THE INFLUENCE OF ENERGY DENSITY ON THE PERFORMANCE OF FEEDLOT CATTLE

by

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I hereby declare that the research reported in this study is my own work. Where use was made of the work of others it has been duly acknowledged in the text.

N.J. Dominy

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"It must not be forgotten that, in the harsh world of science, all evidence in favour of a theory counts zero, while relevant evidence against it counts one" (Emmans and Kyriazakis, 1995)

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CHAPTER FIVE

LEAST COST FORMULATION OF BEEF FEEDLOT RATIONS WITH DIETARY ENERGY AS A CONSIDERATION

ABSTRACT

This study examined the interaction of diets differing in their energy densities and heat increments of feeding on the feed intake patterns, physiological measurements, empty body composition, and animal performance of steers in a feedlot environment. The energy densities of the diets ranged from 7.97 to 11.83 MJ ME and 6.50 to 9.53 MJ Effective Energy (EE) and the ratio of EE to ME ranged from 0.79 to 0.84. The feed intake pattern of steers was not affected by differences in the diets energy densities but was affected by diets that differed in their heat increments of feeding.

The physiological measurements, rectal temperatures measured at 9.00 am and 2.00 pm (T_R 9.00 am and 2.00 pm) and respiration rates of steers in the feedlot were compared to control steers kept on pasture. Steers in the feedlot registered significantly ($P < 0.001$) higher physiological measurements than the controls and the accepted norms for cattle not under heat stress. A relationship exists between the pattern of physiological measurements over time and feed intake pattens over time. Physiological measurements peak and dip during the same weeks as the feed intakes peak and fall. Peaks and the immediate dips thereafter are related to points of acute response resulting in a chronic response and acclimatisation.

All feedlotted steers experienced heat stress within the first week of feeding. Steers feedlotted in summer took 28 days to achieve their peak feed intake whereas steers feedlotted in winter required 42 days to reach their peak feed intake. Steers that required 42 days in which to reach their peak intakes had greater increases in their daily intakes than those that required 28 days to reach their peak intakes. Steers feedlotted in winter lost their winter coat between weeks three and six. Differences in peak feed intakes were recorded for animals of a heavier starting live

weight (late versus early maturing and long yearling versus weaners). Peak feed intake increased in line with increasing live weight at the start of feedlotting. These differences were attributed to their greater surface area and hence greater heat loss capacity.

Comparison of steers tissue deposition rates of steers on diets differing in their ratio of EE to ME revealed non significant differences in the growth rates of protein and lipid. The proportional use of energy intake was significantly different with significantly ($P < 0.1$) more of the daily energy intake being utilised for lipid deposition in diets with a higher heat load. Animals suffering from differing heat loads were inhibited in depositing protein but were able to deposit lipid due to the associated lower heat production. This enforced deposition of lipid results in animals reaching slaughter condition after similar lengths of time but at lower ADG and lower carcass weights. The economic consequences are that the returns are higher due to higher carcass gains for steers fed diets with a higher ratio of EE to ME.

CHAPTER ONE

LITERATURE REVIEW

1.1 Introduction

According to published scientific literature the study of the feed-intake over time of feedlot cattle has been limited. Researchers have concentrated on the preliminary feeding period and total feed-intake. The preliminary feeding period concerns the adaptation to high concentrate rations, with the associated rumen kinetic complications, while the overall feed-intake is an important economic consideration. However, a general trend has been mapped. From entry into a feedlot system the dry matter intake of cattle increases in a linear fashion before reaching a peak. Thereafter the feed-intake plateaus or dips slightly. The level of feed-intake recovers and remains constant until the preslaughter period when intake will decline slightly as steers approach slaughter weights (Owens *et al.*, 1985; Thornton *et al.*, 1985; Hicks *et al.*, 1990*a,b* and Dominy, 1997).

The period of linear increase in feed-intake has been attributed to adaptation with the cattle adjusting to their new environment, pen mates and ration. Hicks *et al.* (1990*b*) ascribed the ration adaptation to the switch from bulk fill to chemostatic regulation of dry matter intake (DMI). The length of time until the feed-intake plateaus varies from 28 days (Owens *et al.*, 1985; Thornton *et al.*, 1985 and Hicks *et al.*, 1990*a,b*) to 42 days (Dominy, 1997). This variation may be due to the rationing strategy used; for instance cattle in the feedlots examined by Thornton *et al.* (1985) and Hicks *et al.* (1990*b*) followed a sequential pattern of reduction in the roughage proportion of the diets during the first 14 to 28 days, while those of Dominy (1997) had access to only one diet. A reduction in feed-intake after 28 days is attributed to the cattle's adaptation to its finishing diet (Hicks *et al.* 1990*b*).

1.1.1 Starting weight

The degree of physiological maturity of an animal determines its desired rate of growth and the corresponding nutrient requirement to sustain this growth. A physiologically more mature animal

will have a greater maintenance requirement but a lower requirement for growth when compared to an animal of lower physiological maturity. The relationship between the starting weight of steers and their feed-intake is illustrated in Figure 1.1.1. The overall shape of the intake curve for all weight groups is similar (Thornton *et al.*, 1985; Hicks *et al.*, 1990*a,b* and Dominy, 1997). The feed-intakes of animals entering the feedlot increase almost proportionally to their starting weight. This corresponds to an increasing maintenance requirement with an increase in live weight. This relationship between starting weight and feed-intake continues for the first 14 days of the feeding period (Thornton *et al.*, 1985).

The DMI of heavy cattle peaks consistently earlier and plateaus at higher levels, than that for light animals. The intake of light animals increases for a longer period of time (Hicks *et al.*, 1990*b*), but fails to reach the levels achieved by heavier groups. Little overlap in intakes between weight groups is apparent, with the intake of heavy animals being consistently higher (Thornton *et al.*, 1985; Hicks *et al.*, 1990*a,b* and Dominy, 1997). This is more stark in the work by Dominy (1997), under which animal weight differences were attributable to condition score or pre-feedlot planes of nutrition and not chronological age. Light animals have a lower maintenance requirement and higher growth rate potential than heavy animals. To meet these nutrient requirements their DMI must increase over an extended period or at an elevated rate over the same period. At the cessation of the period of increase in DMI the difference in the DMI of respective live weight groups should reduce. Parallel patterns of intakes of the cattle in initial weight groups of (273, 318 and 364 kg) show that differences in intakes from the start, which are attributed to maintenance requirements, persist till slaughter. This lack of change in intake, particularly in those animals of a lower physiological age, led Hicks *et al.* (1990*b*) to speculate that DMI is being altered by an external factor.

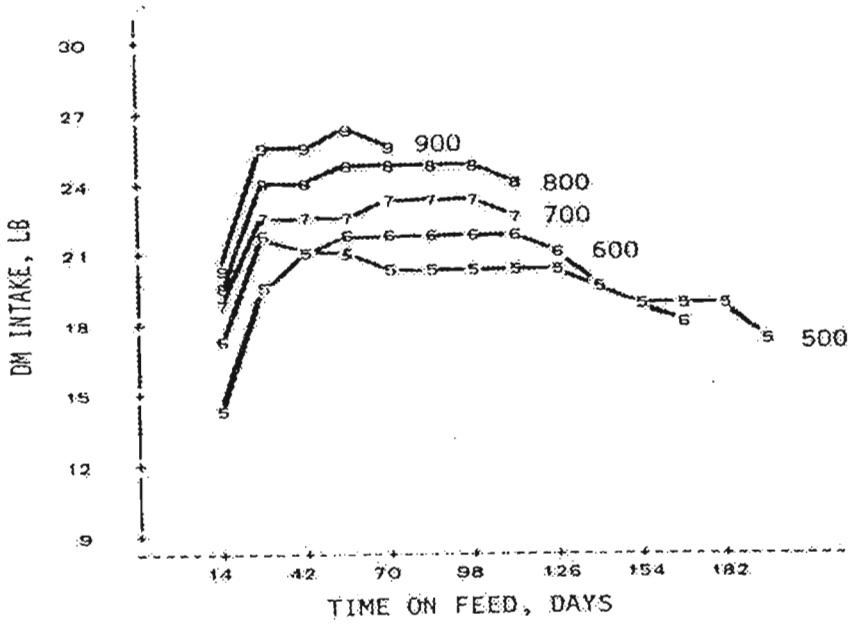

Figure 1.1.1 Feed-intake vs time on feed for steers with different initial weights (500, 600, 700, 800 and 900 lb) (from Thornton *et al.*, 1985)

Irrespective of the starting live weight, it is apparent from the plot of feed-intake against live weight (Figure 1.1.2), (Hicks *et al.*, 1990*b*) that DMI increases linearly with weight for about the first 25 kg of gain or 30 days on feed. Thereafter, DMI plateaus before declining later as required degree of finish is approached. When plotted on the same graph, parallel curves similar to those in Figure 1.1.1 result. This confirms the result by Thornton *et al.* (1985) that mean feed-intake over the feeding period increased as mean starting live weight increases.

Animals of the same genetic potential will follow the same growth curve. At similar live weights animals should achieve the same DMI after diet adaptation, due to their similar nutrient requirements (requirements for maintenance and growth should be identical). The constant differences between animals feed-intakes at similar weights, after starting at different weights, imply that there is a factor controlling feed-intake that depends on starting weight, and is independent of current weight and potential growth rate.

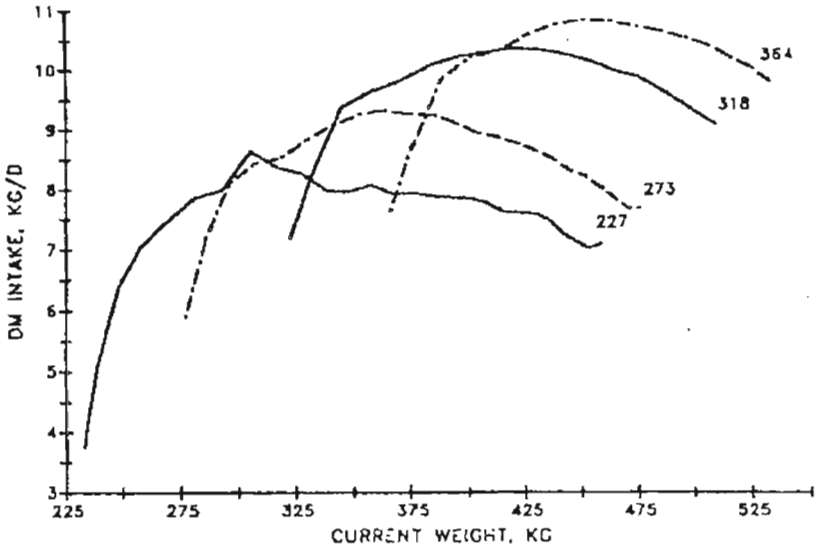

Figure 1.1.2 Daily DM intake vs current BW for steers with initial weights of 227 (216 to 239), 273 (262 to 284), 318 (307 to 329) and 364 (352 to 375) kg received during the summer months of July 31 through October 29 (from Hicks *et al.*, 1990*b*)

1.1.2 Sex

Steers and heifers of the same genotype have different mature live weights. At the same live weight steers will be less physiologically mature than heifers and hence have a higher growth rate potential. At an equal live weight a steer's requirements for nutrients is therefore higher, translating into a greater DMI. Comparison of the respective feed-intakes curves (Figure 1.1.3) finds that they follow parallel patterns within a season (Hicks *et al.*, 1990*a*). Heifers require 28 days to reach peak feed-intake while steers initially peak at 28 days before slowly increasing to a plateau after about 70 days in the feedlot (Owens *et al.*, 1985). A heifers DMI declines earlier than in beef steers (Hicks *et al.*, 1990*a*), due to heifers reaching the fattening phase associated with a decreasing energy requirement sooner. Having a heavier live weight the DMI of beef steers exceeds that of heifers by 2.8%. However when compared at similar live weights DMI are very similar (Owens *et al.*, 1985) or 1 to 3% lower in heifers of equal weight to steers (Hicks *et al.*, 1990*a*). Since the mature weight of steers exceeds that of heifers, the similar feed-intakes of the two sexes is surprising (Owens *et al.*, 1985).

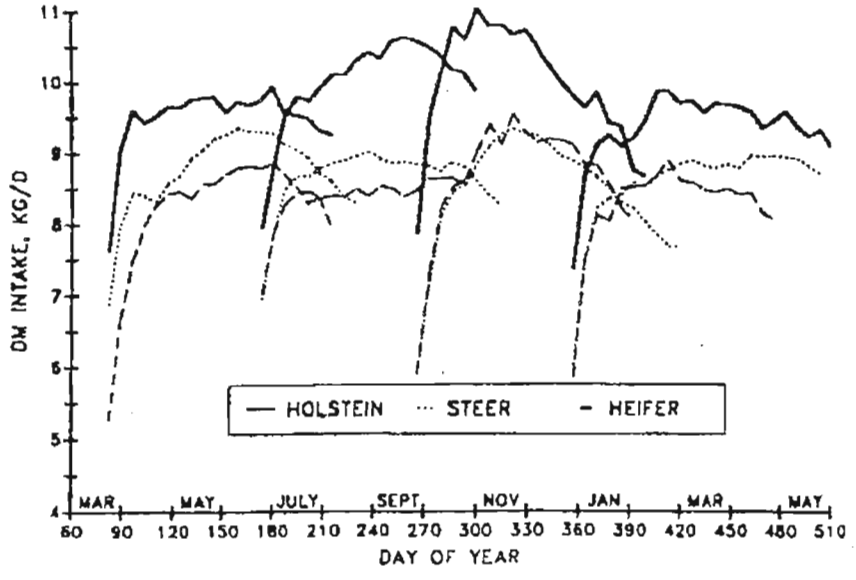

Figure 1.1.3 Daily DM intake means vs month of year for beef heifers, Holstein steers and beef steers with initial weights of 273 kg started on feed during the four different seasons of the year (from Hicks *et al.*, 1990*a*)

1.1.3 Breed

An increase in mature size is coupled with a greater potential growth rate at an equal live weight. A higher DMI is required to satisfy these nutrient demands. Holstein steers are late maturing, pure bred and generally easily available for comparisons (despite being a dairy breed) with early maturing beef breeds. DMI patterns for Holstein steers within a season closely parallel patterns (Figure 1.1.3) noted previously for beef steers (Hicks *et al.*, 1990*a*). Feed-intakes of Holstein steers peak after about 70 days on feed and then follow a steeper decline than that observed for beef steers (Owens *et al.*, 1985). Holstein and late maturing steers eat more feed than beef or early maturing steers, respectively during each period (Owens *et al.*, 1985 and Dominy, 1997). The difference is largest from 14 to 28 days on feed which is near the peak feed-intake for all cattle (Owens *et al.*, 1985). This difference in DMI is as predicted. However, the differences between maturity types remain constant throughout the feedlot period. This parallels the results found in section 1.1.1, whereby differences in DMI appear to be controlled by an external factor and not by nutrient requirement from starting in the feedlot.

Comparison of DMI's on an equal weight basis, shows that Holstein steers to consume 9% (Owens *et al.*, 1985) and 8 to 15% (Hicks *et al.*, 1990a) more than beef steers. Being a late maturing breed this difference in DMI is expected. However, increasing frame score from medium to large according to NRC (1984) would increase feed-intake by only 5.6 per cent. The higher feed-intakes of Holstein steers might be ascribed to their larger mature size or to the genetic selection of Holstein cattle for high milk production (Owens *et al.*, 1985). The parallel nature of the DMI curves between beef breeds of different maturity types (Dominy, 1997) shows that the differences in DMI are constant throughout the feedlot period. The lack of variation in DMI suggests that a factor over and above an animal's nutrient requirement is controlling DMI.

1.1.4 Season

DMI of steers in a feedlot environment (Figure 1.1.4) follow a distinct seasonal pattern. The effect of season on DMI is expected to be prevalent only in the months of extremes such as mid summer (a depression) and mid winter (an increase). A plot over a three year period shows that DMI peaks in October and November (late autumn), but decreases, to a low point in February (late winter). Subsequently DMI increases to a peak between May and June (spring) followed by a decline in July and August (Summer) (Hicks *et al.*, 1990*b*). The expected summer decline occurs and is attributed to heat stress (Hicks *et al.*, 1990*b*). However, DMI does not peak during winter months when colder temperatures were expected to increase the DMI of the feedlotted animals. The peak feed-intakes in autumn (November) are 0.1 kg DM per day higher ($P < .05$) than in the other three seasons (Hicks *et al.*, 1990*b*). This increase in DMI in autumn and spring indicates that the environment of these intermediate seasons is conducive to overcoming the factor controlling the feedlot animals DMI.

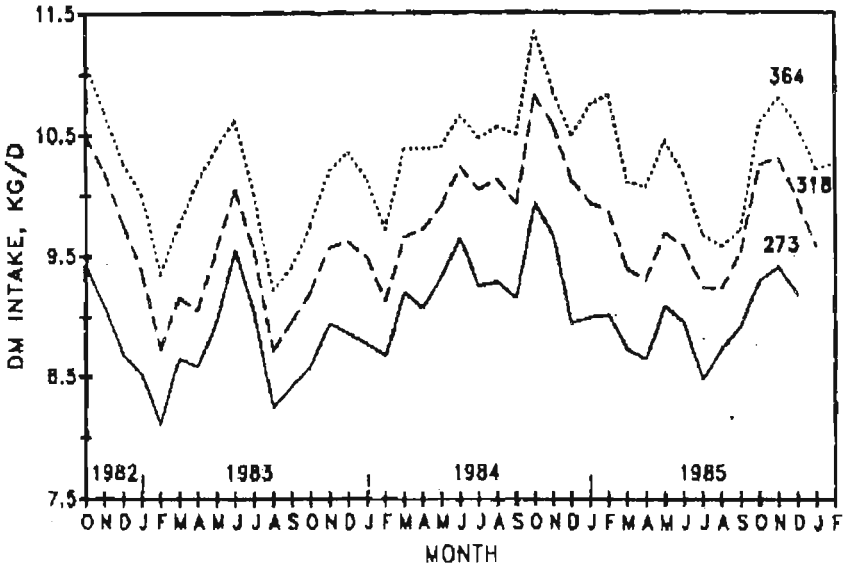

Figure 1.1.4 Monthly averages of daily DM intakes of cattle with initial weights of 273 (262 to 284), 318 (307 to 329) and 364 (352 to 375) kg (from Hicks *et al.*, 1990*a*)

Despite differences among seasonal curves, the overall shape of the intake curve for each weight group within a season proved surprisingly similar (Figure 1.1.5). In all seasons, DMI tends to increase linearly over the first 21 to 28 days. DMI then plateaus or dips slightly for about 14 days after which it increases again, particularly for those cattle placed on feedlot diets in the winter (Hicks *et al.*, 1990*b*).

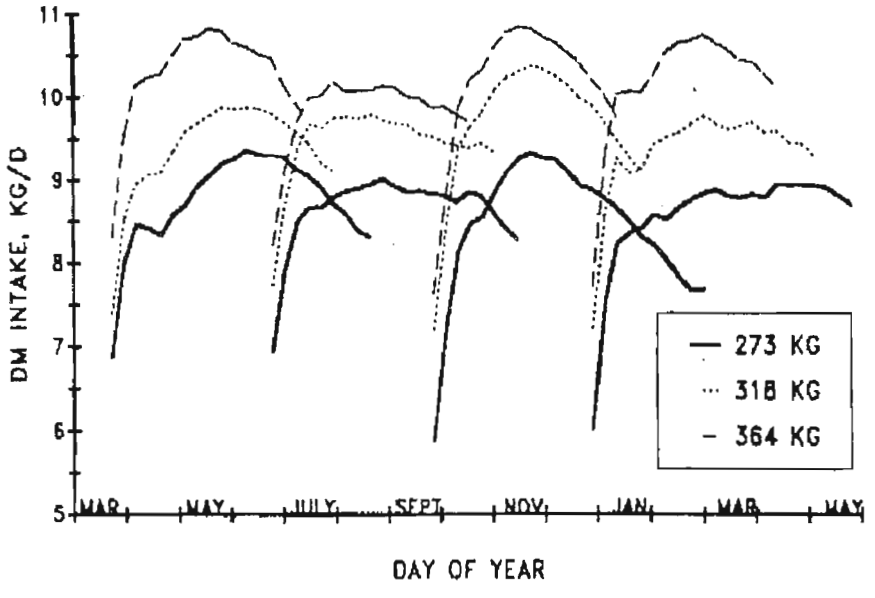

Figure 1.1.5 Mean daily DM intake vs month of year for steers with initial weights of 273 (262 to 284), 318 (307 to 329) and 364 (352 to 375) kg started on feed during the four different seasons of the year (from Hicks *et al.*, 1990*a*)

The same trend was apparent for cattle feedlotted during spring and fall, with the animals exhibiting a gradual but continual increase in DMI over the first 28 days. DMI then remains constant for 14 days before continuing to increase until 60 to 70 days in the feedlot. This is followed by a slow but steady decline in DMI (Hicks *et al.*, 1990*b*). The greater peak intakes of cattle started on feed in the fall could be associated with declining fall temperatures or the fact that fall animals come off dry grass pasture into the feedlot whereas spring animals come off lush wheat pasture (Hicks *et al.*, 1990*b*).

Cattle feedlotted during the summer exhibit a distinct plateau in DMI after 28 days. The distinct plateau in summer fed cattle is probably associated with the high temperatures that occurred in July and August which could reduce DMI during the day (Hicks *et al.*, 1990*b*). The DMI of winter fed cattle only dips at 28 days before continuing to increase for a further 30 days. Animals feedlotted in summer and winter have similar patterns in that the cattle exhibit little decline in DMI as they approach slaughter weight. This is contrary to the pattern of DMI of those feedlotted in spring and fall. Cattle fattened in summer will have also grazed wheat pasture and will be fatter at the start of feeding which could reduce the animals peak DMI and hence the lack of decline in

DMI at the end of the feeding period. The continual increase in DMI of winter fed cattle could be associated with increasing day length during this season. The DMI pattern of winter fed cattle is more erratic than that of cattle fed in other seasons, possibly due to cold stress (Hicks *et al.*, 1990*b*).

Correlations between the mean monthly feed-intakes and nine different components of weather data generally are quite low. However, for heavy cattle, certain indicators of heat stress are negatively related to DMI. This suggests that at elevated temperatures heat depresses DMI more for heavy cattle than for light cattle. Conversely, for light cattle, indicators of cold stress depress DMI more for cattle with light rather than heavy initial weights suggesting that cold is more stressful for light cattle (Hicks *et al.*, 1990*b*).

1.1.5 Implications

From the literature reviewed irrespective of maturity type, sex, starting weight or season, DMI of cattle in the feedlot increases linearly for the first 28 or 42 days. The differences between intakes during this period are proportional to the starting weight. Thus the controlling factor must be related to an animal's size. After 28 days a dip of differing magnitude in the upward trend occurs, which appears to be seasonal and most apparent in summer. The controlling factor appears to relinquish hold during spring, fall and winter allowing DMI to increase further. From this later peak, a plateau is followed by a decline in DMI as slaughter weight is approached.

The work's described by Owens *et al.* (1985), Thornton *et al.* (1985) and Hicks *et al.* (1990*a,b*), all followed a sequential decrease in the level of roughage from about 40 percent in the starting diet to 14 percent in the final finishing diet. Energy densities of the diets increased from 1.16 Mcal NE_g / kg DM to NE_g 1.34 Mcal NE_g / kg DM. Cattle were fed the starting diet for 14 days, then an intermediate roughage / energy diet (20 percent roughage, 1.16 Mcal NE_g / kg DM) for 10 days and then the final finishing diet. The trial described by Dominy (1997) did not employ the sequential feeding pattern, with the animals being placed immediately on a finishing ration of 11 percent roughage and 11.6 MJ ME / kg DM. Hicks *et al.* (1990*b*) suggested that the dip that occurs in the feed-intake curve at 28 days was due to adaptation to the final finishing diet. This

does not explain observations by Dominy (1997), where the same dip was experienced at 28 days, in the absence of any change in diet. It could well be that at this phase of feeding DMI is controlled by a factor that is independent of dietary adaptation, season, sex, maturity type and starting weight, however this factor could interact with season and starting weight to determine the level of intake.

The influence of season on DMI, particularly those seasons with a more constant environment (summer and winter), indicates that the factor controlling the pattern of DMI is influenced by the environment. Examination of the literature covering factors affecting voluntary feed-intake follows, to determine which of these factors may be having an effect on the pattern of DMI of feedlot animals, during the peak and plateau phase, of the DMI curve.

1.2 Voluntary feed intake

The consumption of feed is fundamental to nutrition: it determines the levels of nutrients ingested and therefore, the animal's response and function (Van Soest, 1994). It is not simply a case of consuming feed, as this must also be weighed against the response that once energy-yielding substances have been consumed, the body has little opportunity of preventing storage of the energy. The regulation of body weight and thus body energy content comes about mainly through the regulation of food-intake (Balch *et al.*, 1962 and NRC, 1987). The intake of diets of low digestibility is regulated by rumen capacity, rate of passage and dry matter digestibility, whereas, that of diets of high digestibility are regulated by metabolic size, production and overall digestibility (Bines, 1976 and NRC, 1987). Now there is a good deal of evidence suggesting that the regulation of food-intake is largely nervous, with a substructure of reflexes facilitated or inhibited by centres in the brain, particularly in the hypothalamus, but further influenced from limbie and perhaps neocortical levels (Balch *et al.*, 1962).

It is assumed that animals intend to achieve satiety, which is the theoretical level needed to balance energy losses and achieve optimal production when fed on a balanced diet. However, the functional level the animal achieves is its plane of nutrition, and is influenced by a combination of restricting factors involving feed and environment. The unifying concept in intake is the plane of

nutrition, which is set by the circumstances of the animal in its environment, whether artificial or natural. An animal will achieve the most advantageous food intake to satisfy its desires within the limits of its environment. The concept and demonstration of satiety limits have generally been restricted to ruminants fed high-concentrate diets and are probably of secondary importance in forage-fed animals. The satiety control is not always a fixed limit as animals can adapt to limit the effect of a restriction and thus increase their DMI (Van Soest, 1994).

The scheme for determining the voluntary food intake of an animal is shown in Figure 1.2.1. Factors influencing intake may be broadly categorised as being due to characteristics of the animal, the feed or the environment (Bines, 1976). The animal has physiological demands due to maintenance needs and potential for production, as well as limitations such as gastrointestinal capacity (NRC, 1987). The feed and environment yield resources to an animal which allow it to carry out its functions. They are also the source of constraints which may act to prevent the animal carrying out those purposes (Emmans and Oldham, 1988). Accurate estimates of feed intake are vital to predicting rate of gain and to the application of equations for predicting nutrient requirements of beef cattle (NRC, 1996).

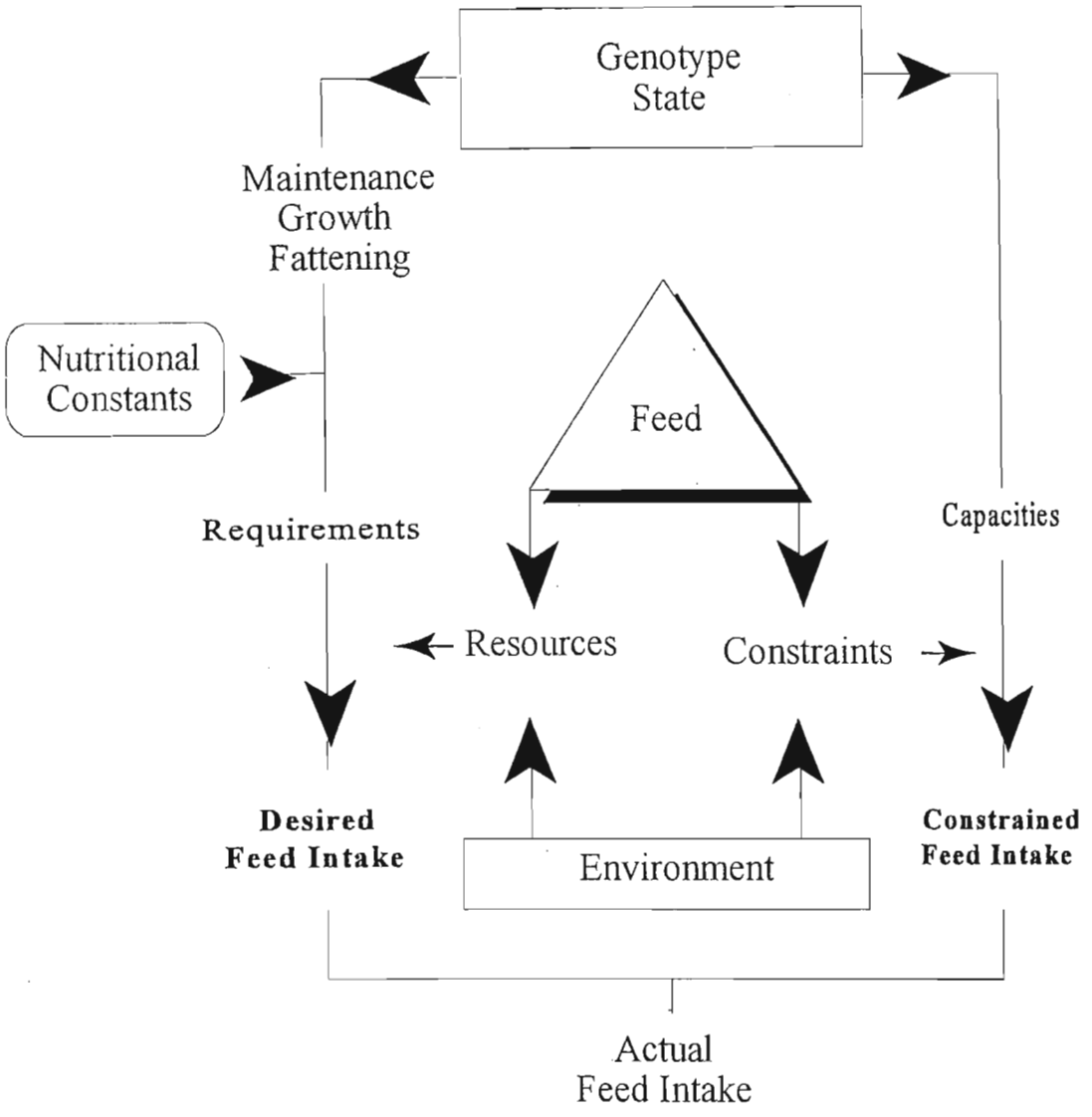

Figure 1.2.1 **A scheme for predicting growth and feed intake (after Emmans and Oldham, 1988).**

1.2.1 Physiological and physical factors

In general, the physiological state of an animal will influence food intake according to the demand for energy (Bines, 1976). The demand for energy can also be tempered by physical factors that inhibit the achievement of satiety . The following reviews the major physiological and physical factors that affect food intake.

1.2.1.1 Mature size

Cattle varying in mature size and sex differ in the weights at which they reach a given degree of maturity (measured as protein (kg) / protein at maturity (kg)) when consuming unrestricted a common diet, e.g. at a given body weight, heifers are more mature than steers. It follows, that animals of different gender, maturity type and degree of maturity would be expected to differ in their DMI (Hicks *et al.*, 1990*a*). The potential mature live weight of males being greater than that of females allows males the capability of a greater growth rate (kg / time or slope of the graph) (NRC, 1987). The higher growth rate potential of the males is reflected in a greater intake of food (Hedrick *et al.*, 1969), and ultimately a higher weight ($W^{0.75}$) at which feed intake begins to decline (NRC, 1987). Despite castration reducing the potential growth rate in the male, it is apparently without effect on intake due to a reduction in the efficiency of food conversion (Bines, 1976).

Intake differences among beef cattle breeds and their crosses may be accounted for largely by differences in mature size (NRC, 1987). Thus, the later maturing an animal, the larger its mature live weight and the greater its DMI. An apparent anomaly is that of Holstein and Holstein X beef crosses that may consume more feed relative to body weight than beef breeds. It is recommend by the NRC (1996) that intake predictions should be increased by 8 per cent for Holsteins and 4 per cent for Holsteins X British breeds crosses relative to British breed cattle. Differences in rearing management between calves of Holsteins and beef breeds may play a role in the usually higher feed intake of Holsteins during most of the growth period. Beef cows usually nurse calves until at least 7 months of age whereas Holsteins are weaned by 6 weeks of age. The early weaning of the Holstein calves results in them attaining a higher intake of ruminally fermented

feeds at early stages of growth. This results in Holsteins being more adapted to forage diets, but are also more likely to have been retarded in growth during pre-feedlot feeding and thus exhibit compensatory growth with the associated higher feed intakes during the feedlot period (NRC, 1987).

1.2.1.2 Age

Older animals (e.g., yearlings vs calves) typically consume more feed per unit BW than younger ones. This has been suggested to be in the region of 10 per cent, when animals of different ages are compared at similar weights and frame sizes (NRC, 1996). Presumably, the greater ratio of age to body weight (age relative to proportion of mature body composition) for yearling cattle prompts greater feed intake. This effect has been likened to increased feed intake by cattle experiencing compensatory growth (NRC, 1987). Other possible effects of age on appetite are likely to result from factors such as condition of teeth, and strength of jaw musculature, and are likely to act on the breakdown of fibrous constituents of food. They are probably only of practical significance where roughage forms a major part of the ration and in animals advanced in age such as old breeding cows (Bines, 1976).

A large proportion of the differences in DMI due to physiological factors is because of an animals degree of maturity. Instead, of directly adjusting for sex, for example, prediction equations for DMI incorporate a frame score equivalent weight (NRC, 1996). An example of such a system, is one for predicting the intakes of cattle varying in frame size and sex developed by Fox and Black (1984). The intake for alternative frame sizes is based on that used for an average-frame-size steer of equivalent body composition.

It is clear that an animal with a poor appetite cannot grow rapidly. Conversely an animal with a good appetite must use the energy it consumes either to produce milk or to produce body tissues. It is likely that this variability in partitioning energy is inherited (Bines, 1976). Genetic selection for feed efficiency could produce animals with increased feed intake potential, suggesting that genetic potential for growth (or increased production demands) may affect feed intake (NRC, 1996). This assumption, however, is dependent on the fact that the animals used as a base

judgement point are unlimited in their DMI. However, if they are limited in their DMI then any improvements in DMI are due to a lifting of the restricting factor on voluntary intake and not due to a genetic improvement with regards to DMI directly.

1.2.1.3 Abdominal volume

Abdominal volume affects intake by providing the space into which the rumen can expand during eating. Thus, as an animal grows, abdominal volume will increase thereby increasing the amount of food which can be eaten. Owens and Gill (1982) found that daily dry matter intake increased by 0.20 kg for every 50 kg increase in initial live weight above 277 kg, when placed on a high-energy diet, and it decreased by the same amount for initial live weights under 277 kg. However, this increase in intake during the growth of an animal, is not linear, but could vary in proportion to the metabolic weight of the animal. Intakes of 90-100 g per kg $W^{0.75}$ are maintained over the range 100-500 kg when a good quality ration is given (Bines, 1976). Abdominal volume as a restricting factor is closely related to the composition of the diet fed to the animals. It will affect animals fed a roughage based diet more than animals fed a concentrate based diet (see section 1.2.3).

1.2.1.4 Body composition

There is now positive evidence that body composition, especially percentage of body fat, has a controlling effect on feed intake. As animals mature, adipose tissue may, in some way, have a feed back role in controlling feed intake. This can have a dual reason. In terms of energy balance, a thin animal has a high requirement for nutrients for fat synthesis which is reduced or absent in a fat cow. In addition, where less concentrated rations are given, deposition of fat within the abdominal cavity will cause a reduction in the effective volume of the cavity into which the rumen can expand during feeding (Bines, 1976; NRC, 1987 and McDonald *et al.*, 1990). The composition of factors given above that body fat affects voluntary intake forms the basis of the *lipostatic regulation* theory.

1.2.2 Environmental factors

It appears that intake changes, due to environmental conditions, vary with changes in the animal's critical temperature (the point at which it must increase or decrease heat production to maintain a normal body temperature). The critical temperature is a function of age, body mass, hide, and external fat thickness, hair coat density and depth, and dietary energy density (NRC, 1987). The primary environmental effects on voluntary intake of cattle occur at temperatures greater than 25°C and less than 15°C and by exposure to wind, storms and mud (NRC, 1987). Below the critical temperature the animal has, by definition, to increase its rate of heat production in order to maintain its deep body temperature within the narrow range compatible with normal function. This increase in energy requirements results in an increase in food intake (Bines, 1976 and Forbes, 1986). Above the thermal neutral zone, body temperature rises and so food intake decreases in order to reduce the heat production associated with feeding, digestion, absorption and metabolism and to prevent an excessive increase in body temperature (Bines, 1976 and Forbes, 1986). This has been referred to as the *thermostatic regulation* theory. The effect of ambient temperature can be short term where an animal reduces or increases its heat production by altering its DMI for that day. It can also be long term, whereby, if the adverse temperatures are continuous and the animal is not able to fully adapt, then DMI will be continually heightened or lowered. An extreme situation can occur whereby continuous high temperatures prevent maintenance of energy balance and above 40 °C cattle of temperate breeds cease to eat altogether (Bines, 1976).

There appears to be an optional ratio of light to dark over a 24 hr period (NRC, 1987). Based on the deviation from the voluntary intake at 12 hours of daylight, voluntary intake would be expected to be 1.5 to 2 per cent greater in long-day months (July in the northern hemisphere) and 1.5 to 2 per cent less in the short-day months (January) (NRC, 1996). This diurnal pattern can be complicated by animals being stimulated to eat, when fresh feed is offered (NRC, 1987).

1.2.3 Management and dietary factors

A dietary nutrient deficiency especially protein has been clearly shown to reduce food intake (Bines, 1976). Nitrogen deficiency has been found to occur in low nitrogen, high fibre forages,

and provision of supplemental nitrogen often increases DMI substantially (NRC, 1996). The reduced intake due to protein deficiency may be attributed to a reduction in bacterial and protozoal cellulolysis in the rumen (Campling *et al.*, 1962) or to a reduced ability of the animal to handle the end products of digestion (Egan, 1965). A reduction in cellulolysis by not meeting the requirements of the rumen bacteria causes a reduction in diet digestibility and thus rate of passage (Van Soest, 1994). An evaluation of data from several studies indicated that most diets satisfy this requirement at 6 to 8 per cent crude protein, but 9 to 11 per cent crude protein may be required for calves, especially when highly digestible forages are the primary diet (NRC, 1987). A standard minimum of 12 per cent crude protein is found in feedlot rations which should satisfy the requirements as specified by the NRC (1987).

Considerable evidence exists that dietary bulk and consequent distension of the digestive tract limit intake (Van Soest, 1994). An increase in the dietary concentration of slowly degraded or indigestible material causes a reduction in the rate of passage and physical fill becomes limiting. For example, feeding a low digestible diet to a lactating cow will prevent her, probably because of fill limitation, from consuming enough feed to meet the requirements set by her level of production. Her production will then fall as body reserves are depleted, until the animal is able to adjust to the feeding situation (Van Soest, 1994). As the net energy concentration in the diet is increased, as in finishing diets, at some point metabolic controls become the dominant factors limiting intake (NRC, 1987).

Evidence that fill limits intake is also supplied by the increase in intake obtained by feeding ground or pelleted forage diets. Grinding and pelleting increase feed density and rate of passage (Bines, 1976; Van Soest, 1994 and NRC, 1996). Consequently, the effect of grinding on intake is inversely related to the quality of roughage. Intake is improved most with processing, where roughage is the major constituent, and the impact increases with increasing concentrations of plant cell wall and with alkali ammonisation or other treatments that increase the potential for cell wall digestion (Bines, 1976 and NRC, 1987). Grinding of concentrate rations may reduce intakes (Bines, 1976 and NRC, 1987). Where time of access to concentrates is very short, intake can be enhanced considerably by the use of slurries of concentrates in water (Bines, 1976).

Eating activity was also stimulated when fresh feed was offered (NRC, 1987). It appears that cattle use the same sensory cues as other mammals for the selection of food and it is quite likely that these cues play a role in initiating a meal (Bines, 1976). As an influence on the voluntary consumption of food, food availability will be of greatest consequence when animals are in competition for it (Bines, 1976). The likely effect of this factor on the intake of feedlot cattle is limited as the animals receive multiple feedings per day and competition for feed is reduced with the provision of ample trough space and *ad libitum* feeding.

There are other management factors that could affect the voluntary food intake but are uniform between animals and so will not provide an answer to the questions posed. For example growth promoting implants tends to increase feed intake. However, feed additives such as Monensin tends to decrease intake, however, Lasalocid seems to have limited effects on feed intake (NRC, 1996). Restricting water reduces dry matter intake and any factor that affects water consumption could reduce intake (Bines, 1976 and NRC, 1987). In the feedlot water availability is unlimited and so should not have an effect on intake of feed.

1.2.4 Optimisation approach

"The idea that animals are, at least in their natural environment, optimal systems follows almost inevitably from (1) the idea of Darwinian evolution and from (2) the presumed fact that the animals that we see around us are the outcome of selection operating to increase fitness over a very long period of time indeed" (Emmans *et al.*, 1995).

Ketelaars *et al.* (1992*a*) critically examined the current ideas about the causes of differences in voluntary feed intake, and particularly roughage intake, in ruminants. They found that explanations for differences have usually been based upon the explicit or implicit assumption that an animal seeks to obtain a genetically determined maximum growth and production rate and therefore required maximum nutrient intake and the subsequent failure of animals to achieve a maximum nutrient intake would be the consequence of constraints imposed on the intake process. There were however instances where animal's were able to increase their intake (i.e. during lactation and cold stress) when it was already supposed that they were at their maximum intake.

The authors went on to propose an alternative theory (Tolkamp *et al.*, 1992), starting from the idea that feed consumption presents both costs and benefits to the animal. For a non-reproducing animal, they considered the intake of net energy for maintenance and gain to be the benefits of feed consumption, and the concomitant consumption of oxygen costs, since the use of oxygen by tissues indirectly causes an accumulation of damage to cell structures, a loss of vitality, aging and a limited life span. This lead to the hypothesis that feed intake behaviour will be aimed at maximising the efficiency of oxygen utilisation : from each feed an animal will consume an amount that the intake of net energy per litre oxygen consumed will be maximal. On searching for a physiological background to their hypothesis these authors further hypothesised that optimum intake was linked to an optimum metabolic acid load (Ketelaars *et al.*, 1992*b*)

Emmans *et al.* (1995) in their paper examining the idea of optimisation in animals concluded that there are both opportunities and dangers in using the idea of optimisation. They went further to discuss the theory proposed by Ketelaars and Tolkamp. In three important ways the predictions of the theory were found to be contradicted by experimental evidence. These were : (1) the failure to deal with the changes in intake of a given food with degree of maturity of a particular animal; (2) the necessary, but apparently false, assumption of a diminishing marginal energetic efficiency above maintenance; and (3) the very small rate of change in the efficiency of using oxygen as dry matter intake changes around that which gives the maximum efficiency. The work by Tolkamp and Ketelaars resulted in accurate predictions of *ad libitum* intake of roughage-fed sheep and as concluded by NRC (1996) additional research will be needed to develop this theory further.

1.2.5 Deductions

The work covered in this section highlights the complex nature of the factors and their interactions that make up voluntary feed intake. Not only do some of these factors drive the demand for nutrients but others control the intake of nutrients. The intake of nutrients can also be divided up into short term, such as meal sizes, and long term, such as overall feed intake. The review has concentrated on those factors with a long term effect on the feed intake. The combination of these factors and how they interact to provide a level of production is best

illustrated in Figure 1.2.1.

The effect of physiological factors on feed intake is that of providing the requirement for nutrients. In general, the higher the mature live-weight of an animal, the faster the potential growth rate of the animal, and thus the greater the demand for nutrients to satisfy the growth rate. This basic breakdown helps explain a lot of differences observed between animals of different sex, maturity type and degree of maturity. The effect of age is also complicated by the chance of some animals having undergone restricted growth previously, which could result in compensatory growth when fed an unlimited diet. These factors all support the anomalies described in section 1.1.5, where the physiological differences between the animals (age, sex, maturity type and degree of maturity) and the associated differences in nutrient requirements are not fully reflected in the feed intakes of the respective animal groups.

The physical restriction imposed by abdominal volume is relevant in the discussion of the intake of roughage based but not that of concentrate based diets. This is supported in the work covered in sections 1.2.1 and 1.2.1.2. The abdominal volume of an animal will increase as the animal grows. If abdominal volume is limiting feed intake then feed intake will increase over time in proportion to the growth of the abdominal volume. During the plateau phase of the feed intake curve there is no increase in feed intake over time suggesting that abdominal volume is not a limiting factor. The length the plateau phase is comparatively short providing a limited period of time for abdominal growth and thus potentially only a small increase is possible which is not easily measurable. The deposition of fat within the abdominal cavity will not limit the growth in the abdominal volume until late in the feedlot period when the animal has deposited enough fat. The controlling effect of body fat levels is certainly illustrated by the decrease of the animals feed intakes as they approached slaughter weight in the trials done on American fattening regimes (Owens *et al.*, 1985; Thornton *et al.*, 1985 and Hicks *et al.*, 1990*a,b*). This restriction comes into effect only right at the end of the feeding period.

The feed intake curves illustrate a seasonal pattern suggesting that an environmental factor limits intake. The effect of ambient temperature on feed intake seems to be dependent on an animal's critical temperature. If the critical temperature is threatened by being lowered then the animal

increases feed intake in an attempt to increase heat production, and the reverse is true if the critical temperature is threatened by being raised. The more defined plateau shown in summer months indicated that the controlling forces are at their most stringent during this period. As temperatures are at their highest in summer, the voluntary feed intake may be restricted by heat stress. The ability to increase intake in other seasons is related to an animal's ability to lose heat in the cooler ambient temperatures. All the factors listed by the NRC (1987) as factors that affect the critical temperature are factors that may play a role in the differences illustrated between the feed intakes of the different groups of animals. The optimum ratio of light to dark does not appear to have an effect on the feedlot animals. The optimum light to dark ratio will benefit (enhance feed-intakes) summer months the most due to the longer day lengths. Feed-intake is however reduced during these months. However, this measurement is compounded with the occurrence of improved feed quality for foraging animals in summer; thus the animals that forage for food are likely to increase their feed intake for this reason.

In most cases the deficiency of a nutrient would be expected to result in an increase in food intake due to a desire to compensate for the deficient nutrient. However, when the nutrient itself is essential for the digestion of the food, as is the case with protein, then food intake can be reduced if the nutrient is limiting. The level of crude protein in feedlot diets is generally set at a minimum of 12 per cent, which far exceeds the minimum requirements suggested by the NRC (1987).

Dietary bulk does not limit the intake of concentrate fed animals. The diets fed to feedlot animals are high in net energy concentration and low in slowly degrades or indigestible material. This also applies to the effects of grinding and pelleting feeds. Potential improvements due to grinding or pelleting of feeds will be limited in feedlot diets as mechanical processing of feeds benefits diets that are high in slowly degraded material best.

The provision of fresh feed as an eating stimulant is well recognised in feedlot management. Animals are generally fed at least twice a day , providing a continuous source of fresh feed. The use of growth implants and feed additives are also generally used when the market allows for it. These factors are used across groups and therefore do not account for differences or lack of, between animal types with respect to feed intake although these factors may interact with others

to enhance or depress the control of DMI.

The optimisation theory proposed, was built primarily on data and anomalies through the feeding of roughage diets differing in quality. On this basis and on the basis of points raised by Emmans *et al.* (1995), this model has potentially limited effect on the problems raised over the feed intake curve of the feedlot animals.

Further investigation needs to cover the role of heat stress on the feed intake of cattle. The review must cover the parameters listed by the NRC (1987) that have an influence over the critical temperature of an animal. The work should also encompass possible ways of manipulating the heat load on a feedlot animal in order to determine whether heat stress is indeed the factor limiting the intake of the feedlot animal during the plateau phase of the feed intake curve.

1.3 Optimum environment for cattle

An optimum environment is defined on the one hand, in animal terms of production and efficiency and on the other hand, from the standpoint of management, economics, and constraints such as energy availability. As production levels increase, environmental factors increase in relative importance to nutrition and genetics until environmental factors eventually become the limiting factor. However, a reasonable level of environmental modification to maintain the productive function is also quite dependent on the potential returns, which in turn is related to the level of production of the specific animals and the cost of the environmental modifications. The optimal environment is therefore that in which a particular combination of genotype, nutrition, and management will operate at their highest efficiency, the corollary being that the optimal environment can only be defined in terms of each unique enterprise (Webster, 1976).

Primault (1979), described the environment for each category of domestic animals as being made up of thermal zones that differ from each other in the amount of work required by the animal to maintain its body temperature at its optimum level. It can be deduced from Primault's description of an animals environment, that an animal utilises energy in some conditions in order to maintain itself in an acceptable framework. This utilisation of energy imposes an inefficiency on the animal

and can be measured in terms of heat production (HP). Figure 1.3.1 shows the relationship between heat production and ambient temperature. Figure 1.3.1 illustrates a thermal neutral zone (TNZ) (AD) which is bounded at its lower end by the lower critical temperature (LCT) and at the upper end by the upper critical temperature (UCT) (Yousef, 1985). Examples of the TNZ's, UCT and LCT for a range of cattle varying in breed, age, production levels, and environment are given in Table 1.3.1.

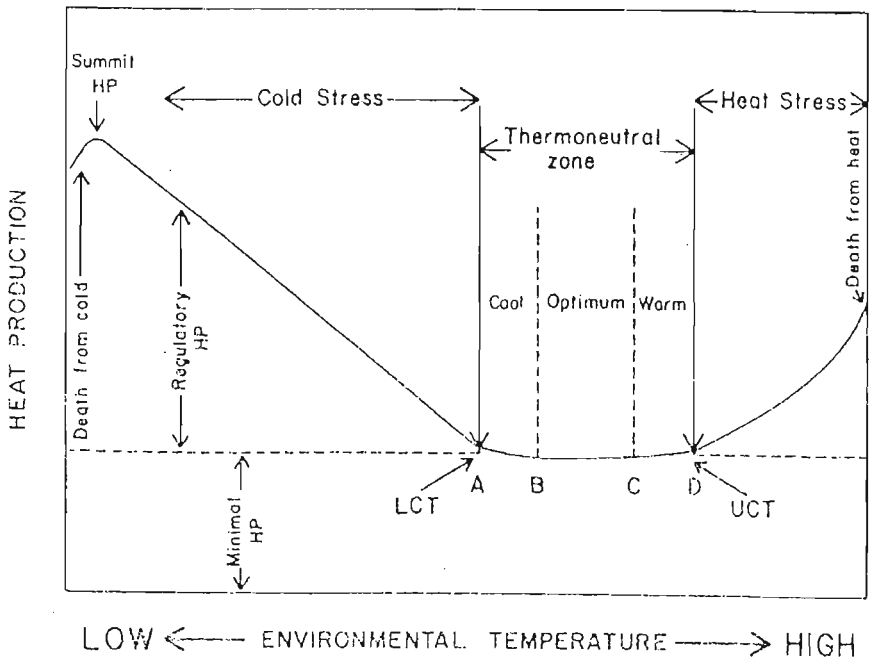

Figure 1.3.1 Diagrammatic representation of heat production as a function of ambient temperature (from Yousef, 1985)

Table 1.3.1 The lower critical temperatures, thermal neutral zones, and upper critical temperatures of cattle at different ages, productions levels, breeds, and planes of nutrition.

