, 1963; Rogerson, 1963). The higher protein level results in more nitrogenous end-products which require a higher obligatory urine volume for excretion (Roubicek, 1969). With diets of equal protein content cattle drink least with high carbohydrate and low fat. Carbohydrate in the diet provides the most oxidation water per calorie (Roubicek, 1969).

At the same dry matter intake, water intake was lower on low-quality-roughage (low-protein level) than high-protein roughage (Vercoe, 1967), probably due to the reduced nitrogenous output on the low-quality diet which requires less water for the excretion.

2.2.2 Other Food Factors Affecting VWI

The higher the proportions of minerals in the diet, the larger the urine excretion, and accordingly, the larger the water requirement.

The salt content of feed or water influences water intake; for example, cattle drink an additional 230 to 440 ml of water for each gram of salt ingested when 1 or 2% salt is added to a diet of chopped lucerne hay (Roubicek, 1969).

Some foods have diuretic properties that are responsible for increased drinking. The higher water intake of sheep on lucerne hay compared with grass hay is attributed to the diuretic properties of the lucerne hay (See Roubicek, 1969). There is some indirect evidence that fat in the diet may have some anti-diuretic effects (Roubicek, 1969).

2.3 Environmental Factors Affecting VWI

Heat stress produces a demand for large quantity of water for thermoregulatory cooling of the body. Low humidity hastens loss of body water through perspiration and respiration.

2.3.1 Heat Stress Due to High Temperature

The effects of high temperature on VWI have been reviewed by Bianca (1965); Thompson (1973); Winchester and Morris (1956) and Payne (1966).

When ruminants are exposed to high ambient temperature, they may use water in at least two ways to remove heat from the body. Firstly, water is used for evaporative cooling. Secondly, water which is consumed in excess of metabolic needs and which is ingested at a temperature lower than body temperature, when excreted at body temperature in the urine or in the faeces, removes heat from the body.

The amount of voluntary water intake by cattle in a hot environment is influenced by three factors: the severity of the thermal stress, the amount of dry matter eaten and breed.

The increased VWI with raising environmental temperature is well documented (Vercoe et al., 1972; Vercoe, 1969; Vercoe and Frisch, 1970; Sharma and Kehar, 1961; Vohnont and Bateman, 1972; Bailey and Broster, 1958; Bianca et al., 1965).

To account for the effect of feed intake, several workers have related the VWI to dry matter intake. Winchester and Morris (1956) reviewed the effect of increasing ambient temperature taking dry matter intake changes into consideration. In the temperature range of -18^{o} to $4.4^{o}C$, the water intake per unit dry matter intake is constant. The quantity of water per unit of dry matter intake consumed by cattle increases with an accelerated rate as temperature rises above $4.4^{o}C$. The litres of water drunk per kg dry matter eaten increased by a factor of two between $4.4^{o}C$ and $32.2^{o}C$. Colditz and Kellaway (1972); Bailey and Broster (1958); Sharma and Kehar (1961) also found that heat stress increases VWI per kg dry matter intake.

Without taking dry matter intake into account, total water consumption may decrease with increasing temperature as shown for Jersey, Holstein and Brown Swiss cows at about $29^{o}C$ (Ragsdale et al., 1949, 1951; Winchester, 1964). This was probably due to the decrease in dry matter intake and the associated reduction in milk yield. Although there was an increase in the requirements of water for thermoregulation at the higher temperature, this was offset by a

reduction in the water requirements for metabolism. Brahman cows kept under the same conditions as the Brown Swiss cows, did not reduce their water intake, but actually increased it. Bianca (1965) explained that this was due to low feed intake and milk production of the Brahman cows at lower temperature which decreased only slightly at higher temperature.

The effect of ambient temperature on VWI of different breeds of cattle also varies. Under the same high ambient temperature, Zebu-type cattle have always been observed to drink less water than temperate breeds. This has been shown when water intake was adjusted for liveweight by Kellaway and Colditz (1975); Colditz and Kellaway (1972); Phillips (1960); Horrocks and Phillips (1961); when adjusted for dry matter intake by Winchester and Morris (1956); Phillips (1960); Colditz and Kellaway (1972).

It also appears that acclimatized cattle require less water than unacclimatized cattle when kept at high ambient temperature (Johnson Yeck, 1964), probably because of greater ability in conservation of water in urine and faeces.

As noted before, in a hot environment, the increased evaporative loss of water from cattle may be aggravated by a decrease in humidity, thus may make an increased water intake necessary. This is shown by Sharma and Kehar (1961) who found that the increased water intake was greatest in low-humidity areas in a hot environment.

2.3.2 Water Deprivation in Cattle

It is difficult to definitely establish water requirements for

cattle because of the wide range of variations under different conditions. However, if the water requirements are not met, there are important consequences.

When water is restricted to the point that dehydration occurs, cattle reduced their feed intake (Bond et al., 1976; French, 1956a; Bianca, 1966; Thortorn and Yates, 1968, see also Payne, 1966), (See Section I.1.2.3). In an attempt to conserve water they also reduce the output of water in urine and faeces; this effect is more pronounced in B. indicus than in B. taurus (Payne, 1963; Kirkbride, 1973), and may contribute to the greater ability of B. indicus to conserve water during water deprivation.

Bonsma (1949), Phillips (1960b) and Payne (1965) have shown that under the same environmental conditions B. indicus do not reduce their feed intake to the same extent as B. taurus when deprived of drinking water. However, B. indicus have a lower feed intake to begin with.

In spite of the reduction in feed intake when deprived of water, which may be accompanied by a fall in metabolic heat production, the animals are less able to tolerate heat than when they have water available (Bianca, 1966). The reduction in heat tolerance is the result of a decreased rate of evaporation.

The beneficial effect of short-period water deprivation in cattle, if any at all, is the increased digestibility of forage by the animal. Increased dry matter digestibility by cattle on restricted water regimes has been reported by Thortorn and Yates (1968); French

(1956a); Phillips, (1961). The explanation for this increase has generally been attributed to a slower rate of passage of the digesta through the gut. However, it may be just because of the reduction of dry matter intake, as shown in sheep by Blaxter et al. (1956); or because of the increased production of additional saliva (Payne, 1966).

The short-term effect of water deprivation on the live weight gain of ruminants can be dramatic (Macfarlane et al., 1956; Payne, 1965), but this may be largely due to loss of body water. The long-term effects are not well-documented, but since water deprivation reduces VFI, it can be expected to reduce live weight gain.

As dehydration of the animal increases, the body temperature rises and the heart rate increases. As water is lost from the blood, the total volume of the blood declines and its viscosity increases. Under conditions of severe dehydration, the body is no longer able to produce sufficient urine to eliminate body wastes, and uremia develops. Continued loss of water causes death (Kirkbride, 1973).

Once normal water intake is restored, following a period of restriction, there is no effect on health, provided that dehydration has not been too severe (Roubicek, 1969; Bond et al., 1976).

2.3.3 Hot Environment with Water ad libitum

If cattle are provided with water ad libitum in hot environments their water metabolism may be different from normal (Thompson, 1973). The cattle will increase VWI, reduce dry matter intake when exposed to heat stress with ad lib. water. The water loss in the faeces is

reduced but increased in urine. There are also other changes:- dilution of blood, increased total body water content and increased water turnover rate. These changes in water metabolism are asscciated with improved capacity for cooling by sweating and respiration and renal output. Thus, an adequate intake of free water is likely to assist the ruminant to improve its "heat tolerance". There is evidence for this in the experiments reviewed by Payne (1966).

Reducing the temperature of the water has been shown to have more effect on heat regulation than raising the amount drunk (Noffsinger et al., 1961; Bailey et al., 1962; Cunningham et al., 1964). Cooling of water had also been shown to reduce the amount of water drunk during heat stress (Winchester and Morris, 1956).

III DIGESTIBILITY

Apparent digestibility of a feed and its constituents is a measure of the percentage of the ingested feed or its constituents which does not appear in the faeces. Thus, it determines the amount of nutrients an animal can obtain from the feed, and a high digestibility is highly desirable.

The main factors affecting digestibility are genetic (breed), food and heat stress factors.

1. Genetic (breed) factors

A number of comparative trials concerning the digestive efficiency of *B. indicus* and *B. taurus*, showed that the expression of breed differences in digestibility is variable.

Low-quality diets. Many have shown that cattle with Zebu blood are superior in dry matter (DM) and nitrogen (N) digestibilities when fed low-quality diets (Duckworth, 1946; Ashton, 1962; Phillips, 1961; Howes *et al.*, 1963; Phillips *et al.*, 1960; Vercoe and Springell, 1969; Moore *et al.*, 1975). Some found no significant difference between the two types of cattle in digestibility (Olbrich *et al.*, 1973; Karue *et al.*, 1972; French, 1940; Arman and Hopcraft, 1975; Kellaway and Colditz, 1975).

High-quality diets. The breed differences in DM and N digestibilities with high-quality diets are not clear. Vercoe (1966, 1967), Vercoe *et al.* (1972) showed that Zebu or Zebu crossbreds are superior in digestibility to British breeds when fed high-quality diets.

Vercoe and Frisch (1970) found no significant difference while Moore et al. (1975) found that digestibility was higher for Herefords than Brahmans.

Since digestibility may be affected by the level of feeding and there is also a tendency for the breeds to respond differently to the level of feeding (see Section III.2), the above experiments with high-quality diets were done with fixed level of feeding, nevertheless, the results are variable.

Overall, Zebus or Zebu crossbreds appear to be slightly more efficient than British breeds in digesting dry matter and nitrogen on low-quality diets rather than high-quality diets. When the animals are fed low-quality diets, the Zebu or Zebu crossbred cattle have never been inferior to British breeds in digestibility, although they have not always been superior.

Moran and Vercoe (1972) reviewed a total of 107 digestibility trials, and their analysis showed that apparent nitrogen digestibility was on average 2-4% higher in Zebu crossbreds.

Heritability of Digestive Ability

Very few attempts have been made to determine the heritability of digestive abilities within types of cattle. Reid (1962) concluded from a comprehensive review of literature that variability in digestive powers between individuals was so low that possibilities for genetic improvement were very small - probably too small to justify selection studies. This is confirmed by Blaxter (1967).

Apparently, genetically determined differences in the ability to digest foodstuffs, if they exist, are of such small magnitude as to be of doubtful practical significance; this is the conclusion made by Warnick and Cobbs (1975) after reviewing the available literature. But, in the tropics, as most of the feeds are of low quality, these differences might be of some practical significance. However, according to the data Preston and Willis (1975, p.171) had accumulated in West Indies, despite superior digestive efficiency in B. indicus on a low-protein diet compared with B. taurus there was no difference in growth rate.

2. Effects of Food Factors on Digestibility

Two important food factors which affect digestibility are the type of food and the level of feeding.

2.1 Type of Diet

At the same level of feeding, a high concentrate ration is more digestible than a high roughage ration. This is because a high concentrate ration contains a high concentration of sugars or easily hydrolysed carbohydrates such as starch and fructosan which result in low faecal losses, while a high roughage ration is associated with the presence of large amounts of structural constituents - lignin, cellulose and hemicellulose, which give high faecal losses. In general, digestibility is inversely proportional to the fibre content of the diet.

There is considerable evidence to show that, when mixtures of different feeding stuffs are given to ruminants, the apparent digestibility of the mixture is not necessarily the same as the weighted

sum of the apparent digestibilities of its components. This is known as associative digestibility and is described by Blaxter (1967). The addition of a large amount of concentrates (e.g. starch grain) to roughage diets often cause a depression in digestibility of the roughage, which partly explains the reason for depressed voluntary intake of the roughage as noted in Section I.2.2.1. This effect can be accounted for by the fact that the rapid growth of starch-fermenting organisms results in a rapid depletion of the soluble nitrogen and possibly other essential nutrients in the fluid phase of the rumen. The cellulolytic flora is depressed in consequence. On the other hand, the addition of a small amount of concentrates to a roughage diet, especially those of very low protein content, can often cause an increase in the digestion of the roughage, which is one of the reasons for an increase in voluntary intake of the roughage. This effect is probably due to the extra nitrogen supplied by the concentrates for the cellulolytic organisms which enable them to function more vigorously.

There is some indication that after a period of time ruminants adapt to mixed diets, and that associative effects tend to be small provided sufficient time has elapsed to enable the microflora of the rumen to adjust to its changed substrates (Blaxter, 1967).

The apparent digestibility of the diet is greatly depressed by the addition of lipids. The reason is unclear. Blaxter (1967) suggested that the associative effects of lipids on the digestibility of structural carbohydrate is intimately concerned with rumen fermentations.

The herbage from tropical pasture plants is always of low nutritive value. This is mainly because tropical pasture plants are more fibrous and are less digestible than temperate plants harvested at similar stages of growth. The digestibility of young grass rarely exceeds 70% and decreases at a rate of 0.1 digestibility unit per day with advancing maturity (Minson, 1971). High temperature and water stress to which plants in the tropics are often subjected are the main causes of the mean 13 digestibility units differences recorded between tropical and temperate species (Minson and McLeod, 1970). However, the quality of improved and planted pastures, particularly legumes, do not decline as rapidly with age as most native pasture (Milford and Minson, 1965).

2.2 Effect of Level of Feed Intake on Digestibility

The results of digestibility studies with respect to the influence of the level of feeding on digestibility have been rather variable. A decrease in digestibility when the consumed feed quantity increases is often observed, but some investigations showed unchanged, or even higher digestibility with increased feed consumption (see Wiktorsson, 1971; Brown, 1966); in their reviews it was suggested that the differences in the results may be due to several reasons, but the most important ones seem to be the choice of feedstuffs and the experimental design.

The kind and physical form of the diets seem to be an important determinant in the effect of level of feeding on digestibility. In all forage rations, the depression in digestibility when quantity of feed consumption increases, was more pronounced when forages were finely ground or ground and pelleted than when fed as long or chopped forage (Blaxter and Graham, 1956; Campling et al., 1963). The

extent to which digestion was depressed appear to be related to the fineness of grinding of the forage (Blaxter and Graham, 1956; Blaxter et al., 1956). When long roughage has been the only feed, apparent digestibility is the same regardless of the quantity of feed consumed or there is only a small decrease (Andersen et al., 1959; Blaxter et al., 1956).

The decrease in digestibility of mixed rations (roughage and concentrates) associated with increased level of feeding is variable. Several reports have indicated little or no decrease in digestion of mixed rations with increasing levels of intake, while others reported significant depression (see Wiktorsson, 1971; Brown, 1966).

The decrease in digestibility associated with high level of feeding appears to be due to several factors. The reduction in retention time in the gut may be the main cause. Regardless of the physical form of roughage, an increased level of feeding generally results in a decreased retention time of digesta in the digestive tract (Blaxter, 1967) and grinding of forages may decrease the retention time further. This may, thus explain the more pronounced depression of digestibility when forages are ground.

The significance of depressions in digestibility associated with level of feeding need not necessarily be of great consequence to energy metabolism of the animal (Wiktorsson, 1971). There is evidence of compensating changes in the losses of energy as methane and in the urine when digestibility is depressed at high level of feeding

(Blaxter and Wainman, 1961; Flatt, 1966). Thus, the effect on the intake of metabolisable energy (ME) by the animal due to depression in digestibility if any, on high plane of feeding may be small and insignificant i.e., ME/GE % may not be affected, but before this can be concluded unequivocally, more evidence is required.

3. Heat Stress and Digestibility

Although it is not yet fully understood how a hot environment affects digestion, the digestibility of feed seems to improve slightly under conditions of mild heat stress. This was shown by Blaxter and Wainman (1961); Davis and Merilan (1960); McDowell et al. (1969). When it is divided into dry matter and nitrogen digestibilities, most of the reports showed no significant effect on nitrogen digestibility due to heat stress (Vercoe and Frisch, 1970; Vercoe, 1969; Colditz and Kellaway, 1972) but showed slight increase in dry matter digestibility (Vercoe and Frisch, 1970; Vercoe, 1969; Colditz and Kellaway, 1972; Johnston et al ., 1961; Vercoe et al., 1972).

However, digestibility does not always increase with heat stress. Vercoe (1969); Olbrich et al. (1973) found no significant change in dry matter digestibility due to high temperature. Kellaway and Colditz (1972) suggested that the trend for an increase in digestibility with high temperature was largely accounted for by differences in feed intake. As digestibility may increase when feed intake decreases (see Section II.2), the reduced voluntary intake in the hot condition may be part of the reasons of the slight increase in digestibility. The alteration of rumen motility is also thought to play a part in the change of digestibility in the heat. It was found that a high

temperature causes a decrease in rumen motility and thus decreases the rate of passage of digesta, and consequently may increase digestion (Attebery and Johnson, 1969).

IV GROWTH RATE

The characteristics that most directly measure productivity are fertility, growth rate, body composition and mortality (Turner, 1975). It is unlikely that any breed will prove superior in all productive traits. The main concern here is performance in growth rate. A breed performing well in one condition will not necessarily do so in another. An attempt is made here to discuss the relative merit of different breeds under tropical conditions.

1. Genetic Differences in Growth Rate

Different breeds of cattle exist in various parts of the world and genetic differences in growth rate certainly exist. Although descriptions of many of these breeds are available, together with estimates of their performances (growth rate, reproductive performance, etc.), such estimates have often been obtained only for the environment in which each breed is usually run, so that genetic differences in productivity between breeds cannot be separated from environmental effects. It is likely that indigenous breeds have become adapted to their environment and may be capable of greater productivity than exotic breeds under that environment.

1.1 Bos taurus

In the temperate conditions, a growing amount of information is becoming available on the comparative performance of B. taurus and it is possible to classify the breeds into groups (Manson, 1971):

Group 1. This includes Charolais, Simmental, Chiana, Romanga and German Yellow. Present results show little difference between

these breeds in growth rate, yield of red meat, rate of maturity, leanness and calving difficulties. The first four characters of these breeds are excellent under favourable conditions, but the high rates of calving difficulties discounts their merit to a certain extent.

Group 2. This includes the Limousin, Blonde Aquitaine, Maine-Anjou, South Devon, MRY and the British Friesian. These breeds are smaller, slightly slower in growth rate than group 1, but also high yielding and lean.

Group 3. includes the Continental Friesians, Devon, Sussex and Danish Red. These cattle are smaller than group 2 and lower yielding as well.

Group 4. includes the remaining British beef breeds: Hereford, Angus, and Shorthorn. These breeds are early maturing compared to other groups, have higher propensities to produce fat at an earlier age. But, they have less calving difficulties.

There is a positive correlation between mature size and absolute daily gain, and a negative correlation between mature size and fatness at the same age, i.e., breeds with a large mature size grow most rapidly and mature most slowly. The less desirable aspects of large mature size are more calving difficulties, insufficient milk production of the dam, reduced fertility, lack of resistance to calfhood diseases and nutritional stress (Gropsey, 1975). All these are broad generalizations and exceptions are evident.

The growth performance of B. taurus cattle with B. indicus under comparable conditions in sub-tropical and tropical countries are shown in Table 1. Statistical information comparing breeds in the same conditions in tropical areas is not readily available and most data come from the Southern sub-tropical states of U.S.A. or the tropical areas of Queensland or experimental stations where general management levels and nutrition must be higher than in most tropical developing countries. Under these conditions, B. taurus cattle seem to have higher growth rate than B. indicus cattle, for example, the work of Flourie and Harwin (1967) in South Africa and Willis and Preston (1968) in Cuba (Table 1). Among the B. taurus breeds, the same trend of growth rate as shown in temperate conditions occurs, i.e., group 1. animals grow faster than group 2, etc.

However, it is not known the degree to which these results can be considered applicable to the developing tropical farming situations where animal husbandry and nutrition are poor. For example, the experiment carried out under semi-arid range conditions in S.W. Africa by Borstlap (1968) (Table 1) showed that the growth rate of all breeds were poor (average daily gain was about 0.23 kg/day). The B. taurus were not superior in growth rate as observed before. These results revealed two main points:

(a) With good husbandry and nutrition in the tropics, B. taurus may perform better than B. indicus; or as nutritional plane is increased, the superiority of B. taurus becomes more obvious. This is fully demonstrated in the Cuban trial which used high energy diets and where the Charolais superiority over the Brahman amounted to some 40% (Willis and Preston, 1968).

TABLE 1: Breed Comparisons in Growth Rate under Sub-tropical or Tropical Conditions

Breed	Growth Rate		Conditions	Sources
Simmental	0.27 kg/day	8 mth to 2½ yr	S.W. Africa Poor nutrition, husbandry	Warnick (1973) using the data of Bortlap (1968)
	0.32	2½ yr to 3½ yr		
Hereford	0.27			
	0.23			
Angus	0.20			
	0.23			
Shorthorn	0.23			
	0.27			
Sussex	0.27			
	0.27			
South Devon	0.23			
	0.18			
Red Poll	0.23			
	0.27			
Pinzganer	0.27			
	0.32			
Africander	0.27			
	0.27			
Bulls	kg/day		South Africa Good nutrition and husbandry	Flourie and Harwin (1967)
Africander	0.89			
Brahman	0.86			
Simmental	1.30			
Hereford	1.16			
Angus	0.94			
Shorthorn	1.16			
Sussex	1.09			
Devon	1.06			
Galloway	1.08			
Drakensberger	1.02			
Steers	kg/day	up to 200 mths or 900 lb	Tennessee Exp. Station, U.S.A. Good nutrition and husbandry	Cole et al. (1965)
Hereford	0.84			
Angus	0.80			
Holstein	0.98			
Brahman	0.68			
Brahman x S. Gertrudis	0.86			

TABLE 1: (continued)

Breed		Growth Rate	Conditions	Sources
Bulls	kg/day	90 days up to 400 kg LW	Cuba High energy diets used	Willis and Preston (1968)
Charolais	1.2			
Criollo	1.00			
	1.06			
Holstein	1.18			
Santa Gertrudis	1.16			
	1.04			
Brahman type	0.88			
Zebu	0.86			

(b) With poor nutrition and husbandry, B. taurus growth rate declines and they are not able to express their growth potentials fully.

1.2 B. indicus

The B. indicus breeds are well-adapted to the tropics in terms of survival but their growth rate is low compared to temperate standards. The comparisons with B. taurus has been discussed (Section IV.1.1).

It may be appropriate to divide B. indicus into two categories. The more "developed" category would include those breeds like Brahman and Africander. They have been used and studied extensively in sub-tropical U.S.A. and Australia. It is possible that due to this selection and better management, their performance in growth is superior to the second category which includes all the thousands of indigenous cattle breeds in different parts of the tropics; often referred to as 'local' or 'indigenous' breeds. These cattle grow more slowly, but are more tolerant in harsh conditions.

1.3 Zebu Crossbreds

In the early 1950's, the Queensland Department of Primary Industries conducted a number of breed comparison trials in different areas, and these consistently showed high growth rate and lower losses in B. taurus-B. indicus crossbreds (A.M.R.C., 1975). These similar results have been reported from other parts of tropical regions - Willis and Preston (1969) in Cuba; Demon et al. (1959) in Gulf Coast Region and in tropical centres in Queensland and New Guinea (Rudder et al., 1975; Anderson, 1968). They all agree with the extensive information from sub-tropical U.S.A. (Koger et al., 1973) indicating

that Zebu crossbreds grow faster than their purebred parents under summer conditions. This advantage was least under exceptionally favourable pasture conditions (Turner, 1975).

Some superiority of crossbreds over purebred cattle is to be expected in view of possible heterotic effects and this is likely to be particularly so when one of the contributing breeds is the Brahman (McCormick and Southwell, 1957).

In crossbred comparisons distinction between first-cross animals and other crosses must be drawn. Although direct comparisons of F_1 and F_2 are few and always inconsistent (Lampkin and Kennedy, 1965; Seifert and Kennedy, 1972; Warnick, 1973), the general evidence is that F_2 calves have an advantage in pre-weaning growth from milk production of their crossbred cows; whereas F_1 calves have an advantage of greater heterosis in both pre- and post-weaning growth (A.M.R.C., 1975).

Another important attribute associated with productivity of crossbreds is their reproductive performance. The calving records at Belmont represent a well-defined set of data on half-breds (Seebeck, 1973). The means summarized in Table 2 have been corrected for effects of age, lactational status and year. They showed a dramatic contrast between the F_1s, where the Brahman cross have the highest fertility, and the F_2-F_3s, where the Brahman cross have the lowest fertility. The Africander cross show consistently high fertility, with no drop from F_1 to later generations. The results emphasize the importance of distinguishing between F_1s and other crossbreds, which has not always been made clear.

TABLE 2: Calving Percentages in Crossbreds in 'Belmont'

Seebeck (1973)

Generation	Africander cross	Brahman cross	Hereford-Shorthorn
$F_1 \times F_2$	76.4	81.2	70.1
F_2 and F_3	76.8	60.7	67.1

TABLE 3: Main Recognized Crossbreds

Name	Composition	Country where first bred
Bonsmara	5/8 Africander 3/8 Shorthorn	South Africa
Santa Gertrudis	3/8 Zebu 5/8 Shorthorn	U.S.A
Beefmaster	½ Zebu ¼ Hereford ¼ Shorthorn	U.S.A.
Droughtmaster	Admixture of *B. indicus* and *B. taurus*	Australia
Quasai	½ *B. indicus* ½ *B. taurus*	Australia
Brangus	Brahman Angus	U.S.A.
Braford	Brahman Hereford	U.S.A
Charby	½ Brahman 3/4 Charolais	U.S.A.

1.4 New Breeds

Many new breeds have been developed based on an admixture of B. taurus and B. indicus as shown in Table 3. Of the many "Zebu-derived" breeds shown, the Santa Gertrudis is perhaps the most widely known and distributed. The published data on reproductive performance of S. Gertrudis are few and they showed that they are poor (Willis, 1976), although its rate of growth was satisfactory as the comparison of Willis and Preston (1968) shows in Table 1. Willis (1976) also indicates that it had satisfactory growth on high energy diets. It does seem probable that breeds like Brangus, Brayford and Droughtmaster will outgain Brahmans under tropical conditions (Francis, 1969).

For crossbreds, it can be said that under rigorous conditions, the crosses quite generally have been superior in growth rate to either parent breeds. However, under improved or advanced managerial conditions in the tropics, the European breeds generally have performed more favourably in growth. Attempts have been made to develop new breeds for hot climates from a crossbred base. The Santa Gertrudis is a notable example. Much crossing of Indian type cattle with temperate breeds has also been undertaken to provide tolerance to heat stress, resistance to tick and insects, and the ability to subsist on sparse fibrous forage.

In the tropics, crossbreeding is basically aimed to combine the survival traits of the B. indicus with the productive traits in B. taurus. The problem in crossbreeding may not be the choice of breeds, but in determining the level of B. indicus and B. taurus blood necessary to maintain productivity in the tropics. For example, in F_2 Brahman cross, reproductive performance may decline.

2. Effects of Nutrition on Growth Rate

A combined deficiency of protein and energy is usually the major nutritional limitation to cattle production in developing countries. Many instances of this deficiency arise from the poor quality of forage which is usually the only feed available to cattle.

2.1 Tropical Pasture and Growth Rate

Direct comparisons of growth rate from tropical pasture are difficult because of the interacting factors such as environment, type and class of stock and management practices.