Type of cattle	LCT	TNZ	UCT	Reference
Cow	0-4°C	0 - 16°C		(Bianca, 1970).
Calf	12-14°C	13 - 25°C		(Bianca, 1970).
Cattle (in a feedlot)	-18°C			(Birkelo *et al.*, 1993).
Holstein dairy cows		22°C		(Bond, 1967).
European cattle		-1.1 - 15.6°C	26.7°C	(Brody, 1956).
Indian cattle		10 - 26.7°C	35°C	(Brody, 1956).
Heifers		20+		(Chudy, 1998).
Beef cattle		4 - 26°C[1]	32°C[2]	(Hahn, 1974).
Growing *ad-lib*-fed cattle		25°C		(Hahn *et al.*, 1993).
		13 - 18°C		(McDowell, 1974).
English beef cattle		21°C		(Morrison *et al.*, 1979).
Beef cattle		15 - 25°C		(NRC, 1996).
Cow		0 - 15°C		(Primault, 1979).
Calf		13 - 25°C		(Primault, 1979).
English beef steers		20°C		(Robinson *et al.*, 1986).
Steers[4] : fasting	18°C			(Smith, 1970).
Steers[4] : maintenance	7°C			
Steers[4] : 500g daily gain	-1°C			
Lactating cows[3] : Holstein	-6.1°C		26.7°C	(Yousef *et al.*, 1966).
Lactating cows[3] : Brahman	2.8°C		35.0°C	

[1] = Acceptable temperatures for long-term exposure (concurrent relative humidity less than 75%). The range should be shifted downward at least 3°C for high radiant heat loads (greater than 1 cal/cm^2-min).

[2] = Acceptable for short duration (not to exceed 1 hour and only when relative humidity is low to moderate (less than 50 %)).

[3] = Experimental animals in thermal environments without exposure to strong radiant heat loads, the threshold for stress above which performance is likely to be reduced.

[4] = coat character normal and 8mm in length

1.3.1 Thermoneutral zone (TNZ)

A paper was circulated to participants after the Twentieth Easter school in agricultural science (Mount, 1974). It had become apparent that a concept as important as that of thermal neutrality needed a clear and generally acceptable definition. This paper marks a watershed in the definition and terminology used to describe the concept of thermal neutrality.

It was suggested that a zone of 'least thermoregulatory effort' should be delineated, and defined as that range of environmental temperature in which, for a given level of feeding, the metabolic rate of an individual resting animal is at a minimum and in which evaporative heat losses did not increase as the result of sweating or increased respiratory ventilation. 'Environmental temperature' in this connection refers to air and mean radiant temperatures, equal to each other in a regime of free convection at a relative humidity arbitrarily held at 50% (Mount, 1974). To which Dr Bianca commented with a simplified definition; the thermoneutral zone is the range of environmental temperatures in which the animal neither combats cold by raising its heat production, nor heat by increasing its rate of evaporation from sweating or panting or both, and in which behavioural thermoregulation is normally absent.

From a fairly extensive range of recording, a thermal neutral zone (TNZ) may be determined by using as its lower limit the LCT and as its upper limit UCT the environmental temperature at which evaporation (from the skin or the respiratory tract) begins to rise (critical temperature for evaporation). Within this temperature zone, therefore, the animal is at normal body temperatures, without increase in heat production from combatting cold by accelerating its metabolism or from combatting heat by sweating or panting (Yousef *et al.*, 1966; Bianca, 1970 and Folk, 1974).

The TNZ shown in Figure 1.3.1 is subdivided into three subzones which are "neutral" in different respects: optimum, cool, and warm zones. The optimum zone (BC) is the range of ambient temperature (Ta) where optimum productivity, efficiency, and performance is demonstrated. Within the optimum zone the animal does not activate thermo-regulatory physical and chemical devices. The environmental temperature is perfectly adjusted to keep the body temperature normal and the animal apparently feels neither hot nor cold (Yousef *et al.*, 1966). The cool zone

(AB) is the range of Ta where heat production remains minimal and the animal conserves energy by behavioural or autonomic mechanism rather than increasing its HP. The warm zone (CD) is the range of Ta where HP is minimal, and the thermoregulatory responses are limited to vasodilation and increasing the surface area by behavioural means rather than increasing evaporative heat loss (Yousef, 1985). Zones may also be defined for particular purposes, preferred thermal environment (comfort zone), animal productivity, and zones which are optimal in any given respect such as growth rate; these zones do not necessarily coincide with either minimal metabolism or least thermoregulatory effort (Yousef, 1985).

Zones of thermoneutrality are dependent upon the functioning of homeothermic and thermo-regulatory mechanisms. These mechanisms include the temperature regulation centres in the hypothalamus and the neuro-endocrine system and related physiological factors (Yousef *et al.*, 1966). The width of the TNZ is the combination of climatic factors e.g. temperature, humidity, and radiation that an animal has the ability to physiologically adjust to (Table 1.3.1). The width of the TNZ depends on age, species and breed, level of nutrition, previous state of temperature acclimation or acclimatization, level of productivity, specific housing and pen conditions, insulation, including tissue insulation (fat, skin), and external insulation (coat), behaviour, etc. The TNZ of animals of the same species and age can shift to the right or left, i.e. the LCT and UCT can increase or decrease, depending upon the same factors mentioned to influence the range of TNZ (Yousef *et al.*, 1966; Smith, 1970 and Yousef, 1985).

The comparison of young animals with adults, finds that the TNZ moves towards lower temperatures as an animal ages (Bianca, 1970 and Primault, 1979). For example, a 50 kg calf will feel comfortable at 18°C, while a 200 kg calf will begin to pant at the same temperature, showing signs of heat stress but will feel comfortable at only 12°C (Primault, 1979). The TNZ for young animals is also much narrower than for adult animals, although this is limited in cattle due in part to the hair coat insulation (see section 1.5 for details on insulation and heat loss) of the calf differing relatively little from that of the cow. The TNZ lying at higher environmental temperatures in younger animals as compared to older animals is as a result of both critical temperatures being higher in the young animals, due to an increased sensitivity to cold and a decreased sensitivity to heat (Bianca, 1970).

The higher the level of production of an animal, the lower the TNZ, and the greater the need for environmental control (Brody, 1956; Smith 1970; Hahn, 1974 and Primault, 1979). In the case of 200 kg beef steers in a feedlot, a temperature of 20°C is ideal but this should be gradually lowered to 10°C for 500 kg animals (Primault, 1979). Comparison between Holstein, Jersey, Brown Swiss and Brahman cattle found the width of the thermoneutral zone to be approximately the same, but the boundaries or the critical temperatures varied considerably among breeds (Yousef *et al.*, 1966). The differences in critical temperatures are due to factors associated with heat production and heat dissipation (see sections 1.4 and 1.5 respectively) that are, in general, concerned with physical and chemical heat regulatory mechanisms, and the relative efficiencies of these mechanism between breeds (Brody, 1956 and Yousef *et al.*, 1966).

1.3.2 Lower critical temperature (LCT)

The LCT has been estimated as the intercept between the slope of the line representing the increment of metabolic rate in the cold and the line describing this rate in the thermoneutral zone (Folk, 1974). When the animal is faced with an Ta below the LCT, it must increase its HP to maintain homeothermy. The animals rate of metabolic heat production (HP) increases in comparison to its resting thermoregulating heat production rate by a degree dependent upon the thermal demand. The increase in HP is achieved by shivering and/or nonshivering thermogenic processes. Therefore, the degree of cold tolerance of an animal is determined primarily by its maximum or summit regulatory HP. If the ambient thermal demand exceeds the summit HP, hypothermia, and in extreme cases death, ensues (Yousef, 1985).

1.3.3 Upper critical temperature (UCT)

The UCT is the Ta at which the physical temperature-regulatory mechanisms can no longer maintain a normal body temperature (Tb) and metabolic rate (Folk, 1974 and Yousef, 1985). Thus the thermoregulatory evaporative heat loss processes of a resting thermoregulating animal are recruited to prevent an explosive rise in body temperature. Above the UCT, the animal increases its heat production as a consequence of a rise in body temperature resulting from inadequate evaporative loss. As the warmth of the thermal environment exceeds the capacity of

the animal's evaporative heat loss, an explosive rise in body temperature occurs and death ensues (Yousef, 1985).

1.3.4 Homeothermy

Homeotherms, are a group of animals (e.g. mammals), that maintain an almost constant, long term mean, deep-body temperature, with considerable precision, over a wide range of environmental temperature changes (Aschoff *et al.*, 1974; Hey, 1974; Kleiber, 1975; Primault, 1979 and Robertshaw, 1985). This temperature is nearly the same for all homeotherms (Kleiber, 1975). Table 1.3.2 lists the body temperatures measured on cattle (homeotherms) under different ages, ambient temperatures, degree of acclimatisation, plane of feeding and levels of production.

The body temperature is maintained through the control of metabolic heat production (HP), and external heat gains (solar radiation) and losses through evaporative and non-evaporative avenues (Aschoff *et al.*, 1974; Robertshaw, 1985; Garner *et al.*, 1988 and Brosh *et al.*, 1998). The relationship is indicated by the equation :

$$M = +/- K +/- C +/- R + E$$

where M = the metabolic heat production

K = the heat exchanged by conduction

C = the heat exchanged by convection

R = the heat exchanged by radiation

E = the heat exchanged by evaporation

For an animal in complete thermal equilibrium there will be no change in heat storage, however, at any one instant in time there is never a complete balance and a value for rate of heat storage can be added to the equation recognising that this would be a non-steady-state condition (Robertshaw, 1985). When heat loss does not equal heat gain, either a lowering of the body temperature, or a rise in body temperature occurs (Johnson, 1967; Whittow, 1971; Primault, 1979 and Brosh *et al.*, 1998).

The ambiguities in describing and defining the zone of thermoneutrality represent no more than the varied viewpoints of homeothermy, i.e., one's reason or interest for describing the zone. Homeothermy has been viewed from the theoretical, agricultural, and engineering perspectives. The theoretical aspect is concerned with homeothermic mechanisms; the agricultural, with the influence of the thermal environment on productivity and energetic efficiency of livestock; the engineering, with housing, i.e. ventilation and air conditioning (Yousef, 1985).

Table 1.3.2 Range of rectal temperatures of cattle at different ages, ambient temperatures, degree of acclimatisation, plane of feeding and levels of production.

Conditions	Rectal temperature	Reference
Ayrshire bull calves (9 months old) :		Bianca, (1963)
normal[1]	37.81 to 38.22°C	
30°C to 40°C (varying humidity)	39.51 to 42.0°C[2]	
Beef cattle at 41.66°C	40.0 to 41.7°C	Bond, (1967)
Yearling Hereford heifers : Low ME	37.6 to 38.6°C	Brosch *et al.*, (1998)
Yearling Hereford heifers : High ME	38.0 to 39.5°C	
Charolais X Angus steers at 15°C	38.0°C	Degen *et al.*, (1993)
Brahman X Hereford cattle[3]	39.1 to 39.8°C	Finch, (1986)
Bos taurus : non- acclimatised[4]	38 to 41°C	Finch, (1986)
Bos taurus : acclimatised[4]	38 to 39°C	
Hereford X Shorthorn at 30°C :	39.58 to 40.23°C	Frisch, (1981)
TNZ Normal homeotherm temp	38.5°C	Garner *et al.*, (1985)
Bos taurus steers (10 to 30°C)	38.2 to 38.6°C	Hahn *et al.*, (1990)
Bos taurus X *Bos indicus* yearlings[5]		Liang *et al.*, (1998)
Low level of feeding	37.1 to 38.7°C	
High level of feeding	37.5 to 39.1°C	
TNZ Normal homeotherm temp	38.33°C	Manuel, (1954)
Bos taurus X steers (10 to 28°C)	38.4 to 38.8°C	Ole Miaron *et al.*, (1992)
Bos taurus X steers (20 to 35°C)	38.5 to 39.9°C	Robinson *et al.*, (1986)
TNZ Normal homeotherm temp	38 to 39°C	Smith, (1970)

[1] = Before exposure to the heated climatic room

[2] = Exposure terminated on reaching a rectal temperature of 42.0°C

[3] = Effective environmental temperature of 44°C outdoors in sunshine

[4] = Equatorial environment of Kenya

[5] = Diurnal cycle

1.3.4.1 Core temperature fluctuation

Animals function in a dynamic environment, and their resultant thermoregulation is an illustration of a dynamic process to maintain a constant body temperature. Phasic and rhythmic responses are observed from short-term changes in body temperature which reflect temporary imbalances in heat production and heat dissipation. Those imbalances are as a result of exogenous or endogenous factors, such as the thermal environment and metabolic processes linked with feed intake (Kleiber, 1975; Hahn *et al.*, 1993 and Mundia *et al.*, 1997). This results in a fluctuation between a maximal and a minimal value once every twenty four hours (Aschoff *et al.*, 1974 and Mundia *et al.*, 1997). The diurnal fluctuations in core temperature are illustrated in Figure 1.3.2. Assuming that there are short steady states during the times of maximal and of minimal body temperature, one has to conclude that heat loss has a rhythm somehow in phase with the rhythm of heat production (Aschoff *et al.*, 1974).

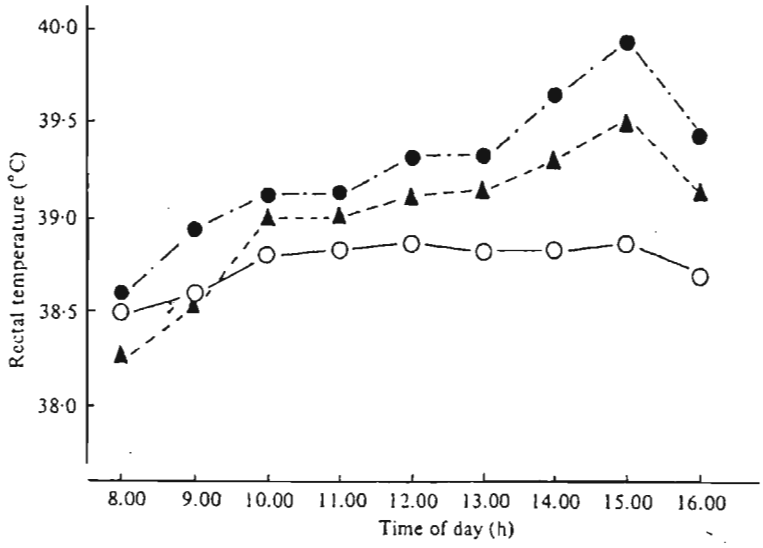

Figure 1.3.2 Least-squares mean rectal temperature for each hour of measurement for each of three breeds. • Brahman; ○ Brahman X Hereford-Shorthorn cross-breds; ▲ Shorthorn (from Finch *et al.*, 1982)

The rhythm of body temperature fluctuation is monophasic with the maximum and minimum levels being determined by heat loss and heat production balances. In general, the body temperature of cattle exhibits, a high during the day (midday) and a low during the night through to the early

morning (4 to 8 am), coinciding roughly in time, with fluctuations in environmental temperature (Whittow, 1971; Finch *et al.*, 1982; Nakamura *et al.*, 1993; Mundia *et al.*, 1997 and Liang *et al.*, 1998). The plane of nutrition and time of feeding affects the rhythm in relation to the balance of heat energy. Animals eating during the day will have an elevated body temperature during the day, due to metabolic heat production and ambient temperature. However, if the animals are fed or choose to eat later in the day their body temperatures will be elevated only later in the day and be due more to the metabolic heat production than to the ambient temperature (Hahn *et al.*, 1990; Hahn *et al.*, 1993; Mundia *et al.*, 1997). The diurnal fluctuation (0.5°C to 2.2°C) varies between individuals, level of feeding, environment, and is greater for animals outdoors (Whittow, 1971; Robertshaw, 1985; Hahn *et al.*, 1990; Hahn *et al.*, 1993 and Liang *et al.*, 1998).

There are thresholds of thermal conditions, which are variable among individual animals, beyond which body temperature is "thermally-driven" (entrained) and rhythms may be disrupted (evidenced by changes in phase, amplitude, and mean) upon exposure to elevated ambient conditions (Hahn *et al.*, 1990 and Hahn *et al.*, 1993). Firsch (1981) imposed different levels of feeding (thus heat loads, see section 1.4.1.1.2) on environmentally heat stressed animals. Maximum rectal temperatures were reached sooner in those animals with the higher heat stresses, those animals fed a diet with a high heat load. Body temperature typically lags air temperature by two to five hours in such conditions (Hahn *et al.*, 1990). Physiological acclimation to an elevated environmental temperature is reflected in tympanic temperature rhythm, with the acclimation rate for individual cattle varying from about 0.1°C to 0.4°C per day (Hahn *et al.*, 1990 and Hahn *et al.*, 1993).

1.3.4.2 Measuring core temperature

It is presumed that cattle which remain more thermostable in the face of radiant conditions are more heat tolerant and thus more productive. The most commonly used measure of body temperature for the judgement of an animals efficiency in maintaining homeothermy is rectal temperature (Bianca, 1959*a* and Finch *et al.*, 1982). Kleiber (1975) reported that Burton, (1935) attempted to derive a weighted mean of temperature measurements in different parts of the body. Noting that the surface of the body has a temperature about 4 or 5°C lower than the rectal

temperature, and that only at a depth of several centimetres is the temperature the same as that in the rectum, he formulated :

$$T_B = 0.65T_R + 0.35T_S$$

where T_B = mean body temperature

T_R = rectal temperature

T_S = surface temperature (mean of several places)

This formula indicates that more than 35% of the mass of the body has a temperature below that of the interior (or the rectal temperature). Biological clocks and circadian rhythms should have a part in the design of each biological experiment. Careful selection of appropriate and consistent times for a singular or a few daily measures of body temperature is needed to assure representative values. The reason for this is that each experimental animal, whether man or rat, is a different individual (physiologically speaking) at noon or at midnight (Folk, 1974 and Hahn *et al.*, 1990).

1.3.4.2 Effects of a rise in core temperature

Heat tolerance in its widest sense has been described as the ability of the body to endure the impact of a hot environment without suffering ill-effects. The most serious ill-effect on an homeothermic animal exposed to heat is a displacement of its body temperature from the normal range (Bianca, 1963). Body temperature is determined by heat input from metabolic heat production and solar radiation and by heat output through evaporative and non-evaporative avenues. When heat dissipation does not attain heat gain, heat is stored, with a resultant increase in body temperature (Johnson, 1967 and Brosh *et al.*, 1998). An increase in body temperature can also constitute a thermoregulatory mechanism because variations in body temperature alter the temperature gradient between the animal and its environment, and therefore the heat loss (Whittow, 1971). However, changes in body temperature above or below certain thresholds may cause the death of the individual (Primault, 1979).

Heat tolerance in a narrower sense may be defined as the ability to maintain normal body temperature in a hot environment (Bianca, 1963). In a hot environment, an animal's body

temperature may rise but still be regulated at this higher level. This phenomenon may be called controlled hyperthermia (Kleiber, 1975). Tropical cattle have been shown to have higher deep-body temperatures at low environmental temperatures, whereas, temperate cattle have higher temperatures in a hot environment, while in the thermoneutral range of environmental temperature there may be little difference between the two species (Whittow, 1971). Calves achieve thermal equilibrium at progressively higher deep-body temperatures when the environmental temperature increases in the range 20°-45°C (Whittow, 1971).

1.4 Heat gain

Body temperature depends on the balance of the heat energy equation (gains = losses). Heat input is mainly in the form of heat produced within the animal and solar radiation (McDowell, 1974 and Brosh *et al.*, 1998). Heat produced within the animal can be divided into basal metabolic heat production and heat associated with performance. McDowell (1974) advises that in extreme environments, within animal heat productions should be divided into the individual circumstances that led to the production of heat. Efforts at heat partitioning indicate that heat arises from a) basal body functions, b) daily maintenance, c) behaviour, d) performance, e) management, and f) the extra heat arising from efforts at thermocompensation.

The heat production of an animal at thermal neutrality is a function of its size, its activity and the quantity and quality of food that it eats (Webster, 1976). Heat stress has the potential to be a greater commercial problem than cold, because animals that have more to eat and those that grow faster have a higher metabolic heat and are therefore more sensitive to heat stresses (Webster, 1976).

1.4.1 Sources of heat

The two main sources of heat for a homeotherm are, heat from the digestion and absorption of nutrients, and solar radiation.

1.4.1.1 Partitions of food energy

An animal obtains energy from its food. The maximum quantity of energy present in a food is measured by the heat of combustion of that food. This is its gross energy (GE). The GE of a food is an inaccurate estimate of the energy available to the animal as it fails to take into account losses from the body as chemical energy, or losses as superfluous heat production.

1.4.1.1.1 Chemical energy losses

Chemical energy losses are as visible excreta and combustible gases. The digestible energy (DE) is the energy remaining after taking into account the losses due to the energy contained in the faeces (FE). The animal has further losses as energy-containing substances in its urine (UE) and combustible gases leaving the digestive tract, which consist almost entirely of methane (MTHE). The energy remaining was named metabolizable energy (ME) by Armsby (1903).

$$ME\ (kJ / d) = GE - (FE + UE + MTHE)$$

The ME of a food is normally measured at maintenance, but a necessary condition is that the rate of protein retention is zero. ME is therefore corrected (ME_n) for any nitrogen retention (NR) and the energy required to retain that nitrogen (a = 5.63 kJ / g) (McDonald *et al.* 1990 and Emmans, 1994).

$$ME_n\ (kJ / d) = ME - a(6.25NR)$$

1.4.1.1.2 Heat energy losses

From the principle of the conservation of energy the ME yielded to an animal by its diet can appear only as heat production (HE) or retained energy (RE).

$$ME\ (kJ / d) = HE + RE$$

HE can be divided into the fasting heat production (FHP) and the heat increment of feeding (HIF). The FHP is the rate at which an animal produces heat when given no feed and the HIF is the increment in heat production resulting from feeding. The HIF is made up of heat produced by the energetic inefficiency of the reactions by which digested nutrients are absorbed; inefficiency in the synthesis of body constituents; the processes of digestion and its attributable work done within the body; and the heat of fermentation (McDonald *et al.* 1990; Emmans, 1994 and NRC, 1996). Fermentation in the diverticulated, gastrointestinal tracts of ruminants is a large source of heat. Large numbers of microorganisms reside and are associated with a complex assortment of exothermic fermentations (Whittow, 1971).

The deduction of the HE from ME gives the net energy value of the food. The net energy (NE) of a food is that energy that is available to the animal for useful purposes. NE was initially calculated by determining the differences in retained energy (RE) at two or more amounts of intake energy (IE). This assumes that the relationship between RE and IE is linear. Garrett and Johnson (1983) found that the relationship was curvilinear with a diminishing return effect. The NE system provides the energy value for different physiological functions (NE for maintenance (NE_m); NE for gain (NE_g)) separately.

$$ME = NE_m + NE_g + H_iE$$

There is still part of the HE not accounted for (H_iE), which is the heat increment associated with the feed consumed for maintenance and each of the productive functions (McDonald *et al.* 1990 and NRC, 1996).

A system that accounts for the energy loses, allows for the energy retained as protein or lipid to have differing energetic efficiencies and is tabulatable as the Effective Energy system (Emmans, 1994). From the following equation :

$$ME\ (kJ / d) = ER + MH + HIF$$

Emmans described the FHP as the maintenance heat production (MH) plus the heat of excretion (HEX) associated with the synthesis and excretion of nitrogen-containing compounds in the urine. He concluded that the MH depended only on the kind of animal and its state. The ER consists of the rates of protein and lipid retention. The ME needed by a given animal in a given state to attain some particular level of performance depends only on the HIF. The HIF was considered linearly related to five measurable quantities with their respective heat increments.

$$HIF = w_d.FOM + w_u.UN + w_m.MTHE + w_p.PR + w_l.LR$$

where : FOM = faecal organic matter; w_d the heat increment (3.80 kJ / g)

UN = urinary nitrogen; w_u the heat increment (29.2 kJ / g)

MTHE = methane energy; w_m the heat increment (0.616 kJ / kJ)

PR = positive protein retention; w_p the heat increment (36.5 kJ / g)

LR = positive lipid retention; w_l the heat increment (16.4 kJ / g)

From these values the energy scale Effective Energy is defined (Emmans, 1994).

1.4.1.2 Radiation

Radiation is the process by which energy is transferred by means of electromagnetic waves and does not require a material medium. All bodies, whether hot or cold, continuously radiate and absorb energy as electromagnetic waves. The wavelength spectrum is divided into short waves (relate to the sun) and long waves (between an animal and its surroundings). The surface of an object plays a significant role in determining how much radiant energy the object will absorb or emit. The solar heat load is direct sunlight impinging on the surface of the animal and solar beams reflecting from the ground - the amount reflected depending on the colour and the presence of vegetation. The magnitude of a solar heat load also depends on the surface area exposed to the radiation and the colour and structure of the coat. The rougher and darker a surface the more radiant energy the object will absorb. A black fur will have an absorbency of essentially one, whereas a white fur has an absorbency of 0.37, and red fur 0.65. If the coat is smooth and sleek with all the hairs aligned in the same direction then the fur surface will present an even surface to

the solar beam and the amount of heat absorbed will be a function of the fur colour. If the fur is irregular then it is possible that with light-coloured coats part of the solar beam will be reflected into the coat and absorbed close to the skin; that is it will penetrate the fur (Robertshaw, 1985).

Shelter is provided to cattle to protect against the heat load from solar radiation. Usually the use of shelter is at the discretion of the animals. It has been determined that the use of shelter depends on the time of the day and season, with steers fed during the summer utilizing shade more during the daylight hours, but less at night, than animals fed in the winter (Ray *et al.*, 1971 and Hoffman *et al.*, 1973). Within a day in summer, cattle use shelter to the greatest extent between 9.00 am and 6.00 pm which is the time of highest daily temperatures (Hoffman *et al.*, 1973). This shows that the heat load from solar radiation is more apparent in summer. As the description of radiation allows, the heat load from radiation (measured as changes in the deep-body temperature) is higher in an animal with a dull coat than in an animal with a glossy coat. This is illustrated in the sleek summer coat of cattle with the corresponding increase in heat tolerance as compared to the dull wooly coats in winter (Whittow, 1971 and Bonsma, 1980).

Measurement of the surface temperature of cattle provides a more direct method of detecting the effect of solar radiation on an animal. It has been demonstrated that the body surface temperatures peak much higher for black and red cattle than for white cattle. The surface temperatures of black steers are consistently higher (mean of 6.2 per cent) than for steers with a red coat colour (Arp *et al.*, 1983*a*). Differences due to coat colour are less during the early morning and late evening (Arp *et al.*, 1983*b*). Comparisons of predominantly black or predominantly white Holstein steers in one pen suggest a direct correlation between respiration rate and surface temperature. The respiration rate of black Holstein steers was 35 per cent greater ($P<.05$) and the surface temperature was 14 per cent greater ($P<.05$) than for white Holstein steers (Arp *et al.*, 1983*b*).

The heat from solar radiation has been observed to affect the level of production of feedlot cattle. The provision of shelter for cattle allows for increased daily consumption of food, with corresponding significantly faster gains than cattle without shelter (Self *et al.*, 1974). The provision of shelter is however only an improvement in summer but does not always improve feed intakes (Hoffman *et al.*, 1970). The varying heat loads associated with animals of different coat

colours is manifested in their feeding habits. Black steers tend to feed more in the morning during periods of low solar radiation loads than red steers that fed more in the afternoon and evening (Arp *et al.*, 1983*a*).

1.4.2 Regulation of heat gain

Sensing of temperature and the resultant thermoregulation depends upon both central and peripheral nervous control (Folk, 1974; Kleiber, 1975 and Robertshaw, 1985). The sensing of temperature is a function of specific cold and warm receptors located principally either in the skin (peripheral) or in the hypothalamus of the brain and the spinal cord (central) (Folk, 1974 and Kleiber, 1975). Peripheral thermoreceptors are thought to comprise specialised nerve cells, each of which sends out impulses at some characteristic temperature. The receptors appear to work as a series of receptors sensitive to a range of temperatures (35 to 42°C) (Kleiber, 1975). The receptors relay messages to the hypothalamus through neuro-regulation of endocrine release or blood temperature (Wilson, 1967). Temperature fluctuations change the magnitude and nature of the sensory input to the hypothalamus (Kleiber, 1975). Information from these receptors is integrated within the hypothalamus and the appropriate responses are activated. The thermodetectors of the brain have been isolated to the preoptic region and the anterior hypothalamus (Whittow, 1971 and Kleiber, 1975). Although not identified histologically, when the anterior hypothalamus was stimulated with localised warming and cooling there were responses and electrical changes over a series of characteristic temperatures (Kleiber, 1975). Regulation of heat loss is attributed to the anterior portion of the hypothalamus and the regulation of heat production to the posterior portion (Wilson, 1967).

Homeostasis depends on the ability of an animal to detect and interpret a disruption in its internal equilibrium. Through a negative feedback function the animal will initiate appropriate behaviour and (or) metabolic responses to restore homeostasis. Often more than one response is evoked when an animal is challenged, and the tendency is for activation of more responses with greater deviation from the normal homeostatic level. Furthermore, when one response capacity is denied or exhausted, others are enlisted (Young *et al.*, 1989). An initial increase in heat production during exposure to cold is determined by the rate of change of temperature of the receptors in the

skin. While the level of heat production during prolonged exposure to cold is determined by the absolute temperature of peripheral and central receptors (Whittow, 1971). The conscious sensation of either heat or cold from the hypothalamus allows for the measuring of behavioural responses to indicate an animal's stress level (Robertshaw, 1985).

The experience of an increase in heat load stimulates an animal to activate its behavioural response mechanisms first (Hey, 1974 and Hahn *et al.*, 1993). The behavioural response affects predominantly the heat loss mechanisms available to an animal discussed in section 1.5.2. With a heat load, the hypothalamus will attempt to sustain homeothermy by reducing its heat production using internal physiological means. The hypothalamus regulates other endocrine glands (the thyroids and the adrenals) to decrease the release of thermogenic / calorigenic hormones (thyroxine, adrenal cortical hormones, growth hormone, insulin and possibly others) which coupled with the reduction in feed intake will lower basal metabolism (Johnson, 1967; Wilson, 1967; Webster, 1976; Alnaimy *et al.*, 1992 and Ole Miaron *et al.*, 1992). A measured reduction of 80 per cent in thyroxine production results in a 32 per cent reduction in heat production (Kibler *et al.*, 1949). The depression in feed consumption is the most important response to heat exposure. High environmental temperatures stimulate the peripheral thermal receptors to transmit suppressive nerve impulses to the appetite centre in the hypothalamus causing a decrease in feed consumption. Thus, fewer substrates become available for enzymatic activities, hormone synthesis and heat production which minimises thermal load (Johnson, 1967 and Alnaimy *et al.*, 1992). The amplitude of the rumen contractions decrease during hot environmental temperatures but do not affect feed intake. Thus, rumen activity is depressed directly rather than indirectly via feed intake illustrating another method of reducing heat production (Attebery *et al.*, 1969). Exposure to heat stress depresses the concentration of volatile fatty acids in the rumen (particularly acetic acid) which reduces the heat increment of the diet (Whittow, 1971). If all these physiological mechanisms fail to balance the excessive heat load the body temperature rises and the animal enters the acute phase of heat stress (Alnaimy *et al.*, 1992).

1.4.2.1 Effect of heat gain regulation on feed intake

When feed is available above maintenance requirements, animals experiencing heat stress will reduce their feed intake (Kibler *et al.*, 1949; Webster, 1976; Morrison *et al.*, 1979; Ames *et al.*, 1983; Arp *et al.*, 1983*c*; Morrison *et al.*, 1983; Garner *et al.*, 1988; Hahn *et al.*, 1990; De Dios *et al.*, 1993 and NRC, 1996). The animal reduces feed intake because of a combination of interrelated factors; heat stress, heat loss restrictions, and length of exposure to the stress. The heat produced by animals fed *ad libitum* is approximately twice the level of heat produced by fasting animals, thereby reducing the ambient temperature beyond which feed intake will reduce (Whittow, 1971). Feed intake is reduced only when a threshold ambient temperature or heat load is reached (Webster, 1976; Morrison *et al.*, 1979 and Morrison *et al.*, 1983). The threshold value is dependent on the animal's previous environment (Webster, 1976), breed (Webster, 1976), diet composition (Morrison *et al.*, 1983), and is outside of the animals thermoneutral zone (NRC, 1996). Recorded reductions in feed intakes have occurred above 21°C (Morrison *et al.*, 1979; Morrison *et al.*, 1983), above 25°C (NRC, 1996) and above 38°C in Zebu type animals (Wilson, 1967). The degree of depression in feed intake is related to the length of time the animal is subjected to heat stress. De Dios *et al.* (1993) recorded a decrease in feed intake of 20 per cent on the first day of heat stress, which increased to 60 per cent by the fourth day of exposure. The initial response on exposure to heat stress is a reduction in feed intake. After two to four days of physiological adaptation (section 1.7) to mobilise heat dissipation functions the animal starts increasing its feed intake. Feed intake will increase for up to eight days or until physiological adjustments are complete. The feed intake will however not necessarily increase to the same level as in moderate conditions (Hahn *et al.*, 1990). The NRC (1996) uses 30 per cent as a maximum rate of reduction of an animal's feed intake, in an environment outside of its thermoneutral zone.

Johnson *et al.* (1958) reared calves of different breeds (Shorthorn, Santa Gertrudis and Brahman) at constant environments of 10°C and 26.7°C. Feed consumption increased linearly to a peak at about six months of age irrespective of breed, although the animals reared at 26.7°C appeared to reach their peak feed intake at an earlier age. The peak intakes at five to six months of age corresponded with the highest feed consumption per unit of surface area, which was in excellent agreement with their heat production per unit surface area at five to six months of age (Kibler,

1957). Thus, growing animals appeared to restrict their intake of feed at a level where their heat production was at a maximum per unit of surface area, which is related to their sensible heat loss capabilities (see section 1.5.1).

1.4.2.2 Effect of heat stress on feeding behaviour

There appear to be two major periods of eating activity over a twenty-four hour period (Figure 1.4.1). The majority of time spent eating (71.7 to 78.8%) occurred during the daylight hours of 6.00 am to 6.00 pm (Putnam *et al.*, 1963). The total amount of time spent eating (two hours twenty minutes) was unaffected by season, however the timing of eating bouts was influenced by season (Hoffman *et al.*, 1973). In winter the first peak occurred around sunrise and the second during the afternoon (3.00 to 6.00 pm). The latter being a more intense feeding period (Putnam *et al.*, 1967; Ray *et al.*, 1971 and Hoffman *et al.*, 1973). During summer, eating activity is more concentrated in the two peaks with essentially no consumption occurring during midday. The afternoon peak was delayed with the greatest frequency of eating occurring around 6.00 pm and an increased frequency of eating from 6.00 pm to midnight (Ray *et al.*, 1971 and Hoffman *et al.*, 1973). Sunrise occurred approximately two hours earlier in summer and sunset approximately two hours later which reflects the differences in peak eating times between the two seasons but does not account for the increased feeding during the 6.00 pm to midnight period (Ray *et al.*, 1971). During the winter period animals responded to the stimulus of placing fresh food in a bunker; this response was absent in the summer period (Ray *et al.*, 1971). These studies of the seasonal influence on eating patterns indicate that the timing of the eating periods is determined by the level of heat stress. This is further supported with similar changes in feeding patterns occurring where animals have differences in heat stress loads; between animals in confined pens versus open dry lot pens and black steers versus red steers (Arp *et al.*, 1983*a*).

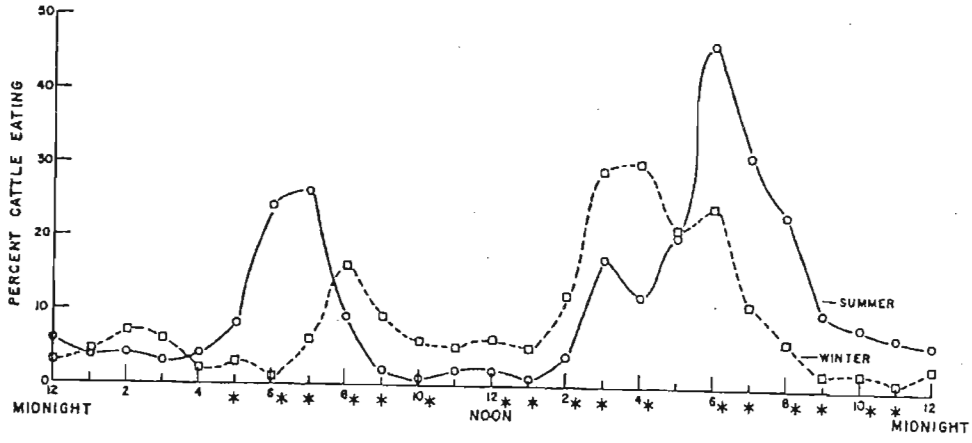

Figure 1.4.1 Seasonal influence on diurnal activity of yearling steers in the feedlot. An asterisk (*) indicates a significant ($P < 0.001$) difference between seasons (from Ray *et al.*, 1971)

During moderate conditions (10 ± 7°C) feeding activities showed a strong association with tympanic temperatures (Hahn *et al.*, 1993). Eating bouts were, in all but two cases, associated with decreases in tympanic temperatures of 0.3 to 0.5°C and forty eight per cent of the eating bouts were six minutes or less in length. Exposure of the animals to high temperatures (30 ± 7°C) disrupted this underlying rhythmic cycle especially during the initial exposure period. Concurrent eating bouts became more frequent with less feed consumed during individual events, forty nine per cent of the eating events being of a four minute duration or less (Hahn *et al.*, 1990 and Hahn *et al.*, 1993). In an experiment to explore the linkage between body temperature changes and feeding activities, the initiation of eating events in moderate and hot conditions were in almost all cases linked with peaking or descending portions of the tympanic temperature oscillations (Hahn *et al.*, 1993).

1.4.2.3 Management methods to limit the reduction in feed intake

As described in section 1.5.1.1.2, the heat increment of a diet is as a result of the fermentation within the rumen adding to the overall heat load. The more fibrous a food, the more action is required by rumen microorganism to break it down, thus the greater the heat production. This can be utilised by managing the proportion of concentrate to roughage in the diet and the degree

of processing of the roughage and thus the heat increment of feeding (Ames *et al.*, 1983; Finch, 1986; Forbes, 1986 and Alnaimy *et al.*, 1992). Kleiber (1975) reported that steers on high and low roughage rations adjusted their food intake so that their daily heat increment (calorigenic effect of food) was the same. These animals expressed the ability to maximise their available energy intakes for production by maintaining a similar level of intake limitation. This ability is used in the approach proposed by Lofgreen (1974), cited by Ames *et al.* (1983) for adjusting diets for the effect of high environmental temperature. He evaluated the influence of reducing the heat increment by changing feed ingredients while holding net energy constant. Although the results of his studies were inconclusive, this approach does offer some theoretical advantages and may warrant further investigations (Ames *et al.*, 1983).

Brosh *et al.* (1998) determined the effect of energy density in the diet, time of feeding and solar radiation on the stress levels in feedlot animals. Feeding the animals in the morning resulted in their peak heat productions occurring at the same time that the heat load from the environment was at its maximum. The animals fed in the afternoon however had peak heat productions at lower environmental heat loads. The stress (measured as increases in rectal temperatures and respiration rates) were obviously highest for the morning fed animals. The heat production was higher on the high energy diet with a corresponding greater response by the animals to being fed in the afternoon versus the morning. Although solar radiation added to the heat load of the animals, the response to diets differing in energy density was greater, indicating that heat stress may be manipulate through dietary means.

1.4.2.4 Reduction in feed intake and production

Production by animals implies the continuous generation of metabolic heat above the basal. Heat stress will affect first the animal that is growing fastest or producing the most milk because of its high metabolic rate. When exposed to heat stress, an animal's body temperature is elevated which reduces its appetite and hence food intake, leading to reduced performance (Webster, 1976; Morrison *et al.*, 1979; McArthur, 1982; Ames *et al.*, 1983; Arp *et al.*, 1983*c* and Alnaimy *et al.*, 1992). During heat stress the response is less obvious because both the intake and the

performance are lowered (Ames *et al.*, 1983). Decreased performance is directly correlated to food intake and hence the threshold ambient temperatures or heat loads that cause a decrease in food intake. This will therefore also correspond to the heat levels at which productivity will decrease (Morrison *et al.*, 1979 and Morrison *et al.*, 1983).

1.5 Heat loss

In section 1.4 it is shown that animals produce heat continuously and, if they are to maintain a constant body temperature they must lose it to their surroundings. Every interaction an animal has with its thermal environment involves heat exchange. The rate of exchange determining the degree to which cattle remain in thermal equilibrium within their environment. The climatological variables, which determine the heat balance of livestock include temperature, wind speed, humidity and radiation (Wilson, 1967 and McArthur, 1982). Additional environmental factors not involved directly in heat loss, but which can be confounded with seasonal variations in temperature include, changes in day length and rainfall patterns (Wilson, 1967). The rate at which heat exchanges occur is dependent on their individual resistance. The resistances to heat exchange that affect the ability of an animal to regulate body temperature are tissue, coat and air resistance, and evaporative resistance (Finch, 1986).

1.5.1 Mechanisms of heat loss

Non-evaporative heat loss (*sensible heat loss*) is the loss of heat from the surface of the body by convection, radiation, and conduction. This heat loss is determined principally by climatic factors; air temperature, wind speed, precipitation, and radiation exchange. Within the thermoneutral zone for adult ruminants, about 13-18°C, the sensible heat loss accounts for nearly 75 per cent of the heat dissipated from the body (McDowell, 1974). Excess heat is dissipated by evaporation of moisture from the surface of the skin and the respiratory tract as a protective mechanism of the body against overheating (Webster, 1976; McDonald *et al.*, 1990 and Alnaimy *et al.*, 1992). Sensible heat loss removes heat with little or no expenditure of energy, whereas active, evaporative heat loss, expends energy and creates heat in doing so (McDowell, 1974). The relationship between sensible heat loss, evaporative heat loss, heat production and the deep body

temperature of a homeotherm is illustrated in Figure 1.5.1.

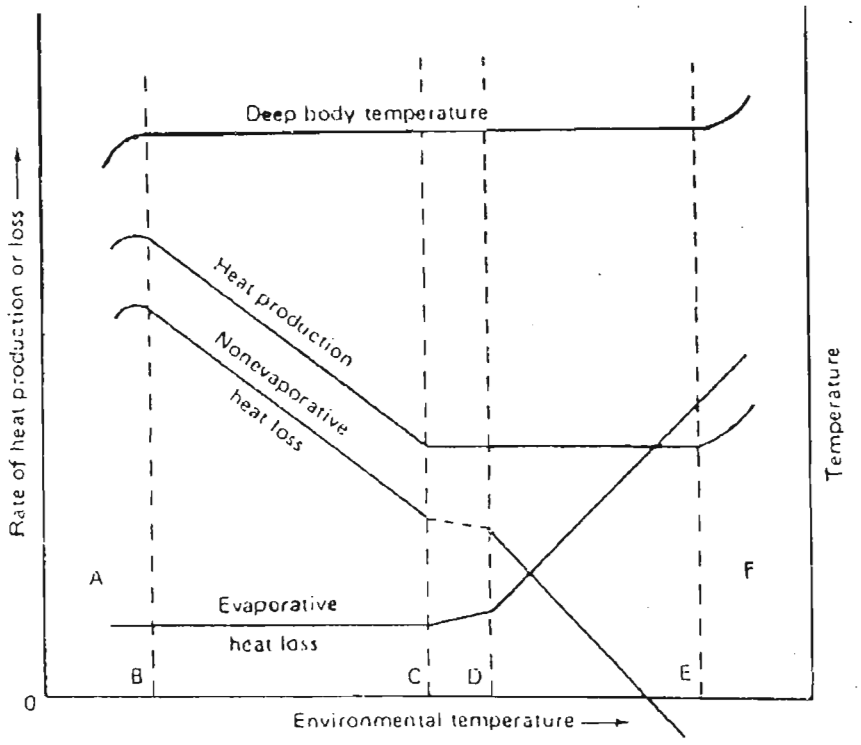

Figure 1.5.1 The relationship between heat production, evaporation, and non-evaporative heat loss, and deep body temperature in a strict homeotherm: A - zone of hypothermia whose border is defined by B; F - zone of hyperthermia whose border is defined by E; C - critical temperature; D - temperature of marked increase in evaporative heat loss; CD - zone of minimal thermoregulatory effort; and CE - zone of minimal metabolism (from Mount, 1974)

1.5.1.1 Conduction

Conduction is the process whereby heat energy is transferred directly through a material, any bulk motion of the material playing no role in the transfer. Heat flow through conduction within the body follows Fourier's law. The rate of heat loss, according to the Fourier's law, is proportional to the surface area, which is proportional to the two-thirds power of body weight (Kleiber, 1975).

$$K = A * h_c * (\bar{T}_s - T_a)$$

where: K = conductive heat exchange

A = surface area

h_c = thermal conductivity of the material in contact with the skin

$\bar{T}_s$ = mean skin temperature

T_a = air temperature

In other words, heat flows from the body core to the external environment at a rate which increases with the surface area and the temperature drop between core and exterior. But heat flow decreases with greater thickness of the barrier between core and exterior (Folk, 1974). The total insulation or resistance to heat flow from the animal can be divided into two terms: the tissue insulation of the animal, and the external insulation (Blaxter, 1977).

Tissue insulation, $I_T = T_R - T_S / H \ m^{-2}d^{-1}$

The temperature gradient rectal to skin divided by rate of heat loss per m^2 per day (H = heat production).

External insulation, $I_E = T_S - T_A / (H - E) \ m^{-2}d^{-1}$

The temperature gradient skin to air divided by the rate of sensible heat loss per m^2 per day (E = minimal heat loss by evaporation).

This was demonstrated in Holstein cows, where, as ambient temperature increased to 25°C the temperature difference between the core and the skin decreased resulting in a drop in heat loss and an increase in rectal temperature (Johnson, 1967). A greater response by heifers to ventilation was attributed by Garner *et al.* (1988) to the heifers being fatter and therefore more resistant to heat flow from their core to their extremities. External conductance for the whole skin surface is not a constant quantity but varies systematically with time of day. Internal

conductance (core to skin) is higher at night than during the day, while total conductance (core to environment) changes in the opposite direction (Aschoff *et al.*, 1974).

The magnitude of the heat transfer from the skin to the surroundings through conduction depends on the thermal conductivity of the material in contact with the skin. Air with its poor thermal conductivity is predominantly the material in contact with the skin. An animal can increase heat losses through conduction by lying in mud or water with their associated higher thermal conductivities (Smith, 1970 and Robertshaw, 1985). Steers confined in "teardrop" floor pens had a reduced ability to lose heat by conduction as compared to animals in more spacious dirt floor feedlot pens (Arp *et al.*, 1983*a* and Arp *et al.*, 1983*c*). The reduced ability to lose heat may be attributable to the thermal conductivity of the respective floor surfaces and/or the inability of the animals to spread out. This decreases the surface area in contact with the floor. Any heat lost by an animal through conduction is from its extremities therefore, conductive heat transfer in cattle is essentially a function of blood flow to the skin. The circulation of blood transfers heat from the core to the periphery (Alnaimy *et al.*, 1992). Small amounts of heat are lost by the conductive transfer of heat to waste products such as urine (Robertshaw, 1985).

1.5.1.2 Convection

Convection is the process by which heat energy is carried from place to place by the bulk movement of a fluid. When a portion of a fluid is warmed the volume of the fluid expands, and the density decreases. According to Archimedes' principle the surrounding cooler and denser fluid exerts a buoyant force on the warmer fluid, which pushes the warmer fluid upward. As warm fluid is pushed upward, the surrounding cooler fluid replaces it. The fluid (air) adjacent to the skin of an animal is heated by conduction, the air then moves upward and away from the skin in a convection current. The amount of heat lost being a factor of the temperature of the air already (Primault, 1979). Johnson (1967) detected that the rectal temperatures of Holstein animals increases primarily because of increasing skin temperatures, and the resultant reduction in heat loss by convection at an ambient temperature around 25°C.

Preventing movement of air will create an insulatory layer. The fur of the animal achieves this by entrapping a layer of air close to the skin. This provides a physiological means for an animal to adjust to an environment by either decreasing or increasing its hair layer depending on its requirements with respect to heat loss. Work by Bonsma (1980), showed that at a given air temperature, the deep-body temperature of cattle with woolly coats was higher than that of animals with smooth coats. The insulatory layer of air can also be broken up by an external wind or by movement of the animal and is known as forced convection (Robertshaw, 1985). Thus, the convective heat exchange coefficient, is some complex function of the mass flow over the animal and the degree of turbulence in the air motion (Smith, 1970). Artificially inducing ventilation improved the feed intakes and ADG's of feedlot cattle (Morrison *et al.*, 1976 and Garner *et al.*, 1988). The performances improved at temperatures above 13°C (Morrison *et al.*, 1976). Convective heat transfer also accompanies respiration, as the inspired air has its temperature adjusted to that of body temperature by the time it reaches the trachea (Robertshaw, 1985).

In an apparent contradiction the vaginal and mean body temperatures have been found to be higher at night than during the day. These measurements increased with increasing environmental temperature by a greater amount at night. This was associated with an increased amount of time engaged in standing activity at night. The authors suggest that thermal sensitivity is lower during the night than during the day, and consequently the greater night responses of vaginal and body temperature over day responses are a requirement for the maintenance of heat balance (Mundia *et al.* 1997). However, external conductance for the whole skin surface is not a constant quantity but varies systematically with time of day, allowing the animals to increase their activity, such as feeding, during the night. This will lead to an increase in their heat production resulting in increased body temperatures. The animals can accommodate this by engaging in activities such as standing to increase their heat losses. Night time was chosen by the animals to increase their heat production due to the improved ability to lose heat.

1.5.1.3 Radiation

The principles behind radiant energy are described in section 1.4.1.2. Although solar radiation adds significantly to the animal's heat load, the animal is able to emit radiant energy in the form of long electromagnetic waves. Up to sixty per cent of the radiant energy absorbed at the fur surface is reradiated to the environment. The factors that determine a body to be a good absorber of radiation (such as coat colour) are also the factors that make a body a good emitter of radiation (Robertshaw, 1985).

1.5.1.4 Evaporative

Evaporation is the conversion of a liquid to a gas when heat energy is supplied. Evaporative heat loss occurs in animals from the respiratory tract and sweating, which is quantitatively superior to panting. Heat is lost continuously by evaporative means from an animal through normal respiratory functions and diffusion of water through the skin as insensible perspiration (Smith, 1970; Robertshaw, 1985 and Alnaimy *et al.*, 1992). When subjected to a heat load an animal increases heat loss by both panting and sweating. The amount of water lost by evaporative means being inversely related to the ambient humidity (Hey, 1974 and Primault, 1979). The humidity of the air would therefore have its greatest effect under conditions in which evaporative cooling mechanisms were important avenues of heat loss (Riggs, 1966; Whittow, 1971 and Morrison *et al.*, 1976).

In cattle panting is an increase in respiratory ventilation, which involves an increased ventilation of the dead space of the lungs. This is achieved by increasing the frequency and decreasing the tidal volume of ventilation. Cattle pant with the mouth closed such that heat exchange takes place at the mucosa of the upper respiratory tract in the region of the turbinate bones (Kleiber, 1975 and Robertshaw, 1985). In cattle, experiencing acute heat stress the body temperature rises (40.5°C) and the animal may show "second stage panting", slow deep gasps which lead rapidly to respiratory alkalosis due to the depletion of the blood carbon dioxide (hypocapnia). At this point the animal is no longer maintaining homeostasis and cannot survive unless the heat stress is withdrawn (Whittow 1971; Kleiber, 1975 and Webster, 1976).

As ambient temperature increases a point is reached at which an animal is unable to dissipate the heat of metabolism, since the energy cost of panting might exceed respiratory evaporative heat loss (McDowell, 1974). The amount of water lost by insensible perspiration increases slightly until active sweating starts (Alnaimy *et al.*, 1992). Sweating or sensible perspiration is the cutaneous moisture evaporation from glands on the general body surface of cattle that are numerous and apocrine in nature. The amount of sweat produced by each sweat gland is sufficiently low that the rate of evaporation is equivalent to the rate of secretion and the skin therefore appears dry (Robertshaw, 1985). The amount of water available for evaporation from an animals surface has been manipulated with the use of sprinklers. The increase in evaporative heat loss led to improved feedlot performance and reduced death rate from heat stress (Ames *et al.*, 1983 and Arp *et al.*, 1983*c*). At temperatures above the comfort range, evaporation from the skin and respiratory tract become the major means of heat loss by ruminants, consequently the animal's capabilities for providing the water for evaporation become important (McDowell, 1974 and Johnson, 1967).

1.5.1.4.1 Respiration rate

The stimulation of evaporative heat loss mechanisms as one of the first reactions, by an animal when it's homeothermic state is threatened, allows for the respiration rate to be used as a measure of heat stress(Alnaimy *et al.*, 1992). Measurements of respiration rates are given in Table 1.5.1.

Table 1.5.1 A composite of ranges of respiration rates of cattle at different ages, ambient temperatures, plane of feeding and coat colour

Conditions		Respiration rate (breaths / minute)	Reference
Holstein : Black vs. White		114.1 and 84.4	Arp *et al.* (1983*b*)
Feedlot steers at 8.00 am :			Arp *et al.* (1983*b*)
	Red	70.1	
	Black	59.0	
	White	62.8	
Feedlot steers at 12.00 pm :			
	Red	138.7	
	Black	132.9	
	White	137.1	
Feedlot steers at 4.00 pm :			
	Red	134.0	
	Black	126.2	
	White	109.9	
Ayrshire bull calves (9 months old) 30°C		193 to 243	Bianca (1963)
Beef cattle at 41.66°C		130 to 165	Bond (1967)
TNZ Normal respiration rate		23	Manuel (1954)
Bos taurus X steers (10 to 28°C)		23.3 to 47.9	Ole Miaron *et al.* (1992)
Bos taurus X steers (20 to 35°C)		18.4 to 60.7	Robinson *et al.* (1986)

Illustrated in Figure 1.5.2 is that respiration rates follow similar patterns to body temperatures (Johnson, 1967; Finch *et al.*, 1982; Arp *et al.*, 1983*b*; Robinson *et al.*, 1986 and Liang *et al.*, 1998). However, because an increase in respiration is only one of a multiple of heat loss mechanisms conclusions drawn solely from respirations rates do not allow for differences which

may be due to efficiencies or inefficiencies in the other mechanisms. For example the respiration rates for Holsteins increased by 300 to 400 per cent whereas in Jerseys a 500 per cent increase was recorded (Kibler *et al.*, 1949).

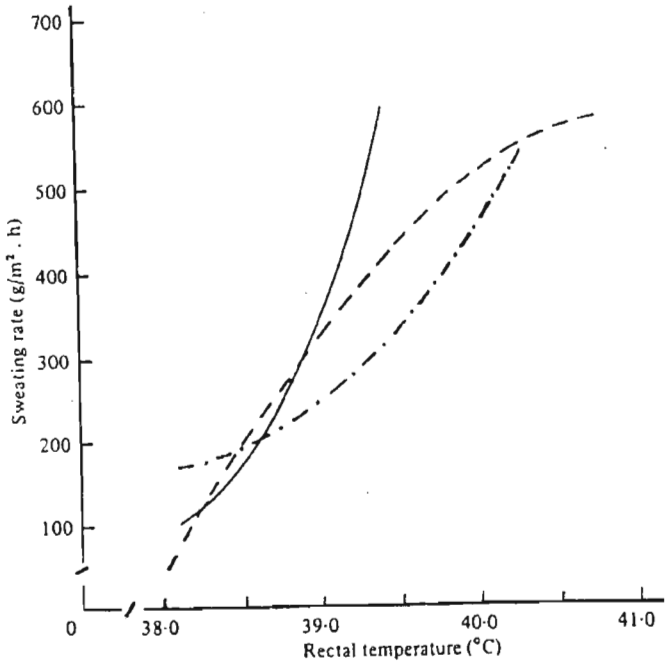

Figure 1.5.2 Within animal relationship of sweating rate and rectal temperature for three breeds. Brahman, ———; Brahman cross, -·-·-·-; Shorthorn, -----. (from Finch *et al.*, 1982)

1.5.2 Regulation of heat loss

Variations in heat production and heat loss may occur without any change in the heat content of an animal. However, if heat production does not equal heat dissipation, body temperature will change, which will be manifested largely by a change in the deep-body temperature (Johnson, 1967 and Whittow, 1971). In nature, it is probable that many cattle fail to thermoregulate towards the end of a very hot day but recover when the sun goes down (Webster, 1976). Such changes constitute a thermoregulatory mechanism because variations in body temperature alter the temperature gradient between the animal and its environment, and therefore heat loss (Whittow, 1971). It is essential for the animal to have the ability to detect and interpret a disruption in its internal equilibrium and then to initiate appropriate behavioural and or metabolic

responses to restore homeostasis (Young *et al.*, 1989). Many of the responses to imbalances in heat load are behavioural rather than physiological. Behavioural factors include simple mechanisms such as standing under a shelter or maximise the wind blowing over it body surface (Hey, 1974).

Heat load such as that created by hot environmental temperatures, activates temperature regulators. The output of the temperature regulator affects heat loss mechanisms such as; the blood flow of the skin (vasomotor control); the erection of the hair to reduce the insulating layer; the secretion by the sweat glands, and with it the rate of water evaporation from the skin (provided the environmental air is not saturated with water vapour and the skin is not already completely wet); the respiratory frequency on which depends the rate of water evaporation in the respiratory system; surface moisture diffusion and urination (Johnson, 1967; Kleiber, 1975 and Primault, 1979). Control of evaporative heat loss provides the body with an extremely efficient means of controlling body temperature (Hey, 1974).

Sensing of temperature and the resultant thermoregulation depends upon both central and peripheral nervous control (Folk, 1974; Kleiber, 1975 and Robertshaw, 1985). The sensing of temperature is a function of specific cold and warm receptors located principally either in the skin (peripheral) or in the brain (hypothalamus) and spinal cord (central). The peripheral thermoreceptors are thought to comprise specialised nerve cells, each of which sends out impulses at some characteristic temperature. The receptors appear to work as a series, sensitive to a range of temperatures (35 to 42°C). Temperature fluctuations change the magnitude and nature of the sensory input to the hypothalamus (Kleiber, 1975). Information from these receptors is integrated within the hypothalamus and the appropriate responses are activated. The thermodetectors of the brain have been traced to the anterior hypothalamus. Although not identified histologically, when the anterior hypothalamus was stimulated with localised warming or cooling there were responses and electrical changes over a series of characteristic temperatures (Johnson, 1967; Wilson 1967; Kleiber, 1975 and Whittow 1976). The conscious sensation of either heat or cold by the hypothalamus allows for the measuring of behavioural responses to indicate an animals stress level (Robertshaw, 1985).

In a wide range of environmental temperatures that compromise the thermoneutral zone, animals maintain their heat balance through vasomotor control. Regulation of the amount of blood flowing through the cutaneous vessels by either vasodilation or vasoconstriction adjusts the resistance to heat flow, (Kleiber, 1975; Primault, 1979 and Alnaimy *et al.*, 1992). An increased blood flow to the body surface decreases the mean thickness of the insulating layer and increases the heat transmissivity of the surface layer by adding convection to the conduction of heat from the internal part of the body to the surface (Kleiber, 1975). Invoking vasodilation, leads to stimulation of the pilomotor centre to flatten the hair cover to allow better heat dissipation through conduction, convection and radiation (sensible means) (Alnaimy *et al.*, 1992). Control of heat loss by increased surface circulation (vasomotor control) becomes ineffective, of course, when the environmental air temperature and the radiation temperature (temperature of the surrounding walls, etc.) are equal to the rectal temperature. In this case overheating may be prevented by an increase in the rate of water evaporation, either at the surface of the body (by increased sweating) or in the respiratory tract (by increased ventilation) (Kleiber, 1975).

1.6 Acclimatisation

An animal can improve its response to a subsequent challenge through the modification of its behavioural or metabolic responses. In an unfavourable environment an animal follows a pattern of response (Figure 1.6.1). In terms of relative rate of production, the initial response exhibited is an acute one that progresses into a chronic response through adaptation. One form of physiological adaptation is that of acclimatisation. Acclimatisation is the functional compensation of tissue or organ responses in an animal. This occurs over a period of days or weeks, in response to a complex of naturally occurring environmental variables (Folk, 1974 and Young *et al.*, 1989)

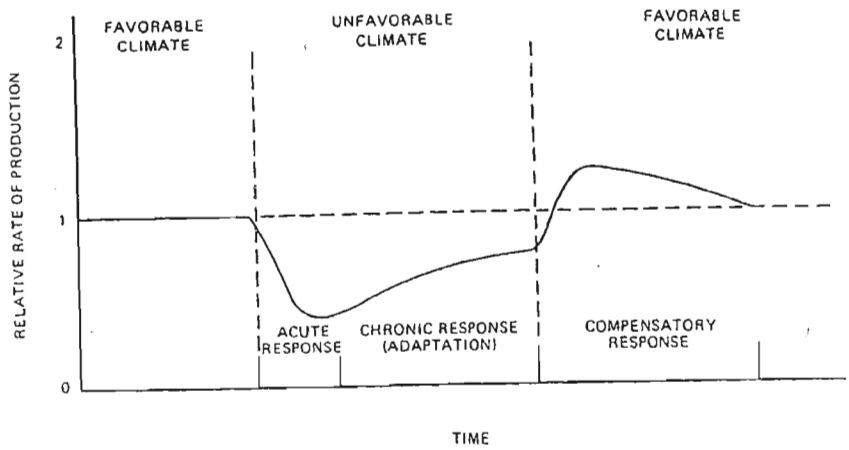

Figure 1.6.1 Theoretical animal response to periodic change. Solid lines represent animal response to changing climatic conditions relative to favourable climate (1 on vertical scale) (from Ames *et al.*, 1983)

Animals differ in their level of improvement when exposed to adverse environmental factors. Manifestation of an animal's capacity to tolerate heat is brought about through "heat training" (Bianca, 1959*a*). A heat load induces the heat regulating mechanism of the body to achieve maximum efficiency and allow adaptive changes to develop. However, a heat load of a higher order will result in deterioration. If, under the influence of repeated or continued exposures to heat, an animal develops changes that result in an increase in its heat tolerance, it has become acclimatized (Bianca, 1959*a*). An acclimatised animal will increase its relative rate of production but, its production will not return to its previous rate until the climate becomes favourable again (Figure 1.6.1). The return of a favourable climate may also generate a compensatory response from the animals (Ames *et al.*, 1983).

1.6.1 Metabolic rate and feeding patterns

Acclimatisation results in a decrease in metabolic heat production. This is achieved by the animal converting food energy into product, at the lowest maintenance cost and voluntary food intake being reduced, with the inevitable metabolic accommodation. A decrease in heat production

allows the heat dissipating mechanism to work for a shorter period, coupled with their increased efficiency at losing heat (section 1.6.2) (Bianca, 1959*b*; Kibler, 1962; Webster, 1976 and Finch, 1986). Acclimatised animals also lower their body temperatures in anticipation of an upcoming heat load (i.e. in the early morning). A lower body temperature requires a lower heat production to maintain (Brosh *et al.*, 1998).

Acclimation to high temperatures shifts feeding activities back towards fewer events with longer duration (1.4.2.2). Meal durations are however not as long as those in moderate conditions. With continued exposure to heat, the quantitative (weight kg's) pattern of feed eaten at various times of the day shifts back towards that observed under moderate conditions. However it was observed that the relatively strong association between tympanic temperature and eating bouts did not redevelop after twelve days of exposure to heat stress(Hahn *et al.*, 1990).

1.6.2 Heat loss

The level of response to heat stress depends on the length of exposure and the degree of heat that the animals have to endure. Mobilization of heat dissipating functions (physiological coping) reaches a point after two to four days whereby an increase in feed-intake can take place. The physiological adjustments approaches completion after eight days of exposure (Hahn *et al.*, 1990). Continual readjustments by the animals follow as they try to equilibrate their heat loss capabilities with their heat production. Heat tolerance is improved with a superior ability to dissipate heat, through a greater capacity to evaporate water and to use that water more efficiently for cooling (Kibler, 1962 and Frisch, 1981).

1.6.3 Rectal temperature and respiration rate

Steers exposed to heat stress over a twenty one day period showed progressive reductions in rectal temperature, heart rate, and respiratory rate, with a change of breathing from a laboured to a less laboured type. The majority of these reactions occur during the first eight to nine days of a heat period (Bianca, 1959*a* and Hahn *et al.*, 1990). The acclimatisation of animals to a hot environment has a twofold reaction, first, rectal and skin temperatures do not increase as much.

The acclimation rate for rectal temperature is in the order of a decrease of between 0.1 and 0.4°C per day. Secondly, the respiratory rate rises earlier and assumes higher levels than that of non-acclimated animals. The consequence is that acclimatised animals have an increased tolerance time and can withstand longer periods of stress (Bianca, 1959*b*; Kibler, 1962; Hahn *et al.*, 1990 and Vizcarra *et al.*, 1991). However, when the demand for body cooling reduces, the respiratory activity declines. Thus, the lowered respiratory activity is a result rather than the cause of acclimatization (Bianca, 1959*a*). Another adaptive mechanism is that the rectal temperature of acclimatised heifers is lower in the morning. This allows the animal to cope better with an upcoming heat load, as maintaining a lower rectal temperature requires a lower heat production (Brosh *et al.*, 1998). Heat adapted, cattle can increase sweating rapidly as soon as their body temperature (either skin or core), commences to rise, reducing the reaction time to heat stress (Finch, 1986 and Vizcarra *et al.*, 1991). Rectal temperatures measured between noon and 2.00 pm (final rectal temperature) prove to be the best for differentiating between the heat tolerance of individual animals. The initial rectal temperature (measured early in the morning) parallel the final rectal temperature, while the increase in rectal temperature during exposure does not vary significantly between the animals. The increase in rectal temperature is therefore considered a less suitable measure of heat tolerance (Bianca, 1963)

1.6.4 Breed

With respect to heat tolerance, the breeds of the world divide themselves naturally into those from temperate regions, the *Bos taurus*, and those from tropical regions, the *Bos indicus*. *Bos indicus* breeds have higher heat tolerances. This is due to a lower heat production, and a greater heat loss capacity. The greater heat loss capacity is achieved through a greater surface area per unit weight, shorter hair, and other body-temperature regulating mechanisms not visually apparent (Brody, 1956 and Finch, 1986). *Bos taurus* breeds through processes of acclimatization can improve their thermoregulatory responses by lowering their metabolic rates and increasing their thermoregulatory ability. However, their voluntary food intake is reduced with the inevitable metabolic accommodation. Their efficiency of heat-loss is never as great as in *Bos indicus* species (Finch, 1986). The exact temperature above which food intake depresses in either *Bos taurus* or *Bos indicus* depends largely on the climate to which each individual has been accustomed

(Webster, 1976). Comparison between the breeds on their sweating rates showed marked differences (Figure 1.5.2). In *Bos indicus* cattle, the sweating rate increases exponentially in response to increased body temperature, while in *Bos taurus* the sweating rate tended to plateau after an initial increase (Finch, 1986).

As energy metabolism exerts an influence on body temperature, a concern is that an animal that has a genetically determined low body temperature might also have an inherently low food-intake and heat production despite the level of environmental heat stress. For instance *Bos indicus* cattle regulate their body temperatures efficiently. They are therefore deemed heat tolerant because their productivity is not greatly depressed in hot-environments. However, in the absence of heat stress these genotypes have lower maintenance metabolic rates, lower feed-intakes and lower growth rates than *Bos taurus* breeds (Johnson *et al.*, 1958 and Finch, 1986). There is therefore a clear distinction between physiological adaptability and productive adaptability. The poor correlation suggests that animals in hot environments should be selected on the basis of production characteristics, and that this in turn will place sufficient emphasis on physiological adaptability (Colditz *et al.*, 1972).

1.7 Heat stress and production

Energy available for production is the difference between available energy intake and the energy used for maintenance (Figure 1.7.1). The thermal environment affects the rate of intake (see section 1.4.2.1) and the maintenance requirement (see section 1.5.1). This in turn alters both the rate and efficiency of production (Ames *et al.*, 1983). A quadratic response was found to be the relationship between average daily gain (ADG) and an ambient temperature range of -3 to 30°C. The ADG increased at a decreasing rate with increasing temperature due to a non-linear increase in maintenance during heat with concurrent decreases in feed-intake (Ames *et al.*, 1975).

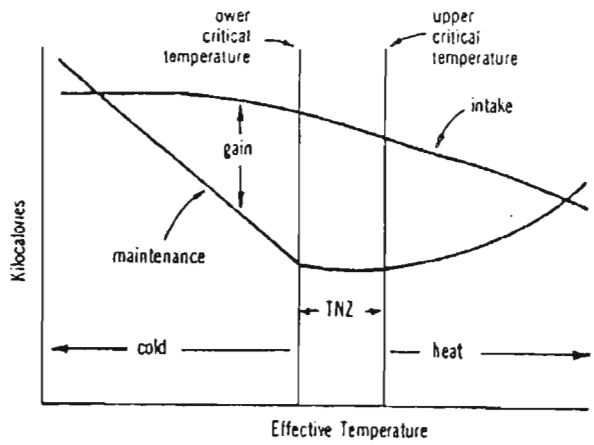

Figure 1.7.1 Schematic drawing showing effect of temperature on the rate of intake, maintenance energy requirement and energy retained as product (gain)(from Ames *et al.*, 1983)

From a mechanistic view, animals are simply converters or producers of protein which have optimum operating efficiencies. When animals operate in an environment, which deviates from the optimum, their rate and efficiency of performance are reduced (Smith, 1970 and Ames *et al.*, 1983). The point to note is how much more rapidly production declines with high temperatures than with low temperatures (Bond, 1967). Heat is potentially a greater commercial problem than cold because it affects the animal that is growing fastest in view of its high metabolic rate. Adaptation to heat invokes physiological mechanisms that may favour survival but are detrimental to performance (Webster, 1976).

1.8 Discussion

From examination of factors that control voluntary feed-intake (section 1.2.5), environmental temperature appeared to be the most likely controlling factor during the plateau phase of the feed-intake curve (section 1.1.5).

Behavioural responses (primarily those that aid in heat loss) provide evidence that animals in a

feedlot environment suffer from heat stress. One such response is the shifting of feed-intake patterns in relation to environmental conditions to optimise heat loss capacity (see section 1.4.2.2). For example, with *ad libitum* feeding, consumption of feed is timed so that the associated heat gains are during the evening hours when environmental conditions are more conducive to heat loss. Performances of animals fed in the morning are lower than those of animals fed in the afternoon (Brosh *et al.*, 1998).

The stability of an animal's core body temperature is the crux of the effect of heat stress on feed-intake. Cattle as homeotherms are required to maintain their core body temperatures within a constant range of 38 to 39°C (see Table 1.3.2) within the TNZ. To maintain this constant core temperature the animal must balance its heat gains (digestion and absorption of nutrients, production, behaviour, and solar radiation) with its heat losses (sensible and evaporative heat loss). High ambient temperatures and increased planes of feeding lead to increased rectal temperatures.

The TNZ is the range of environmental temperatures in which the animal neither combat's cold by raising heat production, nor heat by increasing its rate of evaporation by sweating or panting or both, and in which behavioural thermoregulation is normally absent (Mount, 1974). The UCT (the environmental temperature at which evaporation begins to rise) and the LCT (the point at which HP must rise to maintain homeothermy) form the boundaries of the TNZ. The width of the TNZ relates to an animal's ability to adjust to heat loss and production demands placed by the external environment (see section 1.3.1). The NRC (1996) provision of 15 to 25°C as the TNZ for cattle encompasses most of the TNZ ranges listed in Table 1.3.1.

For feedlot cattle, the two main sources of heat are, the consumption of feed (see section 1.4.1.1.2) and solar radiation (see section 1.4.1.2). Heat gain from feed consumption is greater than that from solar radiation (Brosh *et al.*, 1998). Heat is lost from an animal at all times through sensible heat loss, and accelerated in times of heat stress through evaporative heat loss (see section 1.5.1). To balance the heat equation, adjustments to both heat production and heat loss, are made. In this study, attempts to balance the heat equation through adjustments to feed-intake are the most pertinent.

Examination of cattle's feed intake patterns (section 1.1.5) revealed the following phenomena. Differences in cattles feed intakes are proportional to their starting weights from the first week of feeding. Irrespective of maturity type, sex, starting weight or season, DMI of cattle in the feedlot increases linearly for the first twenty-eight days. After twenty-eight days of feeding a dip in feed-intake of differing magnitudes in the upward trend occurs. These differences appear seasonal and most apparent in summer. During spring, fall and winter DMI increases further. From this later peak, a plateau is followed by a decline in DMI as slaughter weight is approached. Can the phenomena in the cattle's feed intake patterns be explained from the examination of heat stress as the possible first limiting factor of feed-intake.

Following Fouriers law, heat loss through sensible means depends on an animal's surface area (see section 1.5.1.1). The more area in contact with the environment the greater the heat loss. Surface area and feed-intake (see section 1.1.1) of an animal increase in proportion to its live weight. The associated increase in heat loss with surface area may account for the proportional increases in feed-intake with live weight increases that are apparent within the first week of feedlotting. If the differences in feed-intakes between animals differing in live weight are due to their surface area differences and therefore their heat loss capacity then this suggests that heat stress be the controlling factor of voluntary feed-intake from the first week of feeding. However, there must still be a period of time within this first week whereby the rumen microbial population is undergoing acclimatisation to the new diet being fed as well as acclimatisation of the animal to its new environment. This will also be true at other times of the feeding period if diets are changed. This microbial acclimatisation may however proceed rapidly and allow the animals heat production to reach a threshold value within a few days and thus heat stress becomes first limiting. The speed of microbial acclimatisation is illustrated when animals placed on feedlot diets exhibited a dip in their feed intakes after two days of feeding, but were able to recover within five days of feeding (Hironaka 1969 and Kunkle *et al.* 1976).

An increase in feed-intake is either due to an increased demand or a relaxation in the first limiting factor controlling food-intake. The linear increase in food-intake over the first twenty-eight days irrespective of maturity type, sex, starting weight or season is an increase due to a relaxation in the first limiting factor as opposed to an increased demand. Acclimatisation is a dynamic process

under which the animal undergoes physiological adjustments to increase its heat loss capacity (see section 1.7). If heat stress is the limiting factor then feed-intake (heat production) will increase as the animal progresses through acclimatisation. Acclimatisation progresses over a period of a few days to a few weeks and therefore corresponds to the time period of twenty-eight days. It was suggested that the linear period of increase in feed-intake was due to rumen microbial adaptation to the sequential feeding pattern (see section 1.1.5). This could be a period of both microbial adaptation and acclimatisation to heat stress. However, animals will acclimatise to heat stress at constant rates irrespective of live weight, sex, or maturity type. Thus, differences in feed-intakes apparent from the start of feeding are not due to differences in degrees of acclimatisation.

When feed availability is non-limiting, animals reduce their feed-intake when a threshold heat load is surpassed (see section 1.4.2.1). The heat production of an animal rises as its feed intake increases. A higher heat production lowers the UCT and the point at which feed-intake is curbed. This threshold heat load may be surpassed in summer months (see section 1.1.4), when higher ambient temperatures, high intakes and growth rates are prevalent. However, whether the heat load from feed-intake is sufficient for heat stress to be the limiting factor during the other seasons is questionable. Autumn, winter and spring fed animals in comparison to summer fed animals have similar feed-intake curves and higher intake levels suggesting that heat stress may indeed be the most limiting factor. A higher heat production through an increasing feed-intake and production may offset the lower heat load from the environment. This results in an equal heat load (stress) at a higher level of production to animals fed in the summer months. Limited increases in feed-intake after twenty eight days of feeding in summer months (see section 1.1.1), implies that little acclimatisation occurs during the plateau phase. Thus, either acclimatisation occurs during the first twenty eight days, or feedlot animals are not limited by heat stress and do not need to acclimatise. Animals fed in non-summer months increase their intakes after a short plateau period (see section 1.1.4), suggesting that they acclimatise over a longer period of time than animals in summer months.

Heat stress as a factor controlling food-intake appears to have merits in that each phase of a feedlot animals food-intake curve can be related to a heat stress mechanism. However

investigation and proving the relationship is necessary. Manipulation of a diet's heat load is possible through the reduction of the heat increment of feeding. From a practical nutritional view point, altering the heat produced through fermentation by microbial digestion is the most promising. Enhanced digestion through the reduction of the roughage content of the diet, or processing (grinding, pelleting, chopping and ammoniation) of the diet reduces microbial action. Animals appear to have the sensitivity to manipulate their intakes to achieve similar heat loads but different effective energy intakes. Thus, animals offered diets differing in their respective heat loads will have different production responses if limited by heat stress.

Measurement of heat stress is possible through recording rectal temperatures and respiration rates. Rectal temperatures close relationship to core body temperature will measure the animal's success in maintaining a balance in its heat production and loss. The measurement of an animal's respiration rate will measure its short term response to a need to increase heat loss and potentially its rate of acclimatisation.

Hypothesis

The provision of diets differing in their heat load to feedlot animals will allow for the investigation of heat stress being the first limiting factor in the control of feedlot cattle's voluntary feed-intake. Animals will consume feed to satisfy their first limiting requirement, energy, with no significant differences in physiological or animal performance parameters resulting from the dietary heat loads but only from their energy densities.

CHAPTER TWO

THE INFLUENCE OF DIETARY ENERGY ON THE FEED INTAKE "CURVE" OF FEEDLOT CATTLE

2.1 Introduction

The regulation of dry matter intake is a function of a complex array of factors that are not fully understood (NRC, 1996). The satiety hypothesis suggests that animals will seek to obtain nutrients required to satisfy their needs. The amount of feed an animal will attempt to eat is based on the animal's nutrient requirements and the concentration of nutrients in the feed. In ruminants there are however limiting factor's such as rumen fill (NRC, 1987). When steers previously fed a bulky low quality diet such as winter foggage (where rumen fill is the limiting factor) are changed to a concentrate diet, they tend to increase their feed intake until a plateau of nutrient satisfaction is reached. This is substantiated by feed intake curves of animals in a feedlot environment (Owens *et al.*, 1985; Thornton *et al.*, 1985; Hicks *et al.*, 1990*a,b* and Dominy, 1997) where it was found that all animals, irrespective of sex, age, maturity type or condition, achieved a plateau of feed intake after 28 days in the feedlot. While the attainment of a plateau is expected, the lack of significant difference in energy intakes between animals of differing energy requirements by Dominy (1997) is not expected. The data reported by Hicks *et al.* (1990*a,b*) came from the same feedlot in western Oklahoma and the data reported by Owens *et al.* (1985) and Thornton *et al.* (1985) were obtained from a feedlot in western Kansas. The dietary ingredients and predicted energy levels for the finishing ration reported by these authors are similar among the four papers. The lack of variation in diets energy densities for which feed intake curves have been derived, limits comparisons.

The basis behind a level of feed intake being achieved is that an animal eats to satisfy its nutrient requirements due to maintenance, activity and production. An increase in the density of the first limiting nutrient in the diet will allow an animal to meet its requirements for that nutrient at a lower feed intake assuming no other limiting factor is involved. The consensus is that the first limiting nutrient in a feedlot animal's diet is energy (NRC, 1987). As the digestibility of a diet measured as digestible energy (MJ) increases, the intake of the diet increases until the animals

satiety is reached. If the digestible energy density increases further their is a corresponding dip in intake to accommodate for this thereby allowing the animal to maintain a constant energy intake. This has been shown to be where the feed intake control switches from "gut fill" to "chemostatic" (Van Soest, 1994).

The following trial was designed to investigate the hypothesis that animals fed diets of differing energy densities will achieve plateau feed intakes of differing magnitudes. The plateau feed intake will be lower for animals on a diet with a high energy density compared to animals on a diet with a low energy density. However, performance with respect to growth rates will not differ between treatments as all animals irrespective of diet will not be limited in their intake of energy.

2.2 Materials and methods

Three feedlot diets differing in energy density were formulated to investigate the influence they would have on a weaner steer's feed intake curve in a feedlot environment.

2.2.1 Diet formulation and ingredient composition

Three diets were formulated to differ in metabolisable energy (ME) content, and were designated One (maximum ME), Two (medium ME) and Three (minimum ME). Diet Two was formulated by mixing diets One and Three at a 50 : 50 ratio. Winfeed (1.11) software (EFG Software 1996) was used to formulate these diets and the lower and upper boundaries were set as given in Table 2.1. The nutritive values of the ingredients were obtained from ingredient book values (NRC, 1984; Bredon *et al.*, 1987 and Feedstuffs, 1997). The ingredients making up the diets are given in Table 2.2. All ingredients were purchased in one batch at the beginning of the feeding period. This was to avoid potential variation in the nutrient status of the ingredients, which can occur in the by-products due to different manufacturing processes and raw material supplies over time. The diets were mixed in batches of one tonne when required in a rotary mixer (Drotsky, Drotsky Altief Alrode, Republic of South Africa) and bagged into 35 kg bags. This ensured the availability of fresh feed at all times.

Table 2.1 Formulation boundaries on a dry matter basis

Level	Crude Protein (%)	Metabolisable Energy (MJ/kg)	Calcium (%)	Phosphorous (%)	Fat (%)	Crude Fibre (%)
Min.	14.0	9.5	0.0	0.3	0.0	10.0
Max.	16.0	14.0	2.0	1.0	7.0	100.0

Table 2.2 Ingredient composition of the three diets

Ingredient (kg)	Diet[1]		
	One	Two	Three
Maize yellow (cracked)	-	157.5	315.0
Broiler chicken litter	180.0	142.5	105.0
Copra oilcake	-	57.5	115.0
Palm kernel meal	-	75.0	150.0
Sunflower oil	-	9.0	18.0
Veld hay	45.0	122.5	200.0
Lucerne meal	-	37.5	75.0
Feedlime	9.0	11.5	14.0
Salt	4.5	4.5	4.5
Urea	4.2	4.35	4.5
Vitamin A + mineral premix[2]	1.0	1.0	1.0
Romensin	0.15	0.15	0.15
Tylan	0.1	0.1	0.1
Maize germ	520.0	260.0	-
Molasses cane (meal)	40.0	20.0	-
Condensed molasses solids	175.0	87.5	-
Fishmeal	16.5	8.25	-
Morlac	5.5	2.75	-
TOTAL	1000.95	1001.60	1002.25

[1] = Diet One: maximum ME density; Two: medium ME density; Three: minimum ME density
[2] = Vitamin A : 4000000 iu, Vitamin B1 : 3g, Manganese : 10g, Zinc : 10g, Copper : 2g, Cobalt : 0.50g, Magnesium : 100g, Selenium : 0.3g, Iodine : 0.25g.

2.2.2 Animals

Twenty-seven, 7 month old weaner steers, ranging from 174 to 218 kg live weight (mean = 198 (s.d. = 13.37) kg), were overwintered on *Cynodon* hybrid (Coastcross 2 (K11)) pasture foggage before being placed in the feedlot in early summer (October). At the end of the overwintering period the animals had live weights (measured on a full stomach over two consecutive weeks) ranging from 192 to 256 kg (mean = 221.1 (s.d. = 16.98)kg). Animals were blocked by weight into three groups of nine animals each. Within each block animals were then randomly assigned to nine homogenous groups of three animals in each. Each group was assigned to a treatment at random, a three (diet) by three (replication) design.

One month prior to the feedlot period all the animals were inoculated against anthrax, quarter evil, botulism, bovine viral diarrhoea and pasteurella. On entry in to the feedlot all twenty seven steers received a Revalor -S (200 mg Trenbolone Acetate and 20 mg 17β Oestradiol; Hoechst Roussel Vet) implant in the soft skin on the posterior aspect of the ear. The animals were confined in partially covered pens with straw bedding provided under cover.

2.2.3 Measurements

2.2.3.1 Laboratory nutrient analysis

Snatch samples were taken from ten bags of the mixed diets and pooled for laboratory analysis. This was repeated six times over the feedlot period. These samples were analysed for crude protein (CP), calcium, phosphorous, ether extract (EE_f), dry matter (DM), crude fibre (CF) and ash according to standard procedures (AOAC,1990). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to Van Soest *et al.* (1991). The nutrient composition of the diets is located in Appendix 1.1.1.

2.2.3.2 Feed

The feed was offered *ad libitum*. The troughs were scored twice daily to identify the amount of feed being eaten and then topped up accordingly. Thus the animals were fed according to their intakes. The amount fed daily was recorded and totalled for a weekly value. Water was freely available. The dry matter feed intake of an animal per pen is located in Appendix 1.1.2.

2.2.3.3 Animals

Live weights of the animals were recorded weekly on an electronic scale (Roadway scale, Ruddweigh, Australia) to the nearest kilogram. The animal's individual live weights over time is located in Appendix 1.1.3.

2.2.3.4 Carcass

Animals were sent for slaughter at a commercial abattoir after having been visually appraised to have attained the required amount of fat cover. If only one animal remained in a pen after the others had been selected for slaughter, it too was sent for slaughter irrespective of its degree of finish. The carcasses were chilled for 24 hours at 4 °C. The whole carcass, the forequarter, the loin and the hindquarter were classified for fat coverage (Table 2.3), according to the Agricultural Production Standards Act (1990), the fat codes lean and medium being the target at slaughter. The dressing percentages (the ratio of cold carcass weight to live weight) were calculated. The carcass data is located in Appendix 1.1.4.

Table 2.3 Fatness classification of bovine carcasses

Description of fatness	Fatness class	Thickness of subcutaneous fat layer (X, mm)
No fat	0	0
Very lean	1	$X < 1$
Lean	2	$1 < X < 3$
Medium	3	$3 < X < 5$
Fat	4	$5 < X < 7$
Slightly over fat	5	$7 < X < 10$
Excessively over fat	6	$X > 10$

The inclusion of a '+' sign with the fatness class indicates that the measurement tended towards the upper boundary of the class and a '-' sign the lower boundary of the class.

2.2.4 Data derivation and statistical analysis

2.2.4.1 Diet

The digestible energy (DE) content of the diets were calculated using the equations from Dunbar *et al.* (1991).

$$DE = 3.729697 + 0.0080470*CP + 0.0458200*EE_f - 0.0393000*ASH - 0.0392000*CF \text{ Mcal/kg}$$

Van Soest (1994) regressed ME on DE and found a significant negative intercept. This indicated that ME estimated as 0.82 of DE may not be accurate. The equation proposed by van Soest (1994) was thus used to calculate ME.

$$ME = (0.96*DE) - 0.27 \text{ Mcal/kg}$$

The ME values were then converted to MJ/kg by multiplying by a factor of 4.184 (McDonald *et al.*, 1990 and NRC, 1996).

The Effective Energy (EE) was calculated using the equation proposed by Emmans (1994).

$$EE(MJ/kg\ organic\ matter) = 1.15*ME - 3.84 - 4.67*DCP$$

where : DCP = digestible crude protein. Dietary values of DCP were calculated from ingredient contributions (Bredon *et al.*, 1987 and Feedstuffs, 1997). The ratio of EE to ME was calculated to determine the efficiency of energy availability to the animal.

The NE_g values were calculated using the following predictive equation (NRC, 1996) :

$$NE_g = 1.42*ME - 0.147*ME^2 + 0.0122*ME^3 - 1.65\ Mcal/kg$$

where ME = 0.82*DE.

The equation for NE_g was then recalculated by regressing NE_g on the ME values obtained using the equation proposed by van Soest (1994). The resultant equation was :

$$NE_g = 1.14603*ME - 0.0.02887*ME^2 + 0.000434315*ME^3 - 5.57149\ MJ/kg$$

2.2.4.2 Performance

The feeding period of an animal was the time (days) that the animal spent in the feedlot, counting from the start of feeding until slaughter. The total feed intake (kg) of a pen, is the weekly feed intake of a pen divided by the number of animals in the pen during that week, totalled over the feeding period. The dry matter intake (kg) is the total feed intake multiplied by the dry matter content of the diet. The ME, EE, and NE_g intake (MJ) were then estimated based on dry matter intake and the respective nutrient contents.

An animal's weight gain (kg's) is the difference between its weight on entry in to the feedlot (Initial weight) and on leaving the feedlot (Final weight). The average daily gain (ADG) (kg / day) is the weight gain (kg's) divided by the length of time in the feedlot (days). The dressing percentage is the cold carcass weight (kg) of an animal divided by its final weight (kg). The feed conversion ratio (FCR) is the pens dry matter intake, ME intake, EE intake or NE_g intake divided by the pens mean weight gain.

2.2.4.3 Statistical analysis

The GENSTAT V statistical programme (Lawes Agricultural Trust, Rothamstead) was used for all statistical analysis. Differences among diet's nutritional composition were determined using multiple linear regression due to the diets representing a series of nutrient densities. The following is the full linear regression model (an example is Appendix 1.2), with significance of a components being determined using the *T probability test*.

$$y_i = \beta_0 + \beta_1 X_{1i} + \varepsilon_i$$

where: y_i = variate;

β_0 = y intercept;

β_1 = regression (coefficient) of y on X_1;

X_{1i} = treatment effect (Diet); and

ε_i = residual error (N.I.D. ~ $(0, \sigma^2)$).

Various models including, linear, quadratic, broken stick, gomperitz and linear exponential, were fitted to the feed (dry matter), ME and NDF intake data over time to determine a best fitting predictive model. The data was restricted to the period up to the beginning of slaughtering (1 to 12 weeks). The linear exponential model was found to fit the data best.

$$y_i = \mu + \beta_1 \Upsilon^{xi} + \beta_2 x_i + \varepsilon_i$$

where: y_i = variate (feed intake);

μ = common component;

β = linear term;

Υ^{xi} = exponential term;

x_i = time (weeks); and

ε_i = residual error (N.I.D. ~ $(0, \sigma^2)$).

A predictive model was developed for each pen's data (Appendix 1.3.1). These models were then used to predict feed intakes over the feeding period. The predicted values in weeks one, three and five were chosen to represent the linear phase and six, eight, ten and twelve the exponential phase. To determine whether different models are required for different dietary treatments a multivariate analysis of variance (MANOVA) was performed on each chosen week (Appendix 1.3.2). The statistical model used for multivariate analysis of variance was :

$$y_{irj} = \mu_{ij} + \varepsilon_{irj}$$

where: y_{irj} = the observed value of the j th response variable on the r th experimental unit from the i th population;

μ_{ij} = the expected response for the variable j in treatment group i;

i = treatment group (diet);

r = experimental unit (weekly feed intake [1, 3, 5, 6, 8, 10 and 12]);

j = response variable (a weeks feed intake); and

ε_{irj} = residual error (N.I.D. ~ $(0, \sigma^2)$).

The experimental unit was the animal for live weight, live weight gain and carcass data because feed and water were available at all times and the animals reached slaughter condition at different times. Pen data was the experimental unit for intake and food efficiency. The starting live weight was used as a covariate in the analysis when it was found to have a significant effect. The use of a covariate was examined due to the possibility that it's inclusion may reduce the error variance by an appreciable extent (Rayner, 1967). Statistical differences between means were determined using the *Students' t test*. The following statistical model was used :

$$y_{ij} = \mu + t_i + \beta(\times_{ij} - \bar{x}) + \varepsilon_{ij}$$

where: y_{ij} = variate;

μ = overall mean;

t_i = diet effect;

β = regression coefficient of y on μ;

$\times_{ij}$ = concomitant variate (starting weight);

$\bar{x}$ = mean of concomitant variate; and

ε_{ij} = residual error (N.I.D. ~ $(0, \sigma^2)$).

An example of the statistical model where the experimental unit was the pen can be found in Appendix 1.3.3, and where the experimental unit was the animal in Appendix 1.4.

2.3 Results

2.3.1 Diet

The chemical composition of the feeds used in this study is given in Table 2.4. Diet One had a higher ($P < 0.05$) DE, ME, EE, EE / ME and NE_g than diets Two and Three, which were non-significantly different ($P > 0.05$) from each other. Diet Three had a lower ($P < 0.05$) CP content than diets One and Two. The fibre content in the diets followed the reverse order $1 < 2 < 3$. The fat content was significantly higher ($P < 0.05$) in Diet Three than in Diet Two.

Table 2.4 The nutrient content of the three diets on a dry matter basis

Nutrient	Diet[1]			S.E.
	One	Two	Three	
Crude Protein (%)	14.14[a]	13.97[a]	13.17[b]	0.267
Calcium (%)	1.33[a]	1.21[b]	1.01[c]	0.0394
Phosphorous (%)	0.63[a]	0.52[b]	0.41[c]	0.01540
Fat (%)	5.77[ab]	5.28[b]	6.32[a]	0.430
Crude fibre (%)	9.81[c]	13.88[b]	16.90[a]	0.435
Neutral detergent fibre (%)	32.35[c]	39.00[b]	46.29[a]	2.096
Acid detergent fibre (%)	14.70[c]	20.72[b]	25.79[a]	0.453
Moisture (%)	16.80[a]	14.18[b]	11.53[c]	0.530
Ash (%)	10.61[a]	9.28[b]	7.92[c]	0.1377
Digestible Energy (MJ/kg)	13.50[a]	12.90[b]	12.80[b]	0.1344
Metabolisable Energy (MJ/kg)	11.83[a]	11.25[b]	11.16[b]	0.1281
Effective Energy (MJ/kg)	9.53[a]	8.83[b]	8.77[b]	0.1599
Effective Energy / Metabolisable Energy	0.805[a]	0.785[b]	0.786[b]	0.00519
NE_g (MJ/kg)	4.66[a]	4.29[b]	4.23[b]	0.0847

[1] = Diet One: maximum ME density; Two: medium ME density; Three: minimum ME density
[a,b,c] = Values in the same row with different superscripts are different $P < .05$

2.3.2 Feed intake curve

The patterns of dry matter intake were similar across diets (Figure 2.1). The feed intake increased linearly to a peak at about the fourth week. The feed intake then dropped during the fifth week before either decreasing slightly (diets One and Two) or increasing slightly (diet Three) during the remainder of the feeding period.

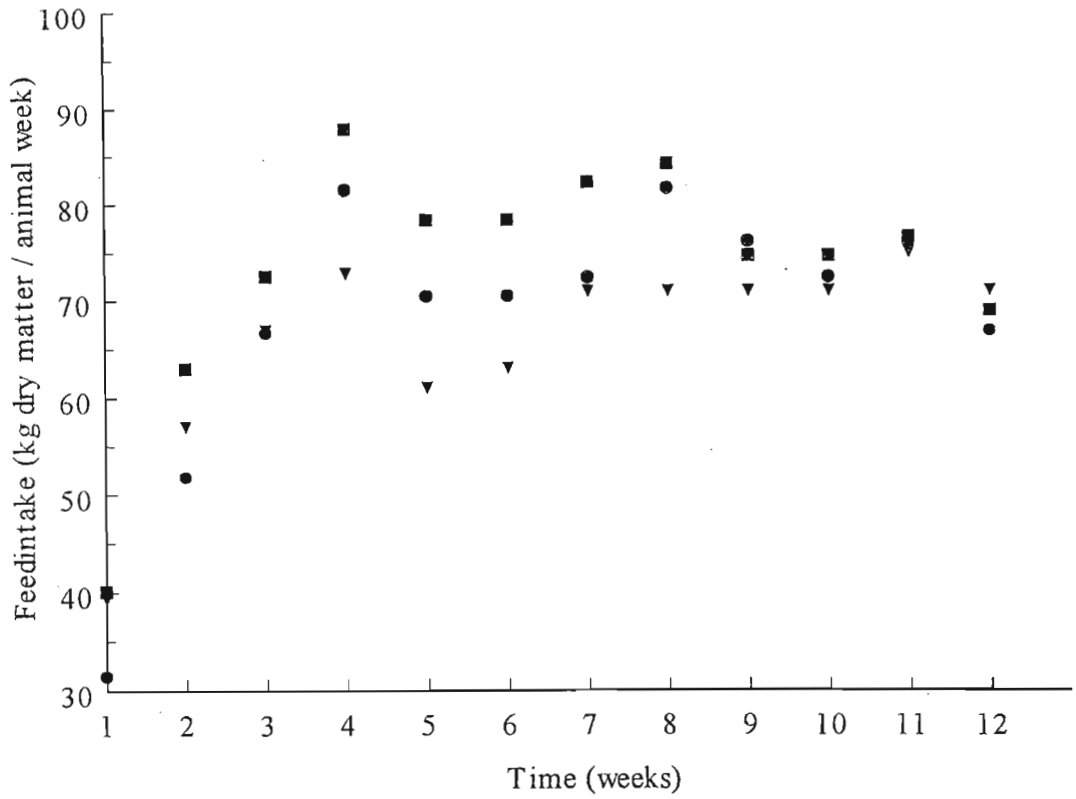

Figure 2.1 Mean feed intakes by feedlot steers (kg dry matter / animal week) fed on diets, ● One, ■ Two, and ▼ Three.

The predictive models are given in Table 2.5. The predictive models accounted for 73.5% of the variance. The rate of increase over the linear phase was in the order: diet One > diet Two > diet Three. Over the exponential phase diet Two tended to have a steeper decline than diet One, while diet Three had an increasing feed intake.

Table 2.5 Predictive models ($y_i = \mu + \beta_1 \Upsilon^{xi} + \beta_2 x_i + \varepsilon_i$) of dry matter intake by feedlot steers ($R^2 = 73.5$)

Diet[1]	μ	β_1	Υ	β_2
One	85.56	-100.4	0.534	-1.237
Two	99.00	-104.1	0.546	-2.360
Three	63.65	-103.5	0.245	0.745

[1] = Diet One: maximum ME density; Two: medium ME density; Three: minimum ME density

The comparisons between the predictive models is given in Table 2.6. During week one of the linear phase diet One had a significantly lower ($P < 0.05$) intake of nutrients than diets Two and Three. The rate of increase in nutrient intake over the linear phase was in the order of diet One > diet Two > diet Three. By week ten (within the exponential phase) the differences ($P < 0.05$) in DM and ME intakes between diets One, Two and Three had become non significant ($P > 0.05$). Significant differences in NDF intake (kg) became magnified over the exponential phase. The NDF intake (kg) of diets Two and Three were significantly different ($P > 0.05$) to that of animals on diet One up to week eight. After week Eight the NDF intake (kg) of animals on diets Two and Three were significantly different ($P > 0.05$) from each other.

Table 2.6 A test of differences among non-linear intake models using predicted intakes over the feeding period

Variate	Week						
	Linear phase			Exponential phase			
	One	Three	Five	Six	Eight	Ten	Twelve
Dry matter intake (kg)							
One	30.97[b]	66.2	75.1[ab]	76.0[ab]	75.4[ab]	73.1	70.2
Two	40.21[a]	74.5	82.0[a]	82.3[a]	79.9[a]	75.5	69.9
Three	39.10[a]	64.3	67.3[b]	68.2[b]	69.6[b]	71.1	72.5
Metabolisable energy intake (MJ)							
One	366[b]	783	887[a]	899[a]	892[a]	865	830
Two	452[a]	838	922[a]	926[a]	899[a]	849	786
Three	436[a]	718	752[b]	761[b]	777[b]	793	810
Neutral detergent fibre intake (kg)							
One	10.01[c]	21.41[b]	24.24[b]	24.57[b]	24.38[b]	23.66[c]	22.70[c]
Two	15.69[b]	29.06[a]	31.98[a]	32.10[a]	31.17[a]	29.42[b]	27.24[b]
Three	18.11[a]	29.76[a]	31.17[a]	31.55[a]	32.24[a]	32.90[a]	33.57[a]

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$.

The feeding periods are given in Table 2.7. The feeding period (CV% = 3.5) increased ($P < 0.05$) in the following order: diet Two < diet One < diet Three. Dry matter, ME and EE intake were not significantly different ($P > 0.05$) among dietary treatments.

2.3.3 Live weight and feed conversion ratio

The final live weights (Table 2.7) and the live weight gains (CV% = 13.9) were non-significantly ($P > 0.05$) different among treatments. Dietary treatments did not affect ($P > 0.05$) ADGs (CV% = 14.4) . There were no significant ($P > 0.05$) differences among diets with respect to the FCR (CV% = 4.5) irrespective of whether it was expressed per unit intake of dry matter or energy (ME, EE and NE_g; Table 2.7).

Table 2.7 Performance results for the whole trial period

Variate	Diet[1]			S.E.D.	Effect of Diet
	One	Two	Three		
Feeding period (days)	88[b]	85[b]	91[a]	1.449	**
Intake / head					
Dry matter (kg)	875	904	873	36.8	
Metabolisable energy (MJ)	10346	10170	9742	416.2	
Effective energy (MJ)	8334	7982	7655	328.7	
Net energy for gain (MJ)	4075	3878	3692	159.1	
Final weight (kg)	396	397	389	11.39	
Weight gain (kg)	175	176	168	11.39	
Average daily gain (kg / day)	2.005	2.075	1.845	0.1351	
Feed conversion ratio					
kg dry matter / kg gain	4.993	5.163	5.236	0.1912	
MJ Metabolisable energy / kg gain	59.09	58.09	58.43	2.157	
MJ Effective Energy / kg gain	47.61	45.60	45.92	1.701	
MJ Net energy for gain / kg gain	23.28	22.15	22.15	0.824	

[1] = Diet One: maximum ME density; Two: medium ME density; Three: minimum ME density

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

2.3.4 Carcass

Dietary treatment did not affect ($P > 0.05$) carcass weights or dressing percentages. Animals were slaughtered at the required fat coverage (section 2.3.3), irrespective of treatment ($P > 0.05$).

Table 2.8 Carcass weight, dressing percentage and fat coverage results after the feedlot period

Variate	Diet[1]			S.E.D.
	One	Two	Three	
Carcass weight (kg)	212.4	210.0	203.1	7.00
Dressing percentage	53.66	52.92	52.18	0.836
Fat coverage[2]				
Overall	3-	2+	2+	1.139
Fore-quarter	3-	2+	2+	1.187
Loin	3-	2+	2+	1.214
Hind-quarter	2+	2+	2+	1.38

[1] = Diet One: maximum ME density; Two: medium ME density; Three: minimum ME density

[2] = Fat codes (Table 2.3) given in brackets

2.4. Discussion

In animals consuming highly digestible, high energy diets, DMI is controlled by the animal's energy demands and by metabolic factors (NRC, 1987). With all the animal's energy demands being equal irrespective of treatment, the significantly lower energy densities of diets Two and Three should have resulted in higher daily DMI's in comparison to diet One. Steers on diet One with a significantly higher energy density should have achieved a similar production at a lower DMI following the report by McDonald *et al.* (1990) that energy supplied by the food in excess of that required for maintenance is used for production.

The use of high levels of condensed molasses solids (CMS) in diets One and Two became questionable after it was noticed that the animals, particularly those on diet One, developed very liquid stool. Potter *et al.* (1985) investigated the use of CMS in feedlot finishing diets and found that CMS in excess of 5% of the diet negatively affected the average daily gains and feed conversion of the steers. The reduction in feed efficiency was related to the decreased production of propionate in relation to acetate. Potter *et al.* (1985) also suggested that an excessively high minerals level may have adversely affected the gastrointestinal tract resulting in the production of liquid stool, which is typical of animals on diet One. The inclusion rate of CMS at 17.5% *as is* in diet One is above this recommended level. From the work by Potter *et al.* (1985), this would have resulted in decreased production due to a lower DMI, poorer digestion and thus lower energy availability. The liquid stool may have also been as a result of subclinical acidosis. All attempts were made to limit this possibility by including Romensin and Tylan in the diets as well as correct bunker management in order to prevent the animals from developing the "roller caster effect". Despite DMI being not significantly lower for animals on diet One compared to those on diets Two and Three the discussion, in respect of the trial's hypothesis, will concentrate on diets Two and Three.

The calculated energy densities of diets Two and Three were non significantly different. However, this is not supported by the performance results of the dietary treatments as the diets produced plateau feed intakes of differing magnitude and the animals on diet Three spent longer in the feedlot which both suggest the diets differed in their energy density. The crude protein (CP) contents of diets Two and Three were below the minimum formulation boundary (Table 2.1), but still met the animals protein requirements (Church 1984 and NRC 1996). Fermentation in the rumen is retarded by high levels of unsaturated fat (Van Soest, 1994), as the capacity of the rumen micro-organisms to digest lipids is strictly limited. The lipid content of ruminant diets is normally low (i.e. < 50 g/kg) and if it is increased above 100 g/kg the activity of the rumen microbes is reduced, the fermentation of carbohydrates is retarded, and food intake falls (McDonald, 1990). Although the levels of unsaturated fat were not measured in these diets the sole source of fat in the diets was vegetable in nature. Fat from vegetable sources is largely made up of unsaturated fat as opposed to animal fats which are largely saturated in nature (Van Soest, 1994). Therefore, comparison of the measured fat levels between diets is a good comparison with respect to the unsaturated fat levels as well. The combination of higher fat and fibre levels in diet

Three may have resulted in a decrease in fermentation and thus energy yield. A lower energy density in diet Three was predicted to have resulted in similar performance results by achieving a higher daily DMI. However, the fat levels were below the 10% threshold suggested by McDonald *et al.* (1990) indicating no decrease in energy yield.