However, the general levels of beef production which can be expected from cattle grazing tropical pastures under reasonable practical management has been estimated by Stobbs (1975, 1976) as shown in Table 4. These estimates are based on extensive experimental work conducted by many workers in 10 different countries in the sub-tropics or tropics. These results showed that there is a tremendous potential for improving beef production from tropical pastures, especially in the humid tropics. For example, by oversowing legumes and using fertilizer in natural grasslands, the estimated kg LWG/ha/yr increased from 60-100 to 250-450.

2.1.1 Natural Grassland and Growth Rate

In arid tropics, the rate of growth of cattle grazing natural grassland is subjected to extreme variation between wet and dry seasons. The 'saw-teeth' pattern of growth (Fig.2) is typical of cattle grazing most natural tropical pastures (Alexander and Chester, 1956; Norman, 1967a, 1967b; Osbourn, 1976; Stobbs, 1976). There is a rapid

TABLE 4: Estimated Beef Production from Natural Grasslands and Sown Grasslands in the Tropics (kg liveweight gain/ha/yr) (from Stobbs, 1975)

	Monsoonal tropics (5-6 months dry)	Humid tropics (long growing season)
Natural grasslands		
Improved grasing	10-80	60-100
Oversown with legumes and fertilized with Mo. super	120-170	250-450
Cultivated grasslands		
Grass/legume mixtures with Mo. super	200-300	300-600
Nitrogen fertilized grass	300-500	800-1500

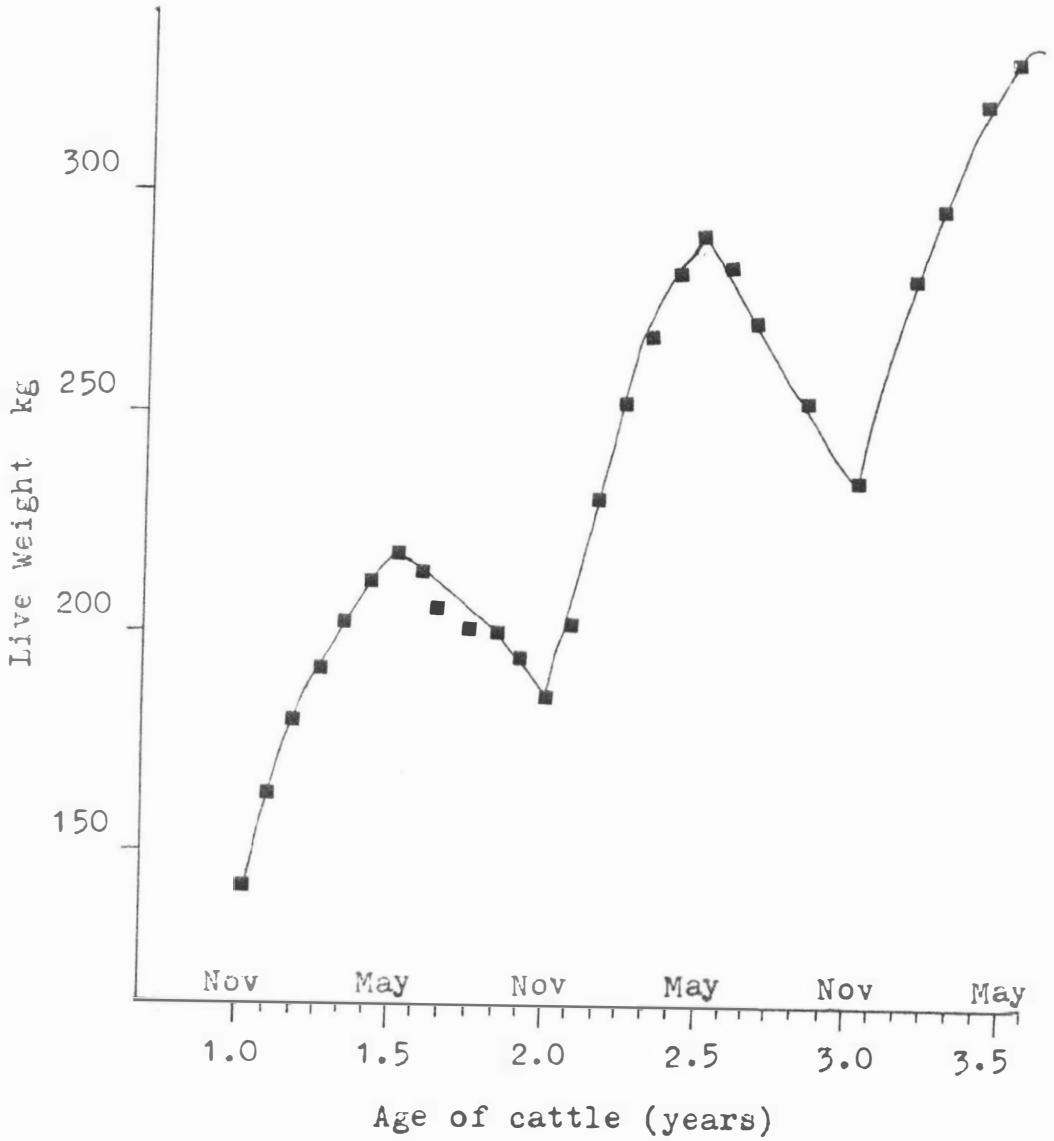


Fig. 2. Seasonal liveweight changes of cattle, 1-4-year-old grazing native pasture at Katherine, N. Australia (from Norman, 1965).

liveweight gain (LWG) in the early wet season, it slows down and then becomes negative in the dry season. The most rapid loss occurs normally before and at the commencement of the rains. The low nitrogen content and low digestibility of the herbage during the late rains and dry season limit the intake and LWG of the cattle.

In the humid tropics, climatic conditions are favourable for forage growth all year around, but the rapid maturity of the natural grasses which leads to low digestibility and low nitrogen content (see Section III.2) is still a setback for optimal growth rate. The estimated potential beef production in the humid tropics as compared to arid tropics are shown in Table 4.

The introduction of legumes in to native grasslands has been shown to improve the quality of the tropical pasture greatly and consequently the LWG. The effect of the legume is twofold: firstly the nitrogen content and digestibility of tropical legumes do not decline as rapidly with maturity as the tropical grasses (Stobbs, 1976), thus improving the quality of the feed, especially during the dry season. Secondly, tropical legumes are capable of fixing annually between 20 and 180 kg N/ha (Henzell, 1968).

Beef production has been greatly increased by oversowing native pastures with tropical legumes both in drier areas of the tropics (Norman, 1968; Shaw and t'Mannetje, 1970) and also in the wet tropics (Stobbs, 1969); beef production generally being greatest where the legume is adequately fertilized (Stobbs, 1976).

2.1.2 Improved Tropical Pasture and Growth Rate

Improved tropical pasture refers to pasture with planted grasses with legume or nitrogen fertilized cultivated grasses. Beef cattle grazing improved tropical pastures are capable of producing rapid weight gains (0.9-1.2 kg/steer/day) during the early growing season (Smith, 1976). However, the decline in herbage quality associated with pasture maturity results in much lower gains, and annual average LWG rarely exceeds 0.6 kg/day (Stobbs, 1976). This is mainly because tropical plants become more fibrous and less digestible faster than temperate grasses as noted before. However, the quality of sown and planted pastures does not decline as rapidly with age as most native pastures (Milford and Minson, 1965) and the animals can continue to grow over a longer period when grazing these pastures.

2.2 Feeding Rations and Growth Rate

Although pasture is the main source of cattle feed in the tropics, there are some agro-industry by-products which are suitable for supplementing the pasture. These include the by-products of sugar cane, oil-palm, rice, coconut, citrus fruits, cassava, etc.

In the temperate countries, concentrate (mainly cereal based) is an important source of cattle feed. The effect of roughage to concentrate ratio on the performance of fattening cattle has been studied extensively in the last two decades. This is an attempt to reduce the cost of the ration by adding the maximum amount of cheap roughage in the diet and yet obtaining the optimum growth performance.

2.2.1 Variation of Energy and Growth Rate

Variation of the constituents in a ration, principally associated with the level of energy, has marked effects on growth rate. Performance in terms of LWG is a result of a number of factors, notably the factors are VFI, digestibility, and composition of the LWG.

The change of ration constituents and its effects on VFI has been discussed in Section I.2.2.1. Replacing part of the concentrates of a diet by an equal weight of roughages, reduces the net energy content of the diet. The animal may to a certain extent, maintain its energy intake by raising its intake of dry matter. But, if the roughage content in the diet exceeds a certain limit, dry matter intake will be depressed.

The nutritive value of the diet declines as roughage percentage increases (Raven et al., 1969; Forbes et al., 1969). This resulted primarily from a substantial reduction in overall digestibility and may be to a lesser extent from the fact that end products of fermentation in the rumen contained a higher proportion of acetic acid and a lower proportion of propionic acid. Moreover, as roughage percentage rises, energy and nitrogen contents declines.

A small decrease in energy intake affects the energy content of gain with little or no effect on the rate of LWG. This is because of an improved efficiency of conversion of feed energy into liveweight (Anderson, 1975; Raven et al., 1969; Lamming et al., 1966; Forbes et al., 1969b). For example, Anderson (1975) restricted bulls to 85% feeding levels in Scandinavian feed units obtained better feed conversion

efficiency than 100% level. Raven et al. (1969) indicate that addition of 20% straw did not decrease LWG significantly compared to 100% concentrates.

But this is not always so. Levy et al. (1976b) found that average daily gain and daily carcass gain was lower for animals on 80% of ad libitum than on 100% ad libitum concentrate intake.

With a more substantial reduction in energy intake (due to VFI depression or decrease in nutritive value of feed) LWG significantly declines (Broadbent et al., 1976; Forbes et al., 1969; Raven et al., 1969). As energy intake decreases substantially, increasing proportion of feed energy has to be used for maintenance purposes, and less will be available for growth. The optimum percentage of roughage in a concentrate ration is variable, because it depends on the quality of the roughage and the animal factors. For example, Levy et al. (1976) found that there is no advantage in raising the percentage of concentrate in a fattening diet above 70, if a certain degree of fatness is not needed.

Thus, the general statement that as the level of concentrate in the ration increases, LWG increases is modified in many circumstances.

2.2.2 Variation of Protein and Growth Rate

Another important constituent in the ration is protein. Provided feeding is ad lib., the evidence so far presented indicates that the use of any of the common cereal grains, either in all-concentrate diets or with a maximum of 10-15% added roughage, will permit realization of

the animals' potential for growth. Protein is usually not a limiting factor.

However, there is a minimum level of protein consistent with normal growth and health. The feedlot operator is also interested in the amount of protein needed to maximize gain. The standard texts on protein requirements are available (NRC, 1963 and ARC, 1965). Besides voluntary intake, three other important variables which determine protein requirements are body weight (age), rate of LWG and the digestibility of protein (Preston, 1966).

2.3 Effects of Refeeding Following Under-nutrition

There is well-documented evidence that cattle which have been retarded in their growth, have the ability to resume their growth when the restriction is removed, at a rate greater than the normal for animals of the same chronological age (Topps, 1976; Prescott, 1976). This is commonly referred to as compensatory growth.

The effects of restriction and the nature of their recovery growth is affected by:

(i) the stage of maturity of the animal at restriction;

(ii) the severity and duration of adverse conditions and,

(iii) the conditions prevailing during the recovery period.

The physiological basis of compensatory growth has not been fully explained. Undoubtedly, some of the initial high rate of gain on realimentation is due to fairly large increases in gut fill (Topps, 1976). An increased feed intake during refeeding has held responsible

partly for compensatory growth (Taylor, 1959). Fox *et al.* (1972) suggest that part of the compensatory growth is due to the deposition of more protein and less fat during recovery. The occurrence of this preferential deposition of protein and how long the effect persists are of obvious importance in considering at what age to slaughter animals that are being refed after a period of poor nutrition.

3. High Temperature and Growth Rate

In the tropics, direct and indirect climatic effects often go hand in hand: grazing animals are subjected to thermal heat stress and have low-quality forage. But, with adequate nutrition, heat stress *per se* is also known to depress growth rate in cattle.

There are not many experiments done which determined the *direct* effects of heat stress on growth rate in cattle. From the available literature, heat stress has invariably proved to have unfavourable effects on growth rate (Vohnout and Bateman, 1972; Hancock and Payne, 1955; Kamal and Johnson, 1971; McDowell, 1966; Shebaita and Kamal, 1975; Cassady *et al.*, 1956).

However, there are breed differences in the response of growth to heat stress. It would seem that Zebu or Zebu crossbred cattle are less affected than unacclimatized temperate breeds at the same high ambient temperature (Colditz and Kellaway, 1972; O'Bannon *et al.*, 1955). This may be expected as Zebu cattle usually have a lower growth rate and known to have better heat tolerance.

Decreased growth rate arising from direct heat stress is likely to be the outcome of a complex of physiological factors. The main ones are the reduction of VFI, and the reduction of energy and nitrogen retention in heat stress.

The experiments which reported reduced growth rate due to heat stress have also invariably reported a reduction of feed intake (e.g. Vohnout and Bateman, 1972; Colditz and Kellaway, 1972). The reduction of feed intake in heat stress decreases the available energy for productive purposes, thereby reduces the animal's ability to achieve its genetic potential for growth, especially in B. taurus.

Cattle in a hot environment forced-fed through rumen fistula, had been shown to have a faster rate of growth than the control animals (see Bianca, 1965; Thompson, 1973). Inevitably, reduced VFI plays an important part in the reduction of growth in heat stress.

The reduction of energy and nitrogen retention in heat stress arise from the possibility that energy, protein and digestive metabolisms may be altered in heat stress.

When exposed to moderate heat stress, the cattle will decrease their activities, feed intake and heat production will be kept to their minimum. In heat-acclimatized cattle, basal metabolic rate may be slightly depressed. While this is done to keep the homeothermy of the animal, lower energy metabolism contributes to a lower productivity. In severe heat, heat production of the animal may increase and add further heat load to the body. This increased heat production

results in undesirable loss of energy as heat rather than for productive purposes. Also, in heat stress, a portion of the energy has to be used for heat loss activities such as increased respiration rate which could otherwise be used for growth (McDowell, 1966).

Despite the minimum heat production during heat stress, there is good evidence of increased excretion of nitrogen or creatinine in the urine (Vercoe, 1969; Vercoe and Frisch, 1970; Kamal et al., 1970; Kamal and Johnson, 1971; Colditz and Kellaway, 1972; Kellaway and Coldits, 1975). It appears that reduction in the proportion of nitrogen retained under heat stress is due to a simultaneous increase in protein catabolism and reduction in protein anabolism (Kellaway and Colditz, 1975). This leads to protein wastage which could otherwise be used for growth.

The effects of high temperature on digestive metabolism are not likely to be a cause in the reduction of growth in heat stress. Heat stress seems to improve digestibility of feed slightly (III.2.3). Experiments have shown that there are changes in the volatile fatty acid production due to heat stress (Olbrich et al., 1972; Kelly et al., 1967) but what alterations are hard to predict. These alterations in VFAs may have an effect on growth.

V THE EFFECTS OF RADIATION

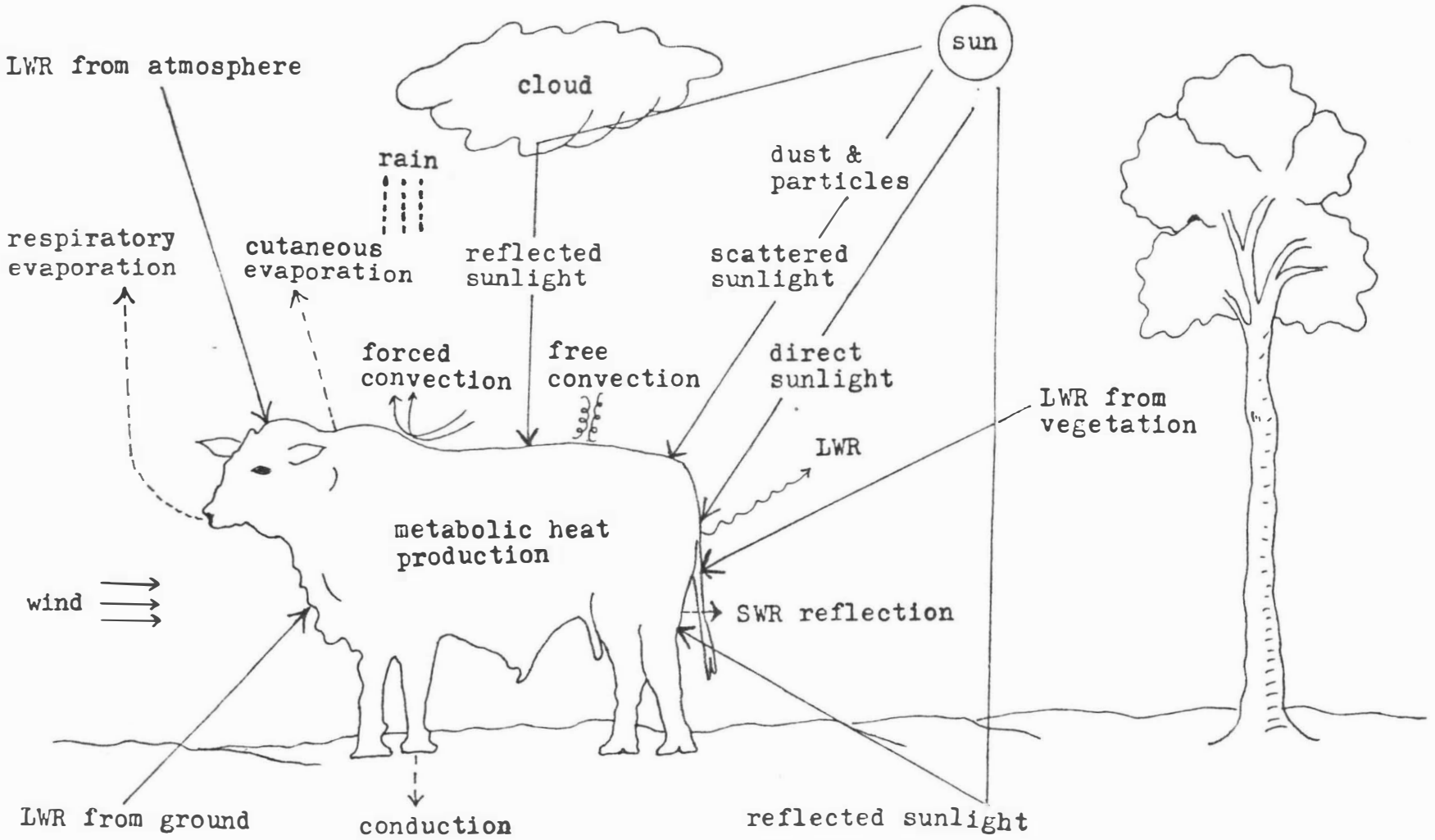
There are many descriptions of the energy exchanges of animal and its environment (Hutchinson et al., 1974; Robertshaw and Finch, 1976) which is illustrated in Diagram 1.

Where continual exposure to sun is unavoidable in tropical pastures, solar radiation becomes an important factor contributing to heat stress. The direct effects of solar radiation are twofold: firstly, there is the chemical effect of the actinic rays, and secondly the heating effects (Riemerschmid, 1943). Only the latter will be reviewed.

Radiant energy incident on an animal increases its thermal load. The effect of the radiation is complex, it may either be absorbed or reflected. The absorbed energy may either be conducted into the body or re-radiated with a wavelength distribution characteristic of the animal's surface temperature. The total radiation absorbed by the animal surface is the product of the incident fluxes of shortwave radiation (0.3-2.5 μm) and longwave radiation (>3μm), the area of the animal exposed to each type of radiation, and the absorptance of the coat (Finch, 1976).

Very few workers had attempted to measure all the components of the energy budget for an animal in a hot radiant environment because of the inherent difficulties in assessing energy exchanges in uncontrolled field conditions. Finch (1972, 1976) had attempted to measure experimentally the thermal exchanges in a natural environment (semi-arid and bush) in Nairobi of African herbivores (eland and hartebeest) and Boran cattle. In the radiation component, there was a total net

Diagram 1. The energy exchanges between an animal and its environment.



gain of about 170 $^{W}/M^{2}$ by the cattle between 0900 and 1500 hr. Longwave radiation from the ground and sky constituted 61% of the total radiation absorbed by the coat. The remainder of the total radiation absorbed consisted of shortwave radiation.

As long as the environmental temperature is below the outer body surface temperature, a large part of the absorbed solar energy is dissipated to the cooler environment. In a hot environment, the heat load of solar radiation will increase the amount of heat which must be lost by evaporative cooling if a constant body temperature is to be maintained. Thus, radiation accentuates the adverse effects of heat stress in a hot environment and even more so in a hot environment with high humidity.

The effects on rectal temperature, respiration rate and heat production provide an interesting comparison of the relative effects of radiation intensity and air temperature (Kibler and Brody, 1954). It appears that the cattle show as great, or greater, heat strain at 70°F (21°C) air temperature with full radiation (500 Kcal/m^2/hr) as at 80°F (26.7°C) without radiation. Continuous radiation at 500 Kcal/m^2/hr level at 21°C air temperature apparently provides a heat stress equivalent to a 5.5°C rise in air temperature at the same level of humidity.

The studies on the thermal effect of solar radiation <u>per se</u> on the cattle are sketchy. The importance of solar radiant heat load on cattle in tropical areas is emphasized by the studies on the provision of shade for cattle. The main effect of shade on the 'heat load' is to minimize heat gain by radiation.

Since radiation accentuates heat stress at high air temperature, it is expected that it will have an adverse effect on VFI, and growth. Indeed, many workers showed that by the provision of shade, growth rate was improved as compared to unshaded treatment (McDaniel and Roark, 1956; Ittner and Kelly, 1951; Kelly and Ittner, 1948; Peacock et al., 1965; Garrett et al., 1960; Boren et al., 1960; Dyer et al., 1967 and Pontif et al., 1971).

However, Garrett et al. (1966), with high energy diets, found no difference in growth performance attributable to the use of shade although respiration, rectal and skin temperature were lower in the hot part of the day in shaded cattle.

From the studies of the effect of different types of shade and details of design, it appears that air temperature will not be lower under a shade unless there is a local cooling due to the evaporation of water (Payne, 1965).

In general, by decreasing the effects of solar radiation in high temperature by using suitable shade, growth rate is likely to be improved.

As expected, water intake per unit dry matter intake has been shown to increase under radiation (Garrett et al., 1960; Macfarlane and Stevens, 1972; Brody et al., 1954). Presumably, this is because the animals use more water for evaporative cooling when subjected to radiation. There is evidence that solar radiation induces sweating directly (Murray, 1966) as well as indirectly by raising the skin temperature (Bianca, 1965; Thompson, 1973).

By judging from the effects of radiation on rectal temperature, respirate rate and pulse rate, Zebu breeds seem to be more tolerant than the temperate breeds (Kibler and Brody, 1954). Thus, shade had a very high significant effect on Friesian crosses, increasing the milk yield by 18%, but a non-significant effect on milk yield of the Borans (Macfarlane and Stevens, 1972). Brody et al. (1954) also showed that the effect of radiation depressed VFI more in Holstein than in Jersey and intake in Brahman was unaffected.

Conclusion

There are a lot of gaps in the knowledge about how growth characteristics of different types of cattle respond to various nutrition conditions in the tropics. The growth rate of an animal is the final expression of numerous factors, which all have separate effects, but interact together. The important factors include basal metabolism, VFI, digestive efficiency, heat tolerance, disease and parasite tolerance, and in arid tropics, VWI. Only VFI, digestive efficiency and VWI are reviewed in this thesis.

Insofar as tropical cattle production is concerned, the crux of the problem is the extent to which high-performing B. taurus breeds can be used in the adverse environments normally inhabited by B. indicus cattle. With respect to physiological indices of response to heat stress, the B. indicus are superior. The superiority results from their better facility to dissipate heat and possible a lower heat production which arise partially from their intrinsically lower productivity.

Preston and Willis (1975) suggested that it is easier and more certain to adapt high producing B. taurus to the conditions than to make B. indicus high producing. Crossbreeding aims at combining the high producing traits of the former and survival trait of the latter and has great potential to improve cattle production in the tropics, especially when the nutrition is improved.

CHAPTER TWO

MATERIALS AND METHODS

I MAIN EXPERIMENT

1. Experimental Design and Layout

The effects of three factors, temperature, type of diet and breed type, were investigated in a 2 x 2 x 2 factorial design, with two animals allocated to each of the eight individual treatments (Table 5). The sixteen animals were randomly allocated to each treatment using a random number table.

The measurements made on each treatment and subsequently analysed statistically were:

(a) daily intake of dry matter;

(b) digestibility of the dry matter, gross energy and nitrogen in the diet;

(c) rate of liveweight gain;

(d) voluntary water intake;

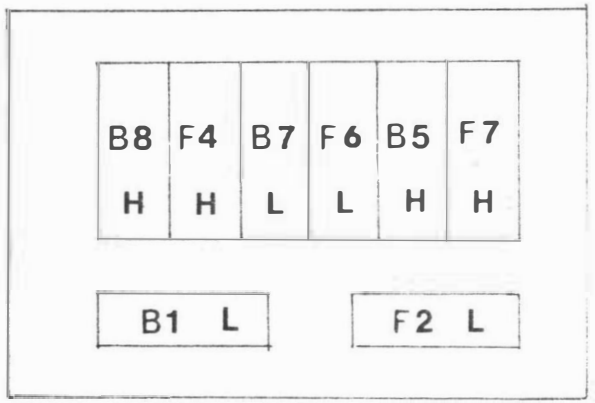
(e) respiration rate and rectal temperature.
(the latter data were the subject of another thesis)

The animals were penned individually and allocated to their pens with Brahman x Friesian and Friesian cattle in alternate positions. The animals in the hot room were re-allocated to different pens in the second half of the experiment. This method of allocation of animals was used to reduce the possible effects of variations in room temperature which might exist within the room. The positions of the animals during the experiment are shown in Diagram 2.