The feed intake curves followed a similar trend to that reported by Owens *et al.* (1985), Thornton *et al.* (1985), Hicks *et al.* (1990*a,b*) and Dominy (1997). The daily feed intakes recorded at peak were similar to those reported by Owens *et al.* (1985), Thornton *et al.* (1985) and Hicks *et al.* (1990*a,b*). As found in previous works (Owens *et al.*, 1985; Thornton *et al.*, 1985 and Hicks *et al.*, 1990*a,b*) there was a dip in feed intake during the fifth week in the feedlot. No stepwise diet system of increasing dietary energy density and decreasing fibre concentration was used in this trial. All three treatments received only one diet from the start to the end of the feeding period, thus casting doubt on the conclusion of Hicks *et al.* (1990*a*) that such a dip is due to adaptation to the final finishing diet. The peak DMI reached, following the conclusion by the NRC (1987) that the DMI is controlled by an animals energy requirements should have resulted in the DMI curve of the animals on diets Two and Three being equal. However, the curve of DMI of steers on diet Three was significantly lower than that of steers on diet Two. Either the energy density of diet Two was higher than that predicted or the steers were inhibited from achieving similar DMI's.

Performance results were similar among treatments except for the length of time in the feedlot. As the animals were slaughtered at a set condition score, length of time in the feedlot was inversely related to the amount of energy available for production. The total DMI's were non-significantly different, thus the amount of energy available for production was therefore equal. An animal that spends a longer period of time in the feedlot and achieves a similar physiological degree of finish must have consumed a lower amount of energy per day than those animals which finished in a shorter period of time. Alternatively the animals that spend a longer period of time in the feedlot may have deposited more lean per day. This is not supported by the performance results as the animals on diet Three spent longer in the feedlot but tended to reach lower final live weights at a lower ADG. Thus a low DMI of the steers on diet Three must have prevented the animals from achieving similar daily intake of energy and performance to their counterparts on other diets.

2.5. Conclusions

The feed intake curves were of a similar shape irrespective of energy density. The feed intake curve of feedlot animals followed a positive linear trend before peaking after 28 days, beyond which it attained a plateau when fed to achieve an acceptable fat code for the South African market. Due to differences in the magnitudes of the modelled plateaus reached and the performance differences between diets Two and Three either a factor other than energy density controlled the animals DMI or the energy density of the diets were incorrectly estimated such that diet Three had a lower energy density than was calculated. The energy density of a diet can be affected by interactive factors related to nutrients (i.e. fibre and fat densities), further experimental trials should make use of metabolism trials to more accurately determine the energy density of a diet. Investigation into possible DMI limiting factors i.e. heat stress resulting from an inability to lose the heat of digestion, should be examined.

CHAPTER THREE

BODY TEMPERATURE AND RESPIRATION RATES AS MEASURES OF HEAT STRESS IN ANIMALS ON CONCENTRATE FEEDLOT RATIONS

3.1. Introduction

The NRC (1987) attributes DMI control to an animal's energy demands and metabolic factors. In Chapter 2, performance differences between diets Two and Three could not be explained on the basis of differences in calculated energy density. Duration of the length of time in the feedlot and feed intake levels reached during the plateau phase of the feed intake curve differed between diets two and three despite there being no significant differences in the diets' calculated energy densities. The investigation of heat stress as an alternative limiting factor is suggested.

Feed intake is limited under heat stress conditions when feed is available above maintenance, and a threshold heat load is surpassed (see section 1.4.2.1). Manipulation of a diet's heat increment of feeding can be used to investigate whether animals are being limited in their intakes by heat stress. The heat increments of feeding can be manipulated while holding net energy constant thus achieving differing Effective Energy densities. Differences in heat increments of feeding can be achieved by increasing the proportion of concentrates in the diets or changing the quality or quantity of food available (Morrison *et al.*, 1983; Finch, 1986 and Forbes, 1986). The observation (Kleiber, 1975) that animals will adjust their food intakes to achieve similar daily heat increments will result in different production responses. The measurement of livestock's production responses to a hot climate is easy, and is measured in terms of weight gain, efficiency of feed use or any other appropriate variable (Bond, 1967).

The most important parameter for cattle as homeotherms is maintaining a constant core body temperature (see section 1.3.4). Rectal temperature may be considered the most meaningful single criterion for judging an animal's heat tolerance, since the rectal temperature indicates the animal's efficiency in maintaining homeothermy in the face of extreme environmental temperatures (Bianca, 1959*a*). Hourly recordings have shown that rectal temperatures rise continuously with

ambient temperature (Frisch, 1981). Rectal temperatures measured in the early morning are lower than temperatures measured at peak daytime temperatures (1400 hours) (Nakamura *et al.*, 1993). Rectal temperatures taken during peak daytime temperatures have proved to be the best indicator for differentiating between the heat tolerance of individual animals (Bianca, 1963).

Heat stress has more of an affect on those animals with a high feed intake and a high level of production. Manipulation of the heat increment of feeding will allow animals with high intakes and production levels, (e.g. late maturing animals), to have differing heat gains. The following trial was designed to investigate the hypothesis that animals fed diets differing in their heat increments of feeding will exhibit physiological heat stress responses and differ in their feed intake curves and performance. Also, there should be differences between the responses of late maturing and early maturing animals to the differing heat increments of the diets.

3.2 Materials and methods

Three feedlot diets differing in their heat of digestion were formulated and fed to weaners representing two maturity types to investigate the effect of heat stress on feedlot steers.

3.2.1 Diet formulation and ingredient composition

A maintenance diet (Table 3.1) was formulated to provide a low energy, high roughage ration to the weaners during adaptation to the calan gates. Calan gates are individual feeding troughs that are operated by transponders located around each animals neck. A bank of ten calan gates were placed in each pen with a gate specific to each animal. The individuals transponder opened the gates of the trough allowing only that animal to feed from the available food in that trough, thus allowing for individual feed intakes to be measured. The diet was fed twice daily at 7.00 am and 4.00 pm and was available *ad libitum*.

Table 3.1 Ingredient composition of the maintenance diet

Ingredient	Inclusion
Molasses cane (liquid)	25 (%)
Veld hay	20 (%)
Broiler chicken litter	55 (%)

Three diets were formulated to differ in their heat load, and were designated Four (maximum EE : ME), Five (medium EE : ME) and Six (minimum EE : ME). Diet Five was formulated by mixing diets Four and Six at a 50 : 50 ratio.

Winfeed (1.11) software (EFG Software 1996) was used to formulate these diets and the lower and upper boundaries were set as given in Table 2.1. The nutritive values of the ingredients were obtained from ingredient book values (NRC, 1984; Bredon *et al.*, 1987 and Feedstuffs, 1997). The ingredients making up the diets are given in Table 3.2. Ingredients were purchased in batches due to the large amount needed and the limited storage space available. The batches were sourced from the same suppliers in order to reduce variation. The rations were mixed when required in a triple auger, flat bed mixer (Henke B240S, Columbus Nebraska) one tonne at a time and bagged into 40 kg bags. This ensured the availability of fresh feed at all times.

Table 3.2 Ingredient composition of the three diets

Ingredient (kg)	Diet[1]		
	Four	Five	Six
Yellow maize (grade2)	-	80	160
Hominy Chop	156	78	-
Molasses cane liquid	222	111	-
Molasses cane meal	-	120	240
Palm kernel meal	150	75	-
Cotton seed oil cake	101	78.5	56
Broiler chicken litter	-	87.5	175
Veld hay	205	152.5	100
Wheat middlings	-	117	234
Sunflower (acid) oil	19	9.5	-
Morlac	-	9.5	19
Defatted maize germ	132	66	-
Salt	4.7	4.6	4.5
Urea	-	2.2	4.4
VitA + mineral premix[2]	1.0	1.0	1.0
Romensin	0.15	0.15	0.15
Tylan	0.10	0.10	0.10
TOTAL	1000.25	1001.65	1002.95

[1] = Diet Four: maximum EE to ME ratio; Five: medium EE to ME ratio; Six: minimum EE to ME ratio

[2] = Vitamin A : 4000000 iu, Vitamin B1 : 3g, Manganese : 10g, Zinc : 10g, Copper : 2g, Cobalt : 0.50g, Magnesium : 100g, Selenium : 0.3g, Iodine : 0.25g.

3.2.2 Animals and feeding management

One hundred and thirty, 7 month old weaner steers were purchased from local farmers' auctions and overwintered on pasture foggage (*Pennisetum clandestinum*). The animals were representative of two maturity types, 65 early maturing (Hereford and Sussex) and 65 late maturing (Simmentaler, Charolais and Simmentaler cross Jersey). At the end of the overwintering period the animals had live weights (measured on an empty stomach, after being starved for 24 hours) ranging from 155 to 333 kg (mean = 208 (s.e. = 2.76) kg). The live weights of early maturing animals ranged from 155 kg to 265 kg (mean = 197 (s.e. = 2.58) kg), while that of late maturing animals ranged from 157 kg to 333 kg (mean = 219 (s.e. = 4.52) kg).

Before being placed in the feedlot, animals within each maturity type were sorted in descending order of live weight. The sixty five animals were blocked by weight into five groups of thirteen animals in each. Five animals of each maturity type representing each weight category within a maturity type were randomly assigned to be kept on pasture (*Pennisetum clandestinum*) as control. The remaining twelve animals within a weight category were then randomly assigned to six groups of ten each (Prof. Clark *pers comm*) ensuring that each group had two animals of each weight category. Three of the groups within each maturity type were assigned to be individually fed (farm 1) but group housed, creating six pens of ten steers in each. The remaining three groups of each maturity type were assigned to be group fed (farm 2). Each of the remaining groups for each maturity type was further randomly split into two, while ensuring that each of the weight categories was represented in the sub groups. Each sub group containing five animals was then assigned to one of twelve pens. The resultant trial design was a 3 (diet) X 2 (maturity type) X 2 (feeding type / farm) factorial.

One month prior to the adaptation period all the animals were inoculated against anthrax, quarter evil, botulism, bovine viral diarrhoea and pasteurella. The facilities housing the individually fed animals were under the control of the state veterinarian who tested the individually fed animals for tuberculosis (*Mycobacterium tuberculosis*) and contagious abortion (*Brucella abortus bovis*). At the start of the feedlot period all steers on the feedlot diets received a Revalor -S (200 mg Trenbolone Acetate and 20 mg 17β Oestradiol; Hoechst Roussel Vet) implant in the soft skin on

the posterior aspect of the ear. The animals were confined in partially covered pens.

The animals fed individually were adapted to the calan gates over a four week period. If after three weeks an animal exhibited a comparative lack of adaptation to its calan gate it was placed in an individual pen with an open trough for feeding. It was allowed to adapt to this environment for the final week of the four week adaptation period. During this period of adaptation all animals, except the control group on pasture, were fed on a maintenance diet (Table 3.1).

3.2.3 Measurements

3.2.3.1 Laboratory nutrient analysis

Snatch samples were taken from ten bags of the mixed diets and pooled for laboratory analysis. This was repeated sixteen times over the feedlot period. These samples were analysed for crude protein (CP), gross energy (GE), calcium, phosphorous, ether extract (EE_f), dry matter (DM), crude fibre (CF) and ash according to standard procedures (AOAC,1990). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to Van Soest *et al.* (1991). The measurements of the diets nutrient composition is located in Appendix 2.1.1.

3.2.3.2 Metabolism study

Eighteen immature male Hampshire sheep (33 kg) were used in a 25 day study. The use of sheep was justified by the comparison of sheep versus cattle in metabolism studies performed by Van Soest (1994). There was no difference between the two species around the 66% dry matter digestibility point, with sheep having a higher digestibility above 66% and cattle a higher digestibility below 66%. The dry matter digestibility of the feedlot diets is not expected to be markedly different from 66%. Sheep were randomly allocated to the three dietary treatments. After an adaptation period of eleven days in individual pens with *ad libitum* access to feed, they were restricted to a maintenance allowance of 520 g / day fed in one amount at 9.00 am (ARC,1980) calculated thus:

$$MME = ((360*(W^{0.75}))/1000)$$

where MME = Maintenance ME requirement (MJ / day); and

W = average live weight (33 kg).

$$MA\ (g / day) = ((MME / DME)*1000)$$

where MA = Maintenance allowance (g / day); and

DME = Estimated metabolisable energy content of the diet (9.5 MJ / kg as is).

After three days on the restricted allowance fifteen of the sheep (five on each diet) were selected based on their adaptation and transferred into metabolism crates where they were harnessed and fitted with faecal collection bags. A three-day adjustment period was allowed, following which total faeces and urine were collected for seven days. Individuals urine production was collected in a bucket containing 50 ml of 10% sulphuric acid (H_2SO_4), (resultant urine pH was < 3), bulked per animal over the collection period and stored (4°C). The daily faeces output of each animal was weighed and dried at 50°C for a minimum of 72 hours. Any remaining feed in the troughs at the end of the trial was collected, weighed and then analysed. The bulked urine was sampled for N analysis within three days of the end of the trial while the dried faeces was reweighed, bulked and then sampled for the analysis of N, GE, and ash. The breakdown of the metabolism study is located in Appendix 2.1.2.

3.2.3.3 Rectal temperature and respiration rate

Rectal temperatures (T_R) and respiration rates were recorded weekly on thirty animals randomly selected from the individually fed group. T_R were recorded before 9.00 am (T_R (9.00 am)) and at 2.00pm (T_R (2.00 pm)) with a mercury thermometer (Krusse d26 Veterinär, Germany). Respiration rates were measured at 9.00 am by counting an animals' flank movements within a thirty-second period in replicate (Kibler, 1962 and Vizcarra *et al.*, 1991). Restraint itself can, however, create a stress response in that an animal can mask or alter the response to an imposed stressor (Hahn *et al.*, 1990). Therefore, readings of the respiration rate were taken two days after

rectal temperatures and while the animals were in their pens to reduce error due to exercise and or stress. The rectal temperatures (9.00 am and 2.00 pm) and respiration rates measured are located in Appendix 2.2.1, 2.2.2 and 2.2.3 respectively.

The maximum, minimum and mean environmental temperatures were obtained for each day of the trial (Appendix 2.2.5) from the neighbouring weather station (Institute of Soil, Climate and Water, Agricultural Research Council, Cedara).

3.2.3.4 Feed and animals

The feed was offered *ad libitum*. Troughs were scored twice daily to identify the amount of feed being eaten and then topped up accordingly. Thus the animals were fed according to their intakes. The amount fed daily was recorded and totalled for a weekly value (Appendix 2.3.1). If any stale food accumulated its weight was subtracted from the weekly total. Water was freely available.

Live weight of the animals was recorded weekly. The individually fed animals' live weights were measured on an electronic scale (Schenck Discomat B, Schenck Ash, South Africa) to the nearest kilogram. The group fed animals' and the control animals' live weights were measured on a balance scale (Berkel, U.S.A.) to the nearest kilogram (Appendix 2.3.2).

3.2.3.5 Carcass

Carcass data were obtained following the procedures described in section 2.2.3.4. The carcass, fat coverage and length of time in the feedlot data is located in Appendix 2.3.3.

3.2.4 Data derivation and statistical analysis

3.2.4.1 Diet

3.2.4.1.1 Metabolisable energy at maintenance

Using the DE values obtained from the metabolism study the equation proposed by Van Soest (1994) (see section 2.2.4.1) was used to calculate ME.

$$ME = (0.96*DE) - 0.27 \text{ Mcal/kg}$$

The ME values were then converted to MJ/kg by multiplying by a factor of 4.184. The ME values were converted to a ME_n at zero nitrogen retention using the values of Emmans (1994).

$$ME_n = ME - (0.0365 * NR)$$

where : NR = nitrogen retention = (N intake - (N faeces + N urine)).

3.2.4.1.2 Effective Energy

The Effective Energy (EE) was calculated using the equation proposed by Emmans (1994).

$$EE \text{ (MJ / kg)} = (ME_n - w_m.MTHE - w_d.FOM) - 0.16.w_u.DCP$$

where : w_m = heat of excretion of methane (0.616 kJ / g);
MTHE = loss of energy as methane (MJ / kg) estimated following the equation proposed by Nsahlai (1998);
w_d = heat of excretion of faecal organic matter (3.80 kJ / g);
FOM = faecal organic matter (kg / kg);
w_u = heat of excretion of urine (29.2 kJ / g); and
DCP = digestible crude protein (kg / kg).

3.2.4.1.3 Depression in digestibility and resultant energy values

The depression in digestibility is related to the level of energy intake above that of maintenance requirements. The unit rise in feeding level (U) is calculated as (ARC, 1980):

$$U = (ME_n \text{ intake} / MH) - 1$$

where : ME_n intake = Weekly dry matter intake * ME_n content of the diet (MJ); and
MH = maintenance metabolism (MJ).

Calculation of a steers maintenance metabolism (MH) is a factor (0.96) of its fasting metabolism (FH) (Emmans, 1994). Calculation of the fasting metabolism (FH) of each steer utilises the equation proposed by ARC (1980):

$$FH = 0.53W^{0.67} \quad (MJ / d)$$

where : FH = fasting metabolism (MJ / d); and
W = fasted weight (kg).

The fasted weight (W) of an animal was the mean of the live weights at the beginning and at the end of each week for that animal. This figure was used to calculate the fasting metabolism for each day of the previous week and was totalled over the seven days for a weekly value.

The ME_n intake was calculated for each individually fed animal and for each pen of group-fed animals.

The mean unit rise in the level of feeding (U_{AVE}) for the entire trial period was calculated as the mean of the U for each week in the trial for each animal and then meaned over the animals within each diet.

The depression in digestibility for each unit rise in feeding was calculated thus (ARC 1980) :

$$\Lambda d_E = 0.107 - 0.113 d_E$$

where : Λd_E = the absolute depression per unit rise in the level of feeding; and

d_E = the apparent digestibility of gross energy.

The corrected digestibility was estimated thus:

$$d_c = d_E - (\Lambda d_E * U_{AVE})$$

where : d_c = the corrected digestibility; and

d_E = the apparent digestibility of gross energy.

From the d_c the expected DE_x, ME_x, EE_x and EE_x / ME_x were calculated using the values from the sheep in the metabolism crates. Van Soest (1994), reported that the response of the beef (NRC, 1984) committee was to bury the difference by adjusting the equations. Thus the expected depression in digestibility is already accounted for in the calculation of net energy values.

3.2.4.2 Performance

The feeding period of an animal is the time (days) from the start of feedlotting until its slaughter. The feed intake (kg) of an individually fed animal, is the weight of the feed bin at the beginning of the week plus the weight of feed added during the week minus the weight of the feed bin at the end of the week. The feed intake (kg) of a pen, is the weekly feed intake of a pen divided by the number of animals in the pen during that week.

An animal's weight gain (kg's) is the difference between its weight on entry into the feedlot (Initial weight) and on leaving the feedlot (Final weight). The average daily gain (ADG; kg / day) is the weight gain (kg's) divided by the length of time in the feedlot (days). The dressing percentage is the cold carcass weight (kg) of an animal divided by its final weight (kg). The feed conversion ratio (FCR) is the intake divided by the weight gain.

3.2.4.3 Statistical analysis

The GENSTAT V statistical programme (Lawes Agricultural Trust, Rothamstead) was used for all statistical analysis.

3.2.4.3.1 Diets nutrient composition

Differences among diet's chemical composition, metabolic variables, and corrected digestibilities were determined using multiple linear regression due to the diets representing a series of nutrient densities. The following is the full linear regression model (an example is Appendix 1.2), with significance of a components being determined using the *T probability test*.

$$y_i = \beta_0 + \beta_1 X_{1i} + \varepsilon_i$$

where: y_i = variate;

β_0 = y intercept;

β_1 = regression (coefficient) of y on X_1;

X_{1i} = treatment effect (Diet); and

ε_i = residual error (N.I.D. ~ $(0, \sigma^2)$).

3.2.4.3.2 Rectal temperatures (T_R) and respiration rates

The ANOVA of the T_R and respiration rates included factors for maturity type and time (weeks). With the inclusion of the control, the treatments were expanded to four. The following is the ANOVA model used to determine treatment means, standard errors and statistical differences among treatment means (*F probability test*)(an example is Appendix 2.4.1.1).

$$y_{ijk} = \mu + t_i + \delta_j + \Psi_k + (t\delta)_{ij} + (t\Psi)_{ik} + (\delta\Psi)_{jk} + (t\delta\Psi)_{ijk} + \varepsilon_{ijk}$$

where: y_{ijk} = variate;

μ = common component;

t_i = treatment effect (Diet);

δ_j = maturity type;

Ψ_k = time;

$t\delta_{ij}$, $t\Psi_{ik}$, $\delta\Psi_{jk}$ and $t\delta\Psi_{ijk}$ = interaction terms; and

ε_{ijk} = residual error (N.I.D. ~ $(0, \sigma^2)$).

Correlations were determined between the maximum, minimum, and average ambient temperatures with the T_R and respiration rates for the day of measurement (an example is Appendix 2.4.1.2).

3.2.4.3.3 Performance factors

The experimental unit was the animal for live weight, live weight gain and carcass data because feed and water were available at all times and the time in the feedlot varied among animals. Pen / animal was the experimental unit for intake and food efficiency. A covariate (starting weight) was included in the ANOVA analysis when found to have a significant effect ($P < .05$). The use of a covariate was examined due to the possibility that it's inclusion may reduce the error variance to an appreciable extent (Rayner, 1967). Factors for maturity type, farm site and the interactions were included when significant ($P < .05$). The following is the full ANOVA model (an example is Appendix 2.4.2), used to determine treatment means, standard errors and statistical differences between treatment means (*F probability test*).

$$y_{ijk} = \mu + t_i + \delta_j + \Psi_k + (t\delta)_{ij} + (t\Psi)_{ik} + (\delta\Psi)_{jk} + (t\delta\Psi)_{ijk} + \beta(\times_{ijk} - \bar{x}) + \varepsilon_{ijk}$$

where: y_{ijk} = variate;

μ = common component;

t_i = treatment effect (Diet);

δ_j = maturity type;

Ψ_k = farm site (feeding system);

$t\delta_{ij}$, $t\Psi_{ik}$, $\delta\Psi_{jk}$ and $t\delta\Psi_{ijk}$ = interaction terms;

β = regression coefficient of y on μ;

$\times_{ijk}$ = concomitant variate (starting weight); and

ε_{ijk} = residual error (N.I.D. ~ $(0, \sigma^2)$).

3.2.4.3.4 Prediction equations

Prediction equations were generated for ADG, cumulative dry matter feed intake and FCR using multiple linear regression. These models were developed to determine the amount of variation that could be accounted for by the diets nutrient densities. Maturity type (dummy variable), farm site (dummy variable) and starting weight (covariate) were included as factors if found to be significant ($P < .05$). The following is the full linear regression model (an example is Appendix 2.4.3), with significance of a components inclusion being determined using the *T probability test.*

$$y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \varepsilon_i$$

where: y_i = response variate;

β_0 = y intercept;

$\beta_{1 \text{ to } 4}$ = regression of y on $X_{1 \text{ to } 4}$;

X_{1i} = energy content;

X_{2i} = maturity type;

X_{3i} = farm site;

X_{4i} = starting weight; and

ε_i = residual error (N.I.D. ~ $(0, \sigma^2)$).

3.3 Results

3.3.1 Diet composition

The chemical composition of the feeds is given in Table 3.3. The CP contents of diets Four and Five are below the minimum formulation boundary (Table 2.1). The CP, calcium, phosphorous and ash contents differed significantly ($P < 0.001$) among the diets, in the order: diet Six > diet Five > diet Four. The crude fibre content of diet Six is significantly ($P < 0.001$) lower than that of diets Four and Five.

Table 3.3 The nutrient content of the three diets on a dry matter basis

Nutrient	Diet[1]			S.E.
	Four	Five	Six	
Protein (%)	12.68^{c}	13.81^{b}	14.85^{a}	0.384
Calcium (%)	0.91^{c}	1.37^{b}	1.86^{a}	0.0732
Phosphorous (%)	0.44^{c}	0.51^{b}	0.61^{a}	0.01066
Fat (%)	4.26	4.79	4.26	0.333
Crude Fibre (%)	14.26^{a}	13.21^{a}	11.97^{b}	0.557
Neutral detergent fibre (%)	42.03^{a}	36.21^{b}	34.63^{b}	1.116
Acid detergent fibre (%)	21.39^{a}	20.15^{b}	19.42^{b}	0.571
Moisture (%)	14.83^{b}	15.12^{b}	16.35^{a}	0.375
Ash (%)	8.18^{c}	9.99^{b}	11.84^{a}	0.333

[1] = Diet Four: maximum EE to ME ratio; Five: medium EE to ME ratio; Six: minimum EE to ME ratio

^{a,b,c} = Values in the same row with different superscripts are different $P < 0.05$

Results of the metabolism study are given in Table 3.4. Dietary treatments differed in urine CP ($P < 0.01$) and apparent CP digestibility ($P < 0.001$) which both followed the order: diet Six >

diet Five > diet Four. Lambs fed on diets Four and Six had positive protein retention, however only those on diet Six differed significantly ($P < 0.05$) from those on diet Five. Calculated methane production of diet Six was significantly ($P < 0.001$) greater than that of diets Four and Five.

Table 3.4 Components of the metabolism study investigating the apparent digestibilities of dry matter, organic matter, nitrogen and gross energy for diets Four, Five and Six

Variate	Diet[1]			S.E.
	Four	Five	Six	
Intake				
Dry matter (g)	4639.95	4665.68	4663.57	
Organic matter (g)	4336.03	4298.95	4330.13	
Crude protein (g)	585.56	580.88	755.50	
Gross energy (MJ)	84.91	82.98	85.33	
Urine crude protein (g)	341.0^{c}	411.0^{b}	477.0^{a}	29.8
Protein retention (g)	5.2^{ab}	-4.2^{b}	13.2^{a}	5.44
Methane (MJ / kg)	1.551^{b}	1.573^{b}	1.747^{a}	0.0308
Apparent digestibility (%)				
Dry matter	67.01	64.56	63.71	1.741
Organic matter	68.57	66.96	65.98	1.672
Crude protein	63.72^{c}	66.14^{b}	74.04^{a}	1.669
Gross energy	66.96	64.82	64.48	1.754

[1] = Diet Four: maximum EE to ME ratio; Five: medium EE to ME ratio; Six: minimum EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$

The dietary energy densities as determined in the metabolism study with sheep are given in Table 3.5. The Effective Energy density and the ratio of EE to ME_n of diet Six are significantly ($P < 0.01$) lower than those of diets Four and Five. The animals on diet Four ate a significantly ($P < 0.05$) higher level of energy in terms of multiples of maintenance than did the animals on diets Five and Six. The corrected digestibilities of the diets were however found to be non-significantly ($P > 0.05$) different. Consequently, the ME density was recalculated and the trends among diets found to be similar to the uncorrected.

Table 3.5 The energy density of the diets used in this study as determined by the metabolism study

Variate	Diet[1]			S.E.
	Four	Five	Six	
Digestable energy (MJ / kg)	12.25	11.53	11.80	0.320
Metabolisable energy at maintenance (MJ / kg)	10.45	10.09	9.72	0.272
Effective Energy at maintenance(MJ / kg)	9.11[a]	8.74[a]	8.08[b]	0.272
Net energy for gain (MJ / kg)	3.743	3.499	3.236	0.1873
Effective Energy / Metabolisable energy at maintenance	0.8722[a]	0.8656[a]	0.8313[b]	0.00411
% change per unit rise in feed level	0.03134	0.03376	0.03414	0.00199
Feeding level (X maintenance)	3.549[a]	3.270[b]	3.223[b]	0.1246
Corrected Gross energy digestibility (%)	55.53	55.65	55.71	0.410
Digestable $energy_x$ (MJ / kg)	10.16	9.90	10.19	-
Metabolisable $energy_x$ (MJ / kg)	8.438	8.526	8.176	0.1977
Effective $Energy_x$ (MJ / kg)	7.048[a]	7.106[a]	6.592[b]	0.1966
Effective $Energy_x$ / Metabolisable $energy_x$	0.8350[a]	0.8334[a]	0.8061[b]	0.00468

[1] = Diet Four: maximum EE to ME ratio; Five: medium EE to ME ratio; Six: minimum EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$

$_x$ = the expected energy density

3.3.2 Physiological measurements

The trends of the respiration rate over time were similar across diets (Figure 3.1). The respiration rates increased up to week three before decreasing linearly over the next three weeks. This was followed by a rapid increase in week seven. A more constant respiration rate was observed for the remaining period. Ambient temperatures recorded on the same days that respiration rate was measured fluctuated marginally over the first six weeks. In the seventh and eighth week the ambient temperatures increased sharply before returning to previous levels.

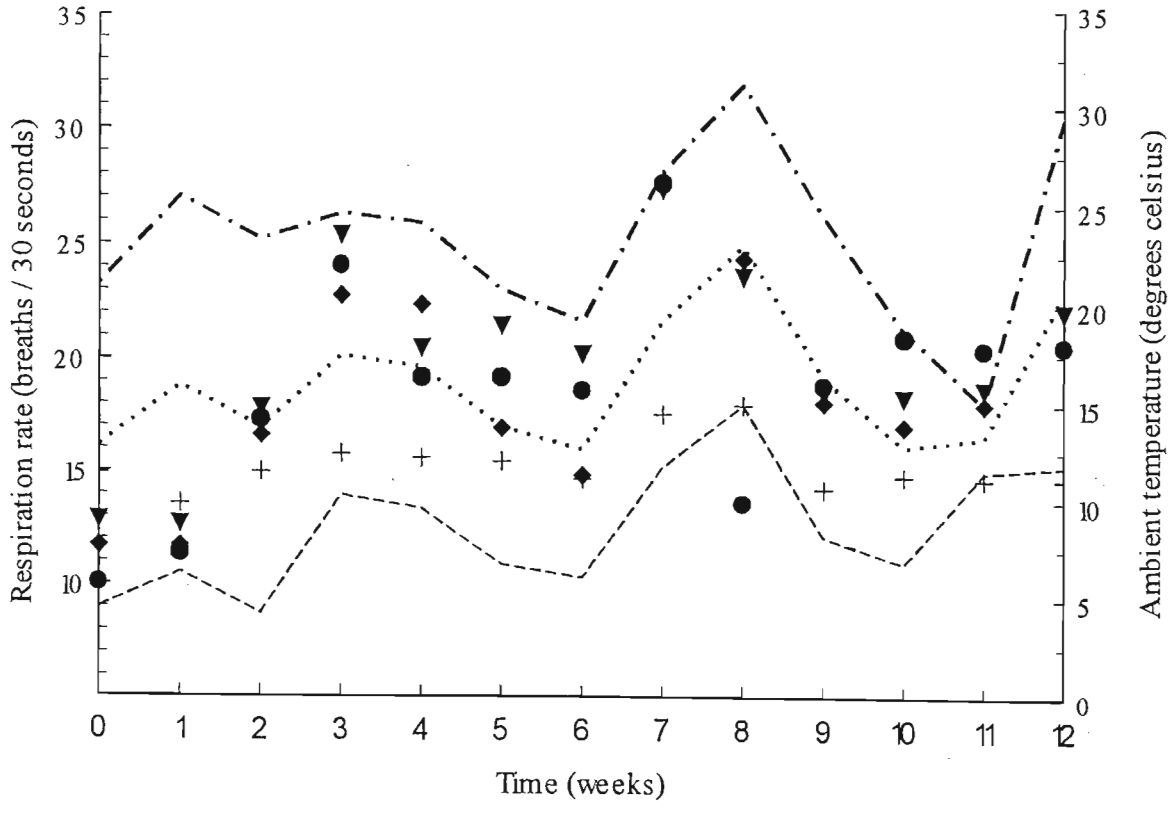

Figure 3.1 **Respiration rates (breaths / 30 seconds) of feedlot steers fed on diet Four ◆, diet Five ▼, diet Six ● and Control ✚. The ambient temperatures (°C), Average ·····, Minimum ---- and Maximum -·-·- for the days the respiration rate were recorded. The lines joining the ambient temperature points are purely descriptive and are not meant to represent a continuum.**

Results of respiration rates are given in Table 3.6. Respiration rates measured at 9.00 am (CV% = 21.7) were significantly affected by diet, maturity type, and time ($P < 0.001$). Animals on diet Five had a significantly ($P < 0.05$) higher respiration rate than those on diet Four while the control steers had a significantly ($P < 0.001$) lower respiration rate than steers on other dietary treatments. The respiration rate of early maturing animals was significantly ($P < 0.001$) higher than that of late maturing ones (37.74 versus 35.17 breaths / min). Respiration rates in weeks three, seven, and eight were markedly higher than the overall mean and the respiration rates in week one was markedly lower than the overall mean.

Table 3.6 The rectal temperature (°C) and respiration rates (breaths / minute) of feedlot cattle on the three trial diets containing various ratios of EE to ME compared to a control group grazed on pasture

Variate		Diet[1]				S.E.D.	Diet	Maturity	Time
		Four	Five	Six	Control				
Respiration rate (breaths / minute)		37.12[b]	39.66[a]	38.50[ab]	30.46[c]	0.982	***	***	***
Rectal temperature (°C)									
	9.00 am	39.30[b]	39.24[b]	39.39[a]	38.93[c]	0.0384	***		***
	2.00 pm	39.49	39.52	39.56	-	0.0448		***	***
Rectal temperature change (°C)		0.165[b]	0.257[a]	0.117[b]	-	0.0370	***	**	***

[1] = Diet Four: maximum EE to ME ratio; Five: medium EE to ME ratio; Six: minimum EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

The T_R (9.00 am) followed a similar trend across diets (Figure 3.2). Rectal temperatures increased up till week three before decreasing during the following two weeks. This was followed by an increase over the next two weeks, a decrease over the following two weeks and then maintenance of a constant level over the final three weeks. Ambient temperatures on the days rectal temperatures were measured remained relatively constant over the feeding period except for sharp dips in weeks five and nine.

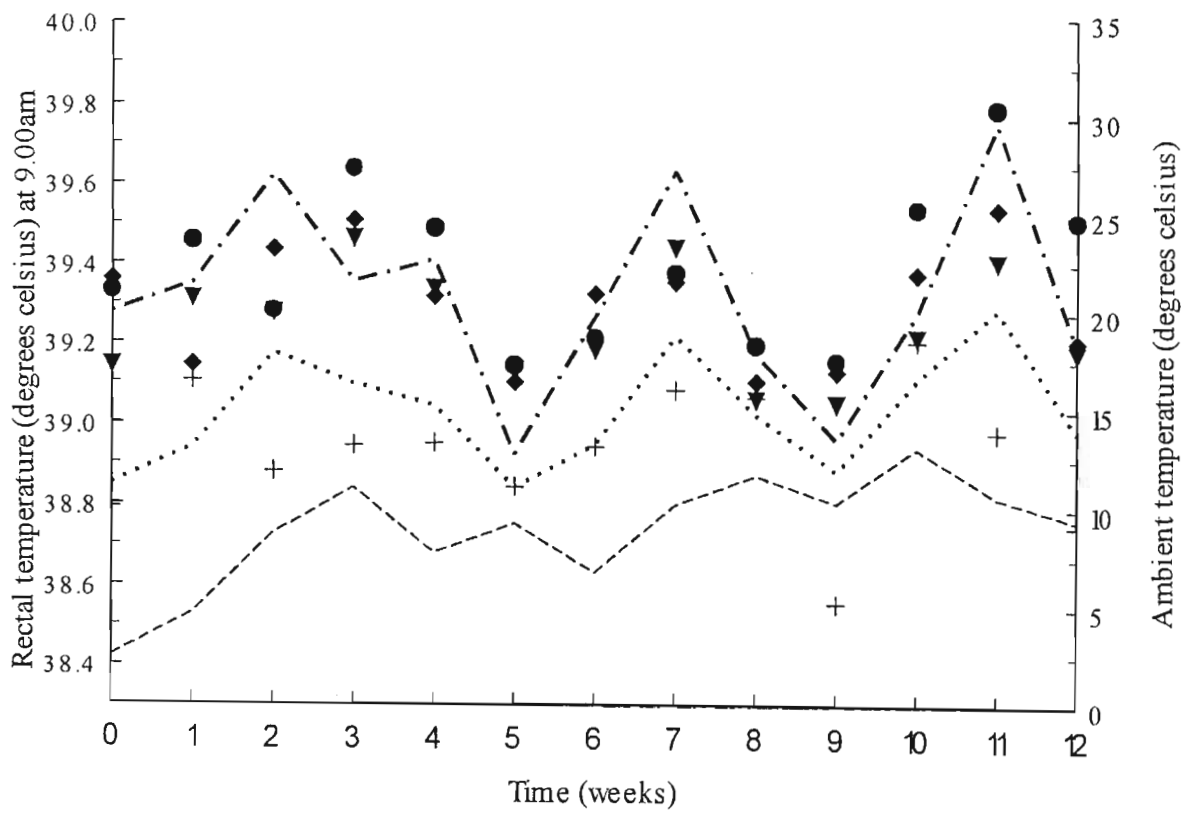

Figure 3.2 **Rectal temperatures (°C) measured at 9.00 am of feedlot steers fed on diet Four ◆, diet Five ▼, diet Six ● and Control ✚. The ambient temperatures (°C), Average ·····, Minimum ---- and Maximum -·-·- for the days the rectal temperatures were recorded. The lines joining the ambient temperature points are purely descriptive and are not meant to represent a continuum.**

The T_R (2.00 pm) over time followed a similar trend across diets (Figure 3.3), having very little variation over time except peaks in weeks four and eight and dips in weeks six and nine.

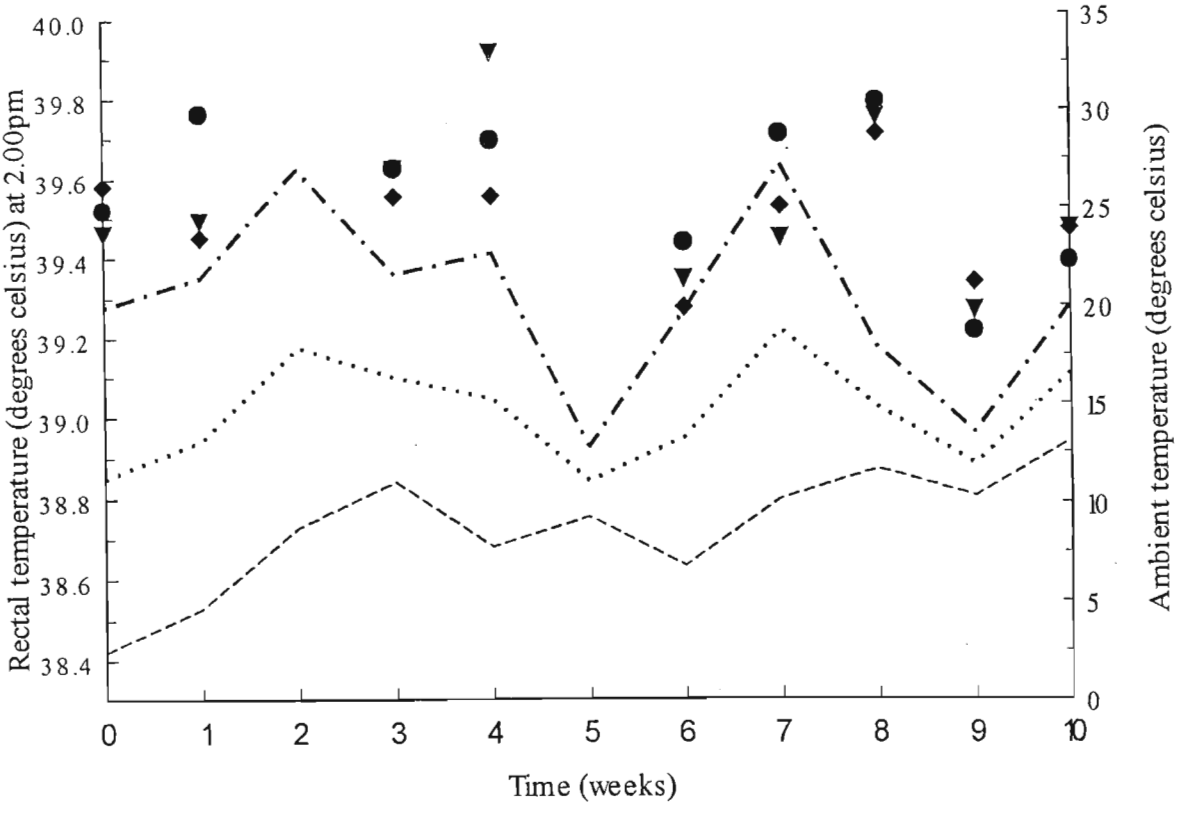

Figure 3.3 **Rectal temperatures (°C) measured at 2.00 pm of feedlot steers fed on diet Four ◆, diet Five ▼ and diet Six ●. The ambient temperatures (°C), Average ·····, Minimum - - - - and Maximum -·-·-· for the days the rectal temperatures were recorded. The lines joining the ambient temperature points are purely descriptive and are not meant to represent a continuum.**

Results of rectal temperatures are given in Table 3.6. Diet and time affected T_R (9.00 am) significantly ($P < 0.001$). Animals on diet Six had significantly higher T_R (9.00 am) than those on diets Four and Five (CV% = 0.8). Animals on the three dietary treatments had significantly higher rectal temperatures than the control animals ($P < 0.001$). T_R (9.00 am) in weeks three and eleven were markedly higher than the overall mean and the T_R (9.00 am) in weeks five and nine were markedly lower than the overall mean.

T_R (2.00 pm) were non-significantly different across dietary treatments (CV% = 0.8). Over time there were significant ($P < 0.001$) differences in T_R (2.00 pm). T_R (2.00 pm) in weeks four and eight were markedly higher than the mean and the T_R (2.00 pm) in weeks six and nine were markedly lower than the mean. Early maturing animals had significantly ($P < 0.001$) higher T_R (2.00 pm) than late maturing animals (39.60 versus 39.45°C).

The temperature change (CV% = 152.6) between the 9.00 am and 2.00 pm records were significantly affected by diet, time ($P < 0.001$) and maturity type ($P < 0.01$). Animals on diet Five had a significantly greater increase in T_R than animals on diets Four and Six. T_R change in weeks three and four were markedly higher than the mean and the T_R change in weeks one and nine were markedly lower than the mean. Early maturing animals experienced a significantly greater increase in rectal temperature than late maturing animals (0.23 versus 0.13°C).

The correlations of ambient temperature with either T_R (9.00 am and 2.00 pm) or respiration rate are shown in Table 3.7. Correlations between T_R (9.00 am) and ambient temperature were positive across all diets. Physiological measurements across diets were poorly correlated with minimum ambient temperature , but were strongly correlated with average and maximum ambient temperatures. The correlations coeffcients between diets Four, Five and Six and the average and maximum ambient temperatures were significantly different from zero ($P < 0.05$).

Correlation coefficients for animals on diets Four, Five and Six were non-significantly different from zero across all three ambient temperature measurements with T_R (2.00 pm). The correlations between the T_R (2.00 pm) of animals on diet Four and all three ambient temperatures were poor (> -0.17). The T_R (2.00 pm) of animals on diets Five and Six were less poorly correlated with the average and maximum ambient temperatures (< -0.30).

Respiration rates and ambient temperatures were strongly correlated across all diets. The correlation coefficients between respiration rates and either minimum or average ambient temperatures were significantly different ($P < 0.05$) from zero across diets.

Table 3.7 Correlations between the mean ambient temperatures and the physiological measurements recorded during the same week

Variate		Ambient temperature		
		Minimum	**Maximum**	**Average**
Rectal temperature (9.00 am) (°C)				
Diet[1]				
	Four	0.089	0.768**	0.708**
	Five	0.078	0.782**	0.717**
	Six	0.177	0.613*	0.622*
	Control	0.186	0.456	0.490
Rectal temperature (2.00 pm) (°C)				
Diet[1]				
	Four	-0.059	-0.160	-0.169
	Five	-0.354	-0.309	-0.403
	Six	0.084	-0.460	-0.414
Respiration rate (breaths / minute)				
Diet[1]				
	Four	0.803**	0.500	0.721**
	Five	0.683*	0.371	0.577*
	Six	0.715**	0.251	0.512
	Control	0.627*	0.471	0.616*

[1] = Diet Four: maximum EE to ME ratio; Five: medium EE to ME ratio; Six: minimum EE to ME ratio

Test of the null hypothesis H_0 : $\rho = 0$; * = < 0.05, ** = < 0.01

3.3.3 Animal performance

The feed intake (on a dry matter basis) curves were similar across diets (Figure 3.4). Feed intake increased for the first three weeks, then dipped in the fourth week, before increasing linearly to a peak in the sixth week. Intake dipped slightly during the seventh week, before plateauing for the remaining five weeks in the feedlot.

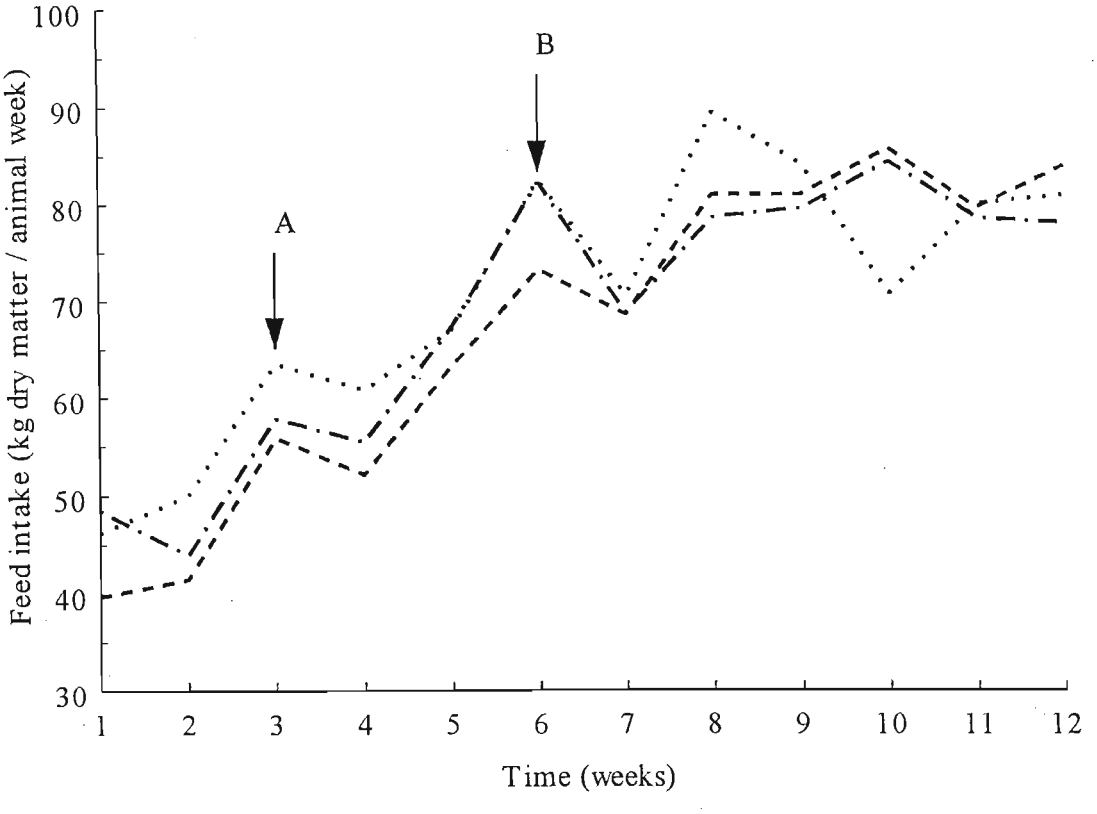

Figure 3.4 **Feed intake by feedlot steers (kg dry matter / animal week) fed on diet Four ·····, diet Five ---- and diet Six -·-·-·. Point A represents the time at which the winter coat was observed to start being lost. Point B represents the point of time at which the loss of winter coat was seen to be completed.**

Feed intake results are given in Table 3.8. The feeding period (CV% = 12.6) differed among the diets in the order of diet Six > diet Five > diet Four, with animals on diet Six spending a significantly ($P < 0.05$) longer period in the feedlot than animals on diet Four. The late maturing animals had a longer ($P < 0.001$) feeding period than the early maturing animals (105 versus 83 days). Group feeding significantly ($P < 0.001$) shortened the feeding period compared to

individual feeding (90 versus 98 days). Group feeding (diet Four 87.5, diet Five 87.9 and diet Six 95.2) also accentuated treatment differences in feeding period (days) verus calan gate feeding (diet Four 92.8, diet Five 102.2 and diet Six 98.9). A significant interaction ($P < 0.05$) between maturity type and diet resulted whereby the late maturing animals on diet Six spent a significantly longer period of time in the feedlot compared to those on diet Four. This difference between animals on diets Four and Six was not apparent within the early maturing group.

Cumulative dry matter and energy intakes (CV% = 15.4) were not significantly ($P > 0.05$) different among treatments. Late maturing animals had significantly ($P < 0.001$) higher cumulative intakes than early maturing animals.

Results of daily intake are given in Table 3.8. The effect of the covariate starting mass was significant ($P < 0.001$) for all daily intake analysis. Dry matter intake was non significantly ($P > 0.05$) different across dietary treatments (CV% = 9.4). Significant ($P < 0.001$) differences occurred among the three diets with respect to daily intake of NE_g in the order of diet Four > diet Five > diet Six. These differences in daily intake of NEg (MJ / day) between dietary treatments was accentuated by feeding method, with group feeding (diet Four 43.89, diet Five 43.00 and diet Six 38.03) showing a greater difference between treatments than calan gate feeding (diet Four 37.61, diet Five 34.79 and diet Six 32.37). Corrected energy intakes showed no significant differences in daily ME_x intakes across diets. Daily EE_x intakes were significantly ($P < 0.01$) different across diets with diet Six being consumed at a significantly lower level than diets Four and Five. Group feeding (diet Four 43.89, diet Five 43.00 and diet Six 38.03) showing a greater difference between treatments with respect to daily EE_x intakes (MJ / day) than calan gate feeding (diet Four 37.61, diet Five 34.79 and diet Six 32.37)

Late maturing animals had higher ($P < 0.001$) daily DM intake (10.75 versus 9.88 kg per day) than early maturing ones. Group fed animals ate significantly ($P < 0.001$) higher amounts on a daily basis than individually fed ones (11.92 versus 9.99 kg dry matter per day).

Table 3.8 Feeding period, total intake and daily intake (dry matter, Net energy for gain (NE_g), effective Metabolisable energy (ME_x) and effective Effective Energy (EE_x)) of feedlot animals

Variate	Diet[1]			Covariate	Maturity	Site	Diet	Maturity.Diet	S.E.D.
	Four	Five	Six						
Feeding period (days)	90.1[b]	95.0[ab]	97.0[a]	10%	***	***	*	*	2.65
Intake / head									
Dry matter (kg)	956.0	1029.0	1015.0	10%	***				45.3
NE_g (MJ)	3574	3601	3287	10%	***				159.9
ME_x (MJ)	8063	8773	8295	10%	***				379.7
EE_x (MJ)	6735	7311	6688	10%	***				313.9
Intake / head / day									
Dry matter (kg)	10.33	10.33	10.28	***	***	***			0.281
NE_g (MJ)	38.66[a]	36.16[b]	33.31[c]	***	***	***	***		0.996
ME_x (MJ)	87.20	88.08	84.05	***	***	***			2.353
EE_x (MJ)	72.84[a]	73.40[a]	67.77[b]	***	***	***	**		1.946

[1] = Diet Four: maximum EE to ME ratio; Five: medium EE to ME ratio; Six: minimum EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$.. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

The live weight gains are given in Table 3.9. The effect of covariate starting weight was significant for final weight, weight gain and ADG. Dietary treatment had a non significant ($P > 0.05$) effect on final weight (CV% = 7.8) and weight gain (CV% = 17.1). Late maturing animals reached significantly ($P < 0.001$) heavier final weights (413 versus 362 kg) and had significantly ($P < 0.001$) greater weight gains than early maturing animals (203 versus 152 kg).