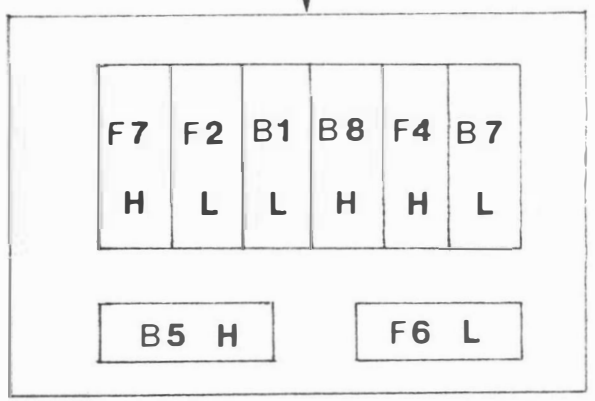
TABLE 5: THE EIGHT TREATMENTS OF THE MAIN EXPERIMENT

3 Factors:	Breeds - Brahman x Friesian (BF) and Friesian (F) calves
	Diets - High concentrate (High ration) and Low concentrate (Low ration) diets
	Temperatures - Hot environments (Hot room) and cool environments (Cool room)
8 Treatments:	1. BF; High ration; Hot room
	2. BF; High ration; Cool room
	3. BF; Low ration; Hot room
	4. BF; Low ration; Cool room
	5. F; High ration; Hot room
	6. F; High ration; Cool room
	7. F; Low ration; Hot room
	8. F; Low ration; Cool room

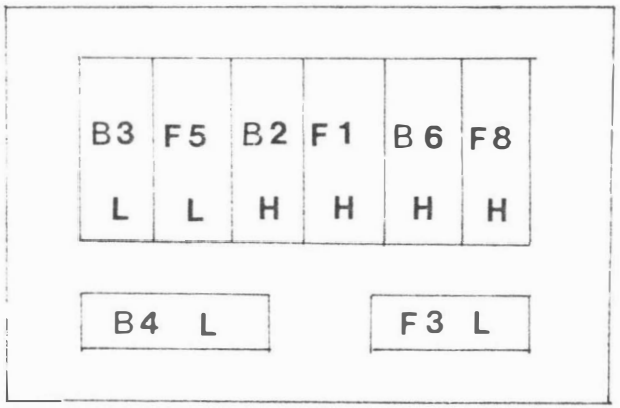
DIAGRAM 2. EXPERIMENTAL LAYOUT.



HOT ROOM - FIRST ALLOCATION



HOT ROOM - SECOND ALLOCATION



COOL ROOM

KEYS:

H = HIGH CONCENTRATE RATION

L = LOW CONCENTRATE RATION

F = FRIESIAN CATTLE

B = BRAHMAN FRIESIAN CROSSBRED

The experiment was carried out over a period of 59 days. The data of the last 45 days were used for statistical analysis, so as to allow two weeks for the animals to accustom to their diets, environments and management.

2. Materials

2.1 Animals

The animals used were 8 Friesian and 8 Brahman x Friesian (F_1) castrated male cattle. The cattle were 6 months old at the start of the experiment and their mean liveweights are shown in Fig. 3. The Brahman x Friesian and Friesian cattle will be referred to as BF and F respectively hereafter.

These cattle prior to this experiment had been subjected to calorimetric measurements and fed on a diet of hay and pellet.

2.2 Diets

The cattle were given two types of diet:

(a) High concentrate ration - Pellets *ad lib*. + 10% of the total feed dry matter as hay.

(b) Low concentrate ration - Hay *ad lib*. + 10% of the total feed dry matter as pellets.

The high and low concentrate rations will be referred to as high and low ration hereafter.

The composition of the pellets and the pasture hay are shown in Table 6.

Figure 3. ORIGINAL LIVE WEIGHTS OF EXPERIMENTAL ANIMALS.

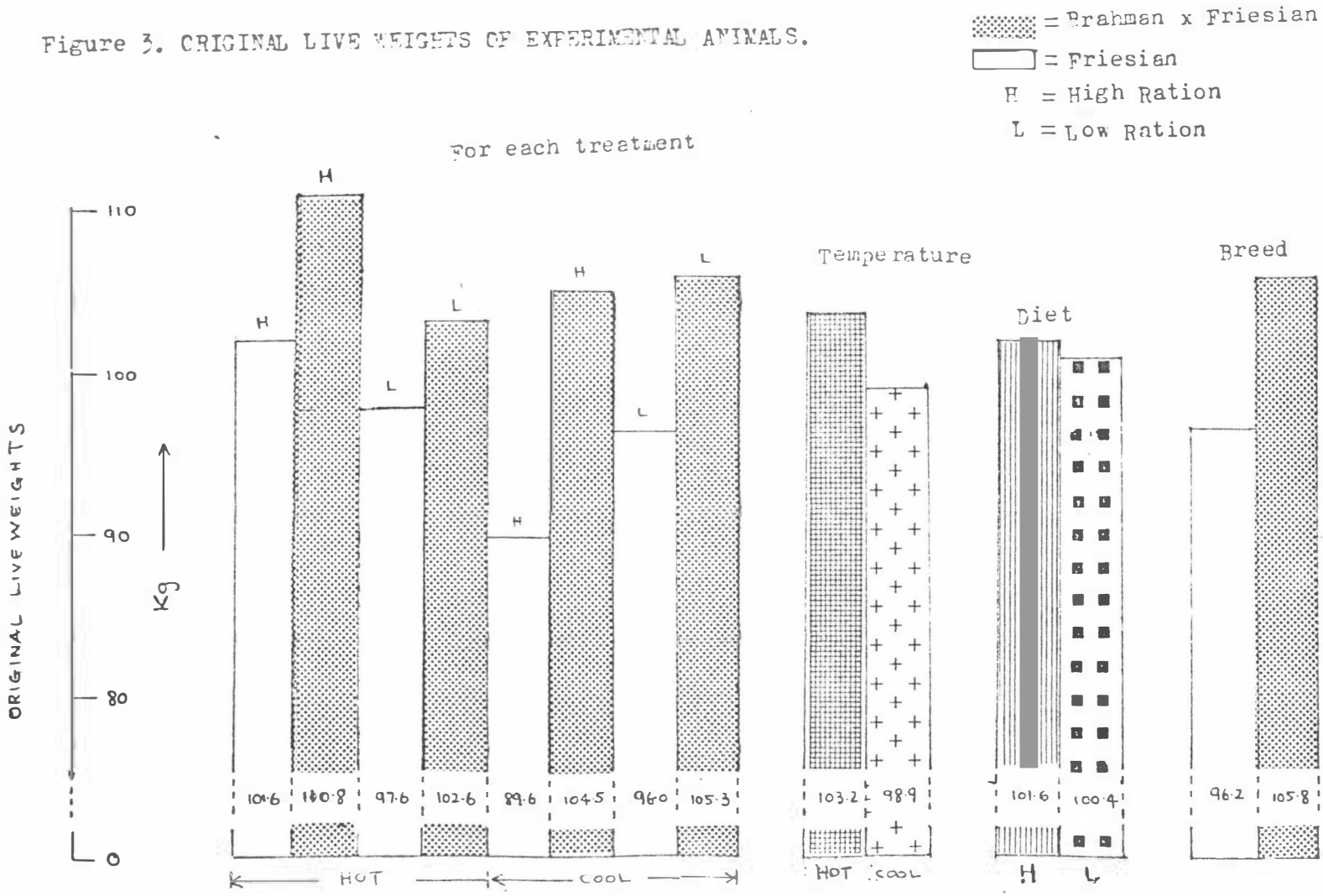


TABLE 6: The Composition of Pellets and Hay

Pellets			
	Ingredients :	maizemeal	sugar
		barleymeal	molasses
		meatmeal	salt
		pollard	lime
	Analysis :	crude protein	21.6% (measured)
		maximum fat	6.00% } stated by manufacturer
		maximum fibre	6.00% } stated by manufacturer
		maximum salt	1.50% } stated by manufacturer
		gross energy	18.04 KJ/g dry matter } measured
		moisture	10% } measured
Hay			
	Analysis :	crude protein	10.4%
		gross energy	18.04 KJ/g dry matter } measured
		moisture content	14% } measured

Vitamins (A, D_3, E), salt and other minerals (Mn, Zn, Co, Fe, Cu, I, Mg) were made available to the animals in wooden troughs.

Water was available to the animals at all times.

2.3 Environmental Conditions

The animals were kept in two temperature-controlled rooms. The average air temperature and relative humidity in one room was 16.9°C and 86% respectively; this was designated the cool room. In the other room, the average air temperature was 34.5°C, black globe temperature 35.2°C and relative humidity 45%; this was designated the hot room. The temperatures were maintained relatively constant for 24 h a day. Fluorescent light was on 24 h a day. Air movement was negligible in the rooms (0.35 km/h).

3. Methods and Management

3.1 Rectal Temperature and Respiration Rate

Rectal temperature was determined with a clinical thermometer inserted about 7 cm into the rectum for at least 3 minutes. Respiration rate was counted by recording the flank movement of the cattle for 30 seconds. The respiration rate was usually taken when the animal was lying down.

Rectal temperature and respiration rate were measured twice daily; once in the morning before feeding and once in the afternoon after feeding.

3.2 Diets

The animals were offered fresh feed twice daily *ad lib.*; with pellets and hay offered in separate metal containers. The feeding was at about 0900 h and 1500 h.

Every morning, the feed and water which had not been consumed were weighed or measured individually for each animal. One sample of refused hay and pellets for each animal, and one sample of hay and pellets offered were taken for the determination of dry matter. One sample of feed offered was also taken every day and bulked for nitrogen and energy analyses.

3.3 Environmental Conditions

Air temperature was recorded from mercury in glass thermometers. The black globe temperature was measured in a black globe 15 cm diameter by a mercury in glass thermometer. The relative humidity was obtained

from a whirling hygrometer. The meteorological measurements were made twice daily at about 0830 h and 1500 h. The averages of these two readings were calculated as the average value for the day.

The room (air) temperature and relative humidity were also recorded by hygrothermograph.

3.4 Liveweight

Fasted liveweights of the cattle were measured at the beginning and at the end of the experiment. During the experiment, the animals were also weighed weekly at about 1000 h without fasting. The gain in liveweight was calculated from the fasted liveweights.

3.5 Digestibility of Diet

Faeces of each animal was collected daily during the last 14 days of the experiment and stored at $-10^{o}C$. The collected faeces were then thawed, mixed and sampled for determinations of dry matter, nitrogen and gross energy contents.

4. Chemical Analyses

4.1 Nitrogen Analysis

The nitrogen content in the faeces and feed was measured using the macro-kjeldahl method.

4.2 Gross Energy Analysis

Gross energy contents of the feed and faeces were measured by using the adiabatic bomb calorimeter (Gallenkamp - England).

4.3 Dry Matter Determination

The samples of feed and faeces were weighed individually before and after drying in the oven at 70°C for at least 24 h.

5. Statistical Analysis

Analysis of variance and analysis of covariance were used for statistical analyses of the data as shown in model 1 and 2 respectively. The methods of analysis of variance and covariance used follow the methods described by Cochran and Cox (1957) and Ray (1960) respectively

Analysis of covariance has many uses (Cochran, 1957), but it was employed in this experiment for two purposes:-

(a) To remove the effects of original liveweight (independent variable) on feed intake (dependent variable), independently of the effects of the treatment applied. Using the regression of feed intake on original liveweight, part of the variability in the observations associated with initial liveweight differences among the objects can be removed. However, an essential condition for this use is that the adjusting or independent variable is unaffected by the treatment applied; this condition applied in the present experiment.

(b) To determine whether a concomitant variable (independent variable) might be in part the agent through which the treatments produce their effects on the principle response (dependent variable). For example, high temperature (treatment) reduced liveweight gain (dependent variable), which might be a result of depressed dry matter intake (independent variable). Covariance analysis using dry matter intake

MODEL 1

ANALYSIS OF VARIANCE OF 2 x 2 x 2 FACTORIAL DESIGN

Three Factor-experiment plan

Temperature (T)	Hot (T1)		Cool (T2)	
Breed (B) / Diet (D)	B1	B2	B1	B2
D1	X_{T1B1D1}..	..	..	..
	..	..	..	..
D2	..	..	..	..
	..	..	..	X_{T2B2D2}

Analysis of variance table

Source of variance	Sum of squares SS	Degree of freedom DF	Mean Square MS SS/DF	Mean Square ratio MSR MS/MS_E	F $v_1 = n-1$ $v_2 = 8(n-1)$
Total	SS_{Total}	N-1			
Breed (B)	SS_B	n_B-1	SS_B/n_B-1 ..	MS_B/MSE	* P<0.05
Diet (D)	SS_D	n_D-1	..	..	** P<0.01
Temperature (T)	SS_T	n_T-1	..	..	
B x D	SS_{BD}	$(n_B-1)(n_D-1)$	..	..	
B x T	SS_{BT}	$(n_B-1)(n_T-1)$	..	..	
D x T	SS_{DT}	$(n_D-1)(n_T-1)$	..	..	
B x D x T	SS_{BDT}	$(n_B-1)(n_D-1)(n_T-1)$	..	MS_{BDT}/MSE	
Error (E)	SS_E	8(n-1)	$SS_E/8(n-1)$		

$n = n_B = n_D = n_T = 2$ = number of replicates in breed, diet and temperature treatments respectively.

N = 16 = total number of observations.

T = Σx, where x is the value of each observation.

The following are the sum of squares for the sources of variations:

1. Among temperatures:

$$SS_T = \frac{\Sigma T_T^2}{n_B n_D n_T} - \frac{T^2}{N}$$

2. Among breeds:

$$SS_B = \frac{\Sigma T_B^2}{n_B n_D n_T} - \frac{T^2}{N}$$

3. Among diets:

$$SS_D = \frac{\Sigma T_D^2}{n_B n_D n_T} - \frac{T^2}{N}$$

4. Breed-diet interaction:

$$SS_{BD} = \frac{\Sigma T_{BD}^2}{n_B n_D} - \frac{T^2}{N} - SS_B - SS_D$$

5. Breed-temperature interaction:

$$SS_{BT} = \frac{\Sigma T_{BT}^2}{n_B n_T} - \frac{T^2}{N} - SS_B - SS_T$$

6. Diet-temperature interaction:

$$SS_{DT} = \frac{\Sigma T_{DT}^2}{n_D n_T} - \frac{T^2}{N} - SS_D - SS_T$$

7. Breed-diet-temperature interaction:

$$SS_{BDT} = \frac{\Sigma T_{BDT}^2}{n} - \frac{T^2}{N} - \text{all previous SS}$$

8. Total:

$$SS_{Total} = \Sigma x^2 - \frac{T^2}{N}$$

9. Residual or error:

$$SS_E = SS_{Total} - \text{all previous SS}$$

MODEL 2

ANALYSIS OF COVARIANCE OF 2 x 2 x 2 FACTORIAL DESIGN

Three factor - Experiment Plan

Temperature (T)	HOT (T1)				COOL (T2)			
Breed (b)	B1		B2		B1		B2	
Diet (D)	x	y	x	y	x	y	x	y
D1	x_{B1D1T1}	y_{B1D1T1}	..	..	..	..	..	..
	..	..	..	..	..	..	..	..
D2	..	..	..	..	..	..	..	..
	..	..	..	..	..	..	x_{B2D2T2}	y_{B2D2T2}

Analysis of Covariance Table

Component	Errors of Estimates				F $v_1 = n-1$ $v_2 = 8(n-9)$
	Sum of squares SS	Degree of freedom DF	Mean Square MS SS/DF	Mean Square ratio MSR MS/MS_E	
Breed (B)	D_B	n_B-1	D_B/n_B-1	MS_B/MS_e	* P<0.05
Diet (D)	D_D	n_D-1	..	..	** P<0.01
Temperature (T)	D_T	n_T-1	..	..	
B x D	D_{BD}	$(n_B-1)(n_D-1)$	..	..	
B x T	D_{BT}	$(n_B-1)(n_T-1)$	..	..	
D x T	D_{DT}	$(n_D-1)(n_T-1)$	..	..	
B x D x T	D_{BDT}	$(n_D-1)(n_B-1)(n_T-1)$	..	MS_{BDT}/MS_e	
Error	W_e	8n-9	$We/8n-9$		

x = adjusting or independent variable

y = dependent variable

X = Σx Y = Σy

n = $n_B = n_D = n_T = 2$ - number of replicates in breed, diet and temperature treatments respectively

N = Total number of observations

Example of computing D_B in analysis of covariance table

D_B, the discrepancy sum of squares for breed and a measure of the apparent treatment effect for breed, is computed as follows:

1. Compute the sums of squares (SS) and products for breed:

$$\text{SS in x} = \frac{\Sigma x_B^2}{n_B n_D n_T} - \frac{X^2}{N} = Bx$$

$$\text{SS in y} = \frac{\Sigma y_B^2}{n_B n_D n_T} - \frac{Y^2}{N} = By$$

$$\text{SS in xy} = \frac{\Sigma (x_B y_B)^2}{n_B n_D n_T} - \frac{XY}{N} = Bxy$$

$$= \frac{(x_1 \cdot y_1) + (x_2 \cdot y_2)}{n_B n_D n_T} - \frac{\Sigma x_B \, \Sigma y_B}{N}$$

2. Compute subtotal sums of squares and products for breed:

$$\text{Subtotal SS in x} = Bx + Wx \quad \text{where } Wx = \Sigma x_B^2 - \frac{(\Sigma x_B)^2}{n_B}$$

$$\text{Subtotal SS in y} = By + Wy \quad \text{where } Wy = \Sigma y_B^2 - \frac{(\Sigma y_B)^2}{n_B}$$

$$\text{Subtotal SS in xy} = Bxy + Wxy \quad \text{where } Wxy = \Sigma x_B y_B - \frac{\Sigma x_B \Sigma y_B}{n_B}$$

3. Compute sums of squares of error of prediction for breed (B_e):

$$B_e = (\text{Subtotal SS in y}) - \frac{(\text{Subtotal in xy})^2}{(\text{Subtotal in x})}$$

4. Compute the adjustment of the within-sample variability (W_e):

$$W_e = Wy - \frac{Wxy^2}{Wx}$$

5. Compute D_B : $D_B = B_e - W_e$

The other six discrepancy SS (D_D, D_T, D_{BD}, D_{BT}, D_{DT}, D_{BDT}) are calculated in a similar way.

(DMI) as an adjusting variable may be used to examine whether the reduced liveweight gain (LWG) was because of depressed DMI.

If there was a significant difference in LWG between high and low temperatures without the consideration of DMI, but the significant difference disappeared after adjustment with DMI (i.e. use of covariance analysis), then the difference in LWG between high and low temperatures was mainly because of the difference in DMI.

In this case, analysis of covariance is applicable even it is known that the treatments may have affected the independent variable (Bartlett, 1936).

Whether the use of covariance increases accuracy of the treatment comparisons may be determined by testing the error regression of the dependent variable on the adjusting variable for significance. If it is not significant, it will not be worthwhile to make the adjustments.

When the preliminary overall analysis of variance or covariance showed significance in the interactions, a more detailed analysis of a posteriori test (Sokol and Rohlf, 1969) was made. In other words. a posteriori test was employed to test the significance of means within the interaction. The a posteriori test used was the sum of squares simultaneous test procedure (SS-STP).

5.1 Feed Intake

Many workers have expressed feed intake in relation to the metabolic weight ($kg^{0.75}$) of the animals in their analyses, especially for the purpose of between species comparisons (Sharma and Rajora, 1977;

Kibler, 1965). However, for feeds which differ widely in digestibility, the relation between feed intake and metabolic weight ($kg^{0.75}$) may not be identical for both feeds (Moir, 1970).

The possibility of expressing feed intake as some function of liveweight had been considered when analysing the data of feed intake in this experiment. But, the two diets used were of very different digestibilities and metabolizabilities (high roughage vs low roughage diets), so, it was decided that metabolic weight would not be used to express feed intake. Instead, feed intake was analysed by covariance using the original liveweight as the adjusting variable.

The regressions of both dry matter and digestible energy intakes on original liveweight were significant (Appendix 1), thus, the use of original liveweight as an adjusting variable would be worthwhile in partially eliminating error from the data.

5.2 Digestibility

Digestibility might be affected by the level of feed intake, thus, a test of significance of regression between the two variables were carried out (Appendix 1). Since it was not significant, the unadjusted data of dry matter digestibility were subjected to analysis of variance. Similarly, gross energy and nitrogen digestibilities were analysed by analysis of variance of the unadjusted data.

5.3 Growth Rate

The cattle used were not of identical weights at the beginning of the experiment, and the growth of a calf may depend on its initial

liveweight. However, the test of significance of the regression between growth rate and original liveweight showed that the use of original liveweight as an adjusting variable would not be worthwhile (Appendix 1). Thus, growth rate was analysed using analysis of variance of the unadjusted data.

Analysis of covariance was also employed to test whether the significant difference between some treatments was due to differences in dry matter intake.

5.4 Water Intake

Water intake may be affected by liveweight (Payne, 1963; Bailey and Broster, 1958). But, in this experiment, the regression of water intake on original liveweight was not significant (Appendix 1). Thus, it was appropriate to use analysis of variance to assess the effects of different treatments on water intake without considering the liveweight of the animal.

As water intake was closely related to the level of dry matter intake (Appendix 1), analysis of covariance with dry matter intake was used to find out whether the significant difference in water intake between some treatments was caused by the differences in the level of dry matter intake.

II. RADIANT HEAT STRESS TRIAL

1. Experimental Layout

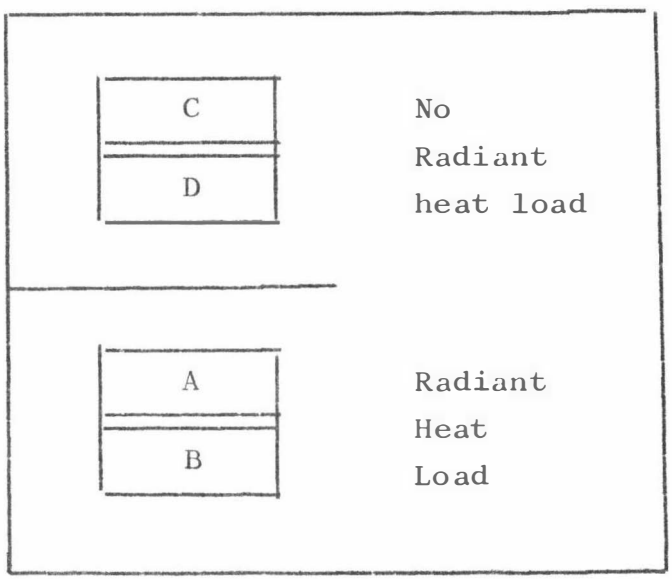
The effects of exposure to a radiant heat load in a hot environment on feed and water intakes were investigated by exposing six animals to a radiant heat load for a period of two weeks, followed or preceded by a period of two weeks in the absence of a radiant heat load. Of the six animals used for these comparisons, four were BF and two were F; three animals were studied at one time (Table 7).

TABLE 7 Time of exposure or without Exposure to Radiant Heat Load

	Animals	No Radiant Heat	Radiant Heat
Period 1	F7, BF5	27th May to 9th June (14 days)	10th June to 28th June (19 days)
	BF1	10th June to 28th June (19 days)	27th May to 9th June (14 days)
Period 2	F6, BF7	18th July to 30th July (13 days)	30th June to 17th July (18 days)
	BF8	2nd June to 17th July (16 days)	18th July to 30th July (13 days)

The experiment was carried out in a layout as shown in Diagram 3

Diagram 3. Experimental Layout



Each animal spent about 1 week in each pen designated by A, B, C and D.

Radiant Heat Room

Water and feed intakes, respiration rate and rectal temperature were measured.

2. Materials

2. 1. Animals

At the start of the experiment, it was intended to use all eight animals which had been kept in the hot room in the main Experiment for this trial. But, due to the death of one Friesian and ill-health of another, only two Friesian and 4 BF calves were used. The age and the fasted liveweights of the animals at the start of the experiment are shown in Table 8.

TABLE 8. Age and Fasted Liveweights of Calves in Radiant Heat Stress Trial

		Age (months)	Fasted Liveweights (kg)
Period 1	F7	9	151.0
	BF5		196.1
	BF1		128.7
Period 2	F6	10	101.9
	BF7		123.9
	BF8		167.8

2. 2 Diets

The ration offered was the same for all animals: 500g of pellets plus hay ad lib. The compositions of hay and pellets used were the same as those used in the Main Experiment (See Table 6).

Water was freely available to the animals at all time.

2. 3 Environmental Conditions

While three animals were kept in the radiant heat room for the study, the other three animals were either kept in the hot room ($33^{o}C$) or in calorimeter at high temperature (about $35^{o}C$) fed at a maintenance level of feeding.

The mean values for black-globe, air temperature, and relative humidity in the radiant heat room are shown in Table 9 and illustrated in Figure 4.

Figure 4. Radiant heat stress trial--- Room Environmental Conditions.

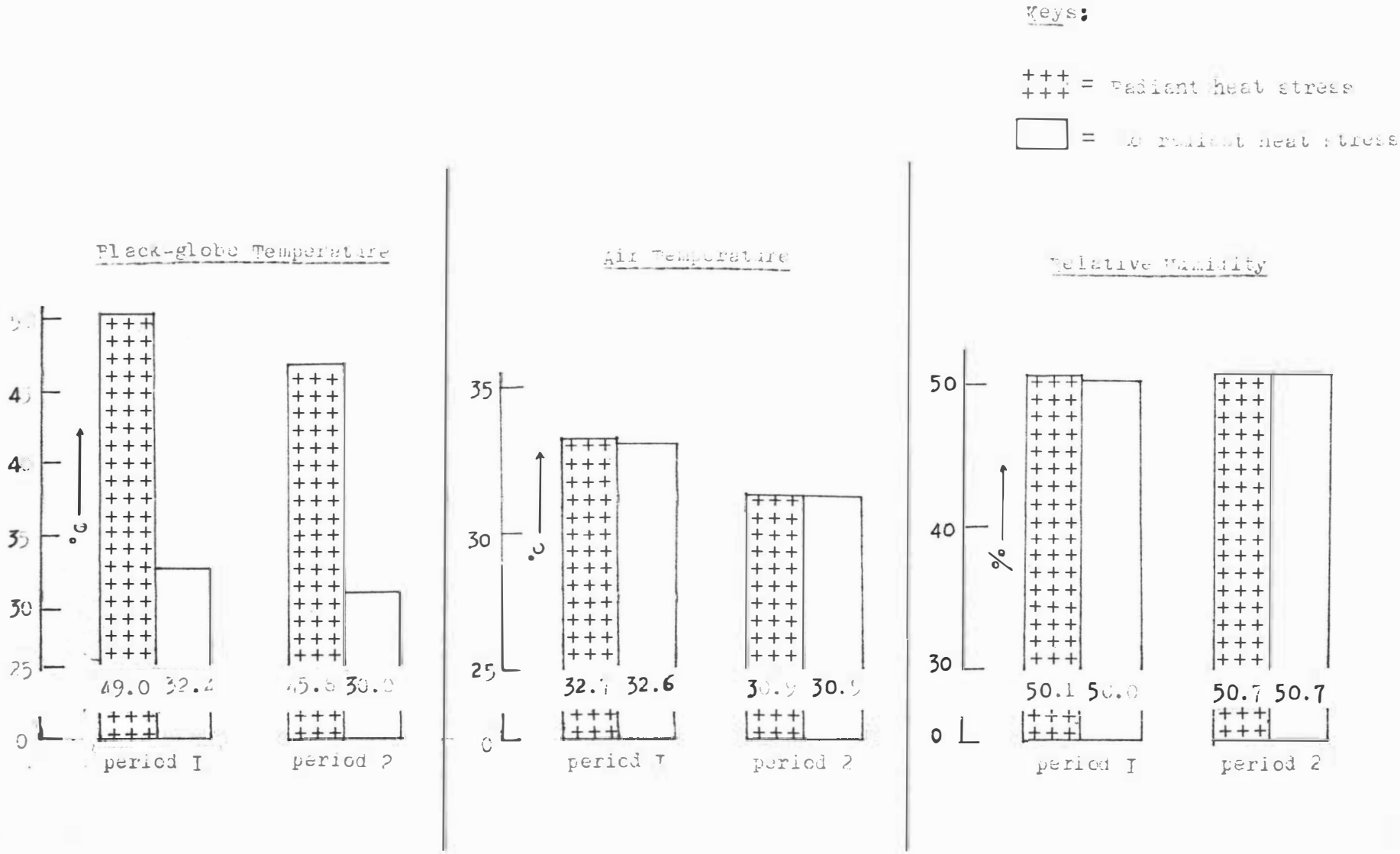


TABLE 9. ENVIRONMENTAL CONDITIONS OF RADIANT HEAT ROOM

Period	Treatment	Time (h)	Blackglobe Temperature (°C)	Air Temperature (°C)	Relative Humidity (%)
F7) Period	Radiant	0800	32.4	32.2	50.9
)	heat	1600	49.0	33.1	49.2
BF5)					
BF1) 1					
	No				
	Radiant	0800		32.2	51.0
	heat	1600		33.0	49.0
F6) Period	Radiant	0800	30.0	30.0	49.5
)	heat	1600	45.8	31.8	51.8
BF7)					
BF8) 2					
	No	0800		30.0	51.8
	Radiant	1600		31.8	49.5
	heat				

The radiant lamps were switched on at about 0800h and off at 1600h each day, thus, the animals were exposed directly to radiant heat for about 8h daily. Fluorescent light was on for 24h a day. Wind movement in the room was negligible (0.4 km/h).

3. Methods and Management

3. 1 Respiration rate and rectal temperature

Respiration rate and rectal temperature were measured twice daily; once in the morning before the radiant lamps were switched on and once in the afternoon just before the lamps were switched off.

3. 2 Diet

The animals were offered feed twice daily; once in the morning (about 0900h) and once in the afternoon (about 1630h).

Every morning, the feed and water which had not been consumed were weighed or measured individually for each animal. One sample of feed refused for each animal, and one sample of feed offered were taken for the determination of dry matter.

3. 3 Environmental Conditions

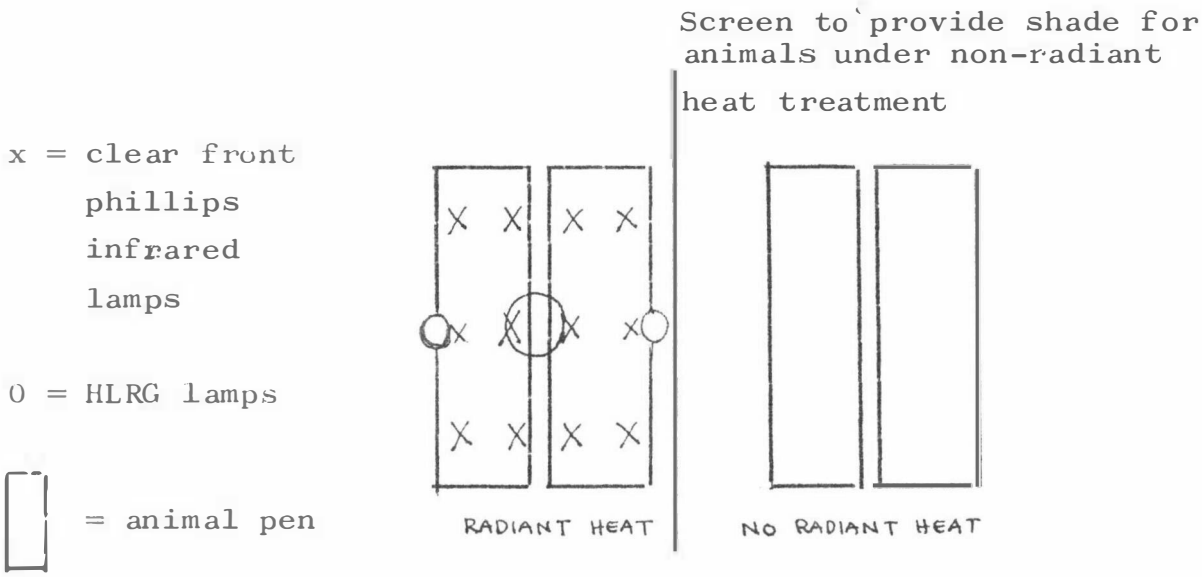
The radiant heat in the radiant heat room was provided by:

(a) Clear front Phillips infrared reflector heat lamps (375 Watts) which give 1.0 - 2.0 μm wavelengths. Ten per animals were used for 10 days, in Period 1, then decreased to six for the rest of the experiment.

(b) Three/Phillips HLRG mercury reflector lamps (400 Watts) per two animals, which give 0.3 - 1.0 μm wavelengths.

The arrangement of the radiant lamps are shown in Diagram 4.

Diagram 4 Plan of Radiant Lamps Layout



The room temperature was measured by a mercury in glass thermometer with bulb shielded by aluminium foil, black-globe temperature by black-globe thermometer and relative humidity by whirling hygrometer. These meteorological instruments were read twice daily at about 0830h and 1630h.

The fluxes of radiant heat in the room were measured using a solarimeter (Solar Radiation Instruments, Australia, SR 13), with polythene and glass hemispheres. The solarimeter with polythene hemispheres measured the longwave and shortwave radiation combined; with the glass hemisphere it measured only the shortwave radiation.

The net radiant heat exchanges between the animal and its environments were measured using a minature net radiometer (Solar Radiation Instruments, Australia, SR17) with polythene hemispheres.

4. Statistical Analysis

Since the same animal was used for radiant heat

and non-radiant heat treatment, thus having the same original liveweight, analysis of variance was employed to analyse the effects of exposure to radiant heat load on water and feed intakes. They were partioned into treatment (radiant heat or non-radiant heat), period (period 1 and 2), and period x treatment intereaction.

CHAPTER THREE

RESULTS

I. MAIN EXPERIMENT

1. Respiration Rate and Rectal Temperature

The mean values of respiration rate and rectal temperature for each calf are shown in Table 10.

The increased respiration rate and rectal temperature for both breeds in the hot room as compared with the cool room indicated that the calves were under heat stress. However, the rectal temperatures of BF calves were lower than F calves by 0.61^{o}C when exposed to the same hot room temperature. This indicated that F calves might be under a higher degree of heat stress than BF calves in the hot room.

The respiration rate and rectal temperature will be examined in detail in another thesis by Mr. P. Sauwa.

Health. All the calves during the experiment were in good health, except for one Friesian which had a minor rectal prolapse during the last week of the experiment. The development of the prolapse was apparentely due to a fault in the flooring of the pen, which resulted in pressure being put on the abdomen of the animal while it was lying down. The prolapse disappeared immediately after the flooring had been improved.

2. Feed Intake

2. 1 Variation of Hay and Pellet proportionsin the Ration

For animals on the High ration, the quantity of hay offered was about 10% of the total feed dry matter (hay + pellets), and the calves in this High ration group were expected to consume all the hay given.

TABLE 10: MEAN VALUES OF RESPIRATION RATE AND RECTAL TEMPERATURE

Temperature	HOT		COOL	
Diet \ Breed	Friesian	Brahman x Friesian	Friesian	Brahman x Friesian
	Respiration Rate	(per minute)		
High ration	(F7) 97.3 (F4) 95.9	(B5) 89.5 (B8)102.0	(F8) 59.7 (F1) 47.8	(B6) 33.6 (B2) 46.2
Low ration	(F6) 92.4 (F2)103.4	(B7) 95.5 (B1) 86.5	(F5) 41.8 (F3) 41.3	(B3) 26.4 (B4) 21.1
	Rectal temperature	(^{o}C)		
High ration	(F7) 40.86 (F4) 40.31	(B5) 39.65 (B8) 39.66	(F8) 39.12 (F1) 39.04	(B6) 39.25 (B2) 38.93
Low ration	(F6) 40.66 (F2) 40.25	(B7) 40.29 (B1) 39.87	(F5) 38.88 (F3) 39.04	(B3) 38.93 (B4) 38.76

Numbers in brackets refer to calf identification numbers

But the variable intake of this fixed allowance of hay by different calves resulted in the amount of hay which was actually eaten varying from 7.5 to 17.6% of the total feed (0.01-0.05 kg of hay per day). The amount of hay was small relative to the quantity of pellets eaten (average about 3 kg/day) on the High ration. Consequently, the variation in hay % within the High ration treatment was ignored.

For calves on the Low ration, the allowance of pellets given was about 10% of the total feed dry matter (hay + pellets); all the calves consumed all the pellets given. Consequently, the small variation of pellets/total feed percentage within the Low ration treatment was also ignored.

2. 2 Dry Matter Intake

The mean values of dry matter intake (DMI) for each calf and the analysis of covariance of the data are shown in Table 11 and Appendix 2 respectively. The mean values of DMI adjusted for original liveweight for all the treatments and the results of analysis are shown in Fig. 5a, b.

At the same adjusted original liveweight, differences in DMI between diet treatment were significant ($P < 0.05$); the temperature treatment and the breed x diet interaction were highly significant ($P < 0.01$).

Breed x diet interaction. Further analysis of the breed x diet interaction in DMI by Sum of Squares simultaneous test procedure (SS-STP) (Appendix 3) revealed that BF calves had significantly higher DMI than F calves fed on the High ration. There were no significant differences in DMI between F calves fed the High ration and BF and F calves given the Low ration (Fig. 5b).

TABLE 11: MEAN VALUES OF DRY MATTER INTAKE AND ORIGINAL LIVEWEIGHT

Temperature	HOT				COOL			
Breed	Friesian		Brahman x Friesian		Friesian		Brahman x Friesian	
Diet	Original liveweight (kg)	Dry matter intake (kg/day)	Original liveweight (kg)	Dry matter intake (kg/day)	Original liveweight (kg)	Dry Matter Intake (kg/day)	Original liveweight (kg)	Dry Matter Intake (kg/day)
High	100.3	2.81	114.9	4.60	96.3	4.36	99.9	4.78
ration	102.8	2.28	106.7	3.63	82.9	3.56	109.0	4.98
Low	85.6	2.35	102.6	2.88	97.6	4.01	101.5	3.92
ration	109.6	3.26	102.6	2.89	94.4	3.89	109.0	3.96

Figure 5a. Dry matter intake (after adjustment for variations in original live weight)

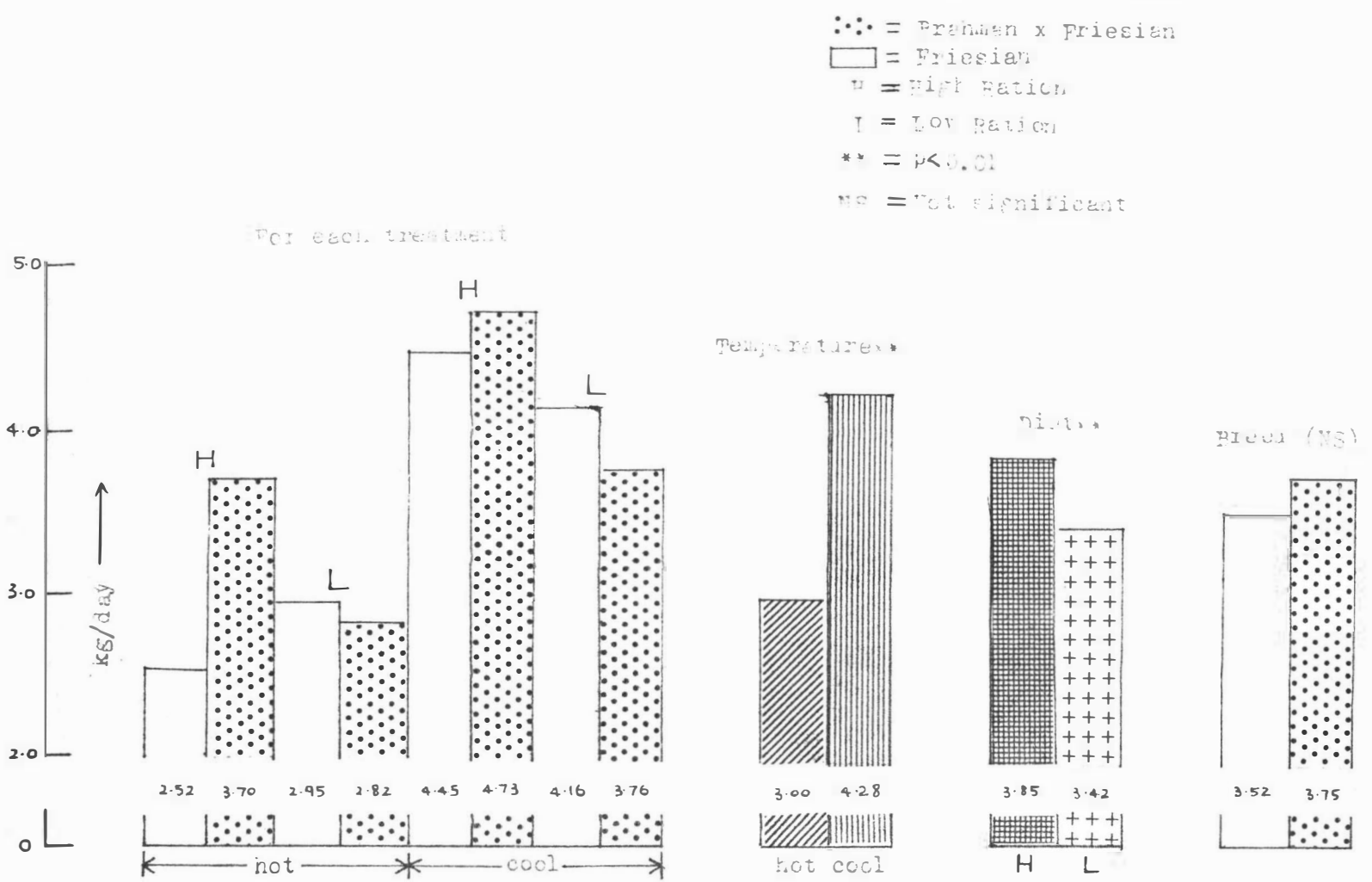
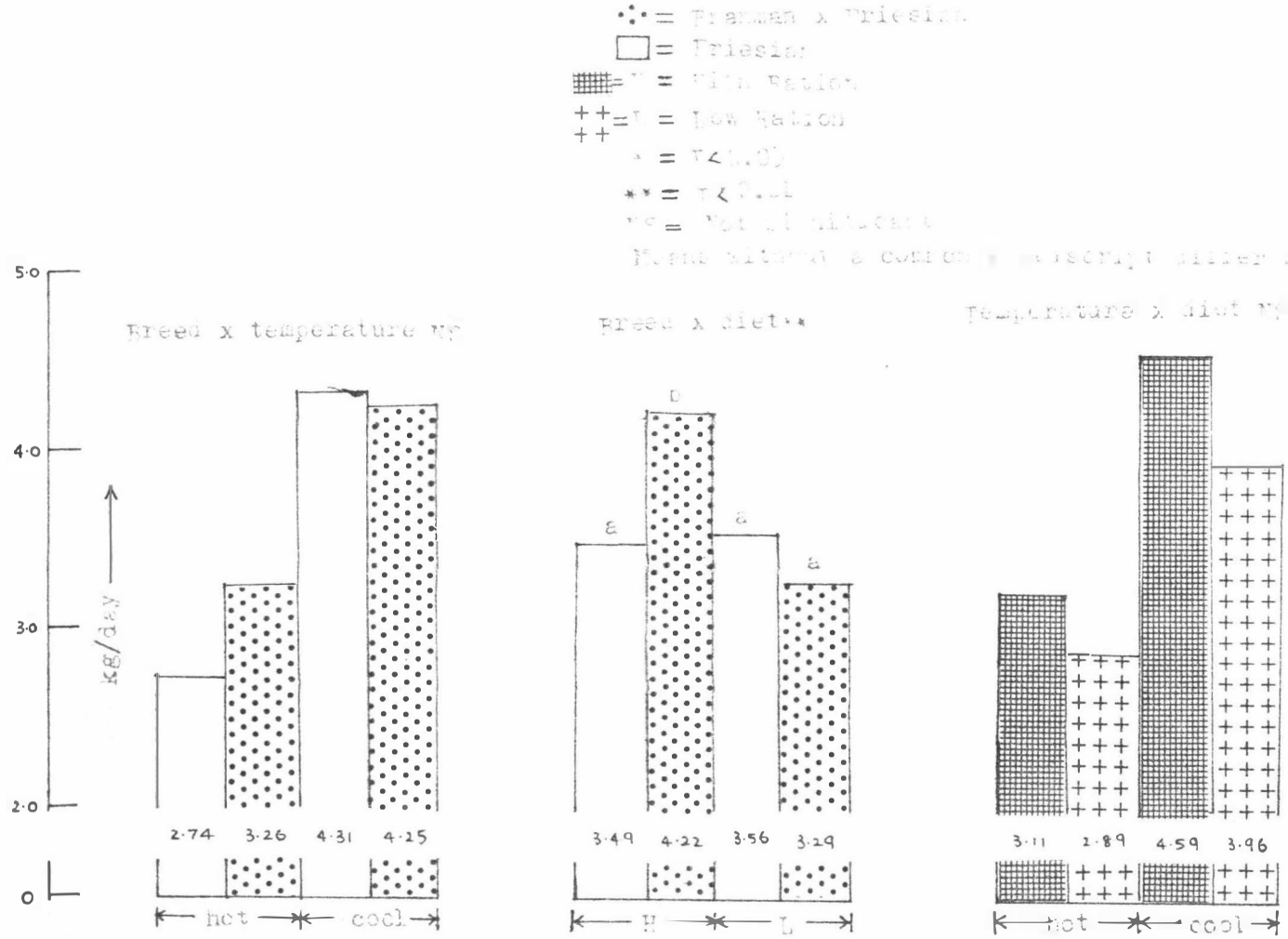


Figure 5b. Dry matter intake (after adjustment for variations in original live weight)



2.3 Digestible Energy Intake

Digestible energy intake (DEI) was calculated by multiplying the gross energy of the feed ingested by the gross energy digestiblility of the feed. The mean values of DEI obtained for each calf and the analysis of covariance of the data are shown in Table 12 and Appendix 4 respectively.

The mean values for all the treatments and the results of analysis are shown in Fig. 6a, b.

At the same adjusted original liveweight, differences in DEI between temperature and diet treatments were highly significant ($P < 0.01$).

3. Digestibility

3.1 Dry Matter Digestibility

Dry matter digestibility (DMD) is given by

$$DMD = \frac{\text{Feed DM} - \text{Faecal DM}}{\text{Feed DM}} \times 100\%$$

The values of DMD obtained for each calf and the analysis of variance of the data are shown in Table 13 and Appendix 5 respectively.

TABLE 12: MEAN VALUES OF DIGESTIBLE ENERGY INTAKE (DEI) AND ORIGINAL LIVEWEIGHT

Temperature	HOT				COOL			
Breed	Friesian		Brahman x Friesian		Friesian		Brahman x Friesian	
Diet	Original liveweight kg	DEI MJ/day	Original liveweight kg	DEI MJ/day	Original liveweight kg	DEI MJ/day	Original liveweight kg	DEI MJ/day
High ration	100.3	38.13	114.9	65.39	96.3	57.18	99.9	59.15
	102.8	30.89	106.7	45.84	82.9	42.70	109.0	67.10
Low ration	85.6	26.96	102.6	31.86	97.6	39.22	101.5	42.78
	109.6	36.04	102.6	32.73	94.4	40.27	109.0	41.36

Figure 6a. Digestible energy intake (after adjustment for variations in original live weight)

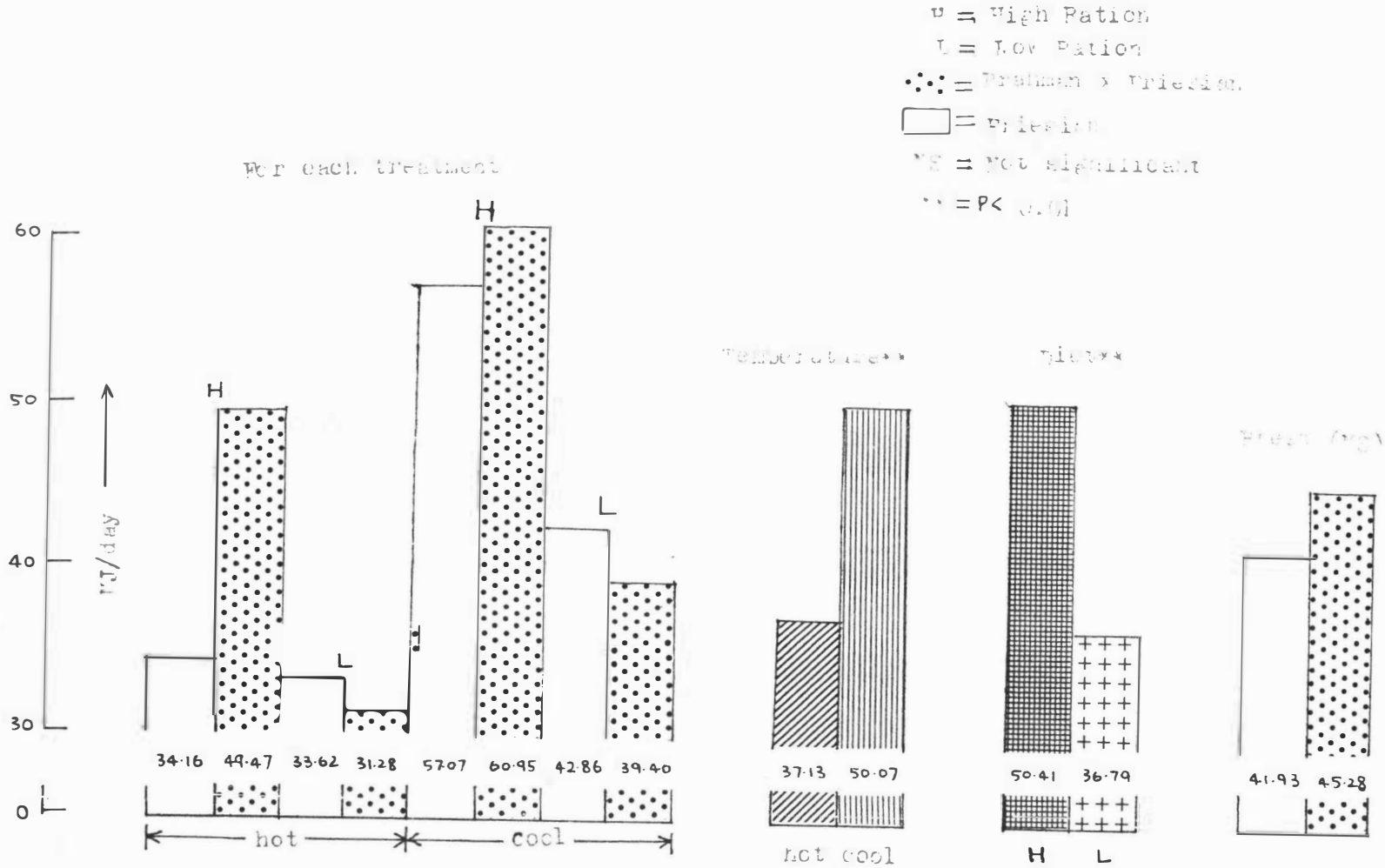


Figure 6b. Digestible energy intake (after adjustment for variations in original live weight)

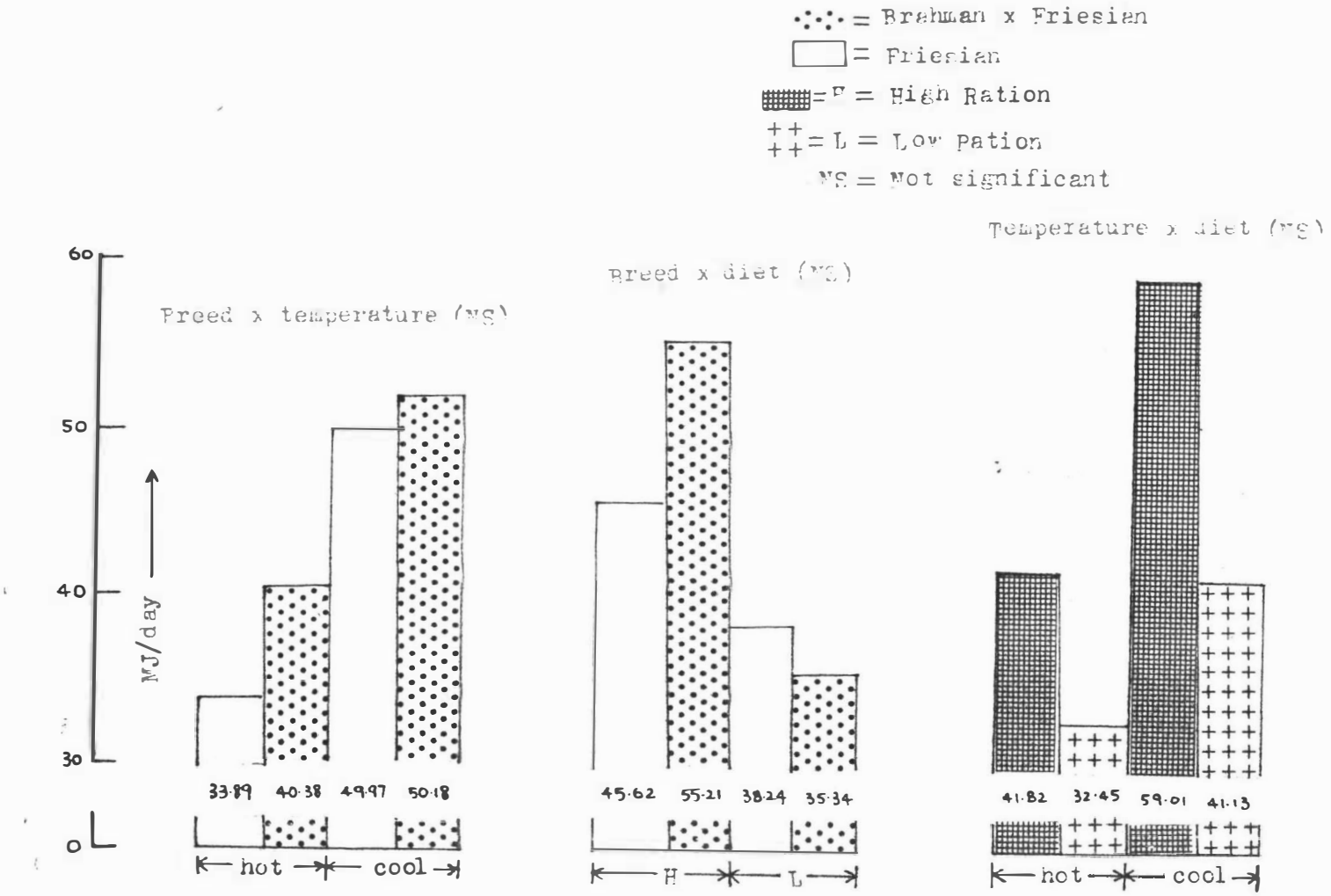


TABLE 13: DRY MATTER DIGESTIBILITY (%)

Temperature	HOT		COOL	
Diet \ Breed	Friesian	Brahman x Friesian	Friesian	Brahman x Friesian
High ration	72.0 72.1	76.4 67.5	72.0 67.9	72.7 69.2
Low ration	64.5 62.2	63.9 60.2	57.7 54.4	60.5 57.6

The mean values of DMD of each treatment, breed, diet and temperature, and the results of the analysis are illustrated in Fig. 7.