Diet had a significant ($P < 0.001$) effect on ADG (CV% = 11.8).. The ADG of steers on diet Six was lower than that achieved by steers on diets Four and Five. No significant ($P > 0.05$) differences were observed for ADG between maturity types. The ADG of group-fed animals was significantly ($P < 0.01$) greater than that of the individually-fed animals (1.946 versus 1.838 kg / day) and differences between dietary treatments were stressed by feeding method, with group feeding (diet Four 2.037, diet Five 2.043 and diet Six 1.759) showing a greater difference between treatments than calan gate feeding (diet Four 1.933, diet Five 1.857 and diet Six 1.723).

The feed conversion ratio of dry matter (CV% = 13.9) was significantly ($P < 0.05$) different across diets. Diet Six had a significantly higher feed conversion ratio than diets Four and Five. No significant differences ($P > 0.05$) were observed for energy conversion ratios among dietary treatment. Group fed animals had significantly ($P < 0.05$) higher feed conversion ratio (6.134 versus 5.494 kg DM / kg gain) and energy conversion ratio (e.g. 51.36 versus 46.00 MJ ME_x / kg gain) than that of the individually fed animals. The differences in feed conversion ratio (kg DM / kg gain) between dietary treatments was emphasised by feeding method, with group feeding (diet Four 5.772, diet Five 5.991 and diet Six 6.639) showing a greater difference between treatments than calan gate feeding (diet Four 5.219, diet Five 5.413 and diet Six 5.849). Late maturing animals had significantly ($P < 0.05$) higher feed conversion ratios (5.799 versus 5.402 kg DM / kg gain) and energy conversion ratio (e.g. 48.57 versus 45.22 MJ ME_x / kg gain) than early maturing animals.

Carcass and fat coverage results are given in Table 3.10. Dietary treatments did not affect ($P > 0.05$) carcass weights (CV% = 8.8) or dressing percentages (CV% = 3.6). The covariate, starting weight, affected carcass weight ($P < 0.001$). The carcass weight was significantly ($P < 0.001$) heavier for late maturing than for early maturing animals (223.5 versus 197.8 kg). All animals

were slaughtered with the required fat coverage (2.3.3). However, animals on diet Six had a lower ($P < 0.05$) fat coverage than those on diets Four and Five. Early maturing and group-fed animals were slaughtered at higher ($P < 0.001$ and $P < 0.05$ respectively) fat levels than late maturing and individually-fed animals. A maturity type by diet interaction was significant ($P < 0.05$) across all fat levels, whereby the fat codes for late maturing animals on diet Six were significantly ($P < 0.05$) lower than codes for late maturing animals on diets Four and Five and significantly lower than codes for all early maturing animals irrespective of dietary treatment.

Correlation between an animals dry matter intake (kg's) with the ambient temperatures and the physiological measurements are given in Table 3.11. Dry matter intake was poorly correlated with maximum and average ambient temperatures, but were more strongly correlated with minimum ambient temperature. The correlation coefficient between minimum ambient temperature and the dry matter intake of animals on diet Five was significantly different from zero ($P < 0.05$).

The correlation coefficients for T_R (9.00 am) with dry matter intake were negative for diets Four and Five and close to zero for diet Six. The correlation coefficients for T_R (2.00 pm) with dry matter intake were negative for diets Four and Six and close to zero for diet Five. The correlation coefficient between T_R (2.00 pm) and the dry matter intake of animals on diet Four was significantly different from zero ($P < 0.01$). The correlation coefficients for respiration rate with dry matter intake were positive across all diets and the correlation coefficient between respiration rate and the dry matter intake of animals on diet Six was significantly different from zero ($P < 0.01$).

Table 3.9 Live weight and performance efficiency results for the whole trial period

Variate	Diet[1]			Covariate	Maturity	Site	Diet	Maturity.Diet	S.E.D.
	Four	Five	Six						
Final weight (kg)	388.8	394.3	379.2	***	***				6.80
Weight gain (kg)	179.0	184.6	169.5	*	***				6.80
Average daily gain (kg / day)	1.985[a]	1.950[a]	1.741[b]	***		**	***		0.0498
Feed conversion ratio									
kg dry matter / kg gain	5.311[b]	5.509[b]	5.980[a]		*	*	*		0.2239
MJ Net energy for gain / kg gain	19.86	19.28	19.38		*	*			0.778
MJ effective Metabolisable energy / kg gain	44.82	46.97	48.90		*	*			1.876
MJ effective Effective Energy / kg gain	37.43	39.15	39.42		*	*			1.547

[1] = Diet Four: maximum EE to ME ratio; Five: medium EE to ME ratio; Six: minimum EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

Table 3.10 Carcass weight, dressing percentage and fat coverage results after the feedlot period

Variate	Diet[1]			Covariate	Maturity	Site	Diet	Maturity.Diet	S.E.D.
	Four	Five	Six						
Carcass weight (kg)	212.2	213.7	206.0	***	***				4.15
Dressing percentage	54.56	54.18	54.38			***		**	0.442
Fat coverage[1]									
Overall	-3[a]	+2[a]	2[b]		***	*	**	*	0.425
Fore-quarter	+2[a]	+2[ab]	2[b]		***	*	*	*	0.410
Loin	-3[a]	-3[a]	+2[b]		**	*	*	*	0.442
Hind-quarter	+2	+2	2		***			*	0.404

[1] = Diet Four: maximum EE to ME ratio; Five: medium EE to ME ratio; Six: minimum EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

Table 3.11 Correlations between the dry matter intake (kg's) with the ambient temperatures and the physiological measurements

Variate		Diet		
		Four	Five	Six
Ambient temperatures(°C).				
	Maximum	-0.229	0.095	0.021
	Average	-0.113	0.211	0.119
	Minimum	0.330	0.370*	0.301
Rectal temperatures (°C)				
	9.00 am	-0.319	-0.148	0.089
	2.00 pm	-0.513**	0.047	-0.027
Respiration rate (breaths per minute)		0.261	0.085	0.408*

[1] = Diet Four: maximum EE to ME ratio; Five: medium EE to ME ratio; Six: minimum EE to ME ratio

Test of the null hypothesis H_0 : $\rho = 0$; * = < 0.05, ** = < 0.01

3.3.4 Predictor equations

Prediction equations for ADG's, cumulative dry matter intake and FCR are given in Table 3.12. A significant ($P < 0.001$) positive relationship was found between ADG, energy density and the covariate (starting weight). ADG increases with an increase in energy density, starting weight and the ratio of effective energy to metabolisable energy. Group fed animals had a significantly higher ($P < 0.01$) ADG than those that were fed individually. The amount of variation (R^2) accounted for was low (28.9 to 31.3%), with the EE_x density and EE_x to ME_x ratio accounting for the most variation.

Energy density was found to have a non significant ($P > 0.05$) role in predicting cumulative dry matter intake. Late maturing animals had a higher ($P < 0.001$) cumulative intake than early maturing animals. The models accounted for a moderate amount of the variation (R^2) with a range of 50.0 to 51.1 %. An increasing energy density is predicted to decrease FCR significantly ($P < 0.01$) and increase with late maturing animals and group feeding ($P < 0.05$). Despite the significance of the factors included in the prediction models very little variation (R^2) was accounted for in the models (17.6 to 20.5 %).

Table 3.12 Predictor equations for average daily gains, dry matter intake and feed conversion ratios using energy density (Net energy for gain (NE_g), effective Metabolisable energy (ME_x) and effective Effective Energy (EE_x))(MJ), starting mass (kg) (covariate), maturity type and farm site as factors

Variate	Predictor	Constant	Covariate	Maturity	Site	R^2 (%)
Average daily gain (kg / day)						
	$0.492.NE_g$***	-0.606	0.003456***		0.1111**	29.1
	$0.675.ME_x$***	-4.57***	0.003583***		0.1120**	29.1
	$0.4561.EE_x$***	-2.065***	0.003560***		0.1119**	30.4
	$8.10.EE_x / ME_x$***	-5.58***	0.003532***		0.1117**	31.2
Dry matter intake (kg)						
	$-115.7.NE_g$	1241***		326.2***		51.1
	$-20.ME_x$	1006		326.2***		50.0
	$-32.2.EE_x$	1060		326.2***		50.1
	$-906.EE_x / ME_x$*	1584		326.2***		50.3
Feed conversion ratio (kg dry matter / kg						
	$-1.345.NE_g$**	9.99***		0.398*	0.641*	20.1
	$-1.623.ME_x$*	18.90***		0.398*	0.641*	17.6
	$-1.127.EE_x$**	13.09***		0.398*	0.641*	18.9
	$-20.54.EE_x / ME_x$**	22.24***		0.398*	0.641*	19.9

Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

3.4 Discussion and conclusions

3.4.1 Diet composition

The depressed ratio of EE to ME_n in diet Six was due to the significantly lower EE density in diet Six compared to that of diets Four and Five. The EE density of diet Six was depressed due to a combination of a high CP content, CP digestibility and calculated methane production of the diet. Calculation of the EE density (see section 3.2.4.1.2) allows a loss of 4.672 kJ / g of digestible CP and a loss of 0.616 kJ / g of methane. Despite the animals on diet Four consuming more in terms of multiples of maintenance the incorporation of this into the corrected digestibilities resulted in no significant changes in the differences between treatments. Thus, the trends between diets with respect to EE and the ratio of EE to ME_n remained the same. The significantly different ratios of EE to ME_n and EE_x to ME_x between diet Six on the one hand and diets Four and Five on the other would have resulted in a higher heat load on those animals consuming diet Six.

Despite the differences in calcium and phosphorous content among diets, these nutrients were in excess of the animals requirements in all diets and should not have affected the animals performance. The CP contents of diets Four and Five were below the minimum formulation boundary (Table 2.1), but would still have met the animals protein requirements (Church, 1984; Secrist *et al.*, 1995 and NRC, 1996). Thus differences in performance on these diets would have been due to their respective energy densities or a factor related to their respective energy densities such as the heat increment of feeding.

3.4.2 Physiological measurements

Discerning whether animals in the feedlot experienced heat stress is dependent on the ambient temperatures, humidity, their T_R, and their respiration rates.

The mean ambient temperatures (Figures 3.1 and 3.2) during the feedlot period were never outside the TNZ of 15 to 25°C for cattle (see section 1.3.1). The maximum ambient temperatures did however exceed the range during the seventh and eleventh week. Minimum ambient

temperatures were below the lower boundary of the TNZ throughout the feeding period. Except during the seventh and eleventh week of feeding it is unlikely that the feedlotted animals suffered from heat stress resulting from the environment.

As a homeotherm (see section 1.3.4) stability of core temperature (38 to 39°C) is essential for cattle. The T_R of the control animals (Table 3.6) was within this range. Significantly higher T_R for animals on diet Four, Five and Six (Table 3.6) compared to the control animals, indicates that the animals within the feedlot experienced heat stress that was not due to the common environment. A further increase in T_R (2.00 pm) illustrates the effect of ambient temperature on top of the stress already expressed. The increase in T_R between 9.00 am and 2.00 pm despite the ambient temperature being within the expected TNZ suggests this is indeed not the TNZ for these animals. The heat gain attributable to the diet is lowering the UCT and thus the threshold value at which heat stress is surpassed (see section 1.3.1). The high CV% values obtained for heat gain may be attributed to the unstable nature of a CV% because of a dependence on an exact balance between negative and positive values of the quantity measured (Mead *et al.*, 1996) and the errors of measurement for both the 9.00 am and 2.00 pm recordings being incorporated in to the heat gain.

When an animal's homeothermic state is threatened, evaporative heat loss mechanisms are stimulated allowing for respiration rate to be used as a measure of heat stress (Alnaimy *et al.*, 1992). Although the respiration rates of the animals (breaths / min) of all diets were higher than suggested for a TNZ environment (see Table 1.5.1) animals on the feedlot diets had significantly higher respiration rates than those on the control diet (Table 3.6). The respiration rate of 30.46 breaths / min by the control animals is higher than the 23 breaths per min (Manuel, 1954; Robinson *et al.*, 1986 and Ole Miaron *et al.*, 1992) expected in a TNZ or less stressful environment. The respiration rates for steers on diets Four, Five and Six were similar to those measured at 8.00 am by Arp *et al.* (1983*b*), 35°C by Robinson *et al.* (1986) and 28°C by Ole Miaron *et al.* (1992). As respiration rate is a short term response and therefore more sensitive to the immediate temperature the higher correlation coefficients between the respiration rates and ambient temperature were expected (Table 3.7).

The physiological measurements over time give an indication of variations in heat stress over time. The pattern of T_R (9.00 am) showed an increasing heat stress over approximately the first three weeks of feeding (see Figure 3.2). The heat stress seems to alleviate for two weeks before increasing again for two weeks, it then stabilises after a further two weeks of lower stress. Less variation in T_R (2.00 pm) over time (see Figure 3.3) indicates there was a constant level of heat stress over time at 2.00 pm. Some of the variation over time can be explained in terms of changes in ambient temperatures. The dips in rectal temperatures in weeks five and nine correspond to lower ambient temperatures and thus the ability of the animals to lose more heat and lower their heat stress levels. The peaks in rectal temperatures in weeks four and eight do not appear to be associated with any abnormally high ambient temperatures and the increased heat stress must have either come from radiation or digestion. The pattern in respiration rate over time (Figure 3.1) shows an increasing heat stress for three weeks followed by a decreasing heat stress for three weeks. The spike in week seven was associated with a sharp increase in ambient temperature. The constant but higher than expected respiration rates for the remaining feeding period suggests the animals experienced a constant heat stress during this period.

The early maturing animals appeared to experience more of a heat load as indicated by the higher ($P < 0.05$) T_R and respiration rates compared to the late maturing animals. As heat stress has more of an effect on animals with a high feed intake and production, late maturing than early maturing animals are expected to have a higher rectal temperatures and respiration rates. In order for the early maturing animals to have an elevated heat load they must have either a higher heat production or a lower heat loss to that of the late maturing animals.

The strong positive correlations (Table 3.7) between T_R (9.00 am) for animals on diets Four, Five and Six, and the average and maximum ambient temperatures show that increases in T_R (9.00 am) are related to increases in average and maximum ambient temperatures. The lack of significant correlations between ambient temperatures and T_R (2.00 pm) are probably reflections of the animals limited ability to allow their core body temperature to increase any higher than the levels reached at 9.00 am. The involvement of acclimatisation factors such as changing feeding behaviour (see section 1.4.2.2), times of heat gain (see section 1.6.1) and core body temperature variation (see section 1.6.3) would have been utilised by the animals to maintain their core body

temperatures at T_R (2.00 pm). Respiration rate is a short term response to a heat stress (Alnaimy *et al.*, 1992) thus the strong correlations between it and the ambient temperatures.

3.4.3 Animal performance

The feed intake curves (see Figure 3.4) followed trends similar to those reported elsewhere Chapter Two, Owens *et al.* (1985), Thornton *et al.* (1985), Hicks *et al.* (1990*a,b*) and Dominy (1997). In this trial there were two peaks (third (A) and sixth (B) weeks), and two troughs (fourth and seventh weeks), in feed intake during the increasing phase of the curve. The peaks A and B occurred when the animals started losing their winter coat (A) and when their winter coat was totally lost (B). Control animals started losing their winter coat only in the nineth week. Examining the shedding of the winter coat of heifers, Bonsma (1980) recorded that the animals were completely smooth-coated within three weeks. The length of time the heifers took to lose their winter coat agrees with the length of time recorded in this trial for the steers to lose their winter coats.

If the animals were indeed experiencing heat stress then the animals reached a threshold of heat loss in the third week which necessitated an acclimatisation reaction (see section 1.6.2). Loss of the winter coat would allow the animal to increase its heat loss through improving its sensible heat loss (see section 1.5.1.1, 1.5.1.2 and 1.5.1.3) and its evaporative heat loss (see section 1.5.1.4). The point of time when the animals had completed losing their winter coats would also be the point of time when acclimatisation was completed i.e. the eighth week. As the animals could no longer lose any more heat from this point on and this point also represented the start of the plateau in the feed intake curve, further increases in feed intake could have been inhibited by the animals inability to lose more heat.

In previous works (Owens *et al.*, 1985; Thornton *et al.*, 1985 and Hicks *et al.*, 1990*a,b*) there was a dip in feed intake in the fifth week in the feedlot, which Hicks *et al.* (1990*a*) explained was due to adaptation to the final finishing diet. As in the first trial (see chapter Two) the animals in this trial received only one ration throughout the feeding period. In this trial two dips were apparent, both of which occurred one week after a peak. If the two peaks are indeed threshold

points due to a heat loss limit then the following week's dips may have been due to the animals reducing heat production while initiating physiological adjustments.

The effect of differences in diet on animal performance was to significantly increase the feeding period, daily energy intake, ADG's and decrease FCR's and to non significantly affect cumulative dry matter and energy intakes, final live weights, live weight gains, carcass weights or dressing percentages. The different lengths of time in the feedlot (Table 3.8) allowed animals to eat different amounts per day but still have similar total intakes. Animals spending longer in the feedlot used more of their total feed intake for maintenance and less for growth. Similarly different lengths of time in the feedlot allowed for similar total live weight gains to be achieved but at different ADG's (see Table 3.9). Carcass weight and dressing percentage (Table 3.10) are related to the animal's final live weight and therefore to the factors that affect final live weight. The lower fat coverage of animals on diet Six suggests that the animals were slaughtered too early and therefore could have had a longer period in the feedlot with the corresponding effects on performance. Although not measured, it was apparent from the feeding regime that the animals consumed more feed from their afternoon feeding than from their morning feeding. This change in feeding behaviour (see section 1.4.2.2) has been documented as an animal's strategy to reduce heat stress (Ray *et al.*, 1971 and Hoffman *et al.*, 1973).

The differences in animal performance due to diet, must result from a difference between the diets. Animals on diet Six spent significantly ($P < 0.05$) longer in the feedlot than those on diet Four and Five with the resultant significant ($P < 0.05$) differences between the diets with respect to daily energy intake, ADG's and FCR's. The factor that limited feed intake must therefore have been operating at a higher magnitude in diet Six. Either the energy density of diet Six was lower than that of diets Four and Five or the heat increment of feeding was higher for animals on diet Six.

That late maturing animals spent significantly longer periods in the feedlot, consumed significantly more in total and on a daily basis, had heavier final live weights and live weight gains, had higher FCR and finished with lower fat levels than early maturing, animals, this accords with previous studies (Hedrick *et al.*, 1969; NRC, 1987 and Hicks *et al.*, 1990*a*). The higher FCR for late versus early maturing animals means that the late maturing animals consumed more feed per

kilogram of production. Thus, either the late maturing animals utilized a significantly larger portion of their energy intake on non production functions (such as maintenance due to their live weight differences) or they had a lower digestion and hence lower uptake of energy than the early maturing animals (due to their greater intakes compared to early maturing animals in terms of multiples of maintenance depressing their dietary digestiblity). Slaughtering the late maturing animals at lower fat codes than the early maturing animals may have affected the comparisons of the results between the two maturity types. If the carcasses were of the same fat code for both maturity types the differences between the maturity types with respect to performance would have increased. The late maturing animals would have remained in the feedlot for longer resulting in a decrease in ADG, and an increase in feed intake and FCR.

Comparison of groups of animals that differ in their live weights at the start of the trial period (i.e. late maturing versus early maturing of the same chronological age) usually requires comparisons to be done as a proportion of their live weight or even their metabolic weight ($W^{0.75}$). Comparisons were done by Dominy (1997) between early and late maturing as well as compensating and non-compensating animals of each maturity type. Feed intake as a proportion of an animal's metabolic weight over time followed a similar trend to that of the animals feed intake over time. Feed intake as a proportion of metabolic weight increased to a peak after six weeks of feeding before following a decrease over the remaining feeding period. The increase over the initial six week period was due to the increase in the feed intake of the animal being greater than its increase in live weight. The decreasing period was as a result of the animals continued increase in live weight without any further increase in feed intake. Feed intake was not related to the animals metabolic weight as there were differences with respect to ratios of feed intake to metabolic weight between animal groups. The feed intakes of late maturing animals was at a higher ratio of metabolic weight than that for the early maturing animals. It was for this reason that similar analysis was not performed in this trial as it was apparent that differences between animals feed intakes were independent of their differences in live weight.

Maturity type by diet interactions occurred in the analysis of animal performance involving late maturing animals on diet six. The late maturing animals on diet six spent longer in the feedlot and were slaughtered at lower fat levels than other late maturing animals on diet Four and Five or

early maturing animals on diet Six. The longer feeding period for the late maturing animals on diet Six suggests that these animals were affected more by the differences in diet than the early maturing animals. If the animals had been slaughtered at the same fat codes then the late maturing animals on diet Six would have spent even more time in the feedlot. This would then have affected their live weight gain, ADG, feed intake and FCR.

Group feeding significantly shortened the feeding period, increased daily intakes, ADG's, FCR's and resulted in higher fat codes as compared to individual feeding. The increased daily intake attributed to the group fed animals having a higher production (ADG) and a decreased length of time to reach the required fat level. However, the high fat level reached also resulted in a decrease in efficiency (FCR). An apparent explanation for the increased daily intake is the stimulation to eat created by a "herd" at the trough resulting in an apparent competition for food (Balch *et al.*, 1962 and Bines, 1976).

The correlation coefficients (Table 3.11) showed that the dry matter intake of the animals was poorly correlated with the maximum and average ambient temperatures. If the environment was the primary cause of the animals heat stress a stronger correlation would have been exhibited. The higher correlation coefficient of the minimum ambient temperature and dry matter intake would be due to the relationship of the animals eating during times of low temperatures. The negative correlation coefficients associated with the rectal temperatures shows that as the rectal temperatures increased the dry matter intake decreased. This is an expected consequence of animals exhibiting heat stress. The low correlations were a result of the large fluctuations in dry matter intake and low rectal temperature fluctuations during the adaptation period. The positive correlation between respiration rate and dry matter intake is due to the animals increased loss of heat through increased respiration there was a possible increase in intake.

3.4.4 Predictor equations

In animals consuming highly digestible, high energy diets, DMI is controlled by the animal's energy demands and by metabolic factors (NRC, 1987), which was not apparent from the prediction equations. The increase in ADG with an increase in energy density or a decrease in the

heat of fermentation is unexpected because if energy was limiting intake then the animals could have increased their intake to attain similar ADG. Similarly the lack of differences in total feed intake were due to an animal merely consuming food over a longer period at a lower daily intake thus, the lack of differences being due to energy density. The very poor fitting model for the prediction of FCR is due to the combination of variation arising from the measurement of live weight gain and feed intake.

The lack of significant effect of the maturity type in the model predicting ADG is due to the covariate starting live weight. Inclusion of maturity type into the model without a covariate provides a significant response. However, inclusion of starting weight accounts for differences due to maturity type and further variation with the resultant better predictive model.

3.4.5 General discussion

Animals in the feedlot experienced heat stress (elevated T_R and respiration rates) when compared to control animals on pasture, with the only differences between the two groups being their respective diets (pasture versus total mixed ration). An additional heat load associated with the consumption of a feedlot diet resulted in an increase in the heat stress levels of feedlot animals. Feedlot diet also had a significant effect on T_R (9.00 am). Animals on diet Six had significantly higher T_R than animals on diets Four and Five. These differences correlated with the diets' differences in heat increments of feeding with Diet Six having a higher heat increment of feeding than diets Four and Five. The animals on diet Six reduced their heat stress by limiting their intake of food resulting in a decrease in their performance (see sections 1.5.2.4 and 1.7). Animals on diet Six spent longer in the feedlot, consumed smaller amounts of Effective Energy per day and achieved lower ADG's than animals on diets Four and Five.

The inclusion of late and early maturing animals in the trial was to determine the effect of heat increment of feeding on animals with differing production potentials. The late maturing animals recorded lower physiological heat stress measurements, due to either a lower production or better heat loss than early maturing animals were capable of. The late maturing animals exhibited a similar level of production to that of the early maturing animals although it was at a lower

proportional rate (ADG / live weight). Following Fouriers law, heat loss through sensible means depends on an animal's surface area (see section 1.5.1.1), the late maturing animals would have been able to lose a greater amount of heat through their larger surface area. As surface area increases at a rate lower than that of live weight it could account for the late maturing animals having a similar ADG but a lower proportional rate of growth. The results of the late maturing animals are also confounded with the differences in their fat coverage at slaughter, this was as a result of the difficulty experienced in determining their slaughter condition due to the Jersey crosses and their uneven fat distribution. However, it does appear as if diet Six had a greater effect on the late maturing animals showing that the combination of heat increment of feeding and the heat of production contributes towards the animals heat stress.

The two peaks (A and B) that appear in the animals feed intake curves coincide with peaks in the animals T_R (9.00 am). A feedlot animal increases its feed consumption until it is no longer able to balance its heat gain with its heat loss, which is represented by its T_R (9.00 am). When the animal reaches this point (week three) the processes of acclimatisation begin (see section 1.6). The loss of its winter coat would constitute as a mechanism of acclimatisation, its loss aiding all heat loss mechanisms. This period of acclimatisation took three weeks to complete allowing for an increase in feed intake (heat gain) as heat loss improved. The second peak (B) occurred after six weeks in the feedlot and again coincided with a peak in T_R (9.00 am). From this point on it appeared that the animal was no longer able to improve its heat loss capability and so it maintained its feed intake and this maximum level of sustainable heat production. The trough in feed intake after peak feed intake is achieved is therefore a period of adjustment to heat stress and not a dietary acclimatisation as hypothesised by Hicks *et al.* (1990*a*).

3.4.6 Conclusions

Heat stress is a major limiting factor of feed intake for steers in a feedlot environment within three weeks of feeding. The pattern of feed intake is correlated to that of core body temperature and respiration rate and to a lesser extent the maximum and average ambient temperatures. The range of ambient temperatures thought to encompass the TNZ must be reassessed. Animals fed diets differing in their heat increments of feeding differed in their physiological heat stress response. The heat increment of feeding and the animals potential production determine the extent to which an animals feed intake and production rate is affected by heat stress.

CHAPTER FOUR

THE EFFECT OF RATIONS DIFFERING IN THEIR HEAT LOAD ON THE CARCASS COMPOSITION OF BEEF FEEDLOT ANIMALS

4.1. Introduction

The returns from a feedlot are determined partly by the economic value of the beef carcass. This is influenced by the relative proportions of the contributing tissues - muscle, fat and bone. The quantitative requirements in the carcass are best met when muscle is maximum, bone is minimum, and fat is at an optimum decided by local consumer preferences (Berg, 1968). Environmental and genetic factors influence the normal differential growth patterns changing the expected tissue proportions at given slaughter weights (Berg, 1968). For example it is possible that cattle in a hot environment deposit relatively more fat and less protein than at thermal neutrality (Webster, 1976).

The rational behind the potential for differences in lipid deposition is the difference in heat production between depositing fat rather than protein. The differences in tissues (fat and protein) respective heat production is found in the heat increment of feeding equation (section 1.4.1.1.2) with an allowance for a zero nitrogen retention (Emmans, 1994). The result is heat increments of 31.83 kJ / g and 16.4 kJ / g for the positive retention of protein and lipid respectively. Thus, an extra 15.43 kJ of heat is generated for every gram of protein deposited compared to a gram of lipid. Coupled with this is the requirement that a gram of protein requires 50 kJ of EE and a gram of lipid 56 kJ of EE(section 4.2.4.2). Due to its inability to lose more heat the feedlot animal will be prevented from depositing protein and may use the absorbed energy to deposit lipid. The deposition of lipid will use more energy and generate less heat. However, the increase in deposition of lipid will increase the resistance to heat flow from the body core to the skin thus reducing the effectivity of heat loss through conduction (section 1.5.1.1).

An animal experiencing heat stress will attempt to reduce its heat production and increase its heat loss. Despite the theoretical advantages of a reduction in heat production by depositing lipid

instead of protein in a heat stressed environment, the control of feed intake and therefore the heat production from digestion could be a more efficient means of adjustment, as the control of heat production from digestion is a more direct and immediate relief from heat stress than the preferential deposition of one tissue over another. The trial to be described was designed to investigate the hypothesis that animals fed diets differing in heat increments of feeding, will differ in the proportion of energy intake they deposit as protein or lipid as a means of relieving further heat stress.

4.2. Materials and methods

Three feedlot diets were formulated to differ in their heat of digestion and fed to yearlings to investigate the effect of heat stress on the proportional deposition of lipid and protein in feedlot steers.

4.2.1. Diet formulation and ingredient composition

A maintenance diet (Table 4.1) was formulated to provide a low energy, high roughage ration to the yearlings during four weeks of adaptation to the calan gates. The diet was fed twice daily at 7.00 am and 4.00 pm and was available *ad libitum*.

Table 4.1 Ingredient composition of the maintenance diet

Ingredient	Inclusion
Molasses cane (liquid)	25 (%)
Veld hay	20 (%)
Broiler chicken litter	45 (%)
Hominy Chop	10 (%)

Three diets were formulated to differ in their heat load, and were designated Seven (maximum EE : ME), Eight (medium EE : ME) and Nine (minimum EE : ME). Diet Eight was formulated by mixing diets Seven and Nine at a 50 : 50 ratio.

Winfeed (1.11) software (EFG Software 1996) was used to formulate these diets and the lower and upper boundaries were set as given in Table 2.1. The nutritive values of the ingredients were obtained from ingredient book values (NRC, 1984; Bredon *et al.*, 1987 and Feedstuffs, 1997). The ingredients making up the diets are given in Table 4.2. Ingredients were purchased in one batch and the diets mixed in a commercial plant in order to reduce variation. The diets were mixed one tonne at a time and bagged into 40 kg bags. As the feeding period was predicted to be shorter than three months (Dr A. Paterson *pers comm*) and the diets had a low fat content no significant deterioration in the diets was expected.

Table 4.2 Ingredient composition of the three diets

Ingredient (kg)	Diet[1]		
	Seven	Eight	Nine
Maize germ	319.82	159.91	-
Molasses cane (meal)	50.45	25.23	-
Molasses cane (liquid)	135.14	142.57	150.00
Wheat bran	45.05	111.05	177.06
Defatted maize germ	-	205.92	411.84
Copra oilcake	9.91	4.95	-
Palm kernel meal	147.75	148.87	150.00
Cottonseed	119.82	59.91	-
Wheat straw	150.45	100.23	50.00
Lucerne hay	-	19.18	38.35
Feedlime	9.01	9.50	10.00
Monocalcium phosphate	0.90	0.45	-
Salt	4.50	4.75	5.00
Urea	4.50	4.75	5.00
VitA + mineral premix[2]	2.70	2.60	2.50
Romensin	0.15	0.15	0.15
Tylan	0.10	0.10	0.10
TOTAL	1000.25	1000.15	1000.00

[1] = Diet Seven: maximum EE to ME ratio; Eight: medium EE to ME ratio; Nine: minimum EE to ME ratio

[2] = Vitamin A : 4000000 iu, Vitamin B1 : 3g, Manganese : 10g, Zinc : 10g, Copper : 2g, Cobalt : 0.50g, Magnesium : 100g, Selenium : 0.3g, Iodine : 0.25g.

4.2.2 Animals and feeding management

Seventy-five, predominantly Bonsmara, Hereford and Sussex type, yearling steers were purchased from local farmers' auctions and kept on pasture (*Pennisetum clandestinum*) for six weeks before being used in the trial. At the beginning of the feedlot period the animals had live weights (measured on an empty stomach, after being starved for 24 hours) ranging from 230 to 368 kg (mean = 296 (s.e. = 2.99) kg).

Before being placed in the feedlot, animals were sorted in descending order of liveweight and assigned to five groups of fifteen animals each. One animal representing each weight category (five animals in total) were assigned to represent a carcass control, to be slaughtered at the start of the feedlot period, to determine the carcass composition of the animals before feedlotting.. The remaining fourteen animals within a weight category were then randomly assigned to seven groups of ten each (Prof. Clark *pers comm*) ensuring that each group had two animals of each weight category. Two groups of ten were assigned to each of the three diets, and the remaining group of ten was kept on pasture (*Pennisetum clandestinum*) as control. The animals were individually fed in pens of ten animals in each in the feedlot using the calan gate method.

One month prior to the adaptation period all the animals were inoculated against anthrax, quarter evil, botulism, bovine viral diarrhoea and pasteurella. The facilities were under the control of the state veterinarian who tested the animals for tuberculosis (*Mycobacterium tuberculosis*) and contagious abortion (*Brucella abortus bovis*). At the start of the feedlot period all steers on the feedlot diets received a Revalor -S (200 mg Trenbolone Acetate and 20 mg 17β Oestradiol; Hoechst Roussel Vet) implant in the soft skin on the posterior aspect of the ear. The animals were confined in partially covered pens.

The animals were adapted to the calan gates over a four week period. If after three weeks an animal exhibited a comparative lack of adaptation to its calan gate it was placed in an individual pen with an open trough for feeding. It was allowed to adapt to this environment for the final week of the four week adaptation period. During this period all animals except the pasture control group were fed on the maintenance diet (Table 4.1).

4.2.3 Measurements

4.2.3.1 Laboratory nutrient analysis

Snatch samples were taken from ten bags of the mixed diets and pooled for laboratory analysis. This was repeated eight times over the feedlot period. These samples were analysed for crude protein (CP), gross energy (GE), calcium, phosphorous, ether extract (EE_f), dry matter (DM), crude fibre (CF) and ash according to standard procedures (AOAC,1990). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to Van Soest *et al.* (1991). The measurements of the diets nutrient composition is located in Appendix 3.1.1.

4.2.3.2 Metabolism study

Eighteen mature male Merino sheep (55 kg) were used in a 25 day study. Sheep were randomly allocated to the three dietary treatments. After an adaptation period of eleven days in individual pens with *ad libitum* access to feed, they were restricted to a maintenance allowance of 710 g / day fed in one amount at 9.00 am (ARC,1980) calculated thus :

$$MME = ((360*(W^{0.75}))/1000)$$

where MME = Maintenance ME requirement (MJ / day); and
W = average live weight (55 kg).

$$MA\ (g / day) = ((MME / DME)*1000)$$

where MA = Maintenance allowance (g / day); and
DME = Estimated metabolisable energy content of the diet (9.5 MJ / kg as is).

After three days on the restricted allowance fifteen of the sheep (five on each diet) were selected based on their adaptation and transferred into metabolism crates where they were harnessed and fitted with faecal collection bags. A three-day adjustment period was allowed, following which

total faeces and urine were collected for seven days. Individual urine production was collected in a bucket containing 50 ml of 10% sulphuric acid (H_2SO_4), (resultant urine pH was < 3), bulked per animal over the collection period and stored (4°C). The daily faeces output of each animal was weighed and dried at 50°C for a minimum of 72 hours. Any remaining feed in the troughs at the end of the trial was collected, weighed and then analysed. The bulked urine was sampled for N analysis within three days of the end of the trial while the dried faeces was re-weighed, bulked and then sampled for the analysis of N, GE, and ash. The breakdown of the metabolism study is located in Appendix 3.1.2.

4.2.3.3 Carcass composition

Twenty-four of the feedlot animals (eight from each dietary treatment) were randomly selected before the start of feedlotting to have their carcass composition analysed after fattening. The five carcass control animals were slaughtered in a commercial abattoir on the same day the sixty animals started feedlotting. Carcass tissue compositions were determined using the technique of Naudé (1972). The prime rib cut (8th to 10th rib) from the left hand side of each carcass was removed, weighed and then dissected into subcutaneous fat, muscle (muscle = proportion of meat including intermuscular fat, but with subcutaneous fat removed) and bone. The masses of the three dissected components for each prime rib cut were recorded. The masses for the dissected components are located in Appendix 3.2.1. Connective tissue was added to the muscle portion. The percentages of these tissues in the whole carcass were determined as follows:

Muscle

$$Y = 15.811 + 0.756.X$$

$R^2 = 94.9$ % (Naudé, 1972)

Where :

Y = percentage muscle in the carcass; and

X = percentage muscle in the prime rib.

Fat

$$Q = 4.566 + 0.823.R$$

$R^2 = 97.1$ % (Naudé, 1972)

Where :

Q = percentage fat in the carcass; and

R = percentage fat in the prime rib.

Bone

$$S = 1.962 + 0.788.T$$

$R^2 = 85.9$ % (Naudé, 1972)

Where :

S = percentage bone in the carcass; and

T = percentage bone in the prime rib.

The subcutaneous fat and lean of each prime rib cut were mixed, ground, mixed and ground again through a nine millimetre sieve before subsampling for chemical analysis in order to determine the percentage protein, ash, fat and moisture (AOAC, 1990). Chemical fat was regarded as prime rib cut fat, while the total mass of protein, moisture and ash was considered to be the prime rib cut muscle. Percentage carcass composition was estimated from the equations of Naudé (1972) and the prime rib cut composition (Slabbert *et al.*, 1992). An assumption was made that prime rib cut protein percentage was equal to carcass protein percentage (Slabbert *et al.*, 1992). This was supported by Berg *et al.* (1976) who allocated the eye-muscle (*Longissimus dorsi*) which is situated in the loin area of the carcass to a growth rate nearly equal to that of total muscle. Thus the growth of the eye-muscle could well mirror the overall growth of muscle within the carcass. The measurements of the animals prime rib cut composition is located in Appendix 3.2.1.

4.2.3.4 Rectal temperature and respiration rate

Rectal temperature and respiration data were obtained following the procedures described in section 3.2.3.3. The rectal temperatures (9.00 am and 2.00 pm) and respiration rates measured are located in Appendix 3.3.1, 3.3.2 and 3.3.3 respectively.

The maximum, minimum and mean environmental temperatures were obtained for each day of the trial (Appendix 3.3.4) from the neighbouring weather station (Institute of Soil, Climate and Water, Agricultural Research Council, Cedara).

4.2.3.5 Feed and animals

The feed was offered *ad libitum*. Troughs were scored twice daily to identify the amount of feed being eaten and then topped up accordingly. Thus the animals were fed according to their intakes. The amount fed daily was recorded and totalled for a weekly value (Appendix 3.4.1). If any stale food accumulated its weight was subtracted from the weekly total. Water was freely available.

Live weight of the animals was recorded weekly. The live weights of the animals were measured on an electronic scale (Schenck Discomat B, Schenck Ash, South Africa) to the nearest kilogram after being starved for 12 hours (Appendix 3.4.2).

4.2.3.6 Carcass

Carcass data were obtained following the procedures described in section 2.2.3.4. The carcass, fat coverage and length of time in the feedlot data is located in Appendix 3.4.3.

4.2.4 Data derivation and statistical analysis

4.2.4.1 Diet

The methods for the derivation of a diets metabolisable energy at maintenance (ME_n), Effective Energy density and depression in digestibility are described in section 3.2.4.1.

4.2.4.2 Carcass composition

To overcome error due to variation in weight of the "fill" in the digestive tract the empty body weight was calculated using the equation (r = 0.98) by Fox *et al.* (1976):

$$EBW\ (kg) = 1.40CW + 40.2$$

Where:

EBW = empty body weight (kg); and

CW = chilled carcass weight (kg).

The weight (kg) of protein and chemical fat in the empty body was calculated by adding the weight of protein and fat in the carcass to the weight of protein and fat in the non-carcass components. References (Jesse *et al.*, 1976; Arnold *et al.*, 1985; Early *et al.*, 1990; Carstens *et al.*, 1991 and Ferrell *et al.*, 1998) were sourced from literature for protein and chemical fat values of the empty body and the carcass from trials where the animals were of similar maturity type, degree of finish and empty body weight. The weight of protein and chemical fat in the carcass was then divided by the weight of the respective component found in the empty body and multiplied by 100. The proportion of the empty body protein and chemical fat found in non-carcass components was the difference of the carcass proportion from 100 (Table 4.3). Multiplying an animals carcass composition by its respective calculate proportional contribution to the empty body generated the amount of protein and chemical fat that made up an animals empty body.

An animal's compositional gain (kg's) is the difference between the composition of a control animal and the composition of an animal leaving the feedlot. The daily gain (kg / day) is the weight gain (kg's) divided by the length of time in the feedlot (days).

The total feed intake (see section 4.2.4.3) on a dry matter basis was calculated for each animal. This was multiplied by either the EE concentration (MJ / kg) (see table 4.6) or the corrected EE_c concentration (MJ / kg) calculated (see section 3.2.4.1.3) for each animal, thus, determining the energy intake of each animal. The energy requirement (MJ of EE) of each animal was estimated using the equation by Emmans (1994):

$$EE_{req} = (MH + 50PR + 56LR)$$

where: EE_{req} = Effective Energy requirement (kJ / d);

MH = maintenance heat production (kJ / d);

PR = protein retention (g / d); and

LR = lipid retention (g / d).

An animals maintenance heat production (MH) was calculated as a factor (0.96) of its fasting metabolism (FH) (Emmans, 1994). The calculation of the fasting metabolism (FH) of each steer utilises the equation proposed by ARC (1980):

$$FH = 0.53W^{0.67} \quad (MJ / d)$$

where: FH = fasting metabolism (MJ / d); and

W = fasted weight (kg).

The fasted weight (W) of an animal was the mean of its live weight at the beginning and at the end of each week. This figure was used to calculate the fasting metabolism for each day of the previous week and was multiplied by seven for a weekly value.

The energy balance was calculated by subtracting the estimated EE_{req} (MJ) from the calculated EE or EE_c intake (MJ). The contribution of each of the components (MH, PR and LR) energy requirement made to the energy intake (EE and EE_c) was calculated.

Table 4.3 Proportion of protein (%) and fat (%) contributed by non-carcass[1] components of the empty body

Author	Breed	n	Empty body weight (kg)	Proportion contributed by non-carcass	
				Protein (%)	Fat (%)
Control					
Carstens *et al.* (1991)	Angus X Hereford	3	290.0	41.33	29.19
Early *et al.* (1990)	Hereford	10	296.6	29.98	36.70
Jesse *et al.* (1976)	Hereford	8	227.0	53.49	44.67
Mean (S.E.)			271.2 (22.18)	41.60 (6.79)	36.85 (4.47)
Finished					
Arnold *et al.* (1985)	Small frame	5	484.0	33.09	27.03
Carstens *et al.* (1991)	Angus X Hereford	5	450.0	35.63	30.18
Ferrell *et al.* (1998)	Angus	4	498.0	40.85	34.87
	Hereford	4	474.0	45.06	34.53
Jesse *et al.* (1976)	Hereford	4	454.0	44.32	30.36
Mean (S.E.)			472.0 (9.03)	39.79 (2.36)	31.39 (1.47)

[1] = stomach, intestines, liver, kidneys, kidney fat, heart, lungs and trachea, spleen, head, hooves and tail, hide and the composite of other miscellaneous tissue.

4.2.4.3 Performance

The feeding period of the animal is the time (days) from the start of feedlotting until its slaughter. The feed intake (kg) of an animal is the weight of the feed bin at the beginning of the week plus the weight of feed added during the week minus the weight of the feed bin at the end of the week.

An animal's weight gain (kg's) is the difference between its weight on entry into the feedlot (Initial weight) and on leaving the feedlot (Final weight). The average daily gain (ADG; kg / day) is the weight gain (kg's) divided by the length of time in the feedlot (days). The dressing percentage is the cold carcass weight (kg) of an animal divided by its final weight (kg). The feed conversion ratio (FCR) is the intake divided by the weight gain.

4.2.4.4 Statistical analysis

The GENSTAT V statistical programme (Lawes Agricultural Trust, Rothamstead) was used for all statistical analysis.

4.2.4.4.1 Diets nutrient composition

The diets chemical composition, metabolic variables and corrected digestibilities were analysed following the method described in section 3.2.4.3.1. An example of an analysis can be found in Appendix 1.2.

4.2.4.4.2 Carcass composition

Due to treatments having differing numbers of animals (the control having 5 and dietary treatments 8 in each) differences between treatments were determined using linear regression. The following is the full linear regression model (an example Appendix 3.5.1), with significance of a component being determined using the *T probability test*.

$$y_i = \beta_0 + \beta_1 X_{1i} + \varepsilon_i$$

where: y_i = response variate;

β_0 = y intercept;

β_1 = regression (coefficient) of y on X_1;

X_{1i} = energy density; and

ε_i = residual error (N.I.D. ~ $(0, \sigma^2)$).

4.2.4.4.3 Rectal temperatures (T_R) and respiration rates

The ANOVA of the T_R and respiration rates included a factor for time (weeks). With the inclusion of the control, the treatments were expanded to four. The following is the ANOVA model used to determine treatment means, standard errors and statistical differences between treatment means (*F probability test*)(an example is Appendix 3.5.2.1).

$$y_{ik} = \mu + t_i + \Psi_k + (t\Psi)_{ik} + \varepsilon_{jk}$$

where: y_{ik} = variate;

μ = common component;

t_i = treatment effect (Diet);

Ψ_k = time;

$t\Psi_{ik}$ = interaction term; and

ε_{ik} = residual error (N.I.D. ~ $(0, \sigma^2)$).

Correlations were determined between the maximum, minimum, and average ambient temperatures with the T_R and respiration rates for the day of measurement (an example is Appendix 3.5.2.2). Due to incomplete and hence missing data there were not enough measurements to generate a correlation matrix for the respiration rate. Due to the amount of missing data the number of means computed by the program to fill the missing data resulted in a correlation of 1. The correlations between respiration rate and the ambient temperatures were therefore rejected.

4.2.4.3.3 Performance factors

The experimental unit was the animal for live weight, live weight gain, carcass data, intake and food efficiency because feed and water were available at all times and the time in the feedlot varied among animals. Three animals on diet Eight were excluded from the trial; one due to an injury, and two due to not attaining sufficient fat coverage at slaughter (see section 2.2.3.4). Differences among treatments were determined using multiple linear regression due to the unbalanced number of animals among treatments. A covariate (starting weight) was included in the linear regression analysis when found to have a significant effect ($P < .05$). The use of a covariate was examined due to the possibility that it's inclusion may reduce the error variance to an appreciable extent (Rayner, 1967). The following is the full linear regression model (an example is Appendix 3.5.3), with significance of a components being determined using the *T probability test*.

$$y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \varepsilon_i$$

where: y_i = response variate;

β_0 = y intercept;

$\beta_{1 \text{ to } 2}$ = regression (coefficient) of y on $X_{1 \text{ to } 2}$;

X_{1i} = energy density;

X_{2i} = starting mass; and

ε_i = residual error (N.I.D. ~ $(0, \sigma^2)$).

4.2.4.3.4 Prediction equations

Prediction equations were generated for ADG, cumulative dry matter feed intake and FCR using multiple linear regression. These models were developed to determine the amount of variation that could be accounted for by the diets nutrient densities. Starting weight was included as a factor if found to be significant ($P < .05$). The following is the full linear regression model (an example is Appendix 3.5.4), with significance of a components inclusion being determined using the *T probability test*.

$$y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \varepsilon_i$$

where: y_i = response variate;

β_0 = y intercept;

$\beta_{1 \text{ to } 2}$ = regression (coefficient) of y on $X_{1 \text{ to } 2}$;

X_{1i} = energy density;

X_{2i} = starting mass; and

ε_i = residual error ~ (N.I.D. $(0, \sigma^2)$).

4.3 Results

4.3.1 Diet composition

The chemical composition of the feeds is given in Table 4.4. The fat contents of the diets differed significantly ($P < 0.001$) in the order: diet Seven > diet Eight > diet Nine. The crude fibre, acid detergent fibre and ash content of diet Nine were significantly ($P < 0.01$) lower than the corresponding constituents of diets Seven and Eight. The phosphorous content of diets Seven and Eight were lower ($P < 0.001$) than the phosphorous contents of diet Nine.

Table 4.4 The nutrient content of the three diets on a dry matter basis

Nutrient	Diet[1]			S.E.
	Seven	Eight	Nine	
Protein (%)	14.60	13.90	14.43	0.351
Calcium (%)	0.85	0.80	0.77	0.0370
Phosphorous (%)	0.51[b]	0.51[b]	0.58[a]	0.01017
Fat (%)	5.52[a]	3.92[b]	1.63[c]	0.398
Crude Fibre (%)	13.54[a]	14.64[a]	11.85[b]	0.686
Neutral Detergent Fibre (%)	39.07	41.17	40.83	1.223
Acid Detergent Fibre (%)	18.60[a]	19.81[a]	17.13[b]	0.622
Moisture (%)	12.91	12.72	12.65	0.598
Ash (%)	7.81[a]	7.79[a]	7.14[b]	0.1886

[1] = Diet Seven: maximum EE to ME ratio; Eight: medium EE to ME ratio; Nine: minimum EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < .05$

Results of the metabolism study are given in Table 4.5. The organic matter intake of lambs on diet Seven was lower ($P < 0.05$) than that of the lambs on diets Eight and Nine. Diet Eight had a higher ($P < 0.001$) urine CP and a lower ($P < 0.01$) protein retention than diets Seven and Nine. Calculated methane production of the lambs differed significantly ($P < 0.001$) across diets, in the order diet Nine > diet Eight > diet Seven. The apparent gross energy digestibility of diet Eight was significantly ($P < 0.05$) higher than that of diet Seven.

Table 4.5 Components of the metabolism study investigating the apparent digestibilities of dry matter, organic matter, nitrogen and gross energy for diets Seven, Eight and Nine

Variate	Diet[1]			S.E.
	Seven	Eight	Nine	
Intake				
Dry matter (g)	5795.0	6095.0	6115.0	138.9
Organic matter (g)	5350.0^{b}	5620.0^{a}	5678.0^{a}	125.1
Crude protein (g)	848.3	849.1	882.3	20.11
Gross energy (MJ)	105.0	110.9	106.9	2.47
Urine crude protein (g)	479.0^{b}	610.0^{a}	514.0^{b}	26.4
Protein retention (g)	18.6^{a}	1.8^{b}	16.7^{a}	4.88
Methane (KJ/g)	1.4294^{c}	1.4842^{b}	1.6090^{a}	0.0168
Apparent digestibility (%)				
Dry matter	63.93	69.92	66.65	2.282
Organic matter	66.57	72.12	69.00	2.179
Crude protein	70.09	73.13	70.12	2.164
Gross energy	66.65^{b}	72.22^{a}	68.39^{ab}	1.815

[1] = Diet Seven: maximum EE to ME ratio; Eight: medium EE to ME ratio; Nine: minimum EE to ME ratio

^{a,b,c} = Values in the same row with different superscripts are different $P < 0.05$

The dietary energy densities as determined in the metabolism study with sheep are given in Table 4.6. The EE density of diet Eight is significantly ($P < 0.05$) higher than that of diet Nine. The ratios of EE to ME_n or EE_x to ME_x of diet Nine were significantly ($P < 0.01$) lower than the respective ratios for diets Seven and Eight. The corrected digestibilities (see section 3.2.4.1.3), showed the animals on diet Nine ate a lower ($P < 0.001$) level of energy in terms of multiples of

maintenance than did the animals on diets Seven and Eight. Animals on diet Eight had a lower ($P < 0.001$) depression per unit rise in maintenance than animals on diet Seven. The corrected digestibility of diet Nine was significantly ($P < 0.001$) higher than that of diets Seven and Eight.

Table 4.6 The energy density of the diets used in this study as determined by the metabolism study

Variate	Diet[1]			S.E.
	Seven	Eight	Nine	
Digestable energy (MJ / kg)	13.05	13.19	11.96	0.557
Metabolisable energy at maintenance (MJ / kg)	10.72	11.46	9.74	0.651
Effective Energy (MJ / kg)	9.36^{ab}	10.07^{a}	8.28^{b}	0.638
Net energy for gain (MJ / kg)	3.90	4.43	3.25	0.437
Effective Energy / Metabolisable energy at maintenance	0.8712^{a}	0.8787^{a}	0.8491^{b}	0.00654
% change per unit rise in feed level	0.03168^{a}	0.02540^{b}	0.02970^{ab}	0.00205
Feeding level (X maintenance)	3.602^{a}	3.776^{a}	2.963^{b}	0.1295
Corrected Gross energy digestability (%)	55.24^{b}	57.06^{a}	57.84^{a}	0.375
Digestable energy$_x$ (MJ / kg)	10.82	10.41	10.11	0.386
Metabolisable energy$_x$ (MJ / kg)	8.58	8.80	7.97	0.511
Effective Energy$_x$ (MJ / kg)	7.22	7.39	6.50	0.504
Effective Energy$_x$ / Metabolisable energy$_x$	0.8388^{a}	0.8393^{a}	0.8153^{b}	0.0085

[1] = Diet Seven: maximum EE to ME ratio; Eight: medium EE to ME ratio; Nine: minimum EE to ME ratio

^{a,b,c} = Values in the same row with different superscripts are different $P < .05$

$_x$ = the expected energy density

4.3.2 Carcass composition

The composition (kg) and gains in composition (kg) of the prime rib cut, carcass and empty body are given in Table 4.7 and 4.8 respectively. The animals on dietary treatments Seven, Eight and Nine were all significantly ($P < 0.001$) heavier in the makeup of their prime rib cut, carcass (bone ($P < 0.05$)) and empty body than the control animals. An exception was in the ash composition where animals on diets Seven and Nine did not differ significantly from the control animals, but animals on diet Eight tended to have a ($P < 0.1$) higher ash content than the control animals. Compositional differences between dietary treatments were found only in the subcutaneous fat weight and subcutaneous fat gain in the prime rib cut ($P < 0.05$) and the subcutaneous fat weight ($P < 0.05$) and subcutaneous fat gain ($P < 0.1$) in the carcass.

Daily compositional gains (kg) in the prime rib cut, carcass and empty body are in Table 4.9. No significant differences between dietary treatments were found. The trend in carcass subcutaneous fat gain per day (kg / d) and chemical fat gain per day (kg / d) in the carcass and empty body was in the order: diet Nine > diet Eight > diet Seven. The trend in carcass protein gain per day (kg / d) was diet Eight > diet Seven > diet Nine, and in empty body protein gain per day (kg / d) diet Eight > diet Nine > diet Seven.

The estimated Effective Energy (MJ) requirements (maintenance, protein and lipid deposition), and intakes are in Table 4.10. No significant differences were found between dietary treatments for their estimated Effective Energy (MJ) requirements. The EE intake (MJ) of animals on diet Nine was lower ($P < 0.05$ and $P < 0.10$) than that of animals on diet Eight and Seven respectively. Animals did not differ significantly in their EE_c intake (MJ). Animals on diet Nine used a greater ($P < 0.05$) proportion of their EE and EE_c intake (MJ) on maintenance requirements compared to animals on diet Seven and Eight. Animals on diets Seven and Eight tended to use less ($P < 0.10$) EE intake (MJ) on chemical fat deposition than animals on diet Nine. Animals on diets Nine and Seven tended to differ ($P < 0.10$) in the proportion of EE_c intake (MJ) used for chemical fat deposition in the order diet Nine > diet Seven.

Table 4.7 The measured tissue makeup of the prime rib cut (kg) and the estimated tissue makeup of the carcass and empty body (kg) of the control and feedlotted steers

Composition	Control	Diet[s]			S.E.
		Seven	Eight	Nine	
Prime rib cut (kg)					
Weight	4.386[b]	7.528[a]	7.429[a]	7.678[a]	0.680
Muscle	2.950[b]	4.371[a]	4.358[a]	4.397[a]	0.357
Subcutaneous fat	0.091[c]	0.498[ab]	0.386[b]	0.542[a]	0.136
Bone	1.094[b]	1.376[a]	1.405[a]	1.369[a]	0.134
Protein	0.824[b]	1.456[a]	1.437[a]	1.467[a]	0.123
Chemical fat	0.539[b]	1.779[a]	1.707[a]	1.911[a]	0.335
Moisture	2.950[b]	4.371[a]	4.358[a]	4.397[a]	0.357
Ash	0.097[a,2]	0.129[a]	0.133[a,1]	0.123[a]	0.035
Carcass (kg)					
Weight	155.20[b]	235.75[a]	239.50[a]	240.62[a]	16.3
Muscle	110.16[b]	171.19[a]	175.30[a]	174.52[a]	12.5
Subcutaneous fat	9.74[c]	23.40[ab]	21.14[b]	24.87[a]	3.39
Bone	33.56[b]	38.71[a]	40.40[a]	38.80[a]	4.22
Protein	29.17[b]	45.70[a]	46.32[a]	46.01[a]	3.40
Chemical fat	22.71[b]	56.30[a]	56.25[a]	60.20[a]	8.04
Empty body (kg)					
Protein	49.94[b]	75.90[a]	76.93[a]	76.42[a]	5.66
Chemical fat	35.96[b]	82.06[a]	81.99[a]	87.74[a]	11.8

[s] = Diet Seven: maximum EE to ME ratio; Eight: medium EE to ME ratio; Nine: minimum EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < .05$

[1,2,3] = Values in the same row with different superscripts are different $P < .10$

Table 4.8 Compositional gain (kg) in the prime rib cut, carcass and empty body between the control and feedlot animals

Composition	Diet[s]			S.E.
	Seven	Eight	Nine	
Prime rib cut gain (kg)				
Weight	3.142	3.043	3.292	0.713
Muscle	1.421	1.408	1.447	0.377
Subcutaneous fat	0.406[ab]	0.294[b]	0.450[a]	0.148
Bone	0.283	0.311	0.276	0.139
Protein	0.632	0.613	0.643	0.131
Chemical fat	1.240	1.168	1.372	0.355
Moisture	1.421	1.408	1.447	0.377
Ash	0.032	0.037	0.026	0.036
Carcass gain (kg)				
Muscle	61.03	65.14	64.36	13.0
Subcutaneous fat	13.67[1,2]	11.40[2]	15.13[1]	3.64
Bone	5.15	6.84	5.24	4.46
Protein	28.04	29.58	22.96	23.3
Chemical fat	33.59	33.55	37.49	8.37
Empty body gain (kg)				
Protein	25.96	26.99	26.48	5.99
Chemical fat	46.10	46.03	51.78	12.2

[s] = Diet Seven: maximum EE to ME ratio; Eight: medium EE to ME ratio; Nine: minimum EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < .05$

[1,2,3] = Values in the same row with different superscripts are different $P < .10$

Table 4.9 The change in prime rib cut, carcass and empty body composition (kg) on a daily basis

Composition	Diet[s]			S.E.
	Seven	Eight	Nine	
Feeding period (days)	75.50	68.00	72.25	9.95
Prime rib cut gain (kg) / day				
Weight	0.044	0.046	0.046	0.0116
Muscle	0.020	0.021	0.020	0.0057
Subcutaneous fat	0.006	0.004	0.006	0.0022
Bone	0.004	0.005	0.004	0.0023
Protein	0.009	0.009	0.009	0.0020
Chemical fat	0.018	0.018	0.019	0.0060
Moisture	0.020	0.021	0.020	0.0057
Ash	0.0004	0.0005	0.0004	0.0005
Carcass gain (kg) / day				
Muscle	0.851	0.978	0.900	0.209
Subcutaneous fat	0.196	0.172	0.208	0.0536
Bone	0.072	0.104	0.077	0.0703
Protein	0.419	0.478	0.338	0.365
Chemical fat	0.477	0.509	0.524	0.144
Empty body gain (kg) / day				
Protein	0.361	0.403	0.369	0.088
Chemical fat	0.654	0.698	0.723	0.208

[s] = Diet Seven: maximum EE to ME ratio; Eight: medium EE to ME ratio; Nine: minimum EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < .05$

[1,2,3] = Values in the same row with different superscripts are different $P < .10$

Table 4.10 The estimated Effective Energy (Effective Energy at maintenance (EE); effective Effective Energy (EE_x))(MJ) requirements for maintenance, protein and lipid deposition, Effective Energy (MJ) intakes and the proportions the respective requirements were of the intakes for the feedlotted steers

Energy Composition	Diet[s]			S.E.
	Seven	Eight	Nine	
Effective Energy requirements (MJ)				
Maintenance	1947	1877	2033	283
Protein	1298	1350	1324	300
Chemical fat	2582	2578	2900	683
Total	5827	5804	6256	941
EE intake (MJ)	7810[1]	8063[a,1]	6690[b,2]	1266
EE_x intake (MJ)	6010	5874	5267	893
EE balance (MJ)	1983[a]	2258[a]	434[b]	1337
EE_x balance (MJ)	183[a]	69[a]	-989[b]	999
Maintenance EE req. / EE intake (%)	25.00[b]	23.35[b]	30.82[a]	2.42
Protein EE req. / EE intake (%)	16.62	17.02	20.35	4.42
Chemical fat EE req. / EE intake (%)	33.68[2]	32.88[2]	44.85[1]	11.7
Maintenance EE req. / EE_x intake (%)	32.40[b]	32.00[b]	38.87[a]	2.09
Protein EE req. / EE_x intake (%)	21.53	23.25	25.62	5.36
Chemical fat EE req. / EE_x intake (%)	43.55[2]	44.99[1,2]	56.32[1]	14.4
Heat production from protein gain (MJ)	826	859	843	95.4
Heat production from lipid gain (MJ)	756	755	849	100.1

[s] = Diet Seven: maximum EE to ME ratio; Eight: medium EE to ME ratio; Nine: minimum EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < .05$

[1,2,3] = Values in the same row with different superscripts are different $P < .10$

4.3.3 Physiological measurements

The trends of respiration rate over time were similar across diets (Figure 4.1). The respiration rate peaked in the first week of feeding, dipped in the second, peaked again in the third from which it followed a relatively constant rate for the remaining period of measurement. Mean ambient temperatures fluctuated marginally over the feeding period. The maximum and minimum temperatures did differ widely in the third, fifth, sixth and seventh weeks.

Results of respiration rates are given in Table 4.11. Respiration rates measured at 9.00 am (CV% = 21.1) were significantly affected by diet and time ($P < 0.001$). Animals on diet Eight had a significantly higher respiration rate than those on diets Seven and Nine while the control steers had a significantly lower respiration rate than steers on other dietary treatments. Respiration rates in weeks one and three were markedly higher than the mean overall respiration rate and the respiration rate in weeks zero and two were markedly lower than the mean overall respiration rate.

Table 4.11 The rectal temperature (°C) and respiration rates (breaths / minute) of feedlot cattle on the three trial diets containing various ratios of EE to ME compared to a control group grazed on pasture

Variate		Diet[1]				S.E.D.	Diet	Time
		Seven	Eight	Nine	Control			
Respiration rate (breaths / minute)		43.66 ^{b}	47.26^{a}	42.92^{b}	39.12^{c}	0.722	***	***
Rectal temperature (°C)								
	9.00 am	39.01^{a}	39.01^{a}	38.99^{a}	38.75^{b}	0.0444	***	***
	2.00 pm	39.30^{b}	39.47^{a}	39.40^{ab}	-	0.0488	**	***
Rectal temperature change (°C)		0.287^{b}	0.464^{a}	0.386^{ab}	-	0.0569	**	***

[1] = Diet : Seven max. EE to ME ratio; Eight: med. EE to ME ratio; Nine: min. EE to ME ratio

^{a,b,c} = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

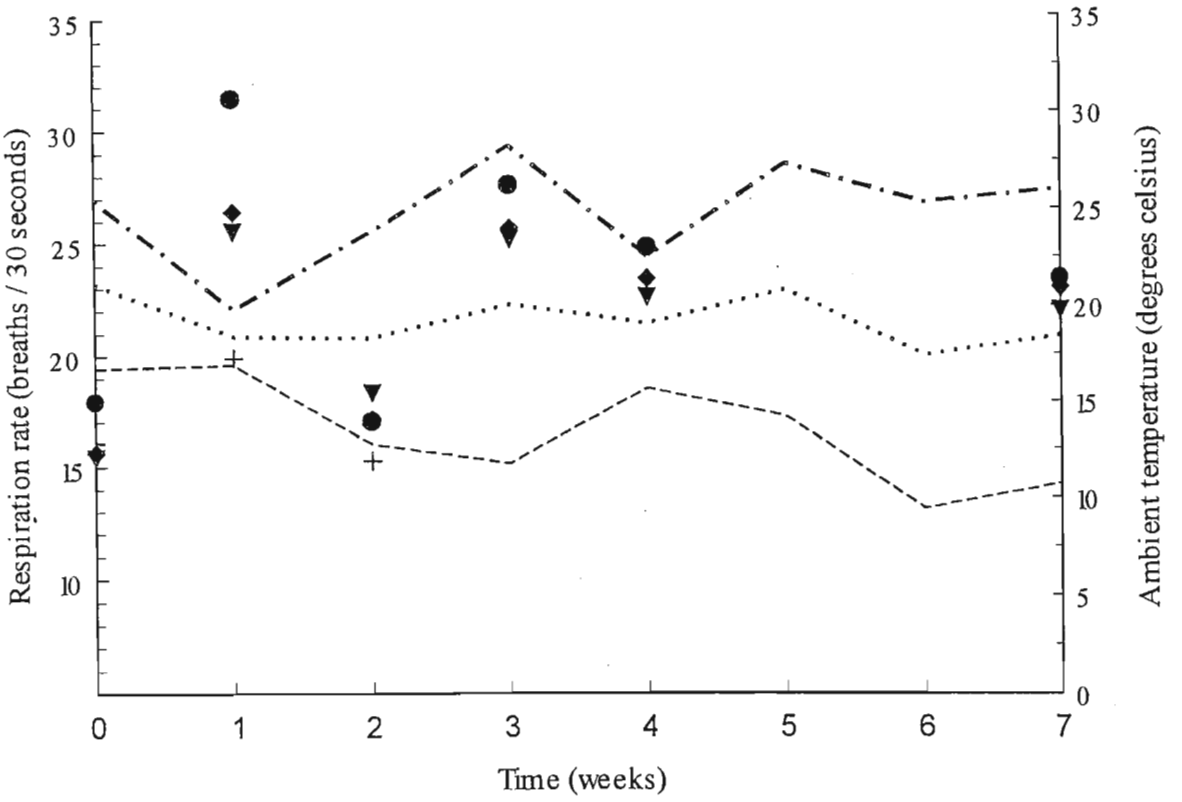

Figure 4.1 **Respiration rates (breaths / 30 seconds) of feedlot steers fed on diet Seven ◆, diet Eight ▼, diet Nine ● and Control ✚. The ambient temperatures (°C), Average ·····, Minimum ---- and Maximum -·-·-· for the days the respiration rate were recorded. The lines joining the ambient temperature points are purely descriptive and are not meant to represent a continuum.**

The T_R at 9.00 am followed a similar trend over time (Figure 4.2). The rectal temperature peaked in the first week of feeding, dipped in the second, peaked again in the third whence it became constant for the remaining period of measurement. The control animals followed a similar trend except in the third week where their T_R (9.00 am) dipped instead of peaking as in the other treatments. Mean ambient temperatures fluctuated marginally over the feeding period. The difference between the maximum and minimum temperatures dropped sharply during the third week.

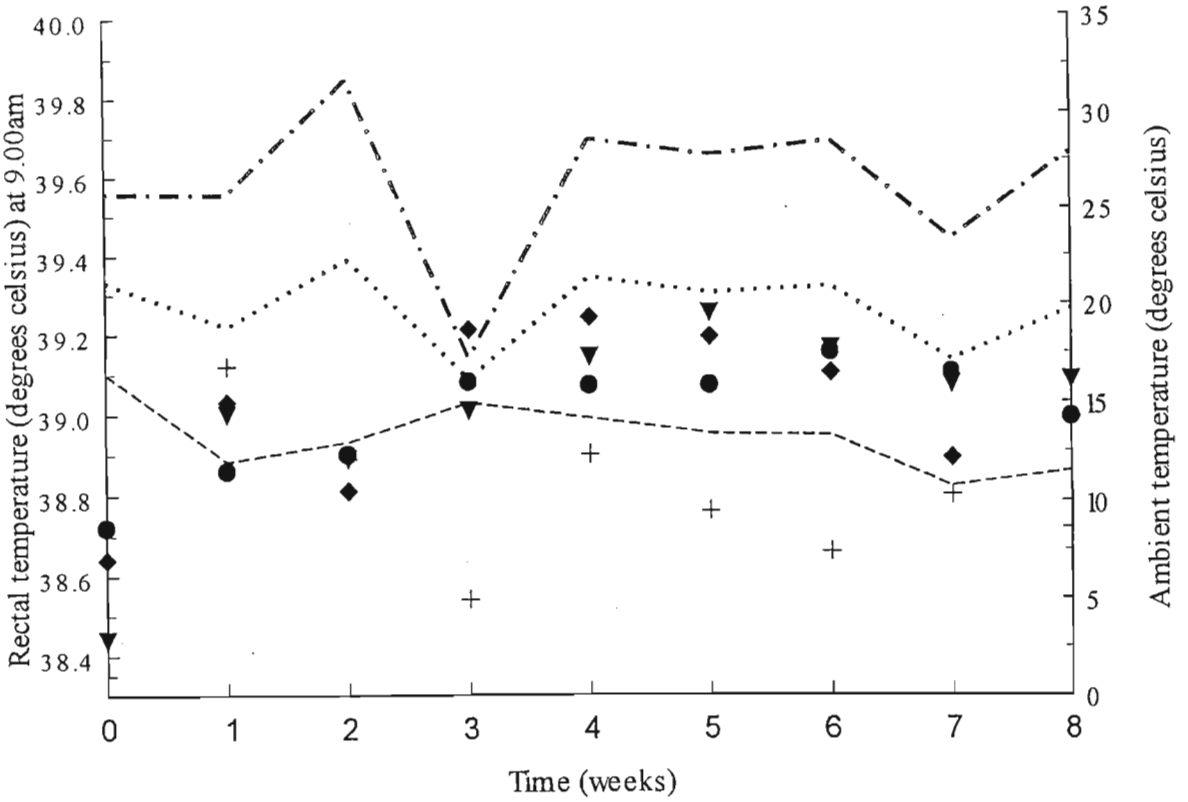

Figure 4.2 **Rectal temperatures (°C) measured at 9.00 am of feedlot steers fed on diet Seven ◆, diet Eight ▼, diet Nine ● and Control ✚. The ambient temperatures (°C), Average ·····, Minimum ----- and Maximum -·-·-· for the days the rectal temperatures were recorded. The lines joining the ambient temperature points are purely descriptive and are not meant to represent a continuum.**

The T_R at 2.00 pm followed a similar trend over time (Figure 4.3). The rectal temperature peaked in the first week of feeding, dipped in the second, peaked again in the third whence it became relatively constant for the remaining period of measurement.

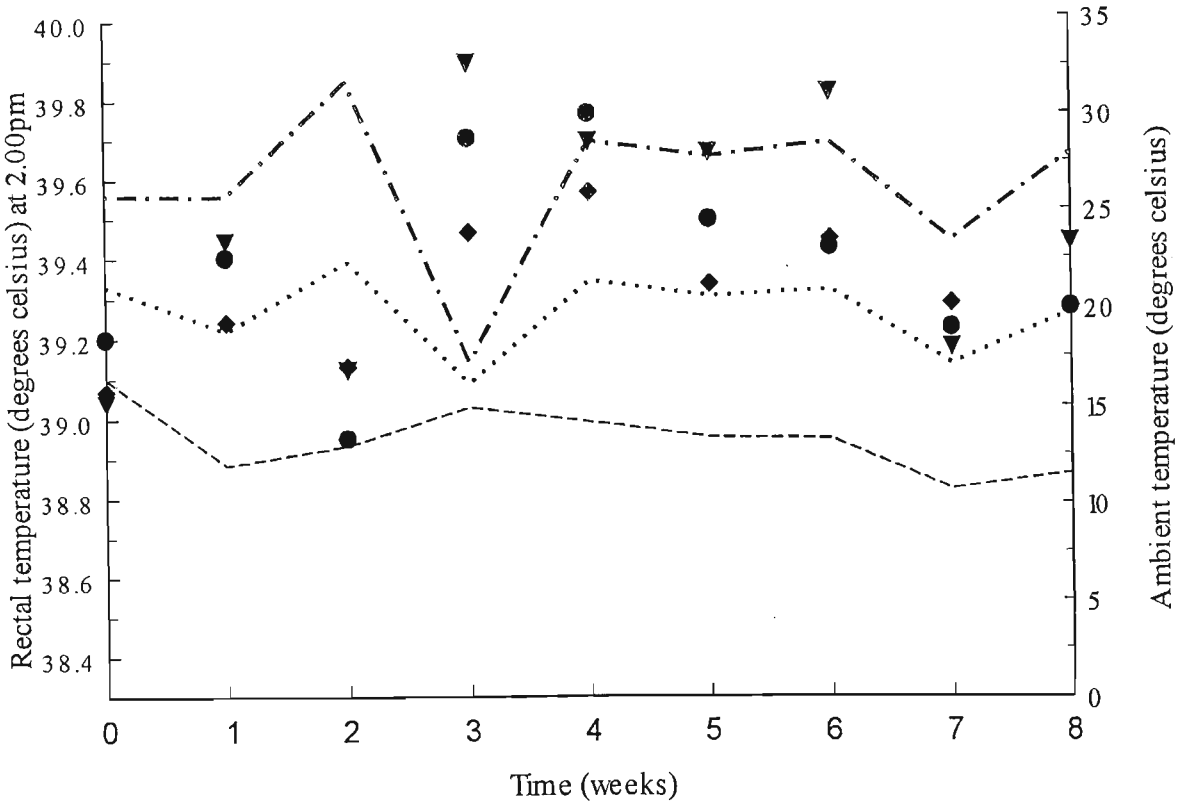

Figure 4.3 **Rectal temperatures (°C) measured at 2.00 pm of feedlot steers fed on diet Seven ◆, diet Eight ▼ and diet Nine ●. The ambient temperatures (°C), Average ·····, Minimum ---- and Maximum -·-·- for the days the rectal temperatures were recorded. The lines joining the ambient temperature points are purely descriptive and are not meant to represent a continuum.**

Results of rectal temperatures are given in Table 4.11. Diet and time (week) affected T_R (9.00 am) significantly ($P < 0.001$). Animals on all three dietary treatments recorded rectal temperatures that were significantly ($P < 0.01$) higher than for the control (CV% = 0.8). There were no significant ($P > 0.05$) differences in the T_R (9.00 am) among diets Seven, Eight and Nine. T_R (9.00 am) in week zero was markedly lower than the mean overall rectal temperature.

Diet and time affected T_R (2.00 pm) significantly at $P < 0.01$ and $P < 0.001$ respectively; CV% = 0.9. The T_R (2.00 pm) of animals on diet Eight were higher ($P < 0.01$) than the T_R (2.00 pm) of animals on diet Seven. T_R (2.00 pm) in weeks three and four were markedly higher than the

mean overall rectal temperature and the T_R (2.00 pm) in week zero was markedly lower than the mean overall rectal temperature.

The rectal temperature change (CV% = 100.7) between the 9.00 am and 2.00 pm were significantly affected by diet ($P < 0.01$) and time ($P < 0.001$). Animals on diet Seven had a significantly greater increase in T_R than animals on diet Eight. T_R change in weeks zero, three and four were markedly higher than the overall mean but the T_R change in weeks two and seven were markedly lower than the overall mean. A significant ($P < 0.05$) time by diet interaction showed that the T_R change for animals on diet Seven decreased during weeks three to five, whereas T_R change increased for animals on diets Eight and Nine during this period.

The correlations of ambient temperature on T_R (9.00 am and 2.00 pm) are in Table 4.12. None of the correlations were found to be significantly different form zero. For animals on diet Seven and Nine correlations between T_R (9.00 am) and minimum ambient temperature were positive, and the correlations between T_R (9.00 am) and average and maximum ambient temperature negative. For the control animals the correlation between T_R (9.00 am) and minimum ambient temperature was negative, while the correlations between T_R (9.00 am) and average and maximum ambient temperatures were positive. Correlation coefficients for animals on diet Eight were close to zero. Correlation coefficients for animals on diets Seven, Eight and Nine were similarly low across all three ambient temperature measurements with T_R (2.00 pm). The correlation coefficients were low and positive for minimum ambient temperatures and low and negative for average and maximum ambient temperatures.

Table 4.12 Correlations between the mean ambient temperatures for that week and the physiological measurements recorded during that week

Variate		Ambient temperature		
		Minimum	Maximum	Average
Rectal temperature (9.00 am) (°C)				
Diet[1]				
	Seven	0.656	-0.505	-0.322
	Eight	0.004	0.017	0.017
	Nine	0.220	-0.344	-0.289
	Control	-0.515	0.420	0.273
Rectal temperature (2.00 pm) (°C)				
Diet[1]				
	Seven	0.056	-0.229	-0.197
	Eight	0.136	-0.303	-0.234
	Nine	0.202	-0.457	-0.353

[1] = Diet Seven: maximum EE to ME ratio; Eight: medium EE to ME ratio; Nine: minimum. EE to ME ratio

Test of the null hypothesis H_O : $\rho = 0$; * = < 0.05, ** = < 0.01

4.3.4 Animal performance

The feed intake (on a dry matter basis) curves were similar across diets (Figure 4.4). Feed intake increased for the first two weeks, then dipped in the third week, before increasing linearly to a peak in the fourth week. Feed intake then plateaued for the remaining four weeks in the feedlot.

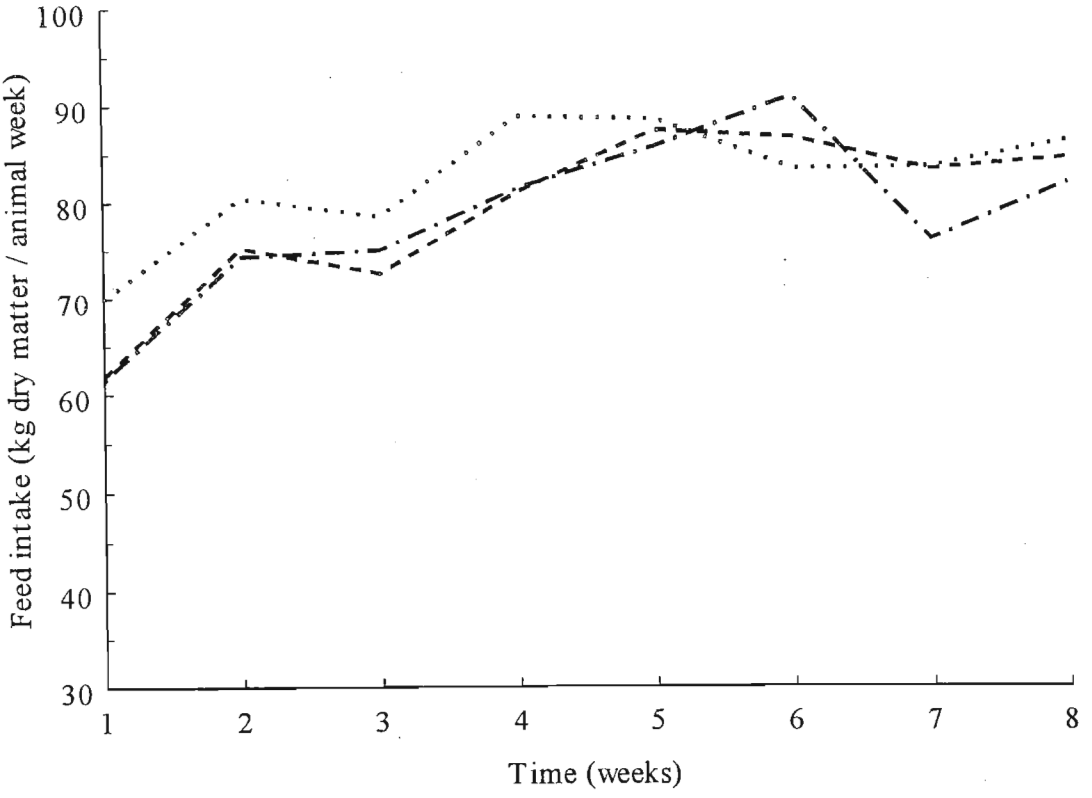

Figure 4.4 Feed intake by feedlot steers (kg dry matter / animal week) fed on diet Seven ·····, diet Eight ---- and diet Nine -·-·-.

Feed intake results are given in Table 4.13. The feeding period differed among the diets ($P > 0.05$), in the order of diet Nine > diet Eight > diet Seven. The covariate, starting mass, had a significant ($P < 0.01$) effect on the length of time (-0.1567 days / kg) an animal spent in the feedlot.

Cumulative dry matter intakes were not significantly ($P > 0.05$) different among treatments. Animals on diet Eight consumed more ($P < 0.05$) energy (ME_n, EE, NE_g and EE_x) (MJ) than the animals consuming diet Nine. The intakes of NE_g (MJ) of animals was higher ($P < 0.05$) for diet Eight than for diet Seven, which in turn was higher ($P < 0.05$) than that of the animals on diet Nine. The covariate starting mass significantly ($P < 0.05$) affected the intake of all nutrients e.g -1.519 kg dry matter / kg starting mass.

Results of daily intake are given in Table 4.13. Daily dry matter intakes were not significantly ($P > 0.05$) different among treatments. The daily energy intakes (MJ) of steers on diets Seven and Eight were higher ($P < 0.05$) than those of steers on diet Nine. Animals on diet Eight consumed significantly ($P < 0.05$) more NE_g (MJ / day) than animals on diet Seven.

The live weight gains results are given in Table 4.14. The effect of covariate starting weight was significant ($P < 0.001$) for final weight (0.615 kg / kg) and weight gain (0.3072 kg / kg). Dietary treatment had a non significant ($P > 0.05$) effect on final weight and weight gain. The ADG of steers on diet Nine was significantly lower ($P < 0.05$) than that achieved by animals on diets Seven and Eight.

The feed conversion ratio of dry matter was non significantly ($P > 0.05$) different across diets. Animals on diet Eight had significantly higher energy (ME_n, EE, NE_g) conversion ratios than animals on diet Nine. The conversion ratios of NE_g were significantly different among diets in the order: diet Eight > diet Seven > diet Nine.

Carcass and fat coverage results are given in Table 4.15. Dietary treatment did not affect ($P > 0.05$) carcass weights, dressing percentages or fat coverages. The covariate, starting weight, affected ($P < 0.001$) carcass weight significantly.

Correlation between an animals dry matter intake (kg's) with the ambient temperatures and the physiological measurements are given in Table 4.16. Dry matter intake was poorly correlated with minimum ambient temperatures, but were more strongly correlated with maximum and average ambient temperature. The correlation coefficient between the average ambient temperature and the dry matter intake of animals on diet Seven was significantly different from zero ($P < 0.05$).

The correlation coefficients for T_R (9.00 am) with dry matter intake were positive for diets Seven, Eight and Nine. The correlation coefficient between T_R (9.00 am) and the dry matter intake of animals on diet Eight was significantly different from zero ($P < 0.01$). The correlation coefficients for T_R (2.00 pm) with dry matter intake were positive for diets Seven and Eight and

close to zero for diet Nine. The correlation coefficient between T_R (2.00 pm) and the dry matter intake of animals on diet Seven was significantly different from zero ($P < 0.05$). The correlation coefficients for respiration rate with dry matter intake were negative across all diets and the correlation coefficient between respiration rate and the dry matter intake of animals on diet Nine was significantly different from zero ($P < 0.01$).

Table 4.13 Feeding period, total intake and daily intake (dry matter, Metabolisable energy at maintenance (ME_n), Effective Energy at maintenance (EE), Net energy for gain (NE_g), effective Metabolisable energy (ME_x) and effective Effective Energy(EE_x)) of feedlot animals

Variate	Diet[1]			S.E.	Covariate
	Seven	Eight	Nine		
Feeding period (days)	64.35	69.12	70.00	2.83	(-0.1567)**
Intake / head					
Dry matter (kg)	755.7	793.2	783.1	32.9	(-1.519)*
ME_n (MJ)	8101^{ab}	9090^{a}	7627^{b}	349	(-16.13)*
EE (MJ)	7074^{ab}	7987^{a}	6484^{b}	303	(-14.02)*
NE_g (MJ)	2947^{b}	3514^{a}	2545^{c}	126	(-5.84)*
ME_x (MJ)	6484	6980	6241	278	(-12.86)*
EE_x (MJ)	5456^{ab}	5862^{a}	5090^{b}	231	(-10.73)*
Intake / head / day					
Dry matter (kg)	11.74	11.54	11.25	0.210	
ME_n (MJ)	125.86^{a}	132.25^{a}	109.60^{b}	2.21	
EE (MJ)	109.89^{b}	116.21^{a}	93.17^{c}	1.91	
NE_g (MJ)	45.79^{b}	51.12^{a}	36.57^{c}	0.797	
ME_x (MJ)	100.74^{a}	101.55^{a}	89.68^{b}	1.76	
EE_x (MJ)	84.77^{a}	85.28^{a}	73.14^{b}	1.46	

[1] = Diet : Seven max. EE to ME ratio; Eight: med. EE to ME ratio; Nine: min. EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

Table 4.14 Live weight and performance efficiency results for the whole trial period

Variate	Diet[1]			S.E.	Covariate
	Seven	Eight	Nine		
Final weight (kg)	458.10	458.06	458.40	6.42	(0.615)***
Weight gain (kg)	137.80	147.06	134.75	5.62	(-0.385)***
Average daily gain (kg / day)	2.14[a]	2.16[a]	1.95[b]	0.0537	
Feed conversion ratio					
kg dry matter / kg gain	5.528	5.437	5.818	0.164	
MJ Metabolisable energy at maintenance / kg gain	59.26[ab]	62.30[a]	56.67[b]	1.77	
MJ Effective Energy at maintenance / kg gain	51.75[ab]	54.75[a]	48.18[b]	1.54	
MJ Net energy for gain / kg gain	21.56[b]	24.08[a]	18.91[c]	0.653	
MJ effective Metabolisable Energy / kg gain	47.43	47.84	46.37	1.40	
MJ effective Effective Energy / kg gain	39.92	40.18	37.82	1.17	

[1] = Diet Seven: maximum EE to ME ratio; Eight: medium EE to ME ratio; Nine: minimum EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

Table 4.15 Carcass weight, dressing percentage and fat coverage results after the feedlot period

Variate	Diet[1]			S.E.	Covariate
	Seven	Eight	Nine		
Carcass weight (kg)	236.40	239.53	235.25	4.08	(0.3072)***
Dressing percentage	51.59	52.25	51.33	0.487	
Fat coverage[1]					
Overall	3	3	3	0.478	
Fore-quarter	-3	3	3	0.464	
Loin	3	+3	3	0.582	
Hind-quarter	-3	-3	-3	0.489	

[1] = Diet Seven: maximum EE to ME ratio; Eight: medium EE to ME ratio; Nine: minimum EE to ME ratio

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

Table 4.16 Correlations between the dry matter intake (kg's) with the ambient temperatures and the physiological measurements

Variate		Diet		
		Seven	Eight	Nine
Ambient temperatures(°C).				
	Maximum	0.332	0.238	0.232
	Average	0.362*	0.325	0.202
	Minimum	0.071	0.251	-0.111
Rectal temperatures (°C)				
	9.00 am	0.310	0.758**	0.551*
	2.00 pm	0.475*	0.237	0.029
Respiration rate (breaths per minute)		-0.248	-0.323	-0.634**

[1] = Diet Seven: maximum EE to ME ratio; Eight: medium EE to ME ratio; Nine: minimum. EE to ME ratio

Test of the null hypothesis H_O : $\rho = 0$; * = < 0.05, ** = < 0.01

4.3.5 Predictor equations

Prediction equations for ADG, cumulative dry matter intake and feed conversion ratios are given in Table 4.17. A significant ($P < 0.001$) positive relationship was found between ADG and energy density. ADG increases with an increase in energy density and an increase in the ratio of effective energy to metabolisable energy. The amount of variation (R^2) accounted for was low (10.7 to 13.0%), with the EE_x density and the ratio of EE_x to ME_n accounting for the most variation. Energy density was found to have a non significant ($P > 0.05$) role in predicting cumulative dry matter intake. The models accounted for a very small amount of the variation (R^2) with a range of 5.8 to 6.2 %. An increasing energy density is predicted to decrease FCR significantly ($P <$ 0.01). Despite the significance of the factors included in the prediction models very little variation (R^2) was accounted for in the models (2.9 to 3.2 %).

Table 4.17 Predictor equations for average daily gains (ADG), cumulative dry matter intake and feed conversion ratios using energy density (Metabolisable energy at maintenance (ME_n), Effective Energy at maintenance (EE), Net energy for gain (NE_g), effective Metabolisable energy (ME_x) and effective Effective Energy (EE_x)) (MJ) and starting mass (covariate) as factors

Variate	Predictor	Constant	Covariate	R^2 (%)
ADG	$0.1285.ME_n$***	0.718		10.9
	0.1246.EE***	0.934**		11.3
	$0.1861.NE_g$***	1.367***		10.7
	$7.55.EE / ME_n$***	-4.46**		12.5
	$0.2699.ME_x$***	-0.196		12.4
	$0.2476.EE_x$***	0.342		12.8
	$8.51.EE_x / ME_n$***	-4.99**		13.0
Dry matter intake (kg)	$-7.9.ME_n$	1354***	-1.549**	5.8
	-8.3.EE	1347***	-1.551**	5.9
	$-11.0.NE_g$	1312***	-1.547**	5.8
	$-638.EE / ME_n$	1825	-1.559**	6.0
	$-22.4.ME_x$	1462***	-1.559**	6.0
	$-22.6.EE_x$	1433***	-1.561**	6.1
	$-916.EE_x / ME_n$	2035	-1.563**	6.2
Feed conversion ratio (kg dry matter / kg gain)	$-0.228.ME_n$	8.02***		3.0
	-0.220.EE	7.62***		3.1
	$-0.332.NE_g$	6.875***		2.9
	$-12.96.EE / ME_n$*	16.82**		3.2
	$-0.464.ME_x$*	9.51***		3.2
	$-0.464.EE_x$*	9.51***		3.2
	$-0.42.EE_x / ME_n$*	8.55***		3.2

Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

4.4 Discussion and conclusions

4.4.1 Diet composition

The significant difference in EE density (Table 4.6) between diets Eight and Nine is due to the higher loss of energy from diet Nine through methane production, the lower level of CP in diet Eight and a lower digestible energy density in diet Nine. Calculation of the EE density (see section 3.2.4.1.2) allows a loss of 4.672 kJ / g of digestible CP and a loss of 0.616 kJ / g of methane. The lower EE density of diet Nine results in a significantly lower EE to ME_n ratio with a resultant higher heat load. The significantly lower consumption of energy in terms of multiples of maintenance by animals on diet Eight resulted in a lower corrected digestibility compared to that of diet Nine. This resulted in the lack of significant difference between the diets' EE_x densities. However, the values of ME_x and EE_x of diet Nine were still lower than those of diets Seven and Eight. This allowed for the significant differences between the diets with respect to the ratio of EE_x to ME_x to remain the same as that for EE to ME_n.

The CP content of diet Eight (Table 4.4) was below the minimum formulation boundary (Table 2.1), but still met the animals' protein requirements (Church, 1984 and NRC, 1996) and was non significantly different to the CP content of diets Seven and Nine. As discussed in section 2.4 a fat content above 100 g / kg may inhibit rumen microbe activity thus reducing fibre fermentation (McDonald, 1990 and van Soest, 1994). The high fat content of diets seven and eight coupled with their higher fibre contents may have resulted in a decrease in digestion of gross energy. However, the fat and fibre contents were well within the suggested boundaries and no significant differences were found between the diets with respect to apparent organic matter digestibility. The lower phosphorous levels in diets Seven and Eight should not have affected performance as the levels were above requirements (NRC, 1996) and the minimum formulation boundary (Table 2.1). Despite being a formulated 50 : 50 mix of diets Seven and Nine, diet Eight was markedly different from expected. Diet Eight had a lower Protein density but a higher fibre and energy density than diets Seven and Nine. The higher dry matter digestibilty recorded for diet Eight indicates that a greater level of palm kernel meal was added to the diet than formulated for. Palm kernel meals high fibre level which has a high digestibility would have diluted the protein level and

increased the fibre and energy levels of diet Eight.

4.4.2 Carcass composition

The realistic nature of the composition values obtained for the prime rib cut, carcass and empty body is important. Two papers which give the breakdown of the prime rib cut were found; Naudé (1972) and Keane *et al.* (1991) and their prime rib cut values compared favourably to the ones obtained in this trial. The prediction equations used in this trial were based (section 4.2.3.3) on the paper by Naudé (1972) but the paper by Keane *et al.* (1991) is an example of the American prime rib cut sampling technique. The American prime rib cut sampling technique utilises the 9 th to 11 th rib sample site as opposed to the 8 th to 10 th rib sampled in this trial. The 9 th to 11 th rib cut is not comparable with the South African commercial cutup techniques. This led to the development of prediction equations by Naudé (1972) using a very practical joint for the South African cutup techniques, from the forequarter, the 8 th to 10 th rib cut.

The moisture and protein composition of the prime rib cut (Table 4.7) for the control animals were within the range obtained by Keane *et al.* (1991), and the muscle and chemical fat within the range obtained by Naudé (1972). The carcass compositions obtained in this study are in close agreement with other reports with respect to muscle (Waldman *et al.*, 1971; Naudé, 1972; Meissner *et al.*, 1980*b* and Slabbert *et al.*, 1992), subcutaneous fat (Meissner *et al.*, 1980*b*), bone (Waldman *et al.*, 1971 and Meissner *et al.*, 1980*b*), protein (Callow, 1947; Waldman *et al.*, 1971; Jesse *et al.*, 1976; Arnold *et al.*, 1985 and Buckley *et al.*, 1990) and chemical fat (Callow, 1948; Waldman *et al.*, 1971; Meissner *et al.*, 1980*b* and Buckley *et al.*, 1990). The protein and chemical fat composition of the empty body of the control animals were within an acceptable range (Hammond *et al.*, 1988).

The prime rib cut muscle, bone and chemical fat results of the fattened animals agreed with those of Naudé (1972). The prime rib cut protein and moisture findings were in agreement with those of Keane *et al.* (1991). The carcass compositions obtained in this study are in close agreement with other reports with respect to muscle (Waldman *et al.*, 1971; Naudé, 1972 and Meissner *et al.*, 1980*b*), subcutaneous fat (Meissner *et al.*, 1980*b* and Slabbert *et al.*, 1992), bone (Waldman

et al., 1971; Naudé, 1972; Meissner *et al.*, 1980*b* and Slabbert *et al.*, 1992), protein (Callow, 1947; Jesse *et al.*, 1976; Arnold *et al.*, 1985; Carstens *et al.*, 1991; Patterson *et al.*, 1995 and Ferrell *et al.*, 1998) and chemical fat (Callow, 1947; Waldman *et al.*, 1971; Naudé, 1972; Meissner *et al.*, 1980*b*; Carstens *et al.*, 1991; Patterson *et al.*, 1995 and Ferrell *et al.*, 1998).

The finished animals empty body compositions obtained in this study are in close agreement with other reports with respect to protein (Jesse *et al.*, 1976; Meissner *et al.*, 1980*a*; Varga *et al.*, 1989; Carstens *et al.*, 1991; Hammond *et al.*, 1991; Patterson *et al.*, 1995 and Ferrell *et al.*, 1998) and chemical fat (Meissner *et al.*, 1980*a*; Carstens *et al.*, 1991; Hammond *et al.*, 1991 and Ferrell *et al.*, 1998).

Disparities were apparent with respect to the proportion of fat (subcutaneous and chemical) in the total (prime rib cut, carcass or empty body) in some of the literature (Jesse *et al.*, 1976; Arnold *et al.*, 1985 and Keane *et al.*, 1991). These differences were, however, limited to trials where the animals were fed to a set weight with a lower fat content (Jesse *et al.*, 1976 and Keane *et al.*, 1991), or fattened to the American carcass grade, with a higher fat content (Jesse *et al.*, 1976 and Arnold *et al.*, 1985) than the carcasses obtained in this trial.

Butterfield (1988) introduced a *maturity coefficient* for the comparative description of growth:

$$y = qx + (1 - q)x^2$$

where y = the weight of the organ divided by its own mature weight (I / I_m)

x = the weight of the total (animal or tissue) divided by its own mature weight (T / T_m)

q = the relationship between y and x

"A 'q' value greater than 1.0 means a lesser rate of growth, i.e., "low impetus" relative to that of the whole animal and therefore a declining proportion of the whole. A 'q' value less than 1.0 means a greater rate of growth, i.e., "high impetus" relative to that of the whole animal and therefore an increasing proportion of the whole. A 'q' value not different to 1.0 means that the structure and the whole are growing at the same relative rate, i.e., "average impetus" and

therefore the proportion of the part to the whole remains unchanged" (Butterfield, 1988).

Butterfield allocated bone and muscle maturity coefficients 'q' of 1.4 and 1.3 respectively. Bone and muscle therefore may be increasing over time in relation to their original weights, but they are becoming a decreasing proportion of the total carcass. The proportion of fat in the carcass increases at a constant level, until an accelerated period of deposition. The accelerated period of deposition is termed the *fattening phase*. During the fattening phase the large increase in the deposition of fat tissue is at a rate greater than that of the other tissues in the carcass (Murray *et al.*, 1974; Berg *et al.*, 1976 and Baker *et al.*, 1991).

The estimated compositional growth (Table 4.8) of the feedlot animals was as predicted. Bone increased in weight, at a rate less than the whole and subcutaneous and chemical fat became an increasing proportion of the whole. A similar rate of gain per day of chemical fat in the empty body was achieved in other trials (Fortin *et al.*, 1980; Patterson *et al.*, 1995 and Ferrell *et al.*, 1998). Protein naturally remained a constant proportion of the prime rib cut and carcass due to its method of determination (section 4.2.4.2). Protein did increase slightly as a proportion of the empty body. This was due to the prediction that carcass protein makes up a greater proportion of the empty body protein as live weight increases (Table 4.3). The daily protein gains achieved in this trial were much higher than others in literature (Slabbert *et al.*, 1992 and Ferrell *et al.*, 1998). These differences were due to complications by the animals following limited feeding patterns (Slabbert *et al.*, 1992) or diets designed for high fat deposition (Ferrell *et al.*, 1998) (13 MJ ME / kg) and fed over a long period of time (140 days versus 75 days in this trial).

The trend across diets was for animals on diet Nine to deposit more chemical fat per day compared to animals on diets Seven and Eight. It appears that the proportion of energy intake deposited as chemical fat was significantly higher for animals on diet Nine compared to Seven and Eight. This increased proportional use of energy for fat deposition suggests that animals on diet Nine had a higher heat stress which forced them to deposit fat and limited their ability to deposit protein in order to avoid excessive heat production. There were no significant differences with respect to rates of protein deposition despite the trend for animals on diet Nine to deposit less protein than those on diets Seven and Eight. The shorter period of time spent in the feedlot

compared to the animals in the first and second trials (Chapters Two and Three respectively), resulted in the animals being exposed to heat stress for a shorter period of time. This may have resulted in a lower response to heat stress in terms of body compositional changes. The reason for the shorter feedlot period is that the animals in this trial were older and more mature on entering the feedlot and therefore had a shorter fattening period. The greater proportional use of energy for maintenance by animals on diet Nine was due to their spending longer in the feedlot than animals on diet Seven and Eight.

4.4.3 Physiological measurements

The ambient temperatures during this feedlot period were higher than those during the second trial (Chapter Three). The maximum ambient temperature exceeded the TNZ of 15 to 25°C (section 1.3.1) on most measurement days. The average ambient temperature was around the mid point of the TNZ (20°C) on most days of the feeding period. Although the minimum ambient temperature in this trial was higher than in the previous one, it was still below the TNZ on most days. It is likely that animals were heat stressed from the environment during peak ambient temperature periods of the day. However, as the average ambient temperature fell well within the published TNZ, on average it is unlikely that the animals exposed to this environment suffered overall heat stress resulting from the environment.

The CV% obtained for the two trials are similar except for the CV% of T_R change. A decrease of 50% in the CV% was found in this trial. As described previously the high CV% values obtained for the measurement T_R change may be attributed to the unstable nature of a CV% because of a dependence on an exact balance between negative and positive values of the quantity measured (Mead *et al.*, 1996).

The T_R (9.00 am) of the control animals (Table 4.11) was within the core temperature range of 38 to 39°C considered essential for cattle as homeotherms (section 1.3.4). Significantly higher T_R (9.00 am) for animals on diet Seven, Eight and Nine compared to the control animals resulted in T_R at the top end of this range. An increase in T_R (2.00 pm) to above the core temperature range illustrates that the animals were under heat stress that was threatening their homeothermic

state. Despite being within the core temperature range when measured at 9.00 am, the significantly higher T_R of animals on diets Seven, Eight and Nine compared to the control suggests that the animals were experiencing a heat stress that is diet related.

The T_R (9.00 am and 2.00 pm) measured for diets Seven, Eight and Nine are lower than those measured for animals on diets Four, Five and Six and the control animals differed similarly. Therefore, despite the high ambient temperatures in this trial, the animals in the previous trial were under more severe heat stress because of the greater deviation in core body temperature from the normal range. This greater heat stress is not related to dietary differences as the control animals were also affected. Therefore the animals in the present trial must have had a greater capacity for losing heat as their environmental heat load was higher and their physiological response was lower.

The respiration rates (breaths / min) of animals on all diets and those of the control animals were higher than suggested for a TNZ environment (see Table 1.5.1). The respiration rate of 39.12 breaths per minute recorded for the control animals is higher than the 23 breaths per min (Manuel, 1954; Robinson *et al.*, 1986 and Ole Miaron *et al.*, 1992) expected in a TNZ or less stressful environment. In comparison the animals in this trial had higher respiration rates than animals in the previous trial. Using the control animals as a baseline the animals in this trial had a higher heat load characterised by their greater utilisation of evaporative heat loss mechanisms. The respiration rates of the animals on diets Seven, Eight and Nine are similar to those measured in feedlot steers at 8.00 am by Arp *et al.* (1983*b*) and animals measured in heat stress environments (35°C) Robinson *et al.* (1986) and (28°C) by Ole Miaron *et al.* (1992).

The combination of a significantly higher T_R (2.00 pm), greater T_R change and higher respiration rate for animals on diet Eight compared to those on diet Seven suggests that these animals experienced a higher degree of heat stress. As all factors other than diet were constant among treatments; the extra heat stress experienced by steers consuming diet Eight could be due to diet Eight having a higher heat increment of feeding although this is not indicated in the metabolism study (Table 4.6).

The patterns in T_R at 9.00 am and 2.00 pm and respiration rate show an increasing heat stress over the first week of feeding. The heat stress was then alleviated for a week before increasing again over the next week, from which it remained stable for the rest of the feeding period. None of this variation in rectal temperature or respiration rate can be explained through environmental fluctuation, for example, the peak in T_R in the third week of feeding is associated with a dip in ambient temperature. As concluded in Chapter Three the variation in physiological measurements may be as a result of feed intake fluctuations.

4.4.4 Animal performance

The feed intake curves (Figure 4.4) followed a similar trend to those reported in Chapters Two and Three, which in turn were similar to those reported by Owens *et al.* (1985), Thornton *et al.* (1985), Hicks *et al.* (1990*a,b*) and Dominy (1997). In this trial, feed intake peaked in the second and fourth weeks of feeding, separated by a dip in the third week of feeding. No dip in feed intake was apparent in the fifth week of feeding and the animals followed a distinctive plateau for the remaining feeding period.

This trial was started in January and finished in April, which covers the period of mid summer to early Autumn. The animals had already acclimatised to the summer environment before entering the feedlot and had therefore lost their winter coat. If the animals were indeed experiencing heat stress in the feedlot, then the animals reached a threshold of heat loss in the second week that demanded an acclimatisation reaction (see section 1.6.2). The acclimatisation would probably result in a lower response in terms of feed intake compared to the animals used in a previous study (Chapter Three) as the animals in this trial were already partly acclimatised.

Comparison between the feed intakes of the animals used in a previous study (Chapter Three) and the animals in this study reveals that the feed intakes were, at all stages, higher in the animals in this study (Chapter Four). However, the animals in the previous study (Chapter Three) increased their feed intakes by a greater amount before reaching a plateau. As discussed in section 1.1.1 the DMI of heavy cattle consistently peaked earlier and plateaued at higher levels than that for light animals. The intake of light animals increases for a longer period of time (Hicks *et al.*,

1990*b*), but failed to reach the levels achieved by heavy groups.