The analysis shows that differences in DMD between temperature were significant ($P < 0.05$) and diet treatments were highly significant ($P < 0.01$).

3. 2 Gross Energy Digestibility

Gross energy digestibility (GED) is given by

$$GED = \frac{\text{Feed GE- Faecal GE}}{\text{Feed GE}} \times 100\%$$

The values of GED obtained for each calf and the analysis of variance of the data are shown in Table 14 and Appendix 6 respectively. The mean values of GED for each treatment, breed, temperature and diet, and the results of the analysis are illustrated in Fig. 8.

Figure 7. DRY MATTER DIGESTIBILITY.

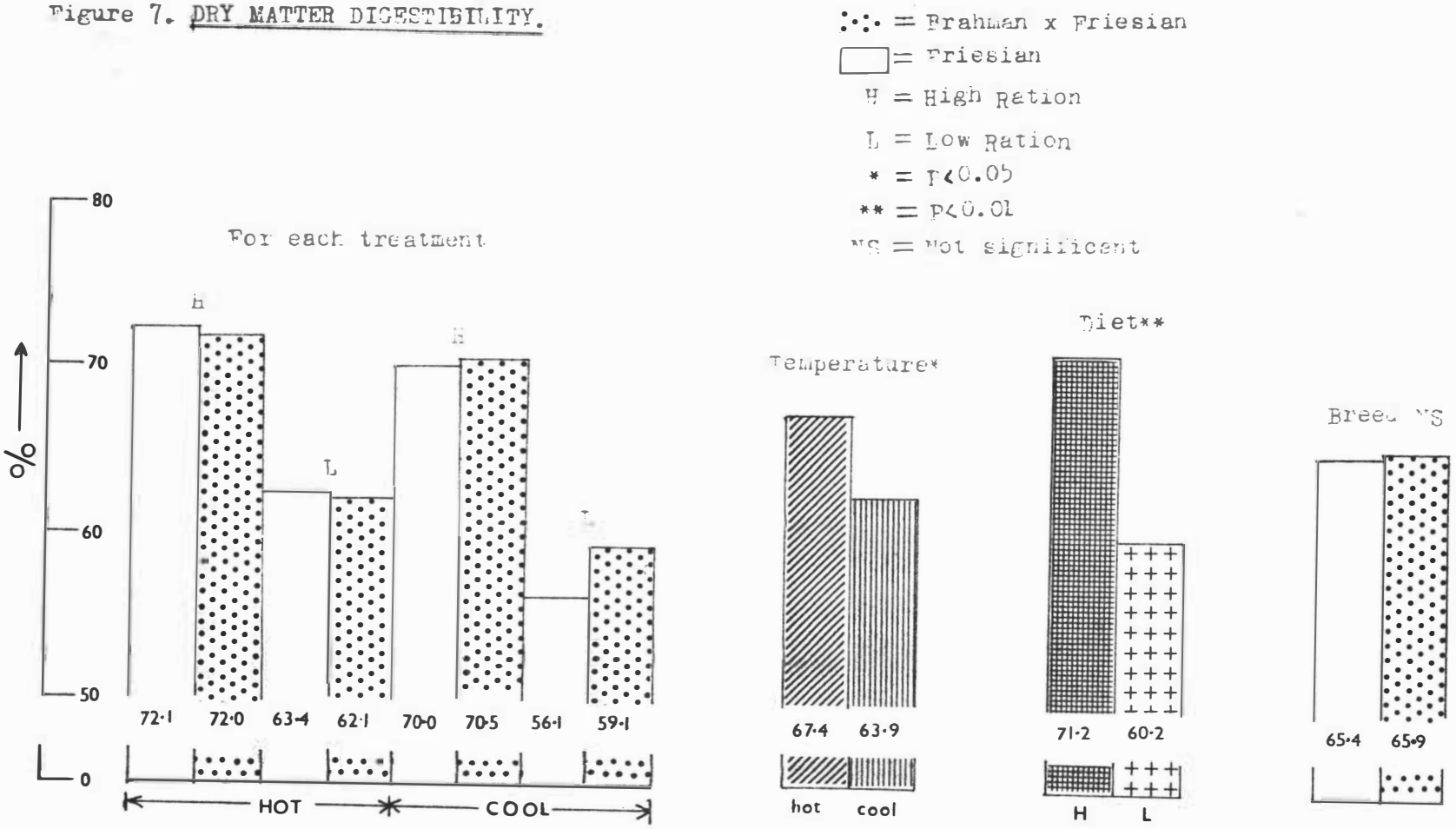
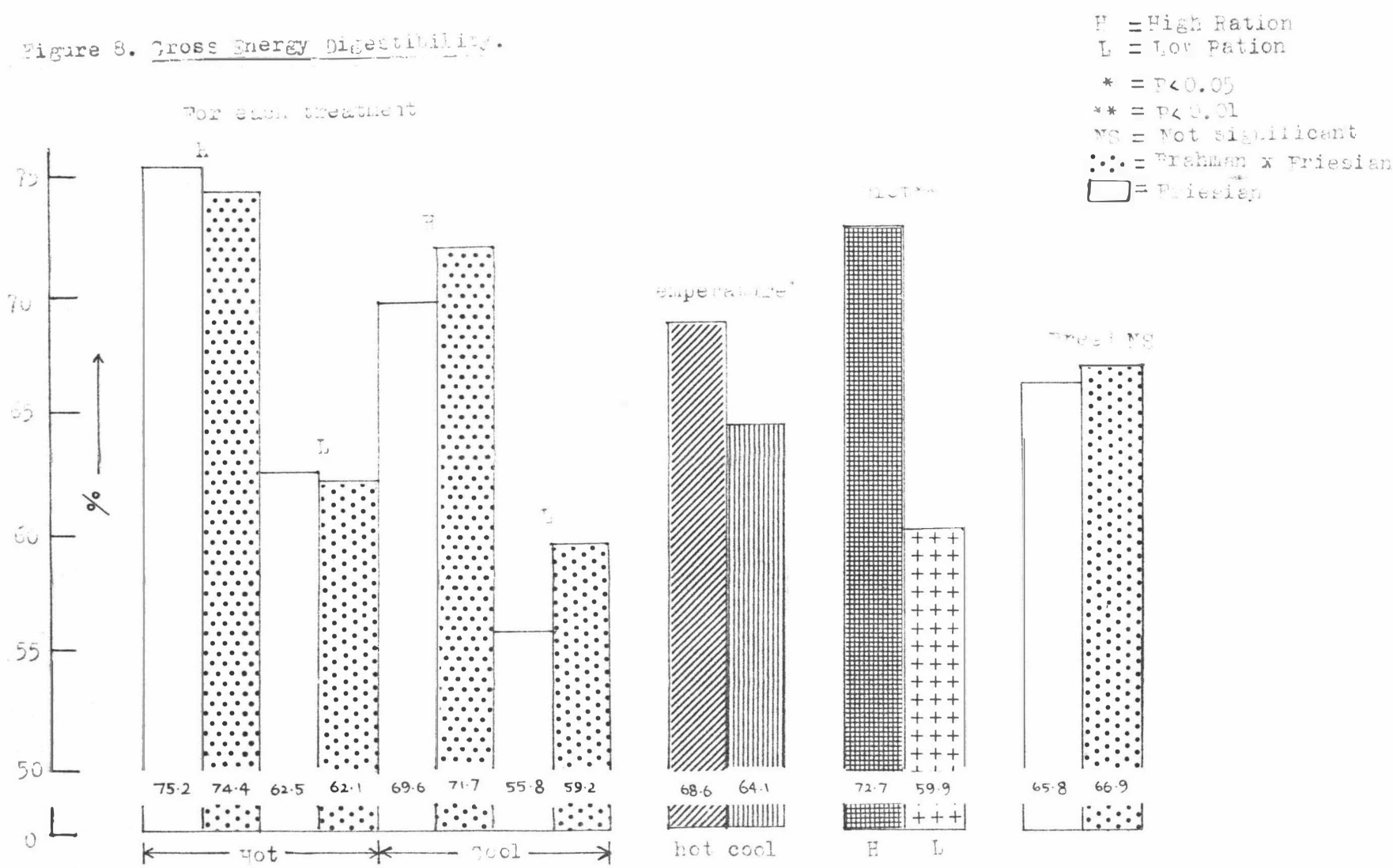


Figure 8. Gross Energy Digestibility.



The analysis shows that the difference in GED between temperature were significant ($P < 0.05$) and diet treatments were highly significant ($P < 0.01$).

TABLE 14: GROSS ENERGY DIGESTIBILITY (%)

Temperature	HOT		COOL	
Diet \ Breed	Friesian	Brahman x Friesian	Friesian	Brahman x Friesian
High	75.1	78.8	72.7	74.7
ration	75.2	70.0	66.5	68.6
Low	63.6	62.8	57.4	60.5
ration	61.3	61.3	54.2	57.9

3.3 Apparent Nitrogen Digestibility

Apparent Nitrogen digestibility (AND) is given as

$$AND = \frac{\text{Feed N - Faecal N}}{\text{Feed N}} \times 100\%$$

Although this ratio takes no account of the heterogeneous origin of faecal nitrogen, it has commonly been employed as a digestibility coefficient. The values of AND obtained for each calf and the analysis of variance of the data are shown in Table 15 and Appendix 7 respectively. The mean values of AND for each treatment, breed, temperature and diet, and the results of the analysis are illustrated in Fig. 9.

TABLE 15: APPARENT NITROGEN DIGESTIBILITY (%)

Temperature	HOT		COOL	
Diet \ Breed	Friesian	Brahman x Friesian	Friesian	Brahman x Friesian
High ration	73.1 72.9	80.4 68.0	73.7 70.4	71.8 70.8
Low ration	52.4 51.8	52.7 50.0	47.2 43.1	51.4 50.0

AND of the High ration was significantly ($P < 0.01$) higher than for the Low ration. All the other treatments were similar.

4. Liveweight Gain

The values of liveweight gain (LWG) for each calf and the analysis of variance of the data are shown in Table 16 and Appendix 8 respectively.

Figure 9. NITROGEN DIGESTIBILITY.

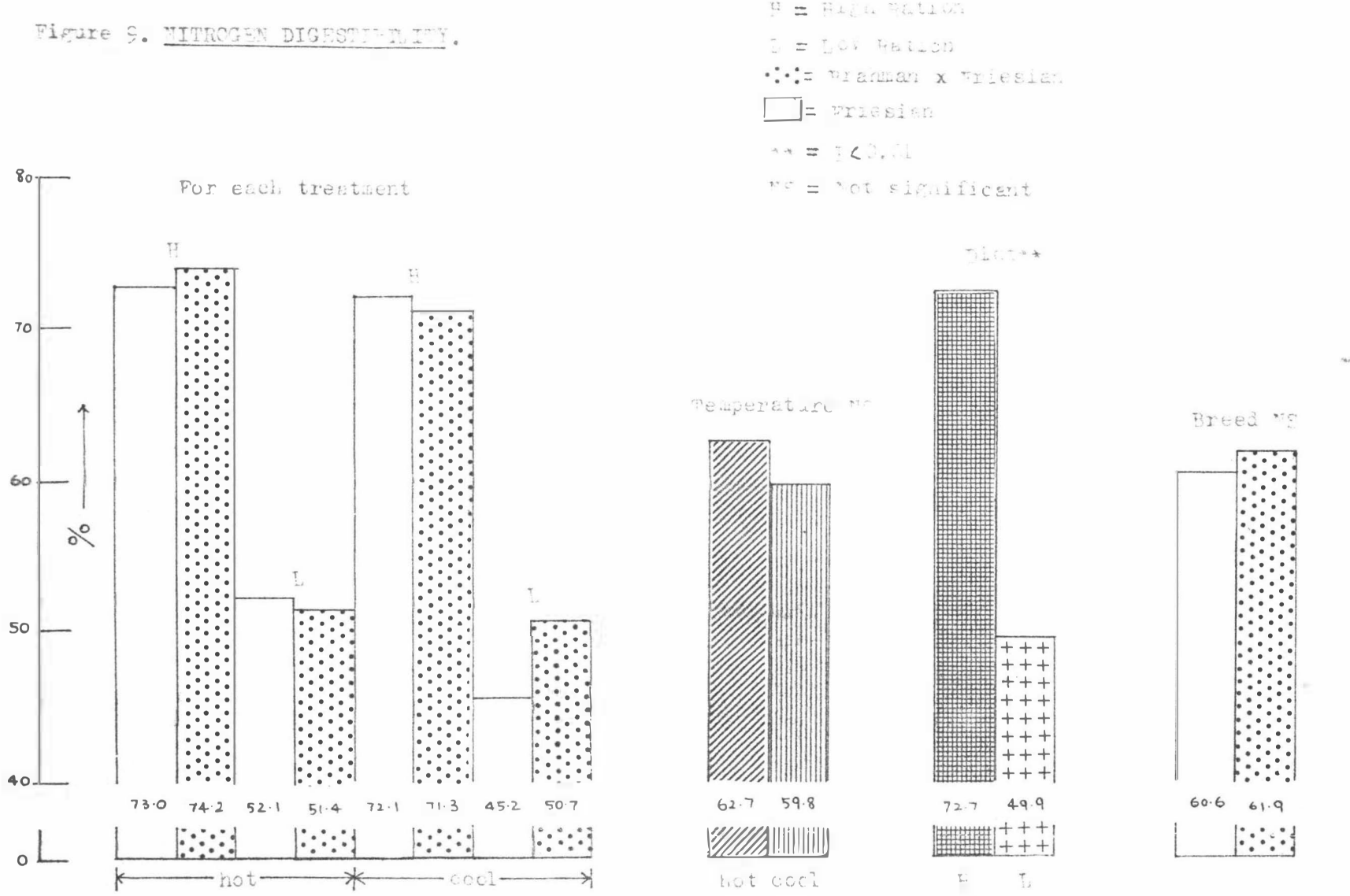


TABLE 16: LIVEWEIGHT GAIN* (kg/day)

Temperature	HOT		COOL	
Diet \ Breed	Friesian	Brahman x Friesian	Friesian	Brahman x Friesian
High ration	0.56 0.25	1.06 0.75	1.07 0.86	1.28 1.20
Low ration	0.21 0.42	0.35 0.38	0.70 0.72	0.79 0.62

* Not adjusted for original liveweight

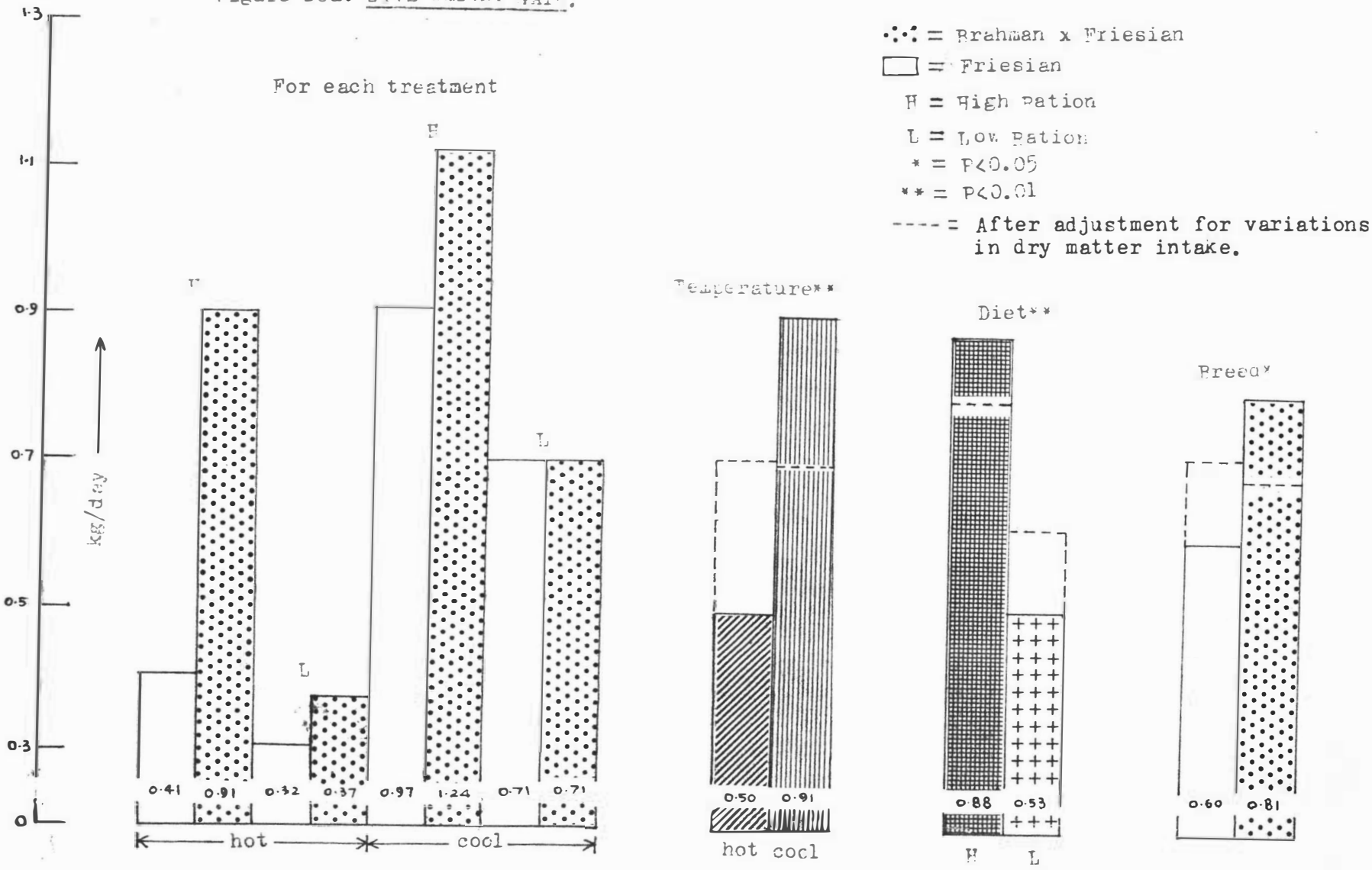
The mean values of LWG and the results of the analysis are shown in Fig. 10 a, b.

The effects of temperature and diets were highly significant ($P < 0.01$); the effects of breed and the breed x diet interaction were significant ($P < 0.05$).

Breed x diet interaction. Further analysis of the breed x diet treatment (Appendix 9) revealed that BF calves fed on the High ration grew significantly faster than F fed the same ration. There were no significant differences in LWG in F fed the High ration as compared with BF and F calves fed the Low ration. As a whole, BF fed the High ration had the highest LWG (Fig. 10b).

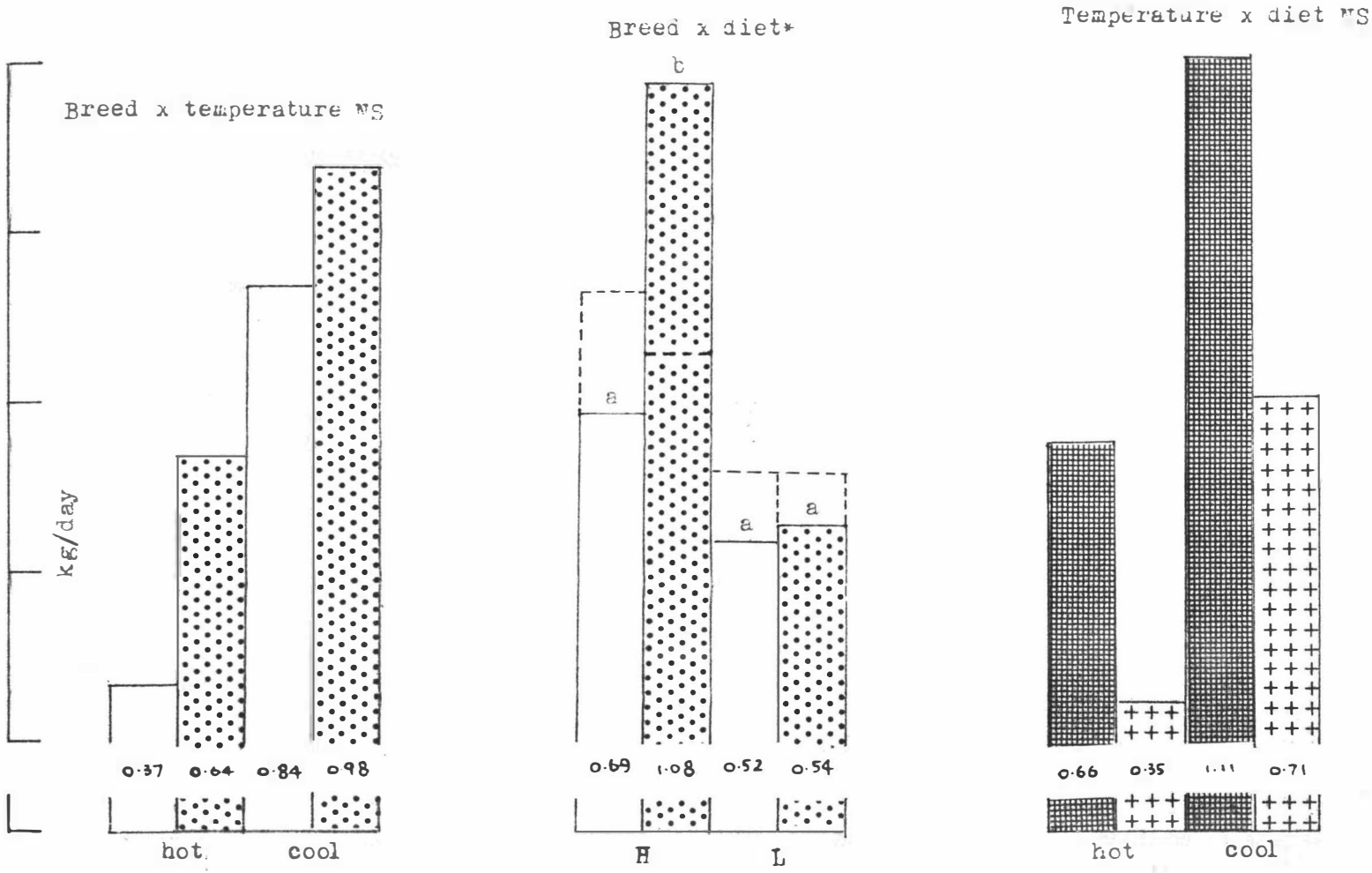
The regression between LWG and DMI was significant (Appendix 10), thus, analysis of covariance of LWG adjusted for DMI was calculated to determine whether higher LWG was due to higher DMI (Appendix 11). The analysis showed that a high proportion of the differences in LWG due to temperature, breed and the breed x diet treatments was attributable to differences in DMI (Fig. 10a, b).

Figure 10a. LIVE WEIGHT GAIN.



For abbreviations and signs see page 136.

Figure 10b. LIVE WEIGHT GAIN.



Abbreviations and signs for Fig.10b.

⁘ = Brahman x Friesian.
▭ = Friesian
▦ = H = High Ration.
++ ++ = L = Low Ration.
---- = after adjustment for variations in dry matter intake
* = $P<0.05$.
NS = Not significant.
Means without a common superscript differ significantly ($P<0.01$).

The difference in LWG between diets was not totally accounted for by difference in DMI as it was still significant after having been adjusted for DMI (Fig. 10a).

The difference in LWG betwen diets was due to their differences in DEI. After adjustment for variations in DEI, the LWG for the High and Low rations were the same (Fig. 10c).

5. Water Intake

Water intake measured was free water intake. The values of water intake and the results of analysis of the data are shown in Table 17 and Appendix 12 respectively.

TABLE 17: WATER INTAKE

Temperature	HOT		COOL	
Breed	Friesian	Brahman x Friesian	Friesian	Brahman x Friesian
Diet \ Water Intake	litres/ day	litres/ day	litres/ day	litres/ day
High ration	30.5 26.3	42.5 38.4	16.1 11.8	14.6 14.5
Low ration	25.5 32.4	28.0 17.8	17.6 14.6	14.1 16.9

The mean values of water intake and the results of analysis are shown in Fig. 11a, b.

There were highly significant differences ($P < 0.01$) in water intake due to the effects of temperature and the

Figure 10c. LIVE WEIGHT GAIN.

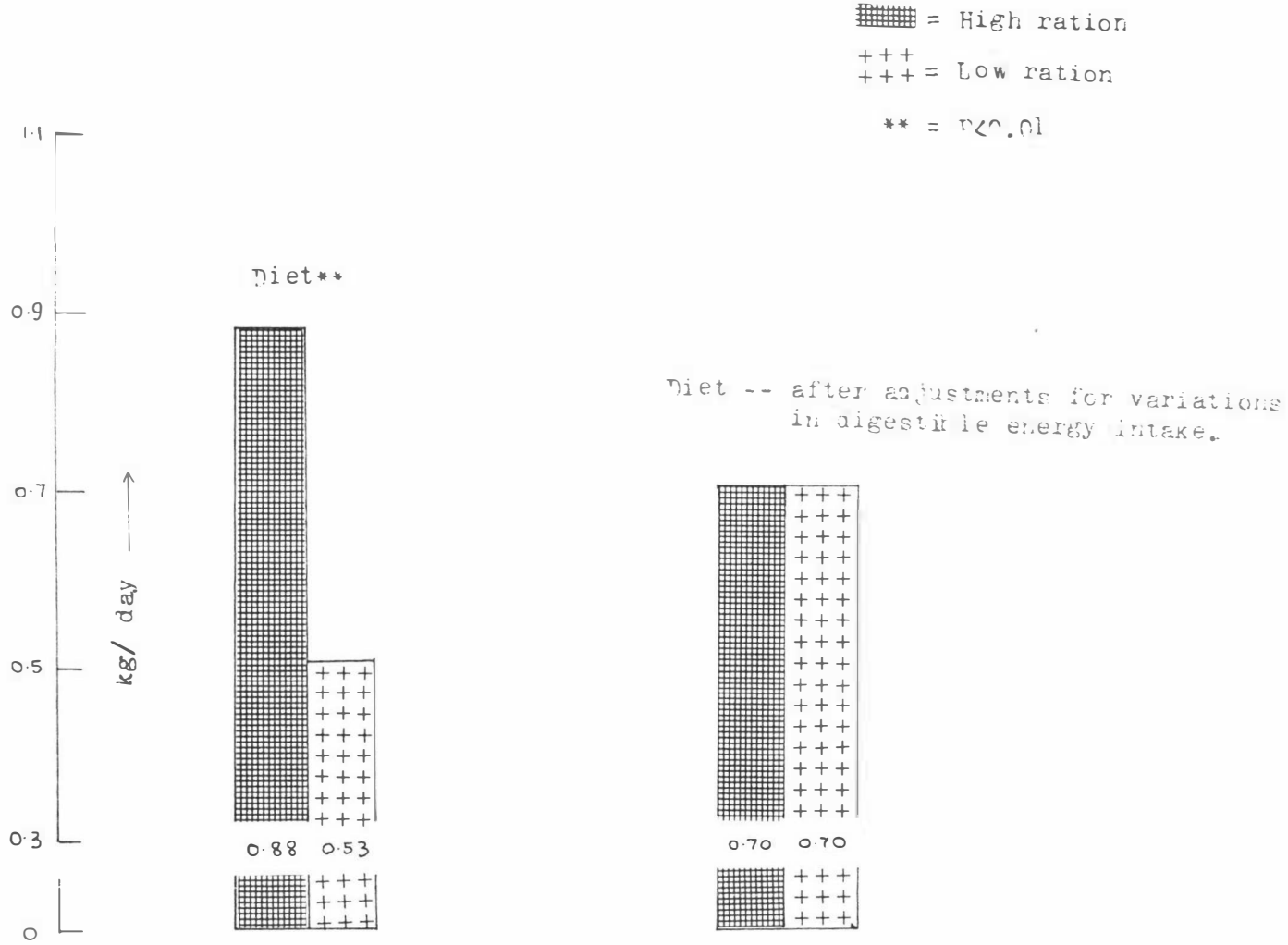


Figure 11a. WATER INTAKE.