As cattle breeding is usually season-based there is an interaction between age, live weight and season. Comparisons of animals differing in live weight can be a comparison of animals differing in age and / or a comparison across seasons. For example weaners are lighter animals, eight months of age and in the South African context are available in Autumn, whereas, long yearlings are heavier animals, sixteen months of age and available in summer. Due to the interaction of age, live weight and season it is possible that differences which have previously been attributed to differences in live weight may in fact reflect differences due to the season the animals are feedlotted in. The animals used in the second trial (Chapter Three) during winter were weaners and in this trial long yearlings were used during summer. Therefore, the differences in time and degree of increase in feed intake between the animals in the two studies can be attributed to the differences in the degree of acclimatisation. It was argued previously (section 3.5.2) that the feed intake of animals in a feedlot is controlled by heat stress. If this is true then the higher feed intake at the start and the lower increase in feed intake until plateuing of the animals in this trial are due to their advanced state of acclimatisation. By being able to lose their winter coats the animals in the previous study were able to acclimatise proportionally more while in the feedlot and thus increase their feed intakes by a greater amount. However, the animals in the previous study did not utilise their time in the feedlot as efficiently as those in this study because of their lower initial intakes and the longer period of time preceding the plateau phase of feed intake e.g the differences in the chapters respective ADG's. It was suggested in section 1.8 that differences in DMI's between cattle differing in live weight is partly attributable to their differences in heat loss capacity. This may however only be correct with animals compared within a season or at the same level of acclimatisation. The differences between the two studies are possibly greater at the beginning due to differences in the degree of acclimatisation. However, the differences at peak feed intake are solely due to heat loss capabilities. This does however disagree with the findings of Hicks *et al.* (1990*b*) where the DMI's of cattle differing in initial live weights followed parallel patterns and were attributed to differences in maintenance requirements. In comparison with other trials (section 1.1.1) DMI patterns between animals differing in live weight were as expected except that the differences in DMI at the start of the feeding period were higher than the differences at peak feed intake.

As the animals fat coverages at slaughter were the same their daily fat deposition rates must have been similar as well. This coupled with the lower energy intakes of animals on diet Nine will have resulted in a greater proportion of the energy intake being used for fat deposition. As an animal's primary desire is protein deposition and it can be deduced from the lower ADG's of those animals on diet Nine that their protein deposition was reduced then the proportionally higher fat deposition of these animals must be due to a non voluntary function. The proportionally higher fat deposition by animals on diet Nine may therefore have been a result of a higher heat stress associated with diet Nine.

The correlation coefficients (Table 4.16) showed that the dry matter intake of the animals was poorly correlated with the maximum, minimum and average ambient temperatures. If the environment was the primary cause of the animals heat stress a stronger correlation would have been exhibited. The positive correlation coefficients associated with the rectal temperatures shows that as the rectal temperatures increased the dry matter intake increased. The shorter acclimatisation period in this trial compared to that in trial Two allowed for a more direct correlation between the physiological measurements and the animals dry matter intake. The better correlations compared to those in trial Two were a result of the small fluctuations in dry matter intake and low rectal temperature fluctuations during the adaptation period. The negative correlation between respiration rate and dry matter intake is due to the animals having to decrease their dry matter intake during periods of high respiration rates. This correlation is related to the closer relationship that the physiological measurements have to dry matter intake due to the short and comparatively limited adaptation.

4.4.5 Predictor equations

All the prediction models accounted for very little of the variation in the animals performances. Thus although there was variation between treatments that could be accounted for by dietary factors there was a larger variation within treatments. This within treatment variation could not be accounted for by any known factors.

As in section 3.6.1 the cumulated DMI of the animals does not appear to be controlled by the

animals's energy demands or by metabolic factors. The increase in ADG with an increase in energy density or a decrease in the heat of fermentation is unexpected. If energy density was limiting intake then the animals could have increased their intake to attain similar ADGs. The lack of differences between diets with respect to total feed intake were due to animals consuming food over a longer period at a lower daily intake, which resulted in no differences being attributable to energy density. The very poor fitting model for the prediction of FCR is due to the combination of variation arising from the measurement of live weight gain and feed intake.

4.4.6 General discussion

In section 3.8 it was concluded that a major limiting factor of the voluntary feed intake of feedlot cattle was heat stress. This was a conclusion based on the similarities between the animals physiological measurements over time and their feed intake measurements over time. Differences in performances were also apparent and were attributable to the diets' heat increments of feeding.

The formulation objective for the present study was to have three diets differing in their heat increments of feeding in the order: diet Seven < diet Eight < diet Nine. From the metabolism trials diet Nine was found to have a higher heat increment of feeding than diets Seven and Eight which were non significantly different from each other (section 3.3.1). Thus, heat stress responses are only expected to differ between diets Seven and Nine; and Eight and Nine and not between diets Seven and Eight.

The hypothesis for this trial was that animals fed diets differing in heat increment of feeding would differ in the proportions of energy intake used for protein and lipid deposition. No differences with respect to the proportion of energy intake used for protein deposition were found. However, animals on diet Nine tended to use proportionally more of their energy intakes for fat deposition. This increased proportional use of energy for fat deposition for those animals with higher heat increments of feeding could be a result of heat stress and the animals avoiding further heat production through protein deposition. As described in section 4.1 the deposition of fat utilises more energy and has a lower heat increment of deposition. The combination of the use of more energy at a lower heat increment of deposition to deposit lipid may have been forced on the

animals on diet Nine in an attempt to maximise their production while preventing further heat production. If this was the case then it could be concluded that these results correspond to the diet analysis in that animals on diet Nine had a higher heat load than animals on diets Seven and Eight.

The animals' physiological measurements do contradict this finding. Animals on diet Eight had higher T_R (2.00 pm) and respiration rates than animals on diet Seven. The heat increments of feeding of their respective diets showed that animals on diet Seven would have had a non significantly higher heat load per kilogram of food than animals on diet Eight. To have a higher physiological response the animals on diet Eight must have had a higher heat production (greater food intake or greater production) or a lower heat loss function. There were however, no significant differences with respect to food intake or production (ADG) between animals on diets Seven and Eight (section 4.6.1), thus showing no compensations for either diet having a higher heat load than the other. Examination of the individual animals physiological measurements (Appendix 3.3.1 and 3.3.2) revealed that animal 385 in diet Eight had rectal temperatures as high as 41°C which may have been as a result of a fever and this influenced the overall dietary result. If the mean physiological measurements of animals on diet Eight were lowered slightly then all animals would have shown a similar degree of heat stress as measured by similar physiological measurements.

The higher T_R (2.00 pm) of animals on diet Eight compared to the animals on diets Seven and Nine may have been compensated for by having higher respiration rates. The animals on diet Eight may have allowed their core body temperature to increase but accommodated for this by increasing their heat loss capacity (respiration rate) whereas animals on diet Seven maintained a lower core body temperature and thus there was no need for an increase in respiration rate. As discussed in sections 1.5 and 1.6, the adjustments and allowances for heat stress are varied and complex. It has been found that an animal's failure to thermoregulate towards the end of a hot day (Webster, 1976) can constitute a thermoregulatory mechanism in that an increase in the body temperature increases the temperature gradient between the animal and its environment (Whittow, 1971). It may follow that animals on diet Eight used this route to control the heat stress situation while animals on diet Seven chose to reduce their heat production during periods of high heat

stress and increase it during periods of lower heat stress such as at night. There is however, no support for one group of animals choosing a completely differing means of controlling their heat stress from another group as it is expected that both groups would follow a combination of all methods to reduce their heat stress. A possibility is that the heat increment of feeding calculated for the respective diets is in fact incorrect and the animals on diet Eight did have a higher heat load than the animals on diet Seven. This is also supported by the lack of significantly higher physiological measurements for animals on diet Nine that were found to have a significantly higher heat increment of feeding. With the metabolism trials providing a true reflection of the diets energy densities then the physiological measurements may be a sufficient measure of only a general trend but not accurate enough for comparisons between animals on similar feeding patterns.

The feedlot performance results for animals on diet Nine were indicative of animals under a higher restriction in food intake, primarily in that they had lower energy intakes on a daily basis than those animals on diets Seven and Eight. This resulted in the animals on diet Nine having a lower ADG but an improved feed conversion efficiency compared to animals on diets Seven and Eight. The animals on diet Nine may have reduced their heat stress by limiting heat production and thus lowered their performance and physiological measurements of heat stress. This does not account for why the animals on diet Eight which must also have been experiencing heat stress did not also reduce their performance in order to achieve a similar heat load as measured by their physiological measurements.

The animals in this trial followed distinctive heat stress patterns over time measured, in terms of rectal temperatures (9.00 am and 2.00 pm) and respiration rates. In all three physiological measurements, peaks were recorded in week one and three, a trough in week two and a plateau was followed from the third week onwards. Similarly distinctive patterns were followed in the animals feed intakes over time. Feed intakes peaked in the second week of feeding, before dipping in the third week, then rising again in the fourth week from which a plateau was followed. As in the previous study (Chapter Three) interpretation of these results shows that there is a relationship between the animals feed intakes and their physiological measurements (Table 4.16).

The animals' physiological measurements rose in the first week of feeding due to access to a feedlot diet and the associated increase in heat production. This will stimulate an initial acclimatisation reaction from the animals that results in a dip in their physiological measurements in the second week, which also allows for a further increase in feed intake. Hahn *et al.* (1990) learned that the initial physiological adjustments to improve heat stress will reach completion within eight days of exposure. However, continued exposure to heat stress will result in continual readjustments to allow the animals to equilibrate their heat loss capabilities with their heat production. The dip in feed intake in the third week is as a result of another peak in the heat stress measurements. The animals during the third week are unable to eat more probably due to a peak in their heat loss capacity having been reached. Further acclimatisation allows for the increase in feed intake in week four from which the animals maintain their feed intake at an elevated heat stress position as compared to the start of the feeding period. The animals physiological limit of acclimatisation was therefore possibly reached in the fourth week of feeding from which no further increase in feed intake is possible. The dietary effect on daily intake is that animals on diet Nine with the predicted higher heat increment of feeding had a lower energy intake suggesting a limitation on feeding at a lower level than for animals on diet Seven and Eight.

4.4.7 Conclusions

Despite the average ambient temperature being within the expected TNZ, heat stress seemed to be the first limiting factor with respect to limiting the feed intake of feedlot animals. The diets differences in heat increments of feeding and the corresponding differences in heat stress resulted in differences in animals performance results in the feedlot. Thus, the higher the heat increment of feeding of a diet the poorer the performance (lower ADG, lower energy intake and higher FCR) of the animals on that diet. The performance of animals on diets differing in their heat increments of feeding extends to their proportional use of their energy intakes. Animals on diets with a higher heat increment of feeding deposit fat as a greater proportion of their energy intake, thus the hypothesis put forward at the beginning of this trial is accepted (section 4.1). Animals under heat stress in the feedlot will deposit more fat in an effort to maximise their energy gain due to a limit in protein deposition caused by the associated heat production.

CHAPTER FIVE

LEAST COST FORMULATION OF BEEF FEEDLOT RATIONS WITH DIETARY ENERGY AS A CONSIDERATION

5.1 Introduction

Bond (1967) described the performance of livestock in a hot environment in terms of weight gain and efficiency of feed utilisation. In Chapters Three and Four it has been shown that feedlot cattle experienced heat stress and this is reflected in their performance (length of time in the feedlot, ADG, intake and FCR). The establishment of the influence of heat stress on voluntary food intake and the ability to measure it requires interpretation into production situations. As suggested by Fox *et al.* (1988) research is conducted with cattle to develop information that can be used to predict requirements, performance and profitability in various cattle production situations. Accurate economic projections are dependent on accurate prediction of performance, which in turn is dependent on the ability to describe and account for the variables that influence requirements of cattle.

The standard means of formulating a feedlot ration is through the least cost method. The available ingredient's nutrient makeup, cost and inclusion allowances are entered in a spreadsheet. The nutrient densities of the diet are determined and entered e.g. Table 2.1. Through the use of a computer program (Winfeed (1.11) software (EFG Software 1996)) the least cost formulation is found through a linear solution of the nutrient requirements and the available ingredients. The consensus has been that cattle on concentrate diets eat to satisfy their energy requirements (NRC, 1996). This implies that formulating diets on the basis of least cost per MJ of energy will provide theoretically a diet with the least cost input. The cost factor incorporated into the linear equation is the cost of each ingredient divided by its energy density in MJ.

The establishment that heat stress affects voluntary food intake in feedlot cattle and that the degree of heat stress is related to the diets heat increment of feeding allows for the manipulation of this factor. The heat increment of feeding in a diet is related to the ratio of Effective Energy

(EE) to metabolisable energy in the diet. Maximising the density of EE in a diet will minimise the ratio and the heat increment of feeding and maximise the performance of the feedlot animals. In a commercial environment the cost of the diet must be considered when formulating a diet with a goal of maximizing the EE; in practise a maximum cost must be introduced as a parameter of the linear equation to restrain the formulation to within economic parameters.

A potential problem with formulating a diet on a least cost per MJ of energy is that this only allows for the inputs to be at a minimum and does not account for returns. If there is a potential increase in production with a return greater than the input then this method will be inefficient. Maximising the density of Effective Energy in a diet with a fixed cost is hampered by the determination of the fixed cost. This method will take advantage of improved performances with increases in energy density. In order for this method to be economical a reliable prediction of the animal's likely performance and the return for the animal at slaughter is essential to determine the maximum cost that one is prepared to pay for the diet.

The following trial was designed to investigate whether animals fed a diet with a formulation objective of least cost per MJ of ME_n will be more profitable than a diet formulated for maximum Effective Energy density at a fixed cost. A diet formulated with least cost per MJ of Effective Energy as its objective is expected to have a lower input cost and a lower performance compared to a diet formulated for maximum Effective Energy density. The trial is divided into two parts. The first part compared the feed intake curves and feedlot performances of animals fed diets formulated on a least cost per MJ of Effective Energy, a maximum Effective Energy density and a least cost basis. In the second part of the trial the diets costs and return performances are examined against a control in a "commercial feedlot" (pen feeding) environment.

5.2 Materials and methods

Three feedlot diets were formulated by altering the least cost formulation objective to investigate the production response from weaner steers.

5.2.1 Diet formulation and ingredient composition

A maintenance diet (Table 4.1) was formulated to provide a low energy, high roughage ration to the weaners during adaptation to the calan gates. The diet was fed twice daily at 7.00 am and 4.00 pm and was available *ad libitum*.

Three diets were formulated to meet different dietary formulation objectives. Diet Ten was formulated to a standard least cost formulation, diet Eleven was formulated to achieve the least cost per MJ of ME_n and diet Twelve was formulated to maximise the EE density at a constrained diet price of R440.00 per tonne. The constrained price was set at the upper level at which the commercial industry considered breakeven at the time (June, 1998) the trial began. A commercial feedlots basic formulation was introduced as a control (Thirteen).

Winfeed (1.11) software (EFG Software 1996) was used to formulate these diets and the lower and upper boundaries were set as given in Table 2.1. The nutritive values for the ingredients were obtained from ingredient book values (NRC, 1984; Bredon *et al.*, 1987 and Feedstuffs, 1997), and ingredient prices from the commercial landed prices of the ingredients at the feedlot. The ingredients making up the diets are illustrated in Table 5.1. Ingredients were purchased in batches due to the large amount needed and the limited storage space available. This resulted in a potential for variation in diets costs as ingredient prices fluctuated independently from each other. The rations were mixed when required in a triple auger, flat bed mixer (Henke B240S, Columbus Nebraska) one tonne at a time and bagged into 40 kg bags. This ensured the availability of fresh feed at all times.

Table 5.1 Ingredient composition of the four diets

Ingredient (kg)	Diet[1]			
	Ten	Eleven	Twelve	Thirteen
Broiler chicken litter	210	210	200	240
Hominy chop	250	220	450	558.5
Molasses cane (liquid)	200	230	200	180
Wheat bran	330	310	110	
Feedlime	10	10	10	10.5
Salt	5	5	5	5
Urea		3.5	4.5	5
Vitamin A + mineral premix[2]	2.5	2.5	2.5	1
Romensin	0.15	0.15	0.15	0.15
Tylan 100	0.10	0.10	0.10	0.1
Acid oil			17	
TOTAL	997.75	991.25	999.25	1000.25

[1] = Diet Ten: least cost; Eleven: least cost / MJ ME_n; Twelve: maximum EE density; Thirteen: control

[2] = Vitamin A : 4000000 iu, Vitamin B1 : 3g, Manganese : 10g, Zinc : 10g, Copper : 2g, Cobalt : 0.50g, Magnesium : 100g, Selenium : 0.3g, Iodine : 0.25g.

5.2.2 Animals and feeding management

One hundred and forty predominantly Bonsmara, Hereford and Sussex type, 7-month old weaner steers were purchased from local farmers' auctions and overwintered on pasture foggage (*Pennisetum clandestinum*). At the end of the overwintering period the animals had live weights (measured on an empty stomach, after being starved for 24 hours) ranging from 214 to 265 kg (mean = 235 (s.e. = 1.17) kg).

Before being placed in the feedlot , animals were sorted in descending order of live weight. The one hundred and forty animals were blocked by weight into five groups of twenty eight animals in each. The twenty eight animals within a weight category were then randomly assigned to fourteen groups of ten each (Prof. Clark *pers comm*) ensuring that each group had two animals of each weight category. Six of the groups were assigned to be individually fed (farm 1) but group housed, creating six pens of ten steers in each. The remaining eight groups were assigned to be group fed (farm 2). Each of the remaing groups was further randomly split into two, while ensuring that each of the weight categories was represented in the sub groups. Each sub group containing five animals was then assigned to one of sixteen pens. A 3 (diet) X 2 (feeding type / farm) factorial for the diet formulation technique study and a 4 (diet) factorial for the economics trial.

One month prior to the adaptation period all the animals were inoculated against anthrax, quarter evil, botulism, bovine viral diarrhoea and pasteurella. The facilities were under the control of the state veterinarian who tested the animals for tuberculosis (*Mycobacterium tuberculosis*) and contagious abortion (*Brucella abortus bovis*). At the start of the feedlot period all steers on the feedlot diets received a Revalor -S (200 mg Trenbolone Acetate and 20 mg 17β Oestradiol; Hoechst Roussel Vet) implant in the soft skin on the posterior aspect of the ear. The animals were confined in partially covered pens.

The animals fed individually were adapted to the calan gates over a four week period. If after three weeks an animal exhibited a comparative lack of adaptation to its calan gate it was placed in an individual pen with an open trough for feeding. It was allowed to adapt to this environment for the final week of the four week adaptation period. During this period of adaptation all animals, except the control group on pasture, were fed on a maintenance diet (Table 4.1).

Due to low feed intakes (see section 5.4) and live weight gains (see Appendices 5.2.1 and 5.2.2) the animals were injected with 1 cc of vitamin A (500 000 IU). It was thought that the animals may be deficient in vitamin A for two reasons; firstly the animals had been overwintered on dried forage which is low in vitamin A precursors and secondly cattle exposed to high temperatures (heat stress) are particularly suspectable (NRC, 1996 and McDonald et al., 1990). However, beef

cattle requirements for vitamin A are 2,200 IU / kg dry feed (NRC, 1996) while the feedlot diets contained 4,000 IU / kg *as is*.

5.2.3 Measurements

5.2.3.1 Laboratory nutrient analysis

Snatch samples were taken from five bags of the mixed diets and pooled for laboratory analysis. This was repeated twelve times over the feedlot period. These samples were analysed for crude protein (CP), gross energy (GE), calcium, phosphorous, ether extract (EE_f), dry matter (DM), crude fibre (CF) and ash according to standard procedures (AOAC,1990). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined according to Van Soest *et al.* (1991). The measurements of the diets nutrient composition is located in Appendix 4.1.1.

5.2.3.2 Metabolism study

Twenty-four immature male Hampshire sheep (33 kg) were used in a twenty-five day study. Sheep were randomly allocated to the four dietary treatments. The methods followed were similar to those described in section 3.2.3.2. The breakdown of the metabolism study is located in Appendix 4.1.2.

5.2.3.3 Feed and animals

The feed was offered *ad libitum*. Troughs were scored twice daily to identify the amount of feed being eaten and then topped up accordingly. Thus the animals were fed according to their intakes. The amount fed daily was recorded and totalled for a weekly value (Appendix 4.2.1). If any stale food accumulated its weight was subtracted from the weekly total. Water was freely available.

Live weight of the animals was recorded weekly. The individually-fed animals' live weights were measured on an electronic scale (Schenck Discomat B, Schenck Ash, South Africa) to the nearest kilogram. The group-fed animals' live weights were measured on a balance scale (Berkel, U.S.A.)

to the nearest kilogram (Appendix 4.2.2).

5.2.3.4 Carcass

Carcass data were obtained following the procedures described in section 2.2.3.4. The carcass, fat coverage and length of time in the feedlot data are located in Appendix 4.3.

5.2.4 Data derivation and statistical analysis

5.2.4.1 Diet

The methods for the derivation of a diets metabolisable energy at maintenance (ME_n), Effective Energy density and correction in digestibility are described in section 3.2.4.1.

5.2.4.2 Performance

The feeding period of the animal is the time (days) from the start of feedlotting until its slaughter. The feed intake (kg) of an individually fed animal, is the weight of the feed bin at the beginning of the week plus the weight of feed added during the week minus the weight of the feed bin at the end of the week. The feed intake (kg) of a pen, is the weekly feed intake of a pen divided by the number of animals in the pen during that week.

An animal's weight gain (kg's) is the difference between its weight on entry into the feedlot (Initial weight) and on leaving the feedlot (Final weight). The average daily gain (ADG; kg / day) is the weight gain (kg's) divided by the length of time in the feedlot (days). The dressing percentage is the cold carcass weight (kg) of an animal divided by its final weight (kg). The feed conversion ratio (FCR) is the intake divided by the weight gain.

5.2.4.3 Economics

The potential costs and returns are given in Table 5.2. Only the animals that were group fed (more representative of a commercial feedlot situation) were considered for the economic analysis. The costs of feedlotting an animal include the costs of the animal, the feed it consumes and a daily management charge. There were no differences with respect to the cost of the animals as they were all purchased at the same time and randomly allocated to treatments. The cost of a weaner was calculated by multiplying its live weight at the start of the feeding period by the purchase price. Two feed costs have been calculated: the first being the predicted feed cost at the beginning of the trial and the second being the actual feed cost that accounts for ingredient price fluctuation during the trial period. A pen's food costs was calculated by multiplying a pen's *as is* food intake by the cost per tonne of food.

Any differences in the length of time in the feedlot will be reflected in the interest on the amount payed for the animal and the management cost. This non-compounding interest charge can either be a real bank charge if a loan is acquired or an opportunity cost of investing the money in an alternative scheme. If animals on a diet spend a shorter period of time in the feedlot than animals on another diet then the feedlot can be restocked sooner on the first diet. This potential gain in production by a treatment spending a shorter length of time in the feedlot than another is not accounted for in this study. Returns were calculated by multiplying the carcass weight of an animal by the price it would have received for its respective grade. The return from the fifth quarter (hide and offal) was not included as it is a fixed payment and all animals have this contributor and treatment cannot affect this factor. This also applies to the cost of transporting an animal to the abattoir.

Table 5.2 The potential costs and returns attributable to feedlotting a steer

Variate	Diet[1]			
	Ten	Eleven	Twelve	Thirteen
Costs				
Animals				
Weaners (R / kg)	4.90	4.90	4.90	4.90
Interest (% / annum)	20.0	20.0	20.0	20.0
Feed (R / tonne)				
Predicted	375.00	364.00	441.00	440.00
Actual	376.34	368.24	425.55	399.02
Mixing	30.00	30.00	30.00	30.00
Management (R / day)[2]	0.95	0.95	0.95	0.95
Returns				
Carcass price (R / kg)[3]				
A1	7.847	7.847	7.847	7.847
A2	8.065	8.065	8.065	8.065
A3	8.087	8.087	8.087	8.087
A4	7.996	7.996	7.996	7.996

[1] = Diet Ten: least cost; Eleven: least cost / MJ ME_n; Twelve: maximum EE density; Thirteen: control

[2] = Dr A. Paterson *pers comm*

[3] = Carcass price is according to grade which is determined as described in section 2.2.3.4.

5.2.4.4 Statistical analysis

The GENSTAT V statistical programme (Lawes Agricultural Trust, Rothamstead) was used for all statistical analysis.

5.2.4.4.1 Diet

The diets chemical composition, metabolic variables and corrected digestibilities were analysed following the method described in section 3.2.4.3.1. An example of an analysis can be found in Appendix 1.2.

5.2.4.4.2 Diet formulation technique study

The experimental unit was the animal for live weight, live weight gain and carcass data because feed and water were available at all times and the time in the feedlot varied among animals. Pen / animal was the experimental unit for intake and food efficiency. Nine animals were excluded from the trial; two from diet Ten because they did not attain sufficient fat coverage (see section 2.2.3.4); four from diet Eleven, two due to injury and two due to insufficient fat coverage; and three from diet Twelve, two due to injury and one due to insufficient fat coverage. Due to the unbalanced nature of the treatments and the possible effect the two feeding regimes (farm) can have on performance, the residual maximum likelihood (REML) method was used for analysis. REML provides efficient estimates of treatment effects in unbalanced designs with more than one source of error (Genstat Ver. 5.0, 1993). In the REML analysis a fixed effect is a treatment imposed in an experiment where it is the effect of the specific choices of treatments that are of interest i.e. diet. A random effect is generally used to describe the effects of factors where the values present in the experiment represent a random selection of the values in some larger homogenous population i.e. farm. A covariate (starting weight) was included in the REML analysis when found to have a significant effect ($P < .05$). The following is the full REML model (an example is Appendix 4.4.1) used to determine treatment means, standard errors and statistical differences among treatment means (*CHI squared test*).

$$y_{ijk} = \mu + t_i + \beta\delta_{ij} + \Psi_k + \varepsilon_{ijk}$$

where: y_{ijk} = variate;

μ = overall constant;

t_i = treatment effect (Diet);

β = slope of the linear relationship between the expectation of y and the covariate δ;

δ_{ij} = covariate (starting mass);

Ψ_k = farm site; and

ε_{ijk} = residual error (N.I.D. ~ $(0, \sigma^2)$).

5.2.4.4.3 Economics

The experimental unit was the animal for live weight, live weight gain and carcass data because feed and water were available at all times and the time in the feedlot varied among animals. Pen was the experimental unit for intake and food efficiency. A covariate (starting weight) was included in the ANOVA analysis when found to have a significant effect ($P < .05$). The following is the full ANOVA model (an example is Appendix 4.4.2) used to determine treatment means, standard errors and statistical differences between treatment means (*F probability test*).

$$y_i = \mu + t_i + \beta(\times_i - \bar{x}) + \varepsilon_i$$

where: y_i = variate;

μ = common component;

t_i = treatment effect (Diet);

β = regression coefficient of y on μ;

$\times_i$ = concomitant variate (starting weight); and

ε_i = residual error (N.I.D. ~ $(0, \sigma^2)$).

5.2.4.4.4 Prediction equations

Prediction equations were generated for ADG, cumulative dry matter intake and FCR using multiple linear regression. These models were developed to determine the amount of variation that could be accounted for by the diets nutrient densities. Farm site (dummy variable) and starting weight (covariate) were included as factors if found to be significant ($P < .05$). The following is the full linear regression model (an example is Appendix 4.4.3), with the significance of an included components being determined using the *T probability test*.

$$y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \varepsilon_i$$

where: y_i = response variate;

β_0 = y intercept;

$\beta_{1 \text{ to } 3}$ = regression of y on $X_{1 \text{ to } 3}$;

X_{1i} = energy content;

X_{2i} = starting weight;

X_{3i} = farm site; and

ε_i = residual error (N.I.D. ~ $(0, \sigma^2)$).

5.3 Results

5.3.1 Diet composition

The ingredient composition of the feeds is given in Table 5.1. Diets Twelve and Thirteen were made up of more hominy chop and less wheat bran compared to diets Ten and Eleven. The chemical composition of the feeds is given in Table 5.3. The crude protein content of diet Eleven was above the maximum formulation boundary and the crude fibre contents of diets Twelve and Thirteen were below the minimum formulation boundary (Table 2.1). The CP content differed among diets ($P < 0.001$), with the CP content of diet Eleven being higher than that of the other diets and the CP content of diet Twelve being lower than that of diet Ten. Diets Ten and Eleven had higher ($P < 0.001$) phosphorous levels than diets Twelve and Thirteen. The fat content of diet Twelve was significantly higher ($P < 0.001$) and the crude fibre content significantly lower ($P < 0.01$) than those of diets Ten, Eleven and Thirteen.

Table 5.3 The nutrient content of the four diets on a dry matter basis

Nutrient	Diet[1]				S.E.
	Ten	Eleven	Twelve	Thirteen	
Protein (%)	15.36^{b}	16.40^{a}	14.31^{c}	14.49^{bc}	0.447
Calcium (%)	1.18	1.18	1.16	1.38	0.1338
Phosphorous (%)	0.89^{a}	0.96^{a}	0.76^{b}	0.77^{b}	0.0541
Fat (%)	3.74^{b}	3.56^{b}	5.24^{a}	3.72^{b}	0.2478
Crude fibre (%)	10.24^{a}	10.76^{a}	9.24^{b}	9.96^{a}	0.435
Neutral detergent fibre (%)	31.55	32.91	29.60	31.27	1.806
Acid detergent fibre (%)	13.50^{a}	13.95^{a}	11.94^{b}	13.33^{a}	0.454
Moisture (%)	16.95	17.53	18.00	18.50	1.086
Ash (%)	9.20	9.22	8.81	9.52	0.375

[1] = Diet Ten: least cost; Eleven: least cost / MJ ME_n; Twelve: maximum EE density; Thirteen: control

^{a,b,c} = Values in the same row with different superscripts are different $P < .05$

Results of the metabolism study are given in Table 5.4. Dietary treatments differed in urine CP ($P < 0.01$) which followed the order: diet Ten > diet Eleven > diet Twelve > diet Thirteen.

Table 5.4 Components of the metabolism study investigating the apparent digestibilities of dry matter, organic matter, nitrogen and gross energy for diets Ten, Eleven, Twelve and Thirteen

Variate	Diet[1]				S.E.
	Ten	Eleven	Twelve	Thirteen	
Intake					
Dry matter (g)	3023.02	3001.91	2984.80	2966.60	
Organic matter (g)	2744.90	2725.13	2721.84	2684.18	
Crude protein (g)	464.34	492.31	427.12	429.86	
Gross energy (MJ)	53.23	52.64	53.65	52.10	
Urine crude protein (g)	334.9[a]	325.8[a]	321.1[a]	258.1[b]	21.60
Protein retention (g)	2.3	8.2	-1.6	9.4	4.05
Methane (kJ / g)	1.50	1.59	1.29	1.46	
Apparent digestibility (%)					
Dry matter	73.11	72.28	73.83	74.09	1.674
Organic matter	73.53	72.35	74.90	75.22	1.730
Crude protein	75.24	76.54	72.79	73.66	1.455
Gross energy	71.63	70.57	73.65	73.49	1.803

[1] = Diet Ten: least cost; Eleven: least cost / MJ ME_n; Twelve: maximum EE density; Thirteen: control

[a,b,c] = Values in the same row with different superscripts are different $P < .05$

The dietary energy densities as determined in the metabolism study with sheep are given in Table 5.5. The energy density (ME_n, EE and NE_g) of diet Twelve was significantly higher ($P < 0.001$) than that of diets Ten, Eleven and Thirteen. The energy densities (ME_n, EE and NE_g) of diets Ten and Thirteen were higher ($P < 0.001$) than that of diet Eleven. The ratio of EE to ME_n of the

diets differed significantly ($P < 0.001$) among diets in the order: diet Twelve > diet Thirteen > diet Ten > diet Eleven. The animals on diet Twelve ate a significantly ($P < 0.001$) higher level of energy in terms of multiples of maintenance than did the animals on diets Eleven and Thirteen. The animals on diet Ten ate a significantly ($P < 0.001$) higher level of energy in terms of multiples of maintenance than did the animals on diet Thirteen. The corrected digestibilities of the diets differed significantly ($P < 0.001$) among diets in the order: diet Thirteen > diet Twelve > diet Ten > diet Eleven. The ratio of EE_x to ME_x of diet Twelve was higher ($P < 0.001$) than that of diets Ten and Thirteen while the ratios of EE_x to ME_x of diets' Ten and Thirteen wre higher ($P < 0.001$) than that of diet Eleven.

Table 5.5 The energy density of the diets used in this study as determined by the metabolism study

Nutrient	Diet[1]				S.E.
	Ten	Eleven	Twelve	Thirteen	
Digestable energy (MJ / kg)	12.61	12.38	13.24	12.91	0.320
Metabolisable energy at maintenance (MJ / kg)	10.90^{b}	10.45^{c}	11.64^{a}	10.92^{b}	0.2023
Effective Energy at maintenance (MJ / kg)	9.43^{b}	8.88^{c}	10.36^{a}	9.52^{b}	0.196
Net energy for gain (MJ / kg)	4.05^{b}	3.75^{c}	4.54^{a}	4.07^{b}	0.1355
Effective Energy at maintenance / Metabolisable energy at maintenance	0.8656^{c}	0.8498^{d}	0.8899^{a}	0.8716^{b}	0.00197
% change per unit rise in feed level	0.02606	0.02726	0.02378	0.02396	0.00204
Feeding level (X maintenance)	3.121^{ab}	3.037^{bc}	3.243^{a}	2.911^{c}	0.0676
Corrected Gross energy digestibility (%)	58.52^{c}	58.41^{c}	58.94^{b}	59.68^{a}	0.1719
Digestable energy$_x$ (MJ / kg)	10.30	10.24	10.59	10.48	-
Metabolisable energy$_x$ (MJ / kg)	8.678^{b}	8.404^{b}	9.100^{a}	8.592^{b}	0.1480
Effective Energy$_x$ (MJ / kg)	7.244^{b}	6.900^{c}	7.810^{a}	7.186^{bc}	0.1552
Effective Energy$_x$ / Metabolisable energy$_x$	0.8345^{b}	0.8209^{c}	0.8581^{a}	0.8363^{b}	0.00367

[1] = Diet Ten: least cost; Eleven: least cost / MJ ME_n; Twelve: maximum EE density; Thirteen: control

[a,b,c,d] = Values in the same row with different superscripts are different $P < .05$

$_x$ = the expected energy density

5.3.2 Animal performance on diets differing in their formulation objectives

The feed intake (on a dry matter basis) curves were similar across diets (Figure 5.1). Feed intake increased for the first two weeks, then dipped in the third week. It increased again in the fourth week before dipping in the fifth week. From a further increase in the sixth week feed intake remained constant until the eighth week, from where the feed intake increased further until the

tenth week. Animals on diets Ten and Twelve followed a plateau from this point on whereas, animals on diet Eleven, continued to increase their intakes for the remaining feeding time.

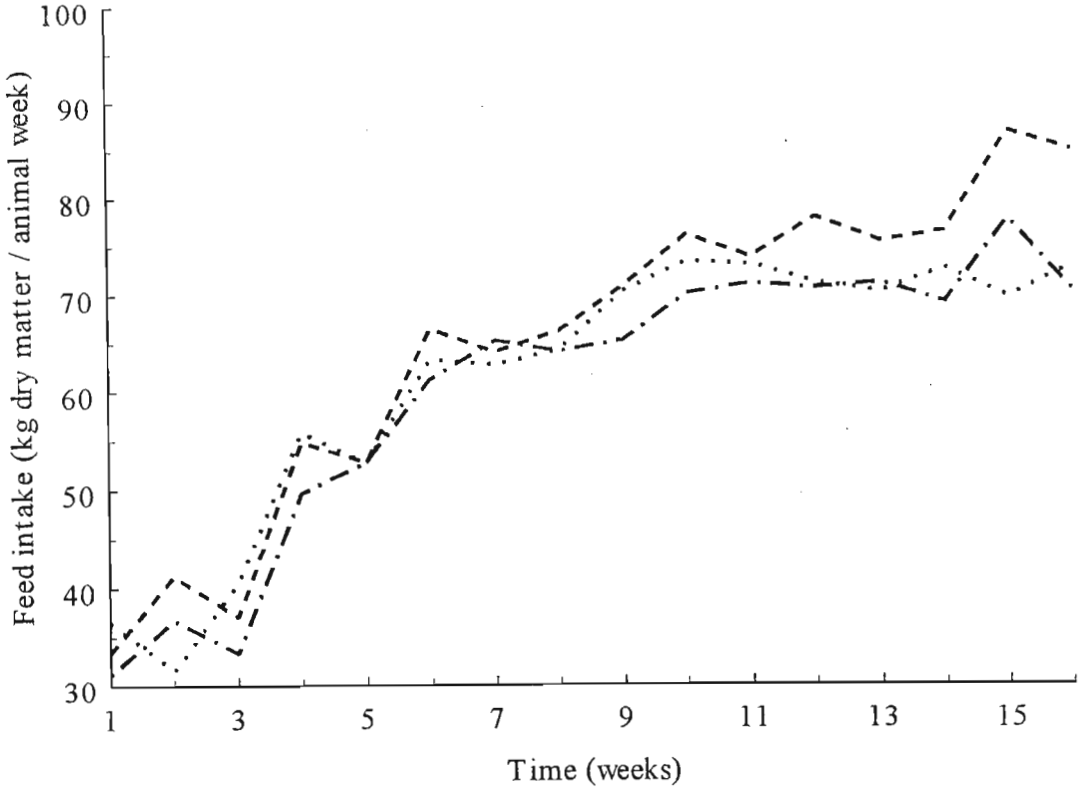

Figure 5.1 Feed intake by feedlot steers (kg dry matter / animal week) fed on diet Ten ·····, diet Eleven ---- and diet Twelve -·-·-.

Feed intake results are given in Table 5.6. The feeding period differed among the diets ($P < 0.05$), in the order: diet Ten > diet Eleven > diet Twelve.

Animals on diet Twelve had a lower ($P < 0.05$) cumulative dry matter intake than animals on diets Ten and Eleven. The EE and NE_g intakes of animals on diet Eleven were lower ($P < 0.01$) than for those of animals on diets Ten and Twelve. No significant differences ($P > 0.05$) were apparent between dietary treatments with respect to cumulative corrected energy intakes.

Results of daily intake are given in Table 5.6. Daily dry matter intakes differed ($P < 0.01$) among treatments in the order: diet Eleven > diet Ten > diet Twelve. The average daily EE intakes of

animals on diet Twelve was higher ($P < 0.05$) than that of animals on diet Eleven, while the average daily NE_g intake of animals on diet Twelve was higher ($P < 0.01$) than that of animals on diets Ten and Eleven. No significant differences were apparent between dietary treatments with respect to the animals daily corrected energy intakes.

The live weight gains results are given in Table 5.7. The covariate starting weight was significant ($P < 0.01$) for final weight. Dietary treatment had a non significant ($P > 0.05$) effect on final weight and weight gain. The ADG of steers on diet Eleven was lower ($P < 0.05$) than that achieved by steers on diet Twelve.

Animals on diet Eleven had a significantly ($P < 0.01$) higher feed conversion ratio than animals on diet Twelve. The feed conversion ratio's based on to energy were non significantly ($P > 0.05$) different across diets.

Carcass and fat coverage results are given in Table 5.8. Dietary treatment did not affect ($P > 0.05$) carcass weights, dressing percentages or fat coverages.

Table 5.6 Feeding period, total intake and daily intake (dry matter, Metabolisable energy at maintenance (ME_n), Effective Energy at maintenance (EE), Net energy for gain (NE_g), effective Metabolisable energy (ME_x) and effective Effective Energy (EE_x)) of feedlot animals

Variate	Diet[1]			S.E.D.	Covariate
	Ten	Eleven	Twelve		
Feeding period (days)	129.1[a]	124.9[ab]	124.1[b]	2.226	
Intake / head					
Dry matter (kg)	1255[a]	1257[a]	1145[b]	36.83	
ME_n (MJ)	13671	13090	13364	408.2	
EE (MJ)	11822[a]	11107[b]	11907[a]	356.2	
NE_g (MJ)	5076[a]	4685[b]	5222[a]	153.9	
ME_x (MJ)	10887	10536	10440	323.2	
EE_x (MJ)	9084	8639	8970	272.0	
Intake / head / day					
Dry matter (kg)	9.749[b]	10.129[a]	9.209[c]	0.1882	
ME_n (MJ)	106.2	105.9	107.0	2.054	
EE (MJ)	91.89[ab]	90.03[b]	95.15[a]	1.780	
NE_g (MJ)	39.46[b]	38.03[b]	41.67[a]	0.7650	
ME_x (MJ)	84.58	85.16	83.68	1.633	
EE_x (MJ)	70.59	69.94	71.77	1.366	

[1] = Diet Ten: least cost; Eleven: least cost / MJ ME_n; Twelve: maximum EE density

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

Table 5.7 Live weight and performance efficiency results for the whole trial period

Variate	Diet[1]			S.E.D.	Covariate
	Ten	Eleven	Twelve		
Final weight (kg)	413.7	403.9	413.7	5.887	***
Weight gain (kg)	176.1	166.1	176.2	5.861	
Average daily gain (kg / day)	1.384[ab]	1.347[b]	1.448[a]	0.04827	
Feed conversion ratio					
kg dry matter / kg gain	7.182[ab]	7.691[a]	6.600[b]	0.3416	
MJ Metabolisable energy at maintenance / kg gain	78.22	80.22	76.90	3.761	
MJ Effective energy at maintenance / kg gain	67.64	68.11	68.48	3.272	
MJ Net energy for gain / kg gain	29.04	28.74	30.02	1.410	
MJ Metabolisable energy$_x$ / kg gain	62.29	64.55	60.10	2.984	
MJ Effective Energy$_x$ / kg gain	51.98	52.95	51.61	2.504	

[1] = Diet Ten: least cost; Eleven: least cost / MJ ME_n; Twelve: maximum EE density

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

$_x$ = the expected energy density

Table 5.8 Carcass weight, dressing percentage and fat coverage results after the feedlot period

Variate	Diet[1]			S.E.D.	Covariate
	Ten	Eleven	Twelve		
Carcass weight (kg)	221.1	216.8	223.5	4.119	
Dressing percentage	53.52	53.54	54.23	0.4828	
Fat coverage[1]					
Overall	+2	-3	-3	0.4229	
Fore-quarter	+2	+2	+2	0.3875	
Loin	+2	-3	-3	0.4384	
Hind-quarter	+2	+2	-3	0.3867	

[1] = Diet Ten: least cost; Eleven: least cost / MJ ME_n; Twelve: maximum EE density

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

5.3.3 Economics

Feed intake results are given in Table 5.9. The feeding period (CV% = 8.2) differed among the diets in the order: diet Ten > diet Eleven > diet Twelve > diet Thirteen. Animals on diets Twelve and Thirteen spent longer ($P < 0.10$) in the feedlot than animals on diet Ten.

Animals on diet Thirteen had a lower ($P < 0.05$) cumulative feed intake (CV% = 8.7) than animals on diets Ten and Eleven and a lower ($P < 0.05$) intake of EE, NE_g and EE_x (CV% = 8.7) than animals on diet Twelve. Steers on diet Twelve had a lower ($P < 0.05$) cumulative feed intake on an *as is* and dry matter basis (CV% = 8.7) than animals on diets Ten and Eleven. Animals on diets Ten and Eleven consumed non- significantly ($P > 0.05$) different amounts of nutrients to each other.

Results of daily intake are given in Table 5.9. Daily *as is* and dry matter intakes (CV% = 8.8) of animals on diets Twelve and Thirteen were lower ($P < 0.05$) than those of animals on diet Eleven. Daily corrected ME intakes (CV% = 8.8) were higher ($P < 0.05$) in animals on diets Eleven and Twelve than in animals on diet Thirteen. No significant differences were apparent between dietary treatments with respect to the animal's daily EE or corrected EE intakes.

The live weight gains results are given in Table 5.10. The covariate starting weight was significant ($P < 0.001$) for final weight. Dietary treatment had a significant ($P < 0.10$) effect on final weight and weight gain. Steers on diet Thirteen were of a lower final weight (CV% = 5.9) and had achieved a lower live weight gain (CV% = 14.6) than steers on diets Ten and Twelve. The ADG (CV% = 15.1) of steers were non-significantly ($P > 0.05$) different with among dietary treatments.

The feed conversion ratio (CV% = 7.3) on an *as is*, dry matter and ME_x and EE_x basis was significantly ($P < 0.01$) higher for animals on diet Eleven compared to animals on diets Twelve and Thirteen. Animals on diet Twelve had a lower ($P < 0.01$) *as is*, dry matter and ME_x feed conversion efficiency than animals on diet Ten.

Carcass and fat coverage results are given in Table 5.11. Dietary treatment did not affect ($P > 0.05$) dressing percentages or fat coverages. The carcass weights of animals on diets Eleven and Thirteen were lighter ($P < 0.05$) than those of animals on diet Twelve.

Table 5.9 Feeding period, total intake and daily intake (dry matter, Metabolisable energy at maintenance (ME_n), Effective Energy at maintenance (EE), Net energy for gain (NE_g), effective Metabolisable energy (ME_x) and effective Effective Energy (EE_x)) of feedlot animals

Variate	Diet[1]				S.E.D.	Covariate	Effect of Diet
	Ten	Eleven	Twelve	Thirteen			
Feeding period (days)	112.7	109.55	106.75	105.7	2.803		$P < 0.1$
Intake / head							
As is (kg)	1388[a]	1441[a]	1202[b]	1144[b]	76.3		**
Dry matter (kg)	1153[a]	1181[a]	986[b]	932[b]	62.5		**
ME_n (MJ)	12568[a]	12418[a]	11472[ab]	10177[b]	691.2		*
EE (MJ)	10873[a]	10552[a]	10221[a]	8872[b]	604.2		*
NE_g (MJ)	4670[a]	4456[a]	4475[a]	3793[b]	260.1		*
ME_x (MJ)	10006[a]	9987[a]	8969[ab]	8008[b]	545.0		**
EE_x (MJ)	8352[a]	8199[a]	7697[a]	6697[b]	458.3		*
Intake / head / day							
As is (kg)	12.34[ab]	13.17[a]	11.26[b]	10.81[b]	0.752		*
Dry matter (kg)	10.25[ab]	10.86[a]	9.23[bc]	8.81[c]	0.619		*
ME_n (MJ)	111.8	113.5	107.4	96.2	6.39		
EE (MJ)	96.7	96.4	95.6	83.8	5.56		
NE_g (MJ)	41.52	40.72	41.90	35.85	2.385		
ME_x (MJ)	89.0[a]	91.3[a]	84.0[ab]	75.7[b]	5.06		*
EE_x (MJ)	74.3	74.9	72.1	63.3	4.24		

[1] = Diet Ten: least cost; Eleven: least cost / MJ ME_n; Twelve: maximum EE density; Thirteen: control

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

Table 5.10 Live weight and performance efficiency results for the whole trial period

Variate	Diet[1]				S.E.D.	Covariate	Effect of Diet
	Ten	Eleven	Twelve	Thirteen			
Final weight (kg)	403.5	396.0	405.5	386.6	7.46	***	$P < 0.1$
Weight gain (kg)	167.7	160.1	169.6	150.6	7.42		
Average daily gain (kg / day)	1.494	1.465	1.593	1.435	0.071		
Feed conversion ratio							
kg as is / kg gain	8.28^{ab}	9.00^{a}	7.08^{c}	7.59^{bc}	0.399		**
kg dry matter / kg gain	6.88^{ab}	7.42^{a}	5.81^{c}	6.19^{bc}	0.326		**
MJ Metabolisable energy at maintenance / kg gain	75.0^{ab}	77.6^{a}	67.6^{b}	67.5^{b}	3.60		*
MJ Effective Energy at maintenance / kg gain	64.9	65.9	60.2	58.9	3.14		
MJ Net energy for gain / kg gain	27.86	27.84	26.37	25.18	1.352		
MJ Metabolisable $energy_x$ / kg gain	59.7^{a}	62.4^{a}	52.9^{b}	53.1^{b}	2.84		*
MJ Effective $Energy_x$ / kg gain	49.84^{ab}	51.23^{a}	45.37^{bc}	44.45^{c}	2.384		*

[1] = Diet Ten: least cost; Eleven: least cost / MJ ME_n; Twelve: maximum EE density; Thirteen: control

^{a,b,c} = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

$_x$ = the expected energy density

Table 5.11 Carcass weight, dressing percentage and fat coverage results after the feedlot period

Variate		Diet[1]				S.E.D.	Covariate	Effect of Diet
		Ten	Eleven	Twelve	Thirteen			
Carcass weight (kg)		219.7[ab]	213.8[b]	225.8[a]	210.9[b]	5.13	***	*
Dressing percentage		54.45	54.01	55.64	54.53	0.681		
Fat coverage[1]								
	Overall	-3	-3	-3	-3	0.663		
	Fore-quarter	-3	-3	-3	+2	0.562		
	Loin	-3	-3	-3	-3	0.691		
	Hind-quarter	-3	+2	-3	+2	0.577		

[1] = Diet Ten: least cost; Eleven: least cost / MJ ME_n; Twelve: maximum EE density; Thirteen: control

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

The breakdown of the costs and returns is given in Table 5.12. The use of the covariate starting live weight on the weaners initial cost results in the weaners starting at the same initial cost per dietary treatment. The interest cost per animal (CV% = 8.2) is significantly ($P < 0.001$) different among diets Twelve, Thirteen and Ten. Animals on diets Twelve and Thirteen had a lower interest cost than animals on diet ten. Predicted feed costs (CV% = 7.8) were not significantly ($P > 0.05$) different among dietary treatments. Animals on diet Thirteen had a lower ($P < 0.001$) actual feed cost (CV% = 7.6) than animals on diets Ten, Eleven and Twelve. The cost of mixing feed was higher ($P < 0.001$) for animals on diet Ten and Eleven than for animals on diets Twelve and Thirteen (CV% = 7.4). The management costs were lower ($P < 0.001$) for animals on diets Twelve and Thirteen than for animals on diet Ten.

The total predicted costs (CV% = 2.5) for animals on diet Thirteen were lower ($P < 0.1$) than the total predicted costs for animals on diets Ten, Eleven and Twelve. Animals on diet Thirteen had significantly lower ($P < 0.001$) total actual costs (CV% = 2.4) than animals on diets Ten, Eleven and Twelve. The total actual costs of animals on diet Twelve were lower ($P < 0.05$) than for animals on diet Eleven. The return for animals on diet Twelve was higher ($P < 0.05$) than the returns for animals on diets Eleven and Thirteen (CV% = 7.5). The balance of predicted costs and returns (CV% = 99.5) shows that animals on diet Twelve tended to have a superior ($P < 0.1$) balance than animals on diets Eleven and Thirteen. The balance of actual costs and returns (CV% = 111.2) for animals on diet Twelve was better ($P < 0.05$) than that for animals on diet Eleven.

The breakdown of the daily costs and returns is given in Table 5.13. No significant differences ($P > 0.05$) between dietary treatments with respect to predicted or actual feed costs per day were found (CV% = 7.5). Animals on diet Twelve had a higher ($P < 0.05$) return per day (CV% = 9.3) than animals on diets Ten and Eleven. The predicted daily balance (CV% = 97.6) of animals on diets Eleven and Thirteen were lower ($P < 0.1$) than that for animals on diet Twelve. The actual daily balance (CV% = 109.4) of animals on diet Eleven was lower ($P < 0.1$) than that for animals on diet Twelve.