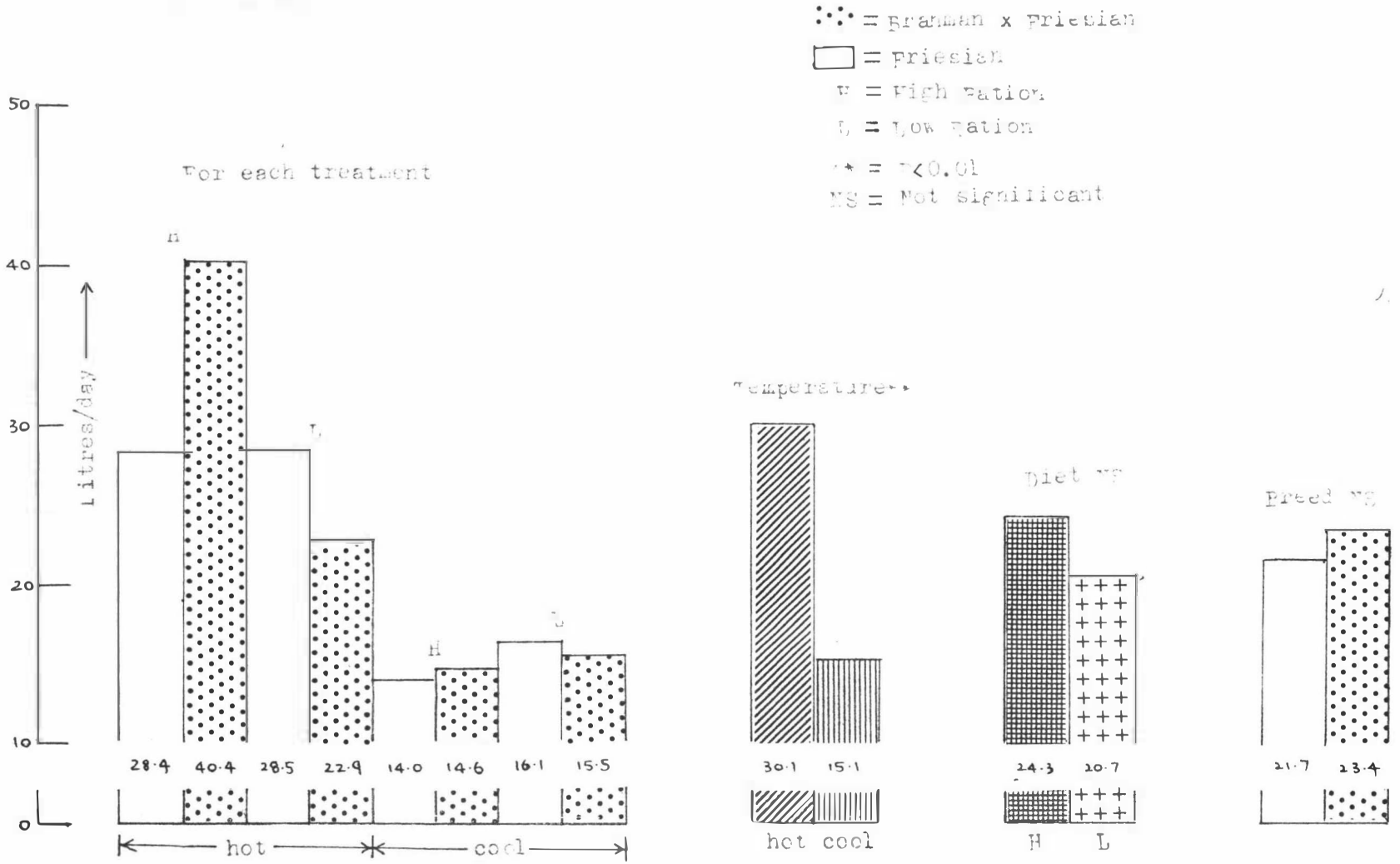
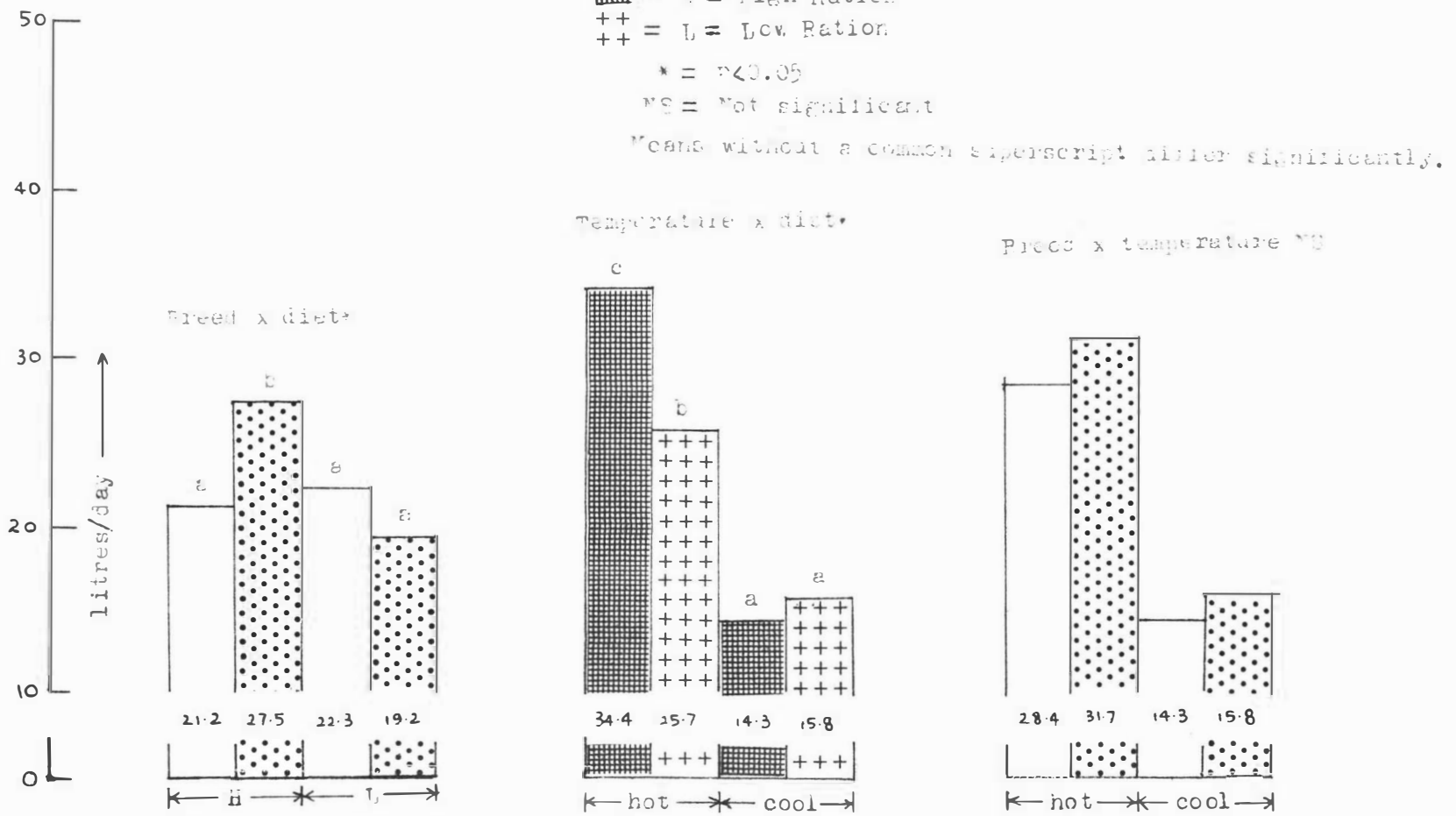


Figure 11b. WATER INTAKE.



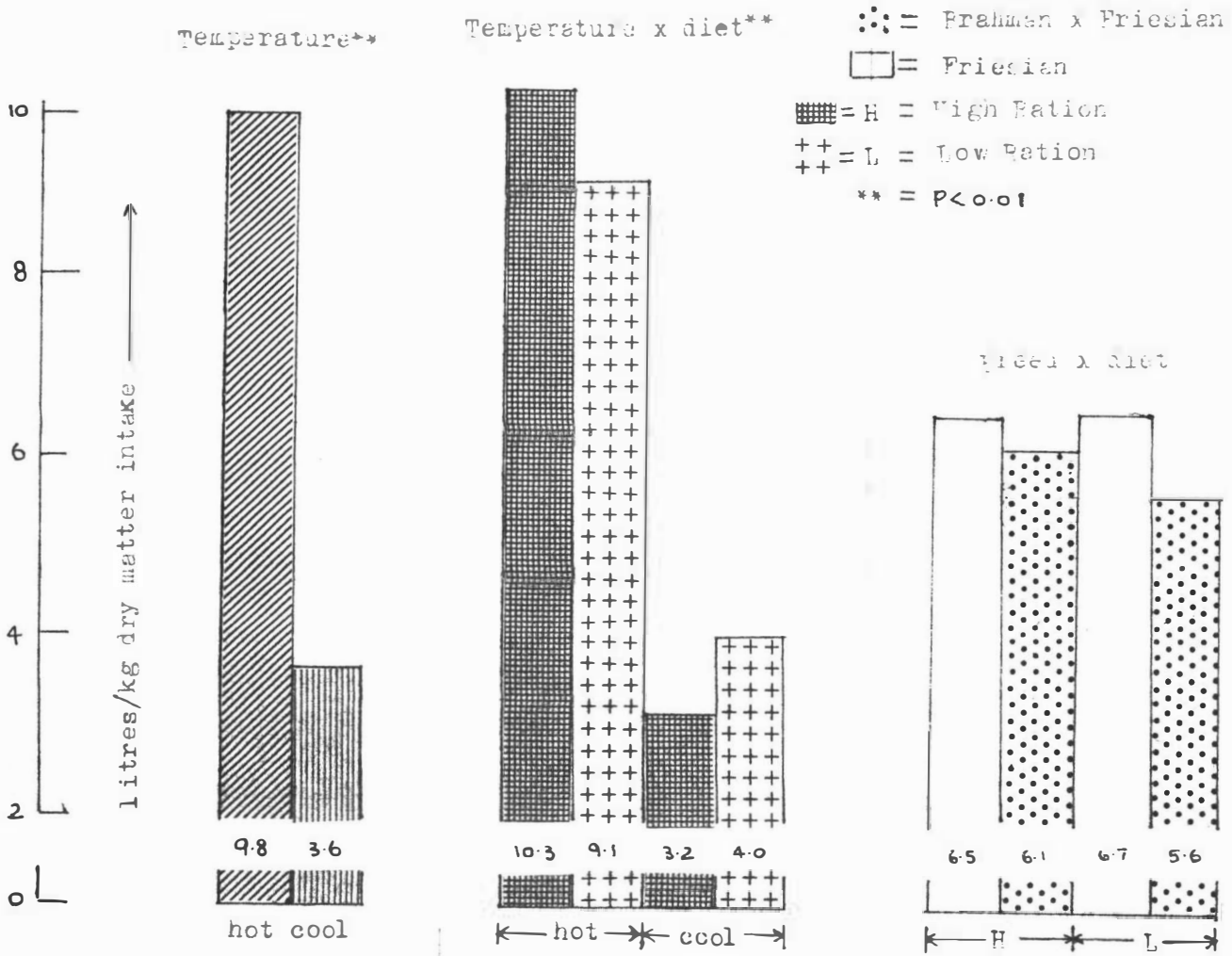
breed x diet interaction. Temperature x diet interaction was significant ($P<0.05$).

Breed x diet interaction. Further analysis of the breed x diet intereaction (Appendix 13a) revealed that BF calves fed on the High ration drank significantly more water than F calves fed on the same diet. There was no significant difference in water intake between F calves fed the High ration and BF or F calves fed the Low ration. As a whole, BF calves fed the High ration had the highest water intake in the breed x diet intereaction (Fig. 11b).

Temperature x diet interaction. Further analysis (Appendix 13b) showed that calves fed the High ration had significantly higher water intake than calves fed the Low ration in the hot room. The calves fed the Low ration in the hot room had significantly higher water intake than the calves fed both the High and the Low ration in the cool room (Fig. 11b).

The regression between water intake and DMI was significant (Appendix 1). The analysis of covariance of water intake adjusted for DMI was employed to determine whether differences in DMI could account for the significant differences in water intake discussed above. The analysis (Appendix 14) showed that the higher water intake in BF calves fed the High ration compared with other treatments was associated with / mainly to their higher DMI. But, the significant effects of temperature, and temperature x diet interaction could not be accounted for by differences in DMI alone, which was expected. The mean values of water intake per unit dry matter intake are shown in Fig. 12.

Figure 12. Water Intake per unit dry matter intake.

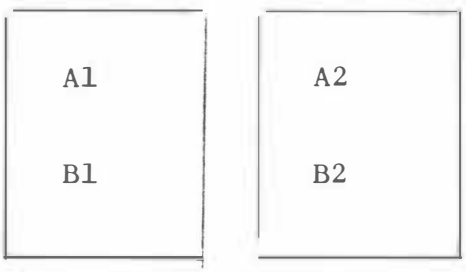


II. RADIANT HEAT STRESS TRIAL RESULTS

1. Radiant Heat Load

The radiant heat fluxes in the two pens with radiant heat load measured on a horizontal surface at two heights from the ground (0.5 and 1.6 m) are shown in Table 18. The total radiant heat fluxes (LWR + SWR) at animal's standing height was 1146 W/M^2, and consisted of mainly SWR (93%).

Table 18 Radiant Heat Fluxes of Radiant Room



Positions of measurements of radiant heat flux

Positions	+ LWR + SWR (W/M^2)		* SWR (W/M^2)		LWR (W/M^2) ‡**	
	0.5 m from floor	1.6 m from floor	0.5 m from floor	1.6 m from floor	0.5 m from floor	1.6 m from floor
A1	952	1103	878	1039	74	64
B1	957	1193	883	1106	74	87
A2	986	1142	905	1057	81	85
B2	913	1146	905	1064	8	82
Average	952	1146	893	1067	59	80

\+ Measured with Solarimeter with polythene hemisphere.

* Measured with Solarimeter with glass hemisphere.

‡** By difference.

2. Net Exchanges of Radiant Heat

The net exchanges of radiant heat between the animal and its environment are shown in Table 19.

Table 19 Net Exchange of Radiant Heat Between the Animal and Its Environment

	Readings of net radiometer (W/M^2)			Surface area $0.097 \times BW^{0.633}$ (M^2)	Net radiant exchanges per animal (W/animal)
	Upper 50% of body	Lower 50% of body	Average net radiant heat exchanges		
BF5	361	-14	174	2.74	477
F7	381	11	185	2.32	429

Negative value means net radiant heat loss from the body of the animal

3. Respiration rate and rectal temperature

The mean values of respiration rate and rectal temperature are shown in Table 20.

Table 20 Mean Values of Respiration Rate and Rectal Temperature

Period	Animals	Respiration Rate (per minute)				Rectal temperature (^{o}C)			
		Radiant Heat		Non-radiant Heat		Radiant Heat		Non-radiant Heat	
		AM	PM ++	AM	PM	AM	PM ++	AM	PM
Period 1	F7)) + BF5)	90.0	120.9	93.2	78.0	40.10	41.22	40.46	40.14
		44.9	65.9	55.2	51.7	38.72	39.41	38.58	38.48
	BF1	89.3	132.2	69.1	58.8	40.25	41.76	39.76	39.44
Period 2	F6)) * BF7)	79.8	126.9	86.2	80.5	39.79	41.07	40.02	40.07
		49.3	82.1	42.7	41.2	38.80	39.79	38.74	38.80
	BF8	71.7	109.8	59.9	58.3	39.32	40.71	39.54	39.16

+, * Pairs of animals subjected simultaneously to the exposure of radiant heat stress

++ PM measurements recorded after approximately 8h of exposure to radiant heat

These data are the subject of another thesis by Mr. P. Sauwa

4. Dry Matter Intake

The mean values of dry matter intake (DMI) obtained in the experiment are shown in Table 21 and Fig. 13.

Table 21 Dry Matter Intake (kg/day) in Radiant Heat Trial

Period	Animals	Radiant Heat		Non-Radiant Heat	
		kgDM/day	kgDM/kg LW/day	kgDM/day	kgDM/kg LW/day
1	F7))+ BF5)	3.30 4.20	0.022 0.021	3.50 3.85	0.023 0.020
	BF1	2.52	0.020	3.10	0.024
2	F6))* BF7)	2.93 3.36	0.029 0.027	3.34 3.64	0.033 0.029
	BF8	4.16	0.025	4.53	0.027

+, * Animals subjected simultaneously to the exposure of radiant heat stress

The analysis of variance of the data are shown in Appendix 15. The mean values of DMI and the results of the analysis are shown in Fig. 14. DMI was reduced by exposure to radiant heat stress, but the effect was not statistically significant. The DMI in Period 1 was lower than in Period 2, but this difference was also not significant. There was no significant Period x treatment interaction.

Figure 13. Radiant heat stress trial -- Dry matter intake.(kg DM/kg LW/day)

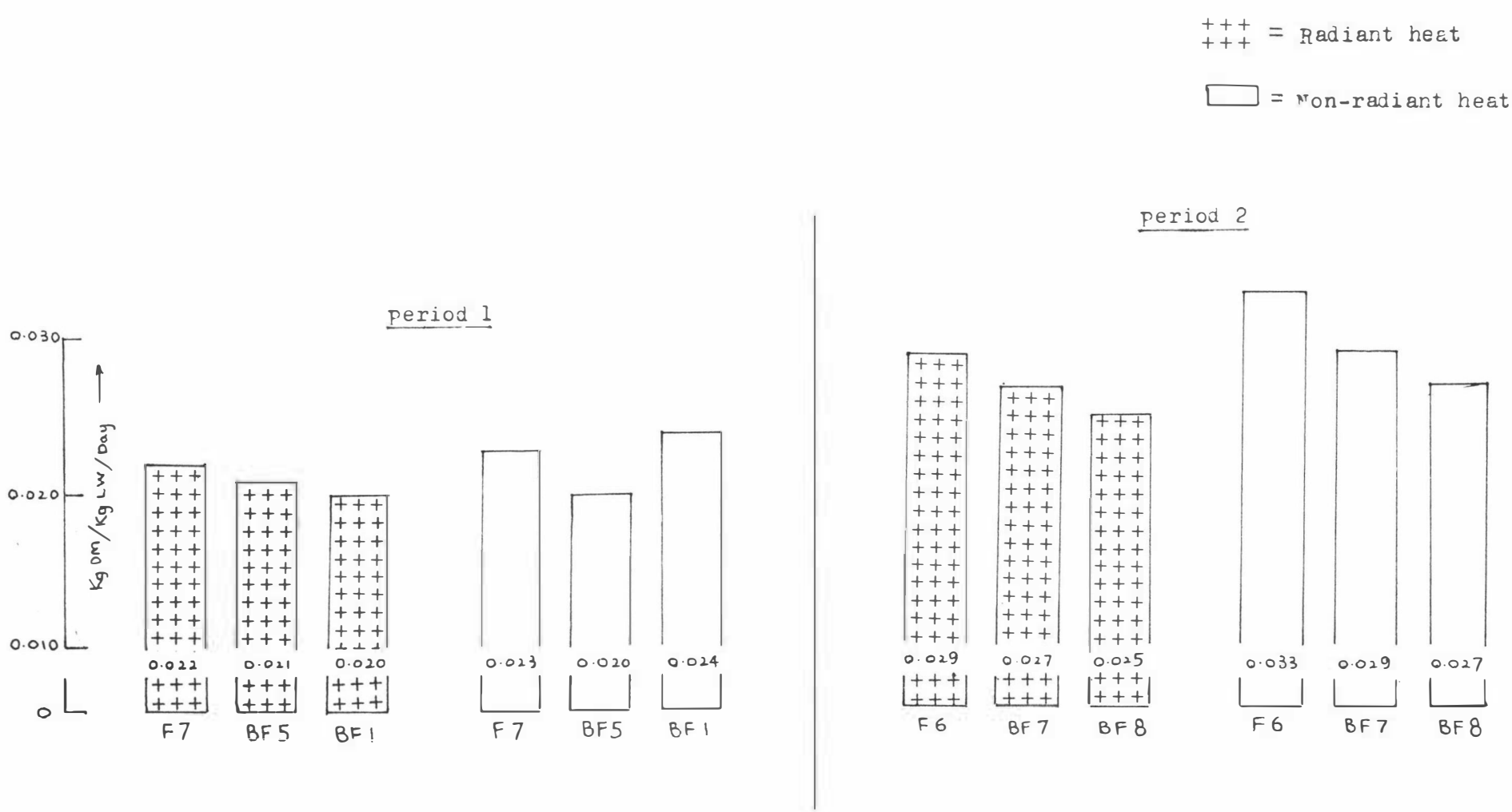
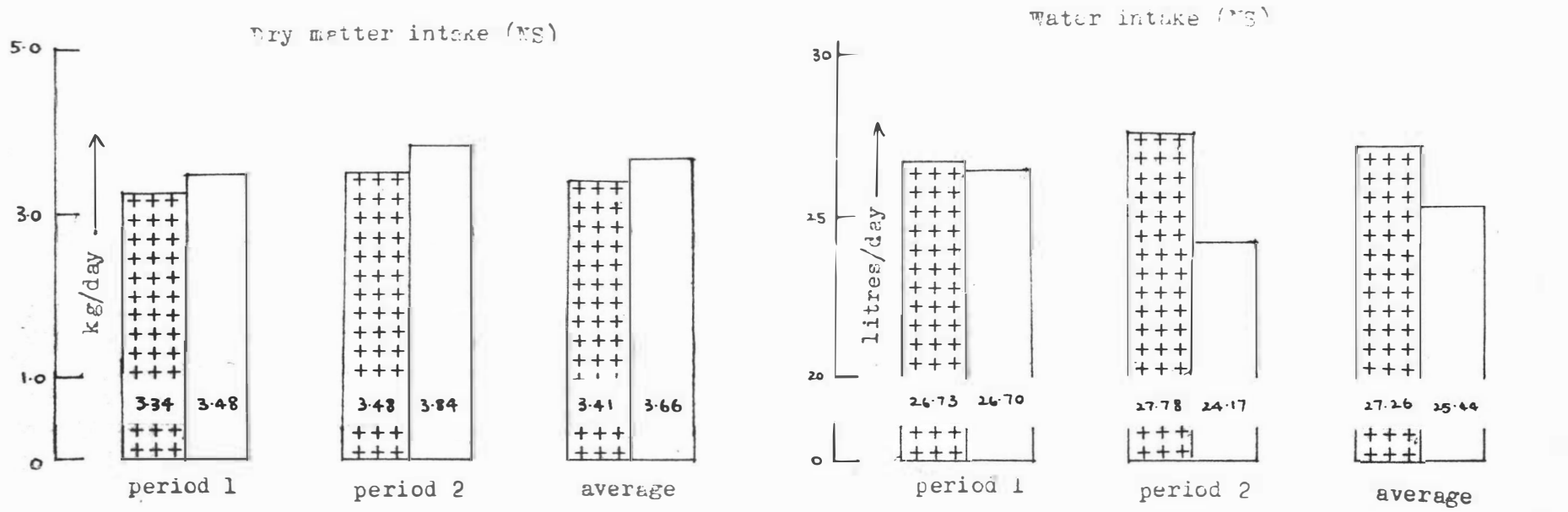


Figure 14. Radiant heat stress trial---Dry matter and water intakes.



5. Water Intake

The mean values of water intake obtained in the experiment are shown in Table 22.

Table 22 Water Intake (l/day) in Radiant Heat Trial

Period	Animals	Radiant Heat	Non-Radiant Heat
1	F7))+ BF5)	21.91 36.78	26.96 36.82
	BF1	21.50	16.32
2	F6	21.46	22.18
	BF7	24.23	22.28
	BF8	37.64	28.05

+, * Animals subjecting to the exposure of radiant heat stress at the same time

The analysis of variance of the data is shown in Appendix 16. The mean values of water intake and the results of the analysis are illustrated in Fig. 14.

Water intake was increased in three calves and decreased in the other three calves when exposed to 8h/day of radiant heat stress, but it was not statistically significant. Water intake in Period 1 was higher than Period 2, but this difference was also not significant. There was no significant Period x treatment interaction.

CHAPTER 4

DISCUSSION

I. MAIN EXPERIMENT

In the hot room, the black-globe temperature was only 0.7°C higher than the air temperature. Thus, the thermal heat stress in the hot room was mainly due to the high air temperature rather than the radiant heat. This was different from the Radiant Heat Stress trial in which both radiant heat load and high air temperature constituted the heat stress, simulating direct sunshine in a hot environment in the tropics.

1. Feed Intake.

Temperature. The consumption of dry matter and digestible energy was significantly lower in the hot room than in the cool room, as expected. Results are in agreement with those of Martz et al (1971), Kellaway and Coldtiz (1975), Colditz and Kellaway (1972), Vercoe and Frisch (1970), Vohnout and Bateman (1972). Feed consumption results in an increase in heat production in the body; in order to reduce this extra heat load in the hot environment, the animal depresses its VFI, probably as a consequence of thermostatic 'signals'.

It is difficult to compare the present results for the amount by which feed intake was reduced in the hot environment with the results of other experiment because different diets, types of animals and degrees of heat stress were used in different experiments. However, the substantial depression of VFI in the hot environment (39% and 34% decrease in DMI and DEI respectively) in the present experiment is comparable with the work shown in Table 23.

The reduction of VFI in the present experiment affected liveweight gain and water intake subsequently (Section I, 3, 4).

Table 23 COMPARISONS OF VOLUNTARY FEED INTAKE IN HOT AND COOL ENVIRONMENTS

	DIET	ANIMAL	ENVIRONMENTAL CONDITIONS
1.	High concentrate (pellets ad lib.) and Low concentrate (hay ad lib.)	Brahman x Friesian and Friesian castrated calves	Hot (34.5°C, 45% RH) Cool (16.9°C, 86% RH)
2.	Cereal-based diet (22% fibre)	Jersey bull calves	Hot (36°C for 9 h/day, 27°C at night) Cool (23°day, 17°C night)
	Cereal-based diet (16% fibre)		Hot (as above) Cool (as above)
3.	Cereal-based diet (10% cottonseed hull)	Scotch Highland and zebu heifers	Hot (31°C) Cool (18°C)
	Cereal-based diet (55% cottonseed hull)	Scotch Highland and zebu heifers	Hot (31°C) Cool (18°C)
4.	Cereal-based pelleted rations (15% and 86% oaten chaff)	Brahman, Friesian and Brahman x Friesian heifers	Hot (38°C, 40% RH) Cool (17°C, 70% RH)
5.	Cereal-based pelleted ration (15% oaten chaff)	Friesian, Brahman x Friesian heifers	Hot (38°C, 46% RH) Cool (20°C, 68% RH)

Continuation of Table 23

	DRY MATTER INTAKE (kg/day)		DIGESTIBLE ENERGY INTAKE (MJ/DAY)	SOURCE OF DATA
1.	3.00	after adjustment for variations in original LW	37.13	The Present Main Experiment
	4.28		50.07	
		per 100 kg LW	MJ/1	
2.	2.97		21.0	
	3.54		25.2	Vohnout and
	2.95		24.7	Bateman (1972)
	3.48		29.1	
3.	4.04			
	4.73			Olbrich
	4.66			et al
	6.42			(1973)
4.	2500 g/100 kg LW			Colditz and
	2740 g/100 kg LW			Kellaway (1972)
5.	2047 g/100 kg LW			Kellaway and
	2795 g/100 kg LW			Colditz (1975)

Diet.

The calves fed the High ration (low roughage diet) ate significantly more dry matter and digestible energy than those fed the Low ration (high roughage diet). This is in agreement with the findings of Vohnout and Bateman (1972), Balch and Campling (1962), Forbes, et al (1969) and Raven et al (1969). It is difficult to compare the differences in VFI between high and low roughage diets in different experiments as the composition of the diets used in different experiments vary widely.

This result contrasted with Colditz and Kellaway (1972), who found that consumption of the high roughage diet was higher than the low roughage diet although the difference was not significant; however, their high roughage diet was pelleted. Grinding and pelleting of roughages would be expected to improve intake (Campling and Freer, 1966).

The higher VFI of the High ration than the Low ration was probably related to the physical control of VFI. With roughage diets containing at least 10% crude protein (CP), control of VFI by physical factors in adult cattle appears to cease at the range of 65-67% digestibility (Campling, 1970). The hay used in the present experiment contained 10.4% CP, and the dry matter and energy digestibilities ranged from 56 to 64 and 56 to 63% respectively. Thus, the low concentration of digestible energy (high bulkiness) and low dry matter digestibility of the Low ration were the probable physical factors which prevented the calves from being able to take in sufficient hay to meet their metabolic demands. The High ration had significantly high dry matter and digestible energy digestibilities (average 71.2 and 72.7% respectively) than Low ration. Thus, when the calves were fed on the High ration, a physical intake-depressing effect would not have been expected to occur.

Besides the dry matter digestibility and digestible energy concentration of the feed, the protein content of the diet *per se* may also affect VFI. The intake of forages was reduced markedly when their CP content was less than 7% (Milford and Minson 1965), or 8.5% (Blaxter and Wilson, 1963). The hay used in the present experiment contained 10.4% CP. The protein content *per se* was, therefore, unlikely to limit VFI of hay in the Low ration. For concentrate (pellets) diets, VFI of steers decreases when the CP content gets below 11% in the diet for growth up to 250 kg liveweight (Robertson *et al*; 1970; Kay and Macdearmid, 1973). The pellets used in the present experiment contained 21.6% CP. It was unlikely that VFI would be limited by the protein content *per se* of the High ration.

Breed. BF calves ate slightly more dry matter and digestible energy than Friesian calves, but it was not significant. This was in agreement with Colditz and Kellaway (1972). In their experiment, BF also had slightly higher dry matter intake than Friesian. However, the voluntary feed intake by the different breeds was complicated by (i) the type of diets fed, and (ii) the temperature of the environment. These breed x diet and breed x temperature interactions will be discussed in detail in the next two sections.

Breed x Diet Interaction. The findings that *B. indicus* usually had a higher intake of high roughage diets than *B. taurus* cattle (e.g. Howes *et al*; 1963; Karue *et al* 1973) was not evident in this experiment. BF and F calves had very similar feed intake when fed the high roughage diet (Low ration).

BF calves ate significantly more dry matter than F calves when fed the low roughage diet (High ration); this is in agreement with the result obtained by Colditz and Kellaway (1972) although their experiment showed that the difference between breed types was small and non-significant for the roughage diet.

BF calves also had a higher DEI than F calves when fed the High ration; the difference in VFI between BF and F calves when fed the High ration in terms of digestible energy (23%) was smaller than in term of dry matter (29%), probably because of the lower GE digestibility of one BF calf, which was 5.0 digestibility units lower than F calves in the same treatment.

These results agree closely with those of Colditz and Kellaway (1972); although their paper does not give any interaction details.

The reason why BF calves ate more than F calves when fed the High ration cannot be fully explained in the present experiment, because not all the factors affecting VFI were studied (e.g. retention time of digesta, etc.). But, it was not due to differences in digestive efficiency, since they had very similar dry matter and digestible energy digestibilities.

In any case, the higher feed intake of BF calves fed the High ration was the main cause of their subsequent higher liveweight gain and water intake (Section I 3, 4).

Breed x temperature interaction. One of the major interests in the present trial was to determine whether BF calves could have higher VFI than F calves in the hot environment. Kellaway and Colditz (1975), Colditz and Kellaway (1972) found significantly higher VFI in BF than F at high temperature. In the present experiment, BF calves also ate more than F calves in the hot room, but this difference was not significant. The higher DMI and DEI of BF than F calves in the hot room was due solely to the higher intake of BF calves on the High ration; on the Low ration, calves of both breeds had very similar intakes at the hot and the cool temperatures.

Diet x temperature interaction. The calves fed the High ration had a higher DMI than those fed on the Low ration in the hot and cool rooms. Since high roughage diets (Low ration) have a greater specific dynamic action (SDA) than low roughage diets (High ration) (Kibler, 1961), the difference in VFI between the two diets was expected to be greater at higher temperature. However, the differences in DMI between the High and Low rations were similar in the hot and cool rooms in the present experiment (Fig. 5b). This is in agreement with the finding of Vohnout and Bateman, (1972).

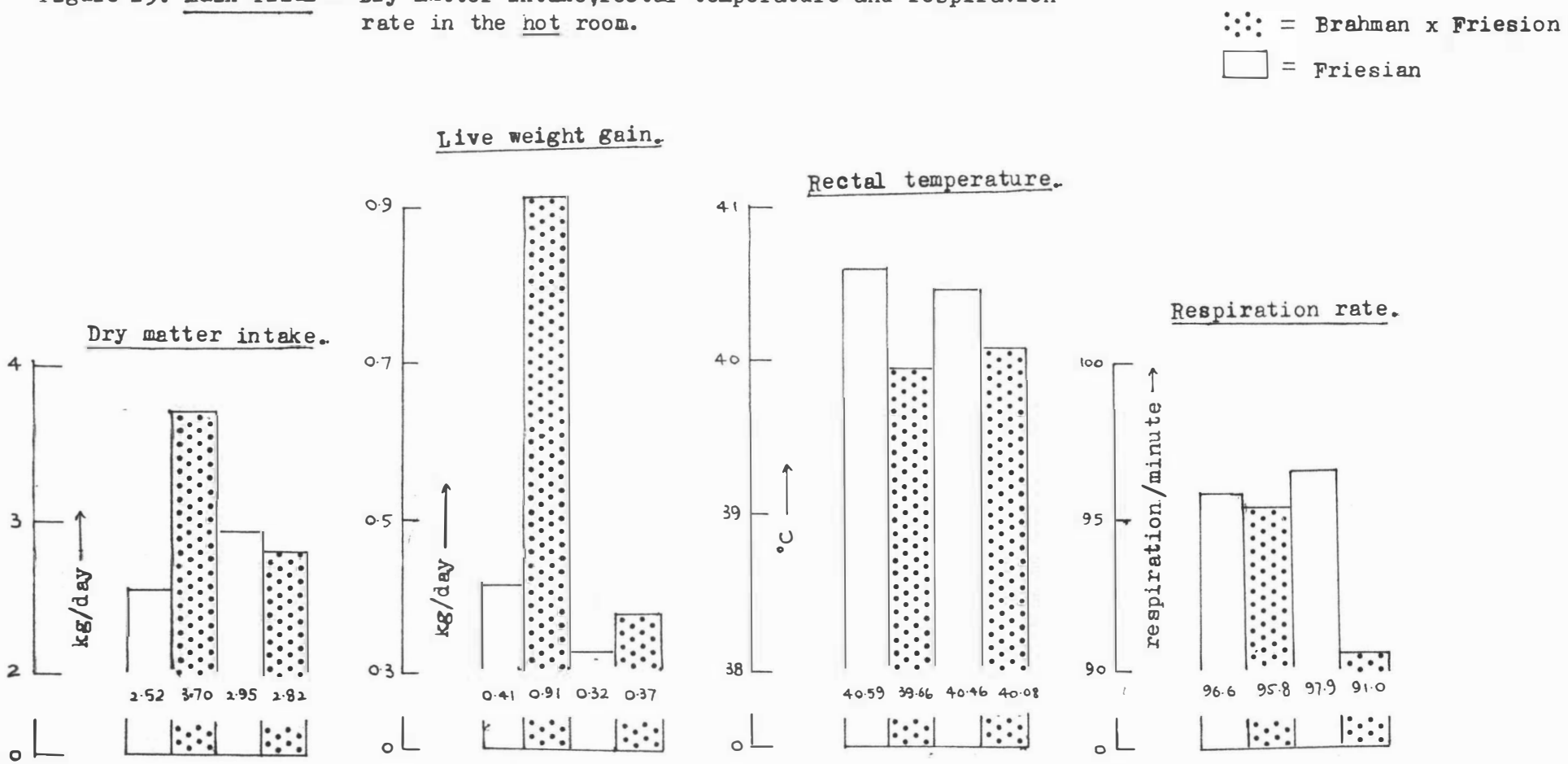
Breed x diet x temperature interactions. Although Breed x diet x temperature interactions were not significant, BF calves ate more dry matter and digestible energy than F calves when fed the High ration in the hot room. The consumptions of dry matter and digestible energy by BF and F calves were similar when fed the Low ration in the hot room.

A major point of interest is that BF calves had lower body temperature (rectal temperature) and respiration rate in the hot room than F calves, but only ate more when fed the High ration, not the Low ration (Fig. 15). This raises the question about the suitability of body temperature and respiration rate as the indicators of heat stress.

Silva (1973) found a high genetic correlation between daily gain and rectal temperature in cattle kept under range conditions in Brazil and suggested the possibility of selecting simultaneously for weight gain and heat tolerance (indicated by rectal temperature) in beef cattle production especially in tropical areas. However, Preston and Willis (1975) suggested that selection should be on growth, not on body temperature and respiration rate.

In the present experiment, the rectal temperature and respiration rate (heat stress indicators) did not serve

Figure 15. Main Trial---Dry matter intake, rectal temperature and respiration rate in the hot room.



as good indicators for dry matter intake and subsequently did not provide a good guide to LWG in the hot room. (This aspect will be investigated further by Mr. P. Sauwa).

2. DIGESTIBILITY

The digestibility in some of the treatments in the present experiment was confounded by two factors: (a) the level of feed intake, and (b) the concentrate: hay ratio. These factors should be considered when comparing the digestibility of the various treatments.

Temperature. In the hot room in the present experiment, there was a slight but significant increase in dry matter digestibility (DMD), but not apparent nitrogen digestibility (AND). This is in agreement with the findings of Vercoe and Frisch (1970), Vercoe et al (1972), Colditz and Kellaway (1972). The 3.5 digestibility units higher DMD in the hot temperature is similar to the result of Colditz and Kellaway (1972), who reported a difference of 3.4 digestibility units. However, Vercoe and Frisch (1970), Vercoe et al (1972) reported a smaller increase in DMD (1.0 and 1.7 digestibility units respectively). All these results were unadjusted by the level of DMI.

There has apparently been no other similar experiment on gross energy digestibility (GED). But, one would expect the GED to follow the trend of DMD as higher DMD would probably lead to higher digestibility of energy, hence GED.

The effect of temperature on digestibility was confounded by differences in the level of feed intake and concentrate: hay ratio between the temperatures. In the hot room, the calves consumed about 2.3 times their maintenance requirement, while those in the cool room consumed about 2.9 times their maintenance requirement (Appendix 17). Anderson et al (1959) reported variable

effects of intake of a mixed ration (concentrate and hay) on DMD by steers. They found no relationship between DMD and level of intake when intake ranged from 1.0 to 2.1 times maintenance. However, Blaxter and Wainman (1964) found that when the level of intake differed from maintenance to 2 times maintenance intake, the AND and GED were found to be lower at the higher level of feeding.

Table 24. Digestibility and Level of Feeding (From Blaxter and Wainman, 1964)

Diet % of		Energy Digestibility (%) Level of Feeding		Nitrogen Digestibility (%) Level of Feeding	
Hay	Maize	slightly less than maintenance (M)	2 x M	slightly less than M	2 x M
80	20	69.6	62.7	57.0	53.4
20	90	83.4	79.4	65.9	64.2
5	95	87.6	85.9	76.5	71.3

In view of these reported results, the difference in DMI between the hot and cool temperatures in this experiment might be large enough to cause some significant increase in digestibility in the hot room. If the level of intake had any effect, it would have increased the digestibility in the hot room and hence it could have accounted for some of the measured difference in digestibility between the temperature treatments.

However, the results of Blaxter and Wainman (1967) were obtained by comparing M with 2 x M whereas the present results were obtained with levels of feeding about 2.3 x M in the hot room and 2.9 x M in the cool room.

The digestibility of the diet decreases as the percentage of hay increased (Table 24); however, since the percentage of hay in the diets of the calves in the hot room was only very slightly higher (0.6%) than the diets of the calves in the cool room, it was unlikely that this had any bearing on the difference in digestibility between temperatures.

The way in which a hot environment may affect digestion is not fully understood. Many workers have attributed the increased digestibility at hot temperatures to a decreased DMI. But, in this experiment, whether depressed DMI have played a part in the increased digestibility is uncertain as noted before. Attebury and Johnson (1969) had speculated that a decreased rumen motility and thus a decrease in the passage of digesta might consequently increase digestion in the hot temperature; the rate of passage of digesta was not measured in this experiment.

Diet. In the present experiment, the High ration was more digestible (dry matter, energy and ntirogen) than the Low ration, which was expected. This was because in the High ration contained much less hay than the Low ration. The hay would have been associated with large amounts of structural constituents which give high faecal losses, thus, has a low digestibility. This substantial difference in digestibility contributed to the higher feed intake of the High ration and the subsequent higher liveweight gain of calves fed the High ration.

It is difficult to compare the difference in digestibility between the high and the low roughage diets with other work as the composition of the diets of different experiments was different. In the present experiment, a 76.4% difference in hay percentage caused digestibility to be 11, 13 and 22.8 units higher for dry matter, gross energy and apparent nitrogen respectively in the High ration compared with the Low ration. These results are comparable to the results of Blaxter and Wainman (1964) (Table 24).

The level of feeding was higher in calves fed the High ration than the Low ration, it might tend to decrease the digestibility in the High ration, if there was a significant effect. But, the High ration still had higher

digestibility even though their higher intake might have lowered digestibility values.

Breed. There is conflicting evidence as regarding to the differences in digestive efficiency between zebu crossbreds and British type cattle in the literature. In the present experiment, no significant differences between BF and F calves in digestibilities (dry matter, energy and nitrogen) were found. Karue et al (1972), Vercoe (1967), Kellaway and Colditz (1975) also found no significant differences in digestibility in Zebu crossbreds and British breeds.

Breed x diet interaction. Of particular interest in this trial was to find out whether Zebu crossbreds had higher digestibility than British breeds when fed the high roughage diets as reported by Ashton (1962), Vercoe (1966), Vercoe and Frisch (1972). In the present experiment, there was no significant differences in digestibilities (dry matter, energy and nitrogen) between BF and F calves when fed the Low ration. However, the digestibility of the Low ration (60%) was not really low, and might not allow the BF calves to show significant superiority in digestibility as with the low digestibility diets (about 53% digestibility) reported above. On the other hand, Colditz and Kellaway (1972) found a lower dry matter and nitrogen digestibilities for BF and Brahman heifers than pure Friesian when fed the high roughage diets (about 58% digestibility).

3. Liveweight Gain (LWG)

Temperature. In the present experiment, hot temperature was clearly shown to reduce LWG which is in agreement with Vohnout and Bateman (1972), Kamal and Johnson (1971), Shebaita and Kamal (1975). The reduction of VFI caused by heat stress was the main cause for the reduction of LWG in the hot room. Assuming the same metabolizability of digested feed for calves in the hot and cool rooms, the VFI were approximately 2.3 times and 2.9 times their maintenance requirements respectively

(Appendix 17). As a result, the higher VFI above maintenance requirements by calves in the cool room gave them more energy available for LWG.

Though reduced DMI was shown statistically to account for the reduced LWG in the hot room in the present experiment, other reports provide the evidence that energy and nitrogen retentions in cattle were reduced at high temperatures (Blaxter and Wainman, 1961). The heat production of both F and BF calves in the present experiment was increased, but only by a small amount, during exposure to a hot environment which caused increases in body temperature of 1^{o} to 1.5^{o}C. (Dr. Holmes, unpublished data). This increased heat production resulted in the loss of some energy which would otherwise be used for LWG. This might have partially contributed to the lower LWG in the hot room when compared to the cool room.

Reduction of nitrogen retention in high temperature has been reported, as indicated by the increased excretion of nitrogen and/or creatinine in the urine (Vercoe, 1969; Colditz and Kellaway, 1972), which might reduce LWG. Nitrogen metabolism was not measured in the present experiment.

Diet. The calves fed the Low ration had significantly lower LWG than those fed the High ration in the present experiment which substantiated the results of Broadbent et al (1976), Forbes et al (1969). The LWG in calves fed the High ration (0.88 kg/day) and the Low ration (0.53 kg/day) in the present experiment were similar to the LWG of the cattle grazing improved pastures during early growing period (0.9-1.2 kg. day) and late mature period (0.6 kg/day) reported by Stobbs (1976).

Higher DMI in calves fed the High ration than those fed the Low ration could not totally account for the subsequent higher LWG of the former calves. At the

same DMI, the calves fed the High ration still grew significantly faster than those fed the Low ration (Fig. 10a), indicated the former had a better efficiency of dry matter utilization (unit DMI to produce unit LWG). A better efficiency of dry matter utilization could be due to a higher metabolizable energy (ME) or better utilization of ME or both (Appendix 19). In the present experiment, a higher digestibility of the High ration than the Low ration probably resulted in a higher ME from the former than the latter.

Another important constituent in the diet which might affect LWG was protein content. The common method of describing protein requirements make use of the term "% protein in the dry matter of the diet" (Preston and Willis, 1975). In steers, weighing 80-420 kg LW and gaining at 1.0-1.3 kg/day, 14% protein in dietary dry matter is adequate at all stages of growth (Robertson et al 1970). The diet containing 11% CP in dry matter reduced growth rates in weight range of 80-270 kg LW in steers (Robertson et al 1970, Kay et al 1968). In view of these findings, the High ration would permit realization of the potential growth of the calves as the pellets contained 21.6% CP in dry matter. For the calves fed the Low ration, low protein content (10.4% CP dry matter) per se would probably be one of the factors which contribute to the lower LWG than those fed the High ration. Moreover, the High ration also had significantly higher AND than the low ration which would result in a higher nitrogen availability per unit DMI.

Breed and Breed x diet interaction. Although the statistical analysis showed that the LWG was significantly higher for BF than F calves, it was solely due to the large superiority in LWG of BF calves fed the High ration over F calves fed on both diets and the BF calves fed the Low ration. The BF and F calves fed the Low ration had very similar LWG. Thus, in the present

experiment, it was not evident that BF calves grew faster than F calves, but it was clearly noted that BF calves grew significantly faster than F calves when fed the High ration.

There are a number of reports which have shown that Brahman-cross cattle up to the age of 2-2½ years have a rate of growth superior to that of British breed cattle under tropical or sub-tropical conditions (Alexander and Chester, 1956; Mawson, 1956; Arbuckle, 1958; Dowling, 1960; Kennedy and Chirchir, 1971), but not exclusively for high quality diets. Some superiority of crossbreds over purebred cattle may be expected in view of possible heterotic effects. Dammon et al (1961) found that the greatest heterosis in beef producing traits occured in crosses involving parent breeds of widely divergent sources such as between Brahman and Friesian cattle in the present experiment. However, when 'indigenous' zebus (e.g. Boran) were used for crossing with British breeds, British breeds had higher VFI and consequently higher LWG than the 'indigenous' zebu crossbreds (Ledger et al; 1970; Rogerson et al; 1968).

The higher LWG of BF than F calves fed the High ration was mainly due to a greater DMI of BF than F calves. Assuming both BF and F calves fed the High ration had the same metabolizability of digested feed, BF calves ate approximately 3.4 times their maintenance requirement and F calves approximately 2.7 times their maintenance requirement (Appendix 18). The higher VFI above maintenance by BF calves resulted in a proportionally greater amount of energy available to produce LWG over that required for maintenance, since both BF and F calves had similar energy requirements for growth and maintenance (Dr. Holmes, unpublished data).

Breed x diet x temperature interactions. The major objective in the present trial was to determine whether BF calves could grow faster than F calves in the hot

environment, and when fed the high roughage diet. BF calves grew faster (not significantly) than F calves in the hot room, but they also did so in the cool room. Thus, the higher LWG of BF than F calves was not restricted to hot environments. Moreover, BF calves grew faster in both temperatures only when fed the High ration as noted before.

4. Water Intake

The water contents of hay and pellets were low (14 and 10% respectively). The mean DMI was 3.64 Kg/day. The calves ordinarily obtained only about 0.5 l/day from the ration. Thus, the calves in the present experiment obtained water mainly as free water.

Temperature. The correlation coefficient of the DMI and water intake (-0.26) was negative (Appendix 14). Even though the DMI in the hot room was significantly lower in the cool room, the water intake was significantly higher in the hot room. This might be expected as much more water was required in the hot room to compensate for the increased losses by evaporation which probably occured at the high temperature. The increase in water intake was greatly influenced by the severity of thermal stress. Winchester and Moris (1956) estimated a 90% increase in water intake for an increase in temperature from 16 to 32^{o}C, with an average of 4.19 kg/day of DMI for steers. This is comparable with the results in the present experiment. The water intake increased by 99% at 34.5^{o}C as compared with 16.9^{o}C, with an average DMI of 3.09 and 4.18 kg/day in the hot and cool rooms respectively.

Breed x diet Interaction. The significantly higher water intake by BF calves fed the High ration than other treatments was because of their higher DMI. When water intake was expressed per unit DMI, their water intakes were

similar (Fig. 12). This might be expected as water intake was closely related to feed intake through its functions in the processes of digestion of food, elimination of undigested residues, the excretion of waste products and general metabolism.

Temperature x Diet Interaction. In the temperature x diet interaction, it was understandable that calves fed both the High and the Low rations in the hot room had a higher water intake than in the cool room. This was again due to the requirements of more water for evaporative cooling of the body, though there was a lower DMI in the hot room. The significantly higher water intake with calves fed the High ration than the Low ration in the hot room was mainly a reflection of higher DMI by calves fed the High ration.

Breed x temperature interaction. B. indicus were frequently reported to have lower water requirements than B. taurus if heat stress was imposed (Rogerson et al; 1968; Horrocks and Phillips, 1961; Colditz and Kellaway, 1972). Although this was not significant in the present experiment, BF calves had a lower increment of water intake than F calves (5.7 and 7.0 l/day/kg DMI respectively) when heat stress was imposed. With the absence of heat stress, BF and F calves had very similar water intake. This is in accordance with the results of Rogerson et al (1968) and Ledger et al (1970).

II. RADIANT HEAT STRESS TRIAL DISCUSSION

1. The Radiant Heat Environment

The solar radiation at the ground for a zenith sun measured in the tropical part of U.S.A. ranged from 0.3 - 2.0 μm (Bond *et al* 1967). The radiation wavelengths supplied by the two types of radiant heat lamps in the radiant heat room closely resembled these actual solar radiation (0.3 - 2.0 μm), if the manufacturers information is accurate.

The potential shortwave radiant heat load near Nairobi, Kenya ranged from 0 w/m^2 at 0700 h to 1200 w/m^2 at 1300 h (Finch, 1972). The radiant heat load in the present trial was 952 w/m^2 at 0.5 m and 1146 w/m^2 at 1.6 m from the floor. These radiant heat fluxes would resemble the solar radiant heat load near Nairobi, Kenya at midday.

The black globe temperatures under radiant heat were about 44-50^{o}C in the present experiment. These black globe temperatures closely resembled the globe thermometer temperatures in the field measured by Murray (1966) in Australia.

Under these radiant heat environments, the calculated net radiant heat gain by the calf was 453 watts/animal. This was much higher than the net radiant heat gain measured by Finch (1976) near Nairobi between 0900 and 1500 h for steer, which was 175 w/animal.

2. Respiration rate and rectal temperature.

The rate of absorption of heat from the environment plus the rate of heat production by metabolism must equal the rate at which heat is dissipated from the body in order for an animal to maintain a constant body temperature. The increase in rectal temperature when the calves were

exposed to radiant heat load indicated that there was a positive storage of heat by the calves. The increased respiration rate represented an attempt to increase heat dissipation by the calves during exposure to the radiant heat stress; however, since body temperature increased in all calves any increases in the rates of heat dissipation were not as large as the rate of heat gain.

Using the two pairs of BF and F calves subjecting to the radiant heat at the same time, the increment in the rectal temperature was higher in F than BF calves. This might indicate that F calves were under a higher degree of stress when subjecting to the same radiant heat load or able to increase evaporative losses to a smaller extent than the BF calves.

3. Dry Matter Intake.

The effects of radiant heat load on the DMI of cattle are likely to be important in the tropics. Unfortunately, the data available is limited. There was no significant decrease in DMI when the calves were exposed to 8h/day radiant heat stress in the present experiment. Johnston et al (1957) compared the DMI of lactating Holstein cows in open barn and exposed to Louisiana Summer sun. There was also no significant difference in the DMI of the two groups. Brody et al (1954) studied the effect of radiant heat stress on the feed intake of lactating Holstein and Jersey and non-lactating Brahman cattle and found that when the animals were exposed to maximum of 568 w/m^2 of radiant heat load while the ambient temperature was 21.1 to 26.9^{o}C, the TDN intake of the Holsteins declined more than that of the Jerseys and that the intake of the Brahmans was unaffected.

One of the interests in the present radiant heat stress trial was to assess the relevance of the Main experiment to the natural tropical conditions simulated by the radiant heat room. The addition of the radiant heat load to the high air temperature in the Radiant Heat Stress

Trial did not significantly reduce dry matter or increase water intake. This showed that the effects of the high air temperature represented by the hot room in the Main Trial would probably resemble the effects of hot environmental conditions in the tropics. Thus, the findings of the Main Trial are probably relevant to the field conditions in the tropics. Moreover, the results in the radiant heat stress trial showed a smaller increase in body temperature in BF than in F calves during exposure to the simulated sunshine, but there was no difference in DMI between both breeds fed the high roughage diet (Fig. 16). This confirmed the findings in the Main experiment that BF and F calves had very similar DMI when fed the Low ration (high roughage diet), although the increment in the body temperature of the F calves was higher than BF calves when subjected to the same heat stress. This also raises the question about the suitability of body temperature as an indicator of heat stress as discussed before.

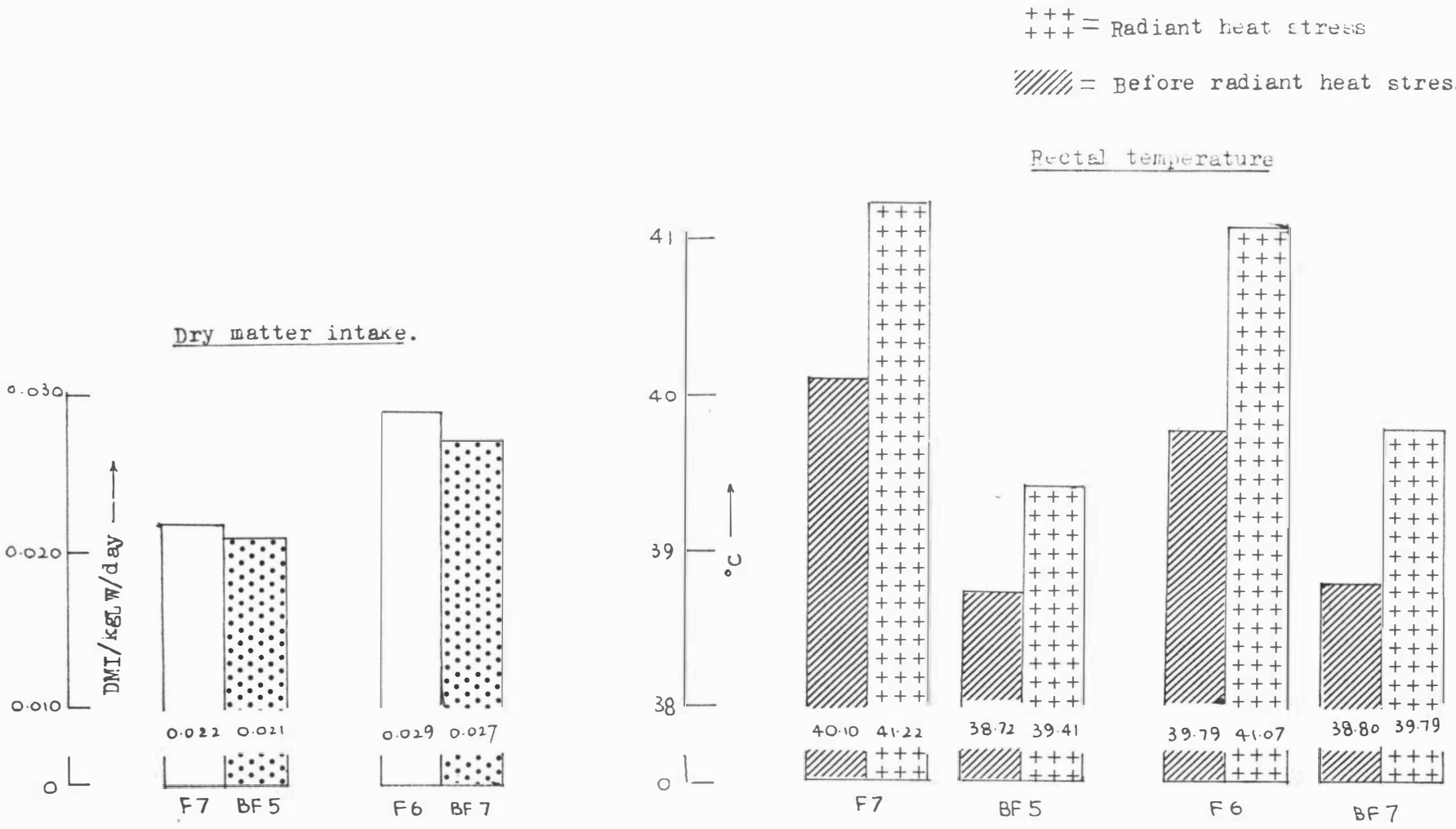
4. Water Intake.

Water intake per unit DMI has been shown to increase under radiant heat stress (Garrett et al 1960; Macfarlane and Stevens, 1972; Brody et al 1954). Presumbaly, this was due to the animals utilizing increasing amounts of water for evaporative cooling purposes when subjected to the radiant heat stress. In the present experiment, there was no significant difference in water intake when the calves were exposed to 8h/day radiant heat stress. This is in contrast to the above findings. There was no apparent explanation.

Period.

Although this trial was carried out in two periods, with slightly higher black-globe and air temperatures in Period 1 than Period 2, there was no significant differences between the two periods in DMI and water intakes. There was also no significant period x treatment interaction.

Figure 16. Radiant Heat Stress Trial--Dry matter intake, rectal temperature.



CHAPTER 5. CONCLUSION

I. MAIN TRIAL.

1. Temperature. The calves in the hot room (34.5°C, 45% RH), had a significantly lower dry matter and digestible energy intakes and subsequently had a lower liveweight gain than those in the cool room (16.9°C, 86% RH). High air temperature was one of the main reasons for low liveweight gain in the hot room in the present experiment and probably it is one of the main limitations to high beef production in the tropics.

In the hot room, there were slight but significant increases in dry matter and energy digestibilities, but not apparent nitrogen digestibility.

Even though the dry matter intake in the hot room was significantly lower than the cool room, the water intake was significantly higher in the hot room. This finding stresses the importance of water availability to the cattle in hot conditions.

2. Diet. The calves fed on the High ration (low roughage diet) ate significantly more dry matter and digestible energy than those fed the Low ration (high roughage diet). The High ration was more digestible (dry matter, energy and nitrogen) than the Low ration. Subsequently, the calves fed on the High ration had significantly higher liveweight gain than those fed the Low ration. In the tropics, most of the beef is produced on Low ration type diets, and this is probably one of the limitations to high beef production attained in some of the agriculturally advanced countries.

3. Breed. There was no significant difference between BF (Brahman x Friesian) and F (Friesian) calves in voluntary feed intake, digestibility, liveweight gain and water intake.

4. Breed x diet interaction. BF calves ate significantly more and grew faster than F calves when fed the High ration. BF calves ate and gained the same amounts as F calves when fed the Low ration. Thus, it is probably advantageous in terms of liveweight gain in rearing BF breed if low roughage diets are fed.

The water intake by BF calves fed the High ration was significantly higher than other treatments and this was because of their higher dry matter intake.

5. Breed x temperature interaction. The higher dry matter and digestible energy intakes, and liveweight gain of BF than F calves in the hot room was due solely to the higher intakes and liveweight gain of BF calves on the High ration; on the Low ration, calves of both breeds had very similar intakes and liveweight gain. Thus, BF breed is not likely to be better in terms of liveweight gain than F breed in hot environments unless low roughage diets are fed. Since in the tropics where cattle feeds are mostly of high roughage types, Friesians might be expected to grow as fast as Brahman x Friesian crossbred in view of the present results.

However, this does not lead us to the conclusion that Friesians are as sutiable as Brahman x Friesian crossbred for beef production in the tropics. This is because not all factors affecting beef production in tropical conditions (e.g. resistance and tolerance to diseases, insects, parasites; reproduction, etc.) were studied in the present experiment.

6. Temperature x diet interaction. The calves fed on the High ration had higher voluntary feed intakes and liveweight gain than those fed on the Low ration, and these differences were similar in both the hot and cool rooms. In view of these, it seems that the advantages of the Low roughage diet, is not accentuated in the hot environment in terms of liveweight gain.

The calves fed the High ration had a significantly higher water intake than those fed the Low ration in the hot room. This was mainly a reflection of the higher dry matter intake by calves fed the High ration.

Two main factors which affected water intake in the present experiment were the temperature and dry matter intake. High water intake was associated with either high temperature or high dry matter intake or both.

7. Breed x diet x temperature. On the High ration, the advantage to the BF calves was considerably greater in the hot room than in the cool room for both voluntary feed intake and liveweight gain. On the Low ration, BF and F calves had very similar voluntary feed intake and liveweight gain in both the hot and cool rooms as mentioned before. The implications of these in the tropics have been discussed in Section I.5.

II. RADIANT HEAT STRESS TRIAL.

In the Radiant heat Stress trial, radiant heat load was added to high air temperature (30.0 - 33.1^{o}C) for 8h/day to simulate direct sunshine in a hot environment in the tropics. When fed on a high roughage diet, there was no significant reduction in dry matter intake or increase in water intake when the calves were exposed to "sunshine". High air temperature was sufficient to represent tropical conditions and indicated the relevance of the findings in the Main Trial to the tropical conditions.

In both the Main Trial and Radiant heat Stress trial, the rectal temperature as heat stress indicator did not correlate well with the dry matter intake and liveweight gain of BF and F calves under heat stress. This castes doubts on the suitability of using rectal temperature as the indicator for heat stress and subsequently for the prediction of liveweight gain.

APPENDIX 1

THE TEST OF SIGNIFICANCE OF REGRESSIONS

Variables	Pw	Vpw	Ew	Vew	$F = \frac{Vpw}{Vew}$	Signif-icance
Dry matter intake and original liveweight	0.888	0.888	0.486	0.069	12.801	**
Digestible energy intake and original liveweight	10.946	20.946	11.712	1.673	6.542	*
Dry matter digestibility and dry matter intake	17.83	17.83	52.45	7.49	2.38	NS
Liveweight gain and original liveweight	0.0292	0.0292	0.1294	0.0185	1.578	NS
Water intake and original liveweight	2.248	2.248	3.448	0.4926	4.564	NS
Water intake and dry matter intake	2.619	2.610	3.086	0.441	5.918	*

The method used followed the method used by Ray (1960).

Pw = Predicted sum of squares, based on the within-sample sums of squares and products.

$$Pw = \frac{(Wxy)^2}{Wx} \quad \text{where} \quad Wxy = \sum_{8}^{1} \left(\Sigma x_i y_i - \frac{\Sigma x_i \; \Sigma y_i}{2} \right)$$

$$Wx = \sum_{8}^{1} \left(\Sigma x_i^2 - \frac{(\Sigma x_i)^2}{2} \right)$$

Vpw = Predicted variance

$$= \frac{Pw}{1}$$

Ew = Within-sample sums of squares of error of estimate:

$$= Wy - \frac{(Wxy)^2}{Wx} \quad \text{where} \quad Wy = \sum_{1}^{8} \left(\Sigma y_i^2 - \frac{(\Sigma y_i)^2}{2} \right)$$

$$Vew = \frac{Ew}{N-C-1}$$ where N = total number of observations (16)
C = number of samples (8)
Vew = error variance

* P<0.05
** P<0.01

APPENDIX 2

ANALYSIS OF COVARIANCE : DRY MATTER INTAKE ADJUSTED FOR ORIGINAL LIVEWEIGHT

Components	Errors of Estimates				
	Sum of Squares SS	Degree of freedom DF	Mean square MS SS/DF	$F = \frac{MS}{MSe}$	Significance of F test v1 = 1 v2 = 7
Breed (B)	0.122	1	0.122	1.758	NS
Temperature (T)	5.677	1	5.677	81.801	**
Diet (D)	0.721	1	0.721	10.389	*
B x T	0.321	1	0.321	4.618	NS
B x D	0.953	1	0.953	13.732	**
D x T	0.108	1	0.108	1.556	NS
B x D x T	0.095	1	0.095	1.375	NS
Error (e)	0.486	7	0.069		

* $P<0.05$

** $P<0.01$

NS Not significant

Mean x (original LW) = 100.98 kg $\pm$ 2.12

Mean y (DMI) = 3.64 kg/day $\pm$ 0.21 (S.E. After regression)

Regression coefficient = 0.03

Correlation coefficient = 0.311

APPENDIX 3

SUM OF SQUARES SIMULTANEOUS TEST PROCEDURE FOR DRY MATTER INTAKE (KG/DAY) IN BREED x DIET TREATMENT

Breed x diet treatment	Sum of Squares (SS)	Critical SS=$F_{\alpha(1,7)}(a-1)(MS_e)$
1. F fed High ration BF fed Low ration, and F fed Low ration	0.122	Not significant
2.BF fed High ration vs BF fed Low ration, F fed High ration, F fed Low ration	1.208	** P<0.01

(a-1) = Degree of freedom where a = number of replicates in the treatment.

Mse = Mean square of error.

$F_{\alpha(1,7)}$ = F ratio, $v_1 = 1$, $v_2 = 7$.

APPENDIX 4

ANALYSIS OF COVARIANCE : DIGESTIBLE ENERGY INTAKE (MCal/day) ADJUSTED FOR ORIGINAL LIVEWEIGHT (kg)

Components	Errors of Estimates				Significance of F test
	Sum of Squares SS	Degree of freedom DF	Mean square MS SS/DF	F = MS/MSe	$v_1 = 1, v_2 = 7$
Breed (B)	1.46	1	1.46	0.87	NS
Diet (D)	41.82	1	41.82	25.00	**
Temperature (T)	33.18	1	33.18	19.83	**
B x T	2.14	1	2.14	1.28	NS
B x D	8.49	1	8.49	5.08	NS
D x T	3.47	1	3.47	2.08	NS
B x D x T	1.51	1	1.51	0.90	NS
Error (e)	11.71	7	1.67		

** P<0.01

NS = not significant

Mean x (original LW) = 100.98 kg ± 2.12

Mean y (DEI) = 10.42 MCal ± 0.71 (S.E. After regression)

Regression coefficient = 0.55

Correlation coefficient = 0.38

APPENDIX 5

ANALYSIS OF VARIANCE : DRY MATTER DIGESTIBILITY (%)

Components	Sum of squares (SS)	Degree of freedom DF	Mean square MS SS/DF	$F = \frac{MS}{MSe}$	Significance of F test $v_1 = 1$, $v_2 = 8$.
Total	622.558	15			
Breed (B)	1.103	1	1.103	0.130	NS
Diet (D)	481.803	1	481.803	54.84	** P<0.01
Temperature(T)	48.303	1	48.303	5.50	* P<0.05
B x T	6.003	1	6.003	0.68	NS
B x D	0.423	1	0.423	0.05	NS
D x T	11.223	1	11.223	1.28	NS
B x D x T	3.443	1	0.39	0.39	NS

Pooled standard error = 2.96

Standard error per animal = 0.19

APPENDIX 6

ANALYSIS OF VARIANCE : GROSS ENERGY DIGESTIBILITY (%)

Components	Sum of squares SS	Degree of freedom DF	Mean square MS SS/DF	$F = \frac{MS}{MSe}$	Significance of F test $v_1 = 1$ $v_2 = 8$
Total	842.80	15			
Breed (B)	4.63	1	4.63	0.42	NS
Diet (D)	657.93	1	657.93	59.27	** P<0.01
Temperature (T)	79.21	1	79.21	7.13	* P<0.05
B x T	10.89	1	10.89	0.98	NS
B x D	0.71	1	0.71	0.06	NS
D x T	0.36	1	0.36	0.03	NS
B x D x T	0.25	1	0.25	0.02	NS
Error	88.82	8	11.10		

Pooled standard error = 3.33

Standard error per animal = 0.21

APPENDIX 7

ANALYSIS OF VARIANCE : APPARENT NITROGEN DIGESTIBILITY (%)

Components	Sum of squares SS	Degree of freedom DF	Mean square MS SS/DF	$F = \frac{MS}{MSe}$	Significance of F test $v_1 = 1$, $v_2 = 8$.
Total	2247.35	15			
Breed (B)	6.89	1	6.89	0.57	NS
Diet (D)	2081.64	1	2081.64	173.33	** P<0.01
Temperature (T)	32.77	1	32.77	2.73	NS
B x T	4.73	1	4.73	0.39	NS
B x D	4.73	1	4.73	0.39	NS
D x T	3.52	1	3.52	0.29	NS
B x D x T	17.02	1	17.02	1.42	NS
Error (e)	96.05	8	12.006		

Pooled standard error = 3.47

Standard error per animal = 0.22

APPENDIX 8

ANALYSIS OF VARIANCE : LIVEWEIGHT GAIN (kg/day)

Components	Sum of squares SS	Degree of freedom DF	Mean square MS SS/DF	$F = \frac{MS}{MSe}$	Significance of F test $v_1 = 1$, $v_1 = 8$.
Total	1.661	15			
Breed (B)	0.168	1	0.168	8.495	* P<0.05
Diet (D)	0.504	1	0.504	25.465	** P<0.01
Temperature (T)	0.664	1	0.664	33.551	** P<0.01
B x T	0.020	1	0.020	0.985	NS
B x D	0.13	1	0.13	6.722	* P<0.05
D x T	0.006	1	0.006	0.318	NS
B x D x T	0.007	1	0.007	0.369	NS
Error (e)	0.1585	8	0.0198	0.0198	

Pooled standard error = 0.14

Standard error per animal = 0.009

APPENDIX 9

SUM OF SQUARES SIMULTANEOUS TEST PROCEDURE FOR LIVEWEIGHT GAIN (KG/DAY) IN BREED x DIET TREATMENT

Breed x diet treatment	Sum of Squares	Critical SS=$F_{\alpha(1,8)}(a-1)(MS_e)$
1. BF fed Low ration vs F fed Low ration	0.001	NS
2. BF fed High ration vs F fed High ration	0.300	** P<0.01
3. F fed High ration vs BF fed Low ration and F fed Low ration	0.069	NS

$(a-1)$ = Degree of freedom where a = number of replicates in the treatment

MS_e = Mean square of error

$F_{\alpha(1,8)}$ = F ratio, $v_1 = 1$, $v_2 = 8$.

APPENDIX 10

THE TEST OF SIGNIFICANCE BETWEEN THE REGRESSION OF LIVEWEIGHT GAIN (KG/DAY) AND DRY MATTER INTAKE (KG/DAY)

Pw	Vpw	Ew	Vew	$F = \frac{Vpw}{Vew}$	Significance
0.1157	0.1157	0.0429	0.00613	18.874	** P<0.01

The abbreviations used are the same as in Appendix 1.

APPENDIX 11

LIVEWEIGHT GAIN (KG/DAY) ADJUSTED FOR DRY MATTER INTAKE (KG/DAY)

Errors of Estimates Components	Sum of squares SS	Degree of freedom DF	Mean square MS SS/DF	$F = \frac{MS}{MSe}$	Significance of F test $v_1 = 1$, $v_2 = 7$.
Breed (B)	0.0007	1	0.0007	0.115	NS
Temperature (T)	0.0073	1	0.0073	1.197	NS
Diet (D)	0.1119	1	0.1119	18.34	**
B x T	0.001	1	0.001	0.164	NS
B x D	0	1	0	0	NS
D x T	0.007	1	0.007	1.148	NS
B x D x T	0	1	0	0	NS
Error (e)	0.0429	7	0.0061		

NS Not significant

** $P<0.01$

Mean x (DMI) = 3.64 kg/day $\pm$ 2.1

Mean y (LWG) = 0.70 kg/day $\pm$ 0.30 (S.E. after regression)

Regression coefficient = 0.375

Correlation coefficient = 0.940

APPENDIX 12

ANALYSIS OF VARIANCE : WATER INTAKE (GALLONS/DAY)

Components	Sum of squares SS	Degree of freedom DF	Mean square MS SS/DF	$F = \frac{MS}{MSe}$	Significance of F test $v_1 = 1$, $v_2 = 8$.	
Total	65.465	15				
Breed (B)	0.512	1	0.512	0.668	NS	
Temperature (T)	43.626	1	43.626	56.953	**	P<0.01
Diet (D)	2.497	1	2.497	3.260	NS	
B x T	0.504	1	0.504	0.658	NS	
B x D	4.305	1	4.305	5.620	*	P<0.05
D x T	5.085	1	5.085	6.638	*	
B c D c T	2.808	1	2.808	3.666	NS	
Error (e)	6.128	8	0.766			

Pooled standard error = 0.875

Standard error per animal = 0.055

APPENDIX 13

SUM OF SQUARES SIMULTANEOUS TEST PROCEDURE FOR WATER INTAKE (GALLONS/DAY)

Components	SS	Critical SS = $F_{\alpha(1,8)}(a-1)(MS_{error})$
(a) Breed x diet treatment		
1. F fed High ration, F fed Low ration, BF fed Low ration	0.95	NS
2. BF fed High ration vs F fed High ration, BF fed Low ration, F fed Low ration.	6.35	*
(b) Temperature x diet treatment		
1. High ration in hot temperature vs Low ration in hot temperature	7.35	*
2. High ration vs Low ration in cool temperature	0.228	NS
3. Low ration in hot room vs Low ration in cool room	14.648	**

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

$(a-1)$ = Degree of freedom where a = number of replicates in the treatment.

$F_{\alpha(1,8)}$ = F ratio, $v_1 = 1$, $v_2 = 8$.

APPENDIX 14

ANALYSIS OF COVARIANCE : WATER INTAKE (GALLONS/DAY) ADJUSTED FOR DRY MATTER INTAKE (KG/DAY)

Errors of Estimates Components	Sum of squares SS	Degree of freedom DF	Mean square MS SS/DF	$F = \frac{MS}{MSe}$	Significance of F test $v_1 = 1$, $v_2 = 7$.
Breed (B)	0.50	1	0.50	1.14	NS
Diet (D)	0.04	1	0.04	0.09	NS
Temperature (T)	20.63	1	20.63	46.89	**
B x T	0.036	1	0.036	0.08	NS
B x D	0.08	1	0.08	0.18	NS
D x T	5.02	1	5.02	11.41	*
B x D x T	1.93	1	1.93	4.39	NS
Error (e)	3.09	7	0.44		

* $P<0.05$

** $P<0.01$

NS Not significant

Mean x (DMI) = 3.64 kg/day $\pm$ 0.21

Mean y (water intake) = 4.96 gallons/day $\pm$ 0.522 (S.E after regression)

Regression coefficient = -2.98

Correlation coefficient = -0.26

Appendix 15 Analysis of Variance : DRY MATTER INTAKE (kg/day) in Radiation Trial

Source of Variance	Sum of Squares ss	Degree of Freedom DF	Mean square MS = SS/DF	Mean Square ratio MS/MSe	F $v_1 = 1$ $v_2 = 8$
Total	3.67	11			
Treatment	0.21	1	0.21	0.52	NS
Period	0.21	1	0.21	0.52	NS
Period x Treatment	0.0085	1	0.0085	0.021	NS
Error (e)	3.24	8	0.405		

Appendix 16 Analysis of Variance : Water Intake (1/day) in Radiation Trial

Source of Variance	Sum of Squares ss	Degree of Freedom DF	Mean square MS = SS/DF	Mean Square ratio MS/MSe	F $v_1 = v_2 = 8$
Total	555.33	11			
Treatment	9.92	1	9.92	0.15	NS
Period	1.65	1	1.65	0.03	NS
Period x Treatment	9.60	1	9.60	0.14	NS
Error (e)	534.16	8	66.77		

Appendix 17. Estimation of Level of Feeding in relation to Maintenance requirement in the Hot and Cool rooms

Energy requirement for maintenance = 0.43 MJ ME/$kg^{0.75}$/day (Dr. Holmes, unpublished data).

GE of feed = 18.04 MJ/kg DM

% digestible in Hot Room = 68.6

" " " Cool Room = 64.1

Assume that ME = DE x 0.82

Average DMI in Hot room = 3.09 kg/day DM

" " " Cool " = 4.18 " DM

Average metabolic weight of calves in Hot room = 32.38 $kg^{0.75}$

" " " " " " Cool " = 31.36 $kg^{0.75}$

Maintenance requirement for calves in Hot room = 32.38 x 0.43
= 13.9 MJ ME/day

" " " " " Cool " = 31.36 x 0.43
= 13.5 MJ ME/day

ME intake by calves in Hot room = 18.04 x 68.6% x 82% x 3.09
= 31.36 MJ/day

ME intake by calves in Cool room = 18.04 x 64.1% x 82% x 4.18
= 39.64 MJ/day

Estimated level of intake by calves in Hot room = $\frac{31.36}{13.9}$
= 2.3 times maintenance

Estimated level of intake by calves in cool room = $\frac{39.64}{13.5}$
= 2.9 times maintenance

Appendix 18 Estimation of the Level of Feed Intake for BF and F calves fed the High ration in relation to Maintenance required.

Energy requirement for maintenance = 0.43 MJ ME/$kg^{0.75}$/day (Dr. Holmes, unpublished data)

GE of feed = 18.04 MJ/kg

% digestible by BF calves fed High ration = 73.01

F " " " " = 72.4

Assume that ME = DE x 0.82

Average DMI by BF calves fed High ration = 4.50 kg/day

" " " F " " " " = 3.25 "

Average metabolic weight of BF fed High ration = 33.42 $kg^{0.75}$

" " " " F " " " = 30.57 $kg^{0.75}$

Maintenance requirement of BF fed High ration = 33.42 x 0.43

= 14.37 MJ ME/day

" " " F " " " = 30.57 x 0.43

= 13.15 MJ ME/day

ME intake by BF fed High ration = 18.04 x 73.03% x 82% x 4.50

= 48.59 MJ/day

" " " F " " " = 18.04 x 72.4% x 82% x 3.25

= 34.81 MJ/day

Estimated level of DMI by BF fed High ration = $\frac{48.59}{14.37}$ = 3.4 times maintenanc

Estimated level of DMI by F fed High ration = $\frac{34.81}{13.15}$

= 2.7 times maintenance

Appendix 19 Explanation for the Higher Liveweight gain (LWG) in calves fed the High ration than the Low ration

Dry Matter intake (kg/day)	High ration	<	Low ration
Liveweight gain (kg/day)	(4.69)		(6.91)

This could be due to:

(i) Metabolizable energy availability from unit DMI

a) Gross energy digestibility: High ration > Low ration

(present experiment) (72.7%) (59.9%)

⇓

Digestible Energy Intake (MJ/day) : High ration > Low Ration

(present experiment) (50.41) (36.79)

b) Assume that ME = DE x 0.82 for both High and Low rations

⇓

Estimated ME availability (MJ/day) : High ration > Low Ration

(41.3) (30.2)

(ii) Utilization of unit ME in LWG

ME (MJ/day) : High ration > Low ration ?

LWG (kg/day)

This was not measured in the present experiment.

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