Table 5.12 Breakdown of costs, returns and the balance for steers over the whole feedlot period on diets Ten, Eleven, Twelve and Thirteen

Variate		Diet[1]				S.E.D.	Covariate	Effect of Diet
		Ten	Eleven	Twelve	Thirteen			
Costs (R) / head								
Animals								
	Weaners	1156.09	1156.09	1156.09	1156.09	0.000		
	Interest	71.25	69.30	67.64	66.90	1.775	***	$P < 0.1$
Feed								
	Predicted	520.60	524.50	530.10	503.20	12.85		
	Actual	522.50^{a}	530.60^{a}	511.50^{a}	456.30^{b}	12.12		***
	Mixing	41.65^{a}	43.23^{a}	36.06^{b}	34.31^{b}	0.909		***
Management		107.06	104.07	101.41	100.41	2.663		$P < 0.1$
Total Costs (R) / head								
	Predicted	1896.50	1897.20	1891.3	1861.00	15.07	***	$P < 0.1$
	Actual	1898.40^{ab}	1903.30^{a}	1872.70^{b}	1814.10^{c}	14.34	***	***
Return (R) / head		1773.00^{ab}	1724.00^{b}	1821.00^{a}	1701.00^{b}	41.90	***	*
Balance (R)								
	Predicted	-123.00	-173.00	-71.00	-161.00	41.50		$P < 0.1$
	Actual	-124.00^{ab}	-179.00^{a}	-53.00^{b}	-114.00^{ab}	41.40		*

[1] = Diet Ten: least cost; Eleven: least cost / MJ ME_n; Twelve: maximum EE density; Thirteen: control

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

Table 5.13 Breakdown of daily costs, returns, and profit for steers over the whole feedlot period on diets Ten, Eleven, Twelve and Thirteen

Variate		Diet[1]				S.E.D.	Covariate	Effect of Diet
		Ten	Eleven	Twelve	Thirteen			
Costs per day (R) / head								
	Predicted	16.97	17.46	17.78	17.69	0.414	***	
	Actual	16.98	17.52	17.61	17.24	0.412	***	
Returns per day (R) / head		15.83^{b}	15.84^{b}	17.10^{a}	16.19^{ab}	0.476	***	*
Balance per day (R) / head								
	Predicted	-1.14	-1.63	-0.68	-1.49	0.382		$P < 0.1$
	Actual	-1.15^{ab}	-1.68^{a}	-0.51^{b}	-1.06^{ab}	0.381		*

[1] = Diet Ten: least cost; Eleven: least cost / MJ ME_n; Twelve: maximum EE density; Thirteen: control

[a,b,c] = Values in the same row with different superscripts are different $P < 0.05$. Significant differences; * = < 0.05, ** = < 0.01, *** = < 0.001

5.3.4 Predictior equations

Prediction equations for ADG's, cumulative dry matter intake and FCR are given in Table 5.14. A significant ($P < 0.01$) positive relationship was found between ADG and energy density. ADG increases with an increase in energy density and an increase in the ratio of effective energy to metabolisable energy. The different feeding methods had a significant effect on the prediction model with those animals that were group fed having a significantly higher ($P < 0.001$) ADG than those that were fed individually. The amount of variation (R^2) accounted for was low (27.8%), with little differences in the amount of variation accounted for between energy densities.

Energy density was found to have a significant ($P < 0.01$) role in predicting cumulative dry matter intake. Cumulative DMI decreased with an increase in energy density. Feeding type had a significant ($P < 0.001$) part in predicting cumulative DMI with individually-fed animals having a greater intake than group-fed animals. The models accounted for a moderate amount of the variation (R^2) with a range of 39.1 to 39.3 %. An increasing energy density is predicted to decrease FCR significantly ($P < 0.01$) overall however, for individually fed animals compared to group fed animals FCR is predicted to increase with increasing energy density ($P < 0.05$). Despite the significant factors included in the prediction models for FCR very little variation (R^2) was accounted for by the models (17.5 to 17.6%).

Table 5.14 Predictor equations for average daily gains, dry matter intake and feed conversion ratios using energy density (Metabolisable energy at maintenance (ME_n), Effective Energy at maintenance (EE), Net energy for gain (NE_g), effective Metabolisable energy (ME_x) and effective Effective Energy (Eex)) (MJ) and farm site as factors

Variate	Predictor	Constant	Site	R^2 (%)
ADG	$0.1276.NE_g$*	0.743**	0.2494***	27.8
	$0.1451.ME_x$*	0.001	0.2494***	27.8
	$0.1108.EE_x$*	0.458	0.2494***	27.8
	$2.7.EE_x / ME_n$*	-1.00	0.2493***	27.8
Dry matter intake (kg)	$-150.6.NE_g$**	1945***	-216.8***	39.1
	$-170.2.ME_x$**	2811***	-216.8***	39.0
	$-130.8.EE_x$**	2283***	-216.8***	39.1
	$-3209.EE_x / ME_n$**	4015***	-216.8***	39.3
Feed conversion ratio	$-1.361.NE_g$**	13.11***	-0.808*	17.6
(kg dry matter / kg gain)	$-1.551.ME_x$**	21.05***	-0.808*	17.6
	$-1.181.EE_x$**	16.16***	-0.808*	17.6
	$-28.78.EE_x / ME_n$**	31.63***	-0.808*	17.5

5.4 Discussion and conclusions

5.4.1 Diet composition

The corrected energy densities of the diets were as predicted in section 5.1. Formulating for a least cost per MJ of ME (diet Eleven) resulted in a diet with a lower energy density (Table 5.5) and the opposite is true when a diet is formulated to achieve a maximum EE density. Formulating for a least cost diet resulted in an energy density between the other two methods. In terms of

potential production if the animals do eat to attain a specific energy intake then greater amounts of diet Eleven will be eaten on a daily basis compared to diet Twelve. However, the differences in the ratios of EE to ME among diets suggest that animals on diet Eleven will have the highest heat increment of feeding and animals on diet Twelve the lowest. If heat stress is indeed controlling intake then feedlot animals will consume a greater amount of energy available for production per day on diet Twelve and the least amount of energy available for production per day on diet Eleven.

Despite the CP content in diet Eleven being higher than the upper formulation boundary (Table 2.1), no negative effect on the animals performance is expected (Church, 1984; Secrist *et al.*, 1995 and NRC, 1996). The differences in CP and phosphorous contents among diets, should not influence performance as all diets met the animals requirements. Fermentation in the rumen is retarded by high levels of fat (Van Soest, 1994), as the capacity of the rumen micro-organisms to digest lipids is strictly limited. The lipid content of ruminant diets is normally low (i.e. < 50 g/kg) and if it is increased above 100 g/kg the activity of the rumen microbes is reduced, the fermentation of carbohydrates is retarded, and food intake falls (McDonald, 1990). The combination of higher fat and fibre levels in diet Twelve may have resulted in a decrease in fermentation and thus energy yield. However, the fat levels were below the 10% threshold suggested by McDonald *et al.* (1990).

5.4.2 Animal performance on diets differing in their formulation objectives

The feed intake curves followed a similar trend to those reported in Chapters Two, Three and Four, which in turn were similar to those reported by Owens *et al.* (1985), Thornton *et al.* (1985), Dominy (1997) and Hicks *et al.* (1990*a,b*). In this trial, feed intake peaked in the second, fourth, sixth and tenth weeks of feeding, separated by dips in the third and fifth weeks of feeding and a plateau in the ninth to tenth weeks of feeding. The animals on diets Ten and Twelve followed a distinctive plateau for the remaining feeding period and the animals on diet Eleven continued to increase their intakes. The differences in the animals' response after the tenth week of feeding appears to be related to their feeding type. In Appendices 4.2.2.1 and 4.2.2.2 the animals feed intakes over time is given. Individually fed animals appear to increase their intakes after ten

weeks of feeding but the group fed animals follow a more distinctive plateau. The individually fed animals on diet Eleven may have suffered from a lack of adaptation to their calan gates and thus continued to increase their intakes as they became more familiar with them.

This pattern of feed intake is similar to that of spring and fall animals in Figure 1.1.5 (Hicks *et al.*, 1990*a*). As in the trial described in Chapter Three this trial took place in late winter early spring. Comparing the feed intake curves between these two trials (Figures 3.4 and 5.1) shows that differences in feed intake occurred from the start of the feedlot period. The animals in this trial consistently had lower feed intakes over the whole feedlot period and despite having a sustained increase in feed intake over ten compared to six weeks in the second study (Chapter Three) animals still failed to reach the same final feed intake. Despite the lower intake levels the animals in this trial still followed a distinct pattern over time.

Following the conclusions made in Chapters Three and Four that heat stress inhibits feedlot cattles' feed intakes then the steers in this trial experienced peaks in heat stress in weeks two, four, six and ten. From weeks two to ten the animals must have undergone acclimatisation (including the loss of winter coat) and reached an equilibrium between heat loss and heat gain in week ten (see section 3.5.2).

In an attempt to stimulate the animals due to comparatively low feed intakes and low live weight gains (see Appendices 4.2.1 and 4.2.2) over the first three weeks of feeding an injection of Vitamin A was given (see 5.2.2). Animal performance did improve after this injection indicating that the animals were stimulated and thus may have been deficient in vitamin A. Assuming that the animals performances were only truly reflective of their feedlot conditions after the injection then a review of the feed intake pattern is necessary. If one was to readjust the feed intake curve so that week four was week one, then feed intake peaked in the first, third and seventh weeks of feeding, separated by dips in the second and fourth weeks of feeding. The animals followed a distinctive plateau from the seventh week of feeding for the remaining feeding period. This trend in feed intake closely resembles that of the animals in the second trial (Chapter Three). The peaks in weeks three (six) and seven (ten) would coincide with the period when the animals would have been expected to lose their winter coat (see section 3.5.2) and thus allowed for an increase in their

heat loss capability.

The steers in this trial (Table 5.7) took the longest to fatten compared to those in the first, second and third studies (Chapters Two, Three and Four). The difference equates to around twenty seven days between this study and the second (Chapters Three). This length of time is the same period of time in which the animals showed poor performance responses at the beginning of the feedlot period. The extra length of time in the feedlot relates to the lower ADG's and daily feed intakes of the animals. The reduced live-weight gain and marginally higher overall food intake combined to reduce the food conversion efficiencies comparatively.

The performance results were confounded by the initial period of time in the feedlot. Animals on diet Twelve reached slaughter condition in a shorter length of time than animals on diet Ten. The lack of significant differences in ADG and cumulative energy intakes between animals on diets Twelve and Ten suggests that the animals on diet Twelve deposited a greater proportion of their energy intake as fat and thus were to be slaughtered in a shorter period of time than animals on diet Ten. Although not significant the results do show a trend in that the animals on diet Twelve consumed more energy on a daily basis and converted this energy more efficiently than animals on diets Ten and Eleven.

5.4.3 Economics

In the trial concerned with the economics only the animals that were group fed (more representative of a commercial feedlot situation) were considered. A review of their performances is important due to the direct relationship this has on the economics and the differences found previously between individually fed animals and group fed animals (Chapter Three). The steers in this trial (Table 5.6) spent approximately three weeks longer in the feedlot than the steers in the second study (Table 3.8). Only the animals on diet Ten spent a significantly longer period of time in the feedlot when compared to animals on diet Thirteen. The animals on diet Thirteen must therefore have had a higher cumulative energy intake or a higher heat increment of feeding than the animals on diet Ten in order for them to finish in a shorter period of time. The opposite was in fact the case, the animals on diet Thirteen tended to have a lower

cumulative energy intake which was non-significantly different on a daily basis to animals on diet Ten. The higher cumulative *as is* and dry matter intakes of animals on diet Eleven compared to animals on diets Twelve and Thirteen appears to offset a lower energy density as their daily energy intakes are non-significantly different.

The lower final live weights and live weight gains of animals on diet Thirteen are compensated for by their shorter length of time in the feedlot resulting in non-significantly different ADG among diets. Similar final live-weights were achieved by the steers in this trial compared to those in Chapter Three, however, lower live weight gains were achieved at lower ADG. The lighter carcass weights of the animals on diet Thirteen compared to animals on diets Ten, Eleven and Twelve is related to their lower final live weights as the dressing percentages between diets was non significant. The lower feed conversion ratios of animals on diet Twelve and Thirteen compared to those of animals on diets Ten and Eleven show that the animals were able to utilise a greater proportion of their intake for growth purposes. Thus the heat increment of these diets could be lower allowing for greater growth and a lower energy use on heat loss functions.

The interest and management costs are related to the length of time the animals remain in the feedlot. The longer feeding period of animals on diet Ten compared to animals on diets Twelve and Thirteen resulted in higher interest and management costs for the animals on this diet. The lower *as is* feed intakes of the steers on diets Twelve and Thirteen compared to the steers on diets Ten and Eleven are reflected in their mixing and feed costs. The lower mixing costs for diets Twelve and Thirteen are simply because less of the diets were consumed and thus mixed. The differences between the predicted and actual costs were due to the fluctuation in ingredient costs during the feeding period, with the greatest fluctuation occurring for the ingredients (hominy chop) making up diet Thirteen (see Table 5.2). Despite diets Twelve and Thirteen being more expensive than diets Ten and Eleven, the lower intake on these diets lowered their feed costs. The greater difference between the actual and predicted feed costs for diet Thirteen compared to diets Ten, Eleven and Twelve explains the significant difference in feed costs for animals on diet Thirteen compared to animals on diets Ten, Eleven and Twelve at the actual feed cost but not at the predicted feed costs.

On a total cost basis animals' on diet Thirteen were the cheapest on a predicted and actual basis while animals on diet Eleven were the most expensive on an actual basis. There was no benefit from formulating the ration on a least cost per MJ of ME (Eleven) because although the diet was the cheapest a greater amount was eaten over a longer period of time in the feedlot. The feed costs for the animals on the maximum EE formulated diet (Twelve) were not higher on a comparative basis due to the lower amount eaten and the shorter period spent in the feedlot. The returns reflect the predictions in that the animals on the least cost per MJ ME formulation had a lower return than the animals on the maximum EE formulated diet. The returns were higher for animals on diet Twelve due to the animals having heavier carcasses than animals on diets Eleven and Thirteen. The returns and costs of the least cost formulation diet (Ten) fell between the two other formulation technique diets. All diets had a negative balance as the market returns were too low to counter balance the costs. However, animals on diet Twelve had better a balance due too their higher returns compared to animals on the other diets.

No significant differences were found on a cost per day basis as interest and management costs were equal and the animals on a cheaper feed (Ten and Eleven) ate more per day than those on a more expensive diet (Twelve and Thirteen). The higher returns and shorter period of time in the feedlot allowed the animals on diet Twelve to have a higher return per day. The animals on diet Thirteen although having a lower return, this lower return was off set by finishing in a shorter period of time compared to animals on diets Ten and Eleven. The higher daily return allowed animals on diet Twelve to have a better balance on a daily basis than animals on diet Eleven.

5.4.4 Predictor equations

The increase in ADG with an increase in energy density and a decrease in the heat of fermentation indicates that a feedlot animal is unable to increase its energy intake to achieve a similar ADG. The relationship of ADG with the heat increment of feeding suggests that an animals feed intake and hence production is indeed partly controlled by the animals ability to balance its heat production with its heat loss capacity. The increase in cumulative feed intake with a decrease in energy density does however show that the animals do have the ability to overcome a portion of a diets lower energy density by increasing its intake of that diet. However, this does not exclude

the possibility that the animals were only able to increase their cumulative feed intakes by increasing their length of time in the feedlot and not their daily feed intakes. A greater proportional use of energy for non-production purposes and / or fat deposition could explain why the FCR increases with an decrease in energy density. If heat stress is the limiting factor then animals with a higher heat increment of feeding will probably use a greater proportion of their diet in active heat loss functions and the deposition of fat relative to protein.

5.4.5 General discussion

Despite the significant differences in energy densities between diets (diet Twelve > diet Ten > diet Eleven) no differences between the diets' respective feed intake curves were apparent except for individually fed animals on diet Eleven. Animals followed the same initial linear intake before plateauing after a similar length of time in the feedlot.

Daily dry matter intakes were the reverse of the diets' energy densities, those animals on diets with a lower energy density (diet Eleven) had a higher dry matter intake than animals on diets with a higher energy density (diet Twelve). The animals were therefore able to adjust their daily dry matter intakes to result in non significantly different energy intakes (Table 5.6). This suggests that the animal's voluntary food intake is driven by a desire to satisfy their energy requirements. The non significant differences in the animals' daily energy intakes should have resulted in the animals having similar daily production rates. This was correct with respect to the conversion of food or energy to live weight (FCR) which were similar irrespective of diet. However, animals on diet Twelve reached slaughter condition in the shortest period of time at a high ADG. Despite the shorter period of time spent in the feedlot by animals on diet Eleven compared to animals on diet Ten their corresponding low live weight gains resulted in lower ADG for animals on diet Eleven compared to animals on diet Ten. Thus with similar daily energy intakes, the animals' growth performances were in line with the diets' heat increments in that the diets with a higher heat increment of feeding had a lower production.

The feed intakes of the individually fed animals were lower than that achieved by the group fed animals. This is a factor of adjustment to the calan gates as the individually fed animals appeared

to exhibit signs of discomfort with using the calan gates for the first few weeks of the trial period. This coupled with the explanation (section 3.5.2) that the increased daily intake is the stimulation to eat created by a "herd" at the trough resulting in an apparent competition for food (Balch *et al.*, 1962 and Bines, 1976) resulted in a decreased dietary response. Despite this difference between feeding type there was still a distinctive feed intake pattern suggesting that heat stress controlled intake.

Analysis of the performances of the group-fed animals shows that these animals differed in their overall and daily dry matter intakes (diet Twelve < diet Eleven) but did not differ in their energy intakes. A high energy diet resulted in a heavy carcass and the gain in live weight was achieved more efficiently. Animals consuming a diet with a high heat increment of feeding (diet Eleven) probably utilised more of their energy intake on non-production functions and for the deposition of fat. Animals reaching set fat levels at differing carcass weights shows a different deposition pattern between diets with respect to fat. To reach the target fat content at lower live weights the animals probably deposited a greater proportion of their energy intakes as fat.

A comparison of energy densities and costs among diets' show that the differences in the costs among diets were greater than the differences in the energy densities among diets. If the animals were indeed eating to satisfy their energy requirements by increasing their daily energy intake then their financial performance on a lower costing diet would be better than on a more expensive diet. If however the animals were unable to increase their daily intake then their financial performance would be lower because a greater proportion of their total energy intakes would be spent on maintenance. Although the animals on diet Eleven did increase their feed intake, their performance on a similar energy intake was poor. This resulted in the animals having similar input costs but low returns and thus a low financial balances. The animals on diet Twelve could have a high return with a similar input cost due to low intakes thus improving their overall financial balance.

Comparison of the diet formulated to maximise Effective Energy density with the one formulated to achieve least cost shows an improved return. The diet formulated on a least cost basis appears to fall between the two other diets on a performance and financial basis. This illustrates that there

is a diminishing marginal return with increasing energy density and decreasing heat increment.

5.4.6 Conclusions

It appears that steers in the feedlot can reach similar energy intakes when offered diets differing in their energy density. Their performances on these diets do however differ and must be attributable to the utilisation of the energy by the animals on the respective diets. Animals on diets with a lower energy density and higher heat increment could spend a greater proportion of their energy intakes on non-production functions and fat deposition. This results in the animals reaching slaughter weights at lower live weights and over a longer period of time.

The financial implications of this are that the animals on a lower energy diet have similar input costs but low returns. Although a diet where the energy is at least cost lowers the overall cost of the diet the decrease in performance on the diet negates this advantage. The inverse is true for a more expensive high energy diet where a greater return is achieved with a similar input cost. The response of animals to diets increasing in energy density as measured in terms of production must be diminishing. Further research must concentrate on determining the potential returns by manipulation of a diets heat increments in order to best formulate future feedlot diets.

CHAPTER SIX

GENERAL DISCUSSION

The influence a diet's energy density would have on a feedlot steer's feed intake curve was examined in four studies (Chapters Two, Three, Four, and Five). Steers in all four trials followed a linear intake pattern for the initial feedlot period, then reached a peak from which a plateau was followed for the remaining feeding period. In Chapter Two the calculated energy densities of the diets ranged from 11.16 to 11.83 MJ ME or 8.77 to 9.53 MJ EE. In Chapters Three, Four and Five the energy densities were obtained from metabolism trials and ranged from 9.72 to 11.64 MJ ME or 8.08 to 10.36 MJ EE. The steers in the first and third trials (Chapters Two and Four) reached their peak feed intakes in their fourth week of feeding and in the second and fourth trials (Chapters Three and Five) in their sixth and seventh week of feeding respectively. A dip in feed intake was also apparent in all trials in the week following a peak in feed intake. Despite the wide range of energy densities of diets offered to the steers in the four trials there was no difference in feed intake pattern that could be associated with energy density differences.

The association of heat stress and an animal's feed intake was examined in the second and third trials. From the literature reviewed (sections 1.3.4 and 1.5.1.4.1) the relevant measurements to determine whether an animal was suffering from heat stress are rectal temperature (T_R 9.00 am and 2.00 pm) which is a measure of homeothermy, and respiration rate (9.00 am) which is a measure of cognizant heat loss. Animals on diets that could elicit varying heat increments of feeding were compared against a control group maintained on pasture. In both trials the respiration rates and T_R 9.00 am were higher in the animals on the feedlot diets than those on pasture. From these measurements it can be deduced that the animals in the feedlot had a higher heat load than the control animals. Whether the animals were suffering from heat stress can be assessed by comparing their measurements with the accepted norm. A normal body temperature range is 37.8 to 39°C (Manuel, 1954; Bianca, 1963; Smith, 1970 and Garner *et al.*, 1985), and a normal respiration rate range is 18 to 23 breaths per minute (Manuel, 1954; Robinson *et al.*, 1986 and Ole Miaron *et al.*, 1992). The T_R 9.00 am of the control animals was within the accepted range of a non heat stressed animal, but their respiration rates were slightly above the

normal range. The T_R at 9.00 am and 2.00 pm and respiration rates of the feedlot animals were above the accepted normal range indicating that the animals were heat stressed. The difference in respiration rates of the control animals and the feedlot animals was significant. The increase in rectal temperature between the 9.00 am and 2.00 pm indicates that ambient temperature does play a role in increasing an animals heat load (see section 1.4.1.2). Based on their physiological measurements feedlot animals do experience heat stress in a feedlot environment. The examination of the fluctuation of an animals physiological measurements with that of the environment and the animals eating habits over a 24 hour period will give a clearer picture of an animal's daily adjustment and acclimatisation.

The physiological measurements were plotted over time to examine whether there were any similarities between the physiological response from the animals and their fluctuating voluntary feed intake. The respiration rates and T_R of the steers in the second and third studies peaked and dipped during the same weeks that their feed intakes peaked and dipped. This close association supports the hypothesis that there is a relationship between an animal's ability to maintain homeothermy and its heat gain from its heat increment of feeding.

Differences in feed intake during the linear phase were found to be proportional to the starting weight. For example differences in feed intake were apparent between the late maturing and early maturing animals in the second study, and between the yearling steers in the third study and the weaners in the first, second and fourth study. The differences in the intakes between the late and early maturing animals was constant throughout the feeding period. Differences in the intakes between the yearlings and weaners decreased over time until a point in time that peak feed intake was reached, any differences remained constant from this point on. Lower physiological measurements for the late maturing animals indicated that they were suffering from heat stress but at a lower degree (T_R 2.00 pm and respiration rates) than the early maturing animals. If both types of animals were experiencing heat stress which was limiting voluntary feed intake then what differences between the types of animals allowed the late maturing animals to have a higher feed intake?

There is a direct relationship between the live weight of an animal and the size of its abdominal

volume. Abdominal volume affects intake by providing the space into which the rumen can expand during eating. As the late maturing animals and the yearlings are heavier than the early maturing animals and weaners it is expected that they will have correspondingly larger rumen volumes. An increase in rumen volume allows for an increased feed intake if rumen volume itself is the first limiting factor affecting feed intake. In section 1.2.1.3 the relevancy of abdominal volume as a physical restriction to feed intake was discussed and was found to be relevant on roughage diets only. If abdominal volume limited feed intake then feed intake should increase in relation to the growth and rate of growth of an animal and associated abdominal volume growth. Weaners are at a lower degree of maturity than yearlings and therefore are expected to grow at a faster rate. Therefore the abdominal volume of a weaner should increase at a faster rate than that of a yearling and differences in their feed intake should decrease. This did occur during the initial feeding period when comparing the feed intakes of the second trial with the first, third and fourth. After the peak in feed intake was achieved the differences between the yearlings and weaners remained constant despite their continued growth and consequent increase in abdominal volume. The comparison of late maturing animals with early maturing animals reveals that despite the lower degree of maturity of the late maturing animals versus the early maturing animals differences in their feed intakes remained constant throughout the feeding period. The late maturing animals did not increase their feed intakes at a faster rate than the early maturing animals despite their higher growth rates and presumed increase in abdominal volume. Differences in feed intake must therefore not only be related to an animals starting weight but also to the season that their feeding period started.

Differences between early and late maturing animals, and weaners and yearlings also exist with respect to their surface areas. An increase in surface area aids the loss of heat by conduction, convection, radiation, and evaporation (see sections 1.5.1.1, 1.5.1.2, 1.5.1.3 and 1.5.1.4). With increasing body size an animal's surface area increases two-dimensionally and its mass three-dimensionally (Bianca, 1970). Thus, the surface area of a late maturing animal of equal age and heavier live weight is greater than that of an early maturing animal. The late maturing animals were 11.2 per cent heavier than the early maturing animals at the start of the feeding period and 14.1 per cent heavier at the end. Although the late maturing animals were fed for a longer period of time, their difference in feed intake was only 8.8 per cent. Thus, if the surface area of an animal

and its relation to the ability of the animal to lose heat is justified then the differences in intake between the late and early maturing animals being lower than their differences in live weight would be appropriate. However, differences due to breed type (e.g. coat thickness and sweat gland density) do play a large role in evaporative heat loss and further research must examine this interaction.

The plot of physiological measurements over time showed that the animals must have been experiencing heat stress at every peak in their measurements. These peaks are followed by a period of lower physiological measurements and correspondingly lower feed intakes. Figure 1.6.1 represents an animal's response to changing climatic conditions, whereby the acute response could be likened to the peaks in physiological measurements in these trials. A subsequent decrease in the measurements would therefore correspond with a chronic response or adaptation period (see section 1.6). The feedlot animals must be acclimatising to cope with this added heat load. The dip in feed intake after 28 days in the feedlot attributed by Hicks *et al.* (1990*b*) to the cattle's adaptation to their finishing diet is also associated with the period directly after peak feed intake is achieved. This dip in intake has also been recorded in these trials and those of Dominy (1997) where there was no use of sequential feeding. This dip in intake is the final adjustment of the animals to their heat stress situation whereby they have reached complete acclimatisation and they can no longer increase their intake due to heat gain being greater than heat loss.

An explanation for the differences in the time length of the linear phase of the feed intake curve was obtained from observing the animals acclimatisation. The main physiological change during acclimatization to heat is the loss of hair (coat shedding) and a decrease in external insulation. The animals in the second study started losing their winter coats in the third week of feeding and completed its loss in the sixth week of feeding. Steers in the second and fourth studies started in the feedlots during late winter early spring and had a full winter coat. Steers in first and third studies started in the feedlots during early summer and mid-summer respectively and had already lost their winter coats. The ability of animals in spring, fall and especially winter to increase their intakes after a dip at 28 days (Hicks *et al.*, 1990*b*) may be an example of these animals extending the linear phase of intake due to greater acclimatisation from the ability to lose their winter coats. The ability to lose their winter coats and thus acclimatise over a longer period of time allowed the

steers in the second and fourth trials to increase the length of the linear period and have a greater increase in their intakes over the linear period. Hicks *et al.* (1990*b*) made reference to this as well when describing the intake of light animals as increasing for a longer period of time but failing to reach the levels achieved by heavier animals. Future research should examine this relationship between acclimatisation and feed intake. A trial could be designed to run throughout the year measuring the physiological aspects of animals introduced to the feedlot on a monthly basis with those of animals on a pasture control. This will provide a better picture of the theory that the difference in feed intake between the yearlings and weaners is a function of size, heat loss capability, the season, and the degree of acclimatisation to hot environmental conditions at the start of the trials.

The deposition of a gram of protein compared to a gram of lipid creates an extra 15.43 kJ of heat and deposits 6 kJ of Effective Energy less (Emmans, 1994). Whether heat stressed animals are forced to deposit absorbed energy as lipid due to the prevention of protein deposition and the associated heat production was examined in the third study (Chapter Four). From the physical and chemical analysis of the prime rib cut and extrapolation to the empty body there was no significant differences in the empty body protein or chemical fat composition among the dietary treatments. The animals had gained non-significantly different amounts of protein and chemical fat at similar daily rates. The animals did eat differing amounts of energy and comparison of this to the amounts used for maintenance and growth found that the animals on the diet with the highest heat load (diet Nine) used proportionally more of their energy intake for maintenance and lipid deposition. The extra energy used for maintenance can be explained as the animals spent longer in the feedlot. The proportional greater energy for lipid deposition could be due to the animals protein deposition being inhibited in an attempt to reduce further heat gain and maintain energy intake. However, differences between dietary treatments were only recorded at the ($P < 0.1$) probability level. The use of light and younger animals (e.g. weaners) may accentuate the response found in this trial as the animals will experience heat stress for a longer feeding period and will have a greater increase in live weight.

In the formulation of the diets different levels of ingredients were used which may have resulted in differing levels of fermentation products. For example the more roughage or the more

digestible the roughage is in a diet then the higher the production of acetic acid. The higher levels of liquid cane molasses, wheat bran and lucerne hay in diet Nine compared to diets Seven and Eight may have resulted in more acetic acid being produced on the fermentation of diet Nine. In the production of milk the level of acetic acid in a diet and the consequent decrease in propionic acid increases the levels of fat in the milk. However, over the range volatile fatty acids (VFA) normally found in the rumen (i.e. between 45 to 75 mol / 100 mol acetic acid and 15 to 45 mol / 100 mol propionic acid) no differences were observed in the level of free fatty acids in the blood (Órskov *et al.* 1991). It was also confirmed by Órskov (*pers comm*) that over the normal range of VFA's no differences will be observed in the composition of tissue growth in a steer. This is supported by the efficiency of utilisation for fattening of the respective VFA's. In concentrate diets there is little difference in the efficiency of utilisation for fattening of the three VFA: acetic acid 0.60, propionic acid 0.56 and butyric acid 0.62 (McDonald *et al.* 1990). Therefore despite the potential differences between the diets with respect to their fermentation products this will have no effect on the composition of growth in the animal and any performance differences that may arise between diets is due to factors other than variation in the products of fermentation.

In the second and fourth studies (Chapters Three and Five) the differences in the animals ADG are greater than the differences in length of time in the feedlot for diets differing in heat increments of feeding. For example in Chapter Three animals on diet Four grew at a rate of 1.985 kg / day and were feedlot for 90.1 days where as animals on diet Six grew at a rate of 1.741 kg / day and were fedlot for 97.0 days. All the animals were slaughtered at similar fat levels. Thus, if an animal has a low rate of growth then it must spend a comparatively longer period of time in the feedlot in order to achieve the desired fat level. The greater difference between animals on diets Four and Six with respect to ADG rather than length of feeding reveals that the animals were able to reach the desired fat level by preferentially depositing lipid.

From the metabolism trials it is obvious that it is possible to have diets that do not differ in their metabolisable energy density but differ in their Effective Energy density. Or as illustrated in the third study there can be no significant differences in energy densities but the ratio of Effective Energy to Metabolisable Energy (EE to ME) can differ significantly. From the physiological measurements, empty body compositional growth and animal performance differences between

treatments are related to the ratios of EE to ME and not to energy densities alone. The effect of formulating a diet to achieve a high ratio of EE to ME also has the result of yielding a diet with a high EE density. The economic result is that the higher the EE density of a diet the better the performance (ADG, feeding period and feed conversion efficiency) of the animals but the more expensive the diet becomes.

Despite the complex interrelationships between energy, feed intake and performance it was proposed in Chapter Five that a diet formulated to provide energy at lowest cost (R / MJ) will result in a cheaper diet but with a lower performance than one formulated to maximise energy density. Animals consuming a diet low in energy eat more over time to compensate for the low energy density but they also have a lower performance and return. The manipulation of a diet's energy density resulted in limited differences in input costs but significant differences in returns.

CONCLUSIONS

The energy density of a diet does not influence the feed intake pattern of steers in a feedlot environment. The feed intake pattern can alter according to differences in the heat load on animals resulting from differences in their diets heat increments of feeding.

Animals in a feedlot environment suffer from heat stress as a result of the heat gains from solar radiation and digestion and absorption of nutrients. The degree of heat stress is related to the heat increment of feeding, the higher the heat increment of feeding the higher the animals rectal temperatures and respiration rates.

The pattern of feedlot animals physiological measurements over time is similar to that of their feed intake patterns. Peaks and dips in their rectal temperature and respiration rate measurements are associated with peaks and dips in their feed intakes. The peaks in the physiological measurements are points of acute response whereby acclimatisation is initiated to reduce the effect of the stress on the animal.

Differences in animals' feed intakes within the first week of feeding are related to their ability to

lose heat. Heavier animals with their larger surface area are able to lose more heat and thus have an associated higher feed intake. Late maturing animals are usually heavier than early maturing animals at an equal age which allows them to have a correspondingly higher feed intake and production. This is also the explanation for the difference in feed intakes between late yearlings and weaners.

The length of the linearly increasing phase of feed intake is dependent on the amount of acclimatisation an animal can invoke. Weaners feedlotted in early spring are able to lose their winter coat whereas late yearlings feedlotted in mid-summer have already lost theirs. Thus, a weaners increasing intake phase is longer (42 days) and daily intake increases by a greater amount than late yearlings who increase their daily intake for only 28 days. The extra peak and dip in the intake pattern of weaners is the points of the start and finish of their loss of their winter coat.

In an attempt to reduce the heat load and maintain production, steers are forced to deposit lipid. As a proportion of their energy intake, animals with a greater heat stress deposit a greater amount of lipid on a daily basis. The increased deposition of lipid shortens the animals feedlot period, reduces its ADG and increases its feed conversion ratio.

From a commercial perspective the findings of this research can be used to manipulate the performances of steers in a feedlot. Diets can be formulated to maximise their return by taking into consideration the heat increment of feeding. Diets with a low heat increment of feeding have similar input costs but higher returns compared to a diet with a high heat increment of feeding. In a situation where the length of time in the feedlot is important, increasing the heat increment of feeding of the diet can possibly increase lipid deposition and shorten the feeding period. Greater emphasis must be placed on the diminishing marginal returns curve to allow for more accurate predictions with respect to production, costs and potential returns. The constraints imposed on production by heat stress will have a greater effect on animals that require to be fed the longest and grow the most, however, this group of animals can also be manipulated the most.

Further research needs to be done to examine the following areas of interest. Physiological measurements should be taken over a 24 hour period in order to map the animals daily fluctuation. These measurements can be correlated with feeding pattern records to determine whether steers

manipulate their feeding times according to overall heat load to maintain a more constant core body temperature. Examination of the differences in the intakes between animals of differing live weights must eliminate the possibility that it is not a function of rumen capacity that causes these differences. The deposition of energy as lipid and the inhibition of protein deposition in animals on a high heat stress must be closely examined to eliminate the potential that other factors such as dietary ingredients did not influence the results. Examination of the effect of acclimatisation through hair loss should incorporate breed differences as well as the possibility of clipping the hair of test animals to determine any differences in their feedlot performances.

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Appendix 1.1.1 Nutrient composition of diets One, Two and Three on a dry matter basis

Diet	Rep.	CP %	Ca %	P %	FAT %	ASH %	C.FIBRE %	NDF %	ADF %	MOISTURE %	DE (MJ/kg)	ME (MJ/kg)	EE (MJ/kg)	NEg (MJ/kg)
1	1	14.39	1.21	0.64	8.01	10.79	11.29	32.51	14.72	16.68	14.00	12.31	10.16	4.97
1	2	14.05	1.23	0.61	7.46	10.73	11.00	35.36	15.27	16.44	13.94	12.25	10.09	4.94
1	3	13.69	1.30	0.56	7.24	10.75	11.15	30.96	14.70	16.87	13.86	12.17	10.00	4.88
1	4	14.03	1.33	0.62	6.34	10.63	12.26	32.68	14.60	16.09	13.53	11.86	9.60	4.69
1	5	13.61	1.36	0.60	4.73	10.72	12.28	33.02	15.52	16.73	13.19	11.54	9.17	4.47
1	6	14.50	1.39	0.64	4.70	10.30	11.56	32.72	14.86	16.00	13.40	11.74	9.37	4.61
1	7	14.60	1.31	0.65	4.94	10.32	12.42	33.38	13.82	15.75	13.31	11.65	9.28	4.55
1	8	14.69	1.48	0.66	4.07	11.29	13.06	31.26	14.62	17.83	12.88	11.24	8.77	4.28
1	9	13.30	1.30	0.63	4.92	10.13	11.79	31.58	14.53	17.59	13.40	11.73	9.41	4.60
1	10	14.55	1.37	0.64	5.30	10.47	11.80	30.00	14.33	17.98	13.45	11.79	9.45	4.64
2	1	12.90	1.24	0.51	4.40	9.50	16.45	41.73	21.80	14.03	12.62	10.99	8.53	4.11
2	2	13.65	1.30	0.54	4.30	9.49	14.86	45.80	20.03	13.19	12.89	11.25	8.80	4.28
2	3	13.24	1.35	0.45	5.97	9.60	16.00	36.78	20.58	14.05	12.99	11.34	8.99	4.35
2	4	14.11	1.25	0.51	6.44	8.96	15.54	33.76	19.80	12.73	13.29	11.63	9.31	4.54
2	5	14.03	1.09	0.50	5.89	9.23	15.24	38.46	21.05	14.50	13.19	11.53	9.17	4.47
2	6	14.85	1.12	0.51	6.13	9.14	15.80	35.08	19.60	12.56	13.19	11.53	9.15	4.47
2	7	15.04	1.22	0.56	5.14	9.26	15.61	42.64	19.82	13.99	13.01	11.36	8.92	4.36
2	8	14.31	1.13	0.52	3.92	9.15	19.33	39.86	21.83	14.15	12.16	10.55	7.96	3.81
2	9	13.75	1.25	0.54	5.28	9.52	16.89	36.86	20.66	17.59	12.74	11.11	8.67	4.19
2	10	13.80	1.11	0.53	5.34	8.96	16.78	39.02	22.05	15.02	12.87	11.22	8.81	4.27
3	1	13.17	1.14	0.41	6.39	8.25	17.35	43.16	24.89	10.56	13.07	11.42	9.07	4.40
3	2	13.36	1.14	0.41	6.00	8.33	17.12	40.91	24.06	10.37	13.03	11.38	9.00	4.37
3	3	12.85	1.01	0.37	5.82	7.39	18.10	42.71	24.05	11.43	12.97	11.32	8.95	4.33
3	4	12.24	0.85	0.38	6.71	8.07	21.36	65.88	28.24	10.82	12.47	10.84	8.46	4.02
3	5	12.65	0.90	0.39	6.20	7.59	19.85	43.86	26.13	11.39	12.72	11.08	8.69	4.17
3	6	14.22	1.03	0.43	6.70	7.98	19.33	43.84	24.54	10.71	12.89	11.24	8.84	4.28
3	7	13.25	1.01	0.38	6.88	7.45	21.25	47.24	27.51	14.40	12.66	11.02	8.64	4.14
3	8	12.43	1.06	0.36	6.61	8.01	20.15	45.20	26.46	10.80	12.67	11.03	8.66	4.14
3	9	13.79	1.01	0.50	5.81	8.31	17.97	45.54	25.93	11.96	12.87	11.22	8.81	4.27
3	10	13.73	0.91	0.45	6.10	7.79	19.94	44.54	26.05	12.88	12.69	11.05	8.62	4.15

Appendix 1.1.2 An animal's dry matter feed-intake (kg's) per pen over time (weeks)

		Week												
Diet	Pen	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	40.00	60.00	66.67	73.33	66.67	66.67	73.33	80.00	73.33	73.33	86.67	80.00	86.67
1	2	46.67	66.67	73.33	86.67	66.67	73.33	80.00	80.00	73.33	80.00	73.33	73.33	93.33
1	3	46.67	66.67	86.67	86.67	73.33	73.33	86.67	80.00	93.33	86.67	93.33	86.67	106.67
2	1	46.67	66.67	80.00	93.33	80.00	86.67	86.67	86.67	80.00	80.00	80.00	86.67	86.67
2	2	46.67	73.33	73.33	106.67	86.67	93.33	93.33	106.67	93.33	86.67	93.33	73.33	
2	3	46.67	80.00	100.00	106.67	106.67	93.33	106.67	100.00	86.67	93.33	93.33	80.00	
3	1	40.00	60.00	80.00	100.00	66.67	80.00	80.00	93.33	86.67	86.67	86.67	80.00	106.67
3	2	33.33	60.00	80.00	93.33	93.33	86.67	86.67	93.33	93.33	86.67	93.33	86.67	106.67
3	3	40.00	66.67	80.00	100.00	93.33	86.67	93.33	106.67	93.33	86.67	93.33	73.33	

Appendix 1.1.3 Individual animals live weights (kg's) over time (weeks)

			Week													
Diet	**Pen**	**ID**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	1	3	214	212	228	262	*	282	288	298	302	316	336	*	356	364
1	1	17	208	210	244	264	*	292	304	316	330	342	354	*	390	388
1	1	83	192	184	182	194	*	234	226	234	240	252	266	*	288	294
1	2	5	226	242	250	256	*	302	304	326	320	344	362	*	386	392
1	2	8	218	226	252	264	*	292	300	310	324	346	346	*	340	354
1	2	95	212	228	256	264	*	306	322	340	352	368	384	*	410	428
1	3	10	232	254	266	294	*	326	338	352	364	370	384	*	400	414
1	3	13	240	252	308	312	*	344	336	362	380	380	394	*	380	420
1	3	41	240	240	241	290	*	312	332	340	358	366	382	*	390	432
2	1	19	208	218	250	262	*	304	300	330	342	358	376	*	398	400
2	1	55	208	220	234	240	*	272	280	288	302	300	320	*	334	342
2	1	94	202	216	242	248	*	292	308	324	338	332	332	*	348	358
2	2	24	208	228	230	250	*	296	308	328	350	350	364	*	394	*
2	2	51	256	246	262	268	*	310	326	340	352	364	378	*	408	*
2	2	59	222	244	264	270	*	316	330	348	356	364	372	*	414	*
2	3	31	234	250	272	294	*	328	336	352	370	380	396	*	412	*
2	3	40	234	262	280	304	*	348	360	382	398	408	422	*	454	*
2	3	87	248	256	264	280	*	320	338	364	382	394	408	*	440	*
3	1	20	196	216	226	250	*	272	288	300	312	318	342	*	354	360
3	1	42	204	208	212	242	*	274	284	296	312	330	348	*	360	370
3	1	78	202	208	226	246	*	272	288	304	316	328	344	*	370	376
3	2	4	226	236	256	264	*	310	306	330	336	350	356	*	382	394
3	2	15	224	234	262	282	*	316	330	350	346	356	376	*	408	412
3	2	21	216	226	238	246	*	292	290	310	320	326	358	*	392	384
3	3	2	226	244	264	272	*	308	326	342	354	362	372	*	400	*
3	3	6	252	264	288	298	*	348	364	382	386	406	412	*	452	*
3	3	80	222	234	244	250	*	296	300	320	336	348	358	*	384	*

Appendix 1.1.4 Length of time in the feedlot (days) and carcass data for individual animals

Diet	Pen	ID	Days	Carcass weight (kg)	Fat score Overall	Hind quarter	Loin	Fore-quarter	Dressing Percentage
1	1	3	91	182	2	2-	2	2	50.00
1	1	17	91	208	3	3+	3	3+	53.61
1	1	83	91	149	1	2-	1+	1	50.68
1	2	5	91	199	2	2-	2-	2-	50.77
1	2	8	91	184	2	2	2	2-	51.98
1	2	95	91	231	2	2	2+	3-	53.97
1	3	10	91	221	3	2+	3	3-	53.38
1	3	13	91	229	3	3+	3	3	54.52
1	3	41	91	219	2	2	2	2	50.69
2	1	19	91	217	5	5+	5+	5+	54.25
2	1	55	91	185	2	2	2	2	54.09
2	1	94	91	198	2	2+	2-	2+	55.31
2	2	24	82	203	2	2-	2-	2+	51.52
2	2	51	82	215	2	2	2+	2	52.70
2	2	59	82	202	2	2	2	2+	48.79
2	3	31	82	230	2	2	2	2	55.83
2	3	40	82	237	2	2	2+	2	52.20
2	3	87	82	227	2	2	2-	2	51.59
3	1	20	91	190	3	2+	3	3-	52.78
3	1	42	91	206	2	2-	2-	2-	55.68
3	1	78	91	203	2	2	2+	2+	53.99
3	2	4	91	212	2	2	2	2	53.81
3	2	15	91	220	4	3+	4	4	53.40
3	2	21	91	208	3	3-	3	3	54.17
3	3	2	82	205	3	2+	3	3-	51.25
3	3	6	82	239	3	2	3	3	52.88
3	3	80	82	211	2	2+	2-	2	54.95

Appendix 1.2 Example model of the statistical analysis of the dry matter nutrient composition of diets One, Two and Three

```
  20  For I= PROTEIN,CALCIUM,PHOS,FAT,ASH,CF,NDF,ADF,MOIST,ME,EE,EE_ME,NEg,DE
  21
  22  for J=Treat,Q2,Q3
  23  model I
  24  terms J
  25  add [nomes=1,r;tprob=yes] J
  26  endfor
  27  endfor

27.....
.....


***** Regression Analysis *****

 Response variate: PROTEIN
     Fitted terms: Constant, Treat


*** Summary of analysis ***

             d.f.         s.s.         m.s.      v.r.
Regression      2        5.377       2.6885      7.54
Residual       27        9.627       0.3566
Total          29       15.004       0.5174

Change         -2       -5.377       2.6885      7.54

Percentage variance accounted for 31.1
Standard error of observations is estimated to be 0.597


*** Estimates of regression coefficients ***

                estimate         s.e.     t(27)  t pr.
Constant          14.141        0.189     74.89  <.001
Treat 2           -0.173        0.267     -0.65  0.523
Treat 3           -0.972        0.267     -3.64  0.001
```

Appendix 1.3.1 Example model of the determination of the intake (kg's) over time (weeks) curve

```
 21  model FI
 22  terms time*ID
 23
 24  fitcurve[curve=lexponential;fprob=yes;sense=right] time
 25  add [ fprob=yes] ID
 26  add [ fprob=yes] time.ID
 27  add [nonlinear=separate;fprob=yes]

***** Nonlinear regression analysis *****

 Response variate: FI
      Explanatory: time
  Grouping factor: ID, all parameters separate
     Fitted Curve: A + B*R**X + C*X
      Constraints: R < 1

*** Summary of analysis ***

              d.f.         s.s.         m.s.       v.r.  F pr.
Regression      35      16095.       459.86      12.99  <.001
Residual        72       2548.        35.39
Total          107      18643.       174.24

Change           8       -292.       -36.54      -1.03  <.001

Percentage variance accounted for 79.7
Standard error of observations is estimated to be 5.95

*** Estimates of parameters ***
                              estimate         s.e.
R  ID 1                          0.182        0.367
B  ID 1                          -114.         219.
C  ID 1                          1.459        0.752
A  ID 1                          54.55         6.29
R  ID 2                          0.338        0.269
B  ID 2                          -85.1         60.9
C  ID 2                         -0.342        0.914
A  ID 2                          70.24         8.07
R  ID 3                          0.222        0.281
B  ID 3                          -122.         145.
C  ID 3                          1.036        0.784
A  ID 3                          66.95         6.64
R  ID 4                          0.457        0.201
B  ID 4                          -86.6         31.0
C  ID 4                          -0.83         1.16
A  ID 4                           79.7         10.9
R  ID 5                          0.785        0.142
B  ID 5                         -139.9         82.5
C  ID 5                          -6.91         6.21
A  ID 5                          158.5         92.2
R  ID 6                          0.477        0.122
B  ID 6                         -138.3         27.9
C  ID 6                          -3.05         1.22
A  ID 6                          108.6         11.6
R  ID 7                          0.413        0.202
B  ID 7                          -94.2         39.5
C  ID 7                          -0.07         1.05
A  ID 7                          71.12         9.59
R  ID 8                          0.507        0.147
B  ID 8                         -109.5         24.0
C  ID 8                          -0.81         1.33
A  ID 8                           83.1         13.0
R  ID 9                          0.696        0.131
B  ID 9                         -119.4         28.4
C  ID 9                          -4.42         3.11
A  ID 9                          121.5         37.8
```

Appendix 1.3.2 Example model of the statistical analysis of differences between pens intake curves over time

```
 13  Factor[levels=3] Diet
 14  Manova[print=ssp,tests;treatments=Diet;LRV=!P(TLRV)]V[]

***** Multivariate analysis of variance *****

***  _units_ stratum  ***

*** Diet ***


*** SSP-matrix, with   2   degrees of freedom ***


        V[1]       21754
        V[2]       31346       48685
        V[3]       22526       36494       27954
        V[4]       -3890       -2781        -789        2962

                    V[1]        V[2]        V[3]        V[4]


*** Tests ***

         Wilk's  Lambda     0.07165
     Approximate Chi sq       11.86    d.f.   8
     Approximate F test        2.05     on    8   and   6  d.f.
  Pillai-Bartlett trace       1.368
Roy's maximum root test      0.8521
 Lawley-Hotelling trace       6.826


*** Residual SSP matrix, with   6   degrees of freedom ***


        V[1]       27055
        V[2]       25207       30636
        V[3]       15789       23514       21515
        V[4]        5821        3801        5514       14742

                    V[1]        V[2]        V[3]        V[4]
```

Appendix 1.3.3 Example model of the statistical analysis of a pens intake (kg's)

```
  66  covariate Start mass
  67  for I= Feed-intake (DM)
  68  treatmentstructure Diet
  69  anova[uprint=aov,means,%cv;\
  70        print=aov,means,covariate,%cv;fprob=yes;pfactorial=2] I
  71  endfor

***** Analysis of variance *****

Variate: Feed-intake (DM)

Source of variation     d.f.       s.s.       m.s.    v.r.  F pr.
Diet                       2      1835.       917.    0.45  0.657
Residual                   6     12210.      2035.
Total                      8     14045.


***** Tables of means *****

Variate: Feed-intake (DM)

Grand mean  884.

   Diet       1.00     2.00     3.00
              875.     904.     873.


*** Standard errors of differences of means ***

Table                 Diet
rep.                     3
d.f.                     6
s.e.d.                36.8


***** Stratum standard errors and coefficients of variation *****

Variate:Feed-intake (DM)

   d.f.          s.e.          cv%
      6          45.1          5.1
```

Appendix 1.4 Example model of the statistical analysis of the individual animals live weights (kg's)

```
  27  covariate Start mass
  28  for I=Final mass
  29  treatmentstructure Diet
  30  anova[uprint=aov,means,%cv;\
  31        print=aov,means,covariate,%cv;fprob=yes] I
  32  endfor

***** Analysis of variance (adjusted for covariate) *****

Variate: Final mass
Covariate: Start mass

Source of variation     d.f.       s.s.       m.s.    v.r. cov.ef.  F pr.
Ration                     2      385.4      192.7    0.33    0.99  0.720
Covariate                  1    18518.3    18518.3   32.06          <.001
Residual                  23    13286.2      577.7            2.29
Total                     26    32867.9


***** Covariate regressions *****

Variate: Final mass

Covariate                  coefficient        s.e.
 Start mass                       1.59       0.281


***** Tables of means (adjusted for covariate) *****

Variate: Final mass
Covariate: Start mass

Grand mean  394.1

   Diet       1.00     2.00     3.00
             396.3    397.1    388.7


*** Standard errors of differences of means ***

Table                  Diet
rep.                      9
d.f.                     23
s.e.d.                11.39


***** Stratum standard errors and coefficients of variation
     (adjusted for covariate) *****

Variate: Final mass
Covariate: Start mass

   d.f.          s.e.          cv%
     23         24.03          6.1
```

Appendix 2.1.1 Nutrient composition of diets Four, Five and Six on a dry matter basis

Diet	Rep.	CP %	Ca %	P %	FAT %	ASH %	C.FIBRE %	NDF %	ADF %	MOISTURE %
4	1	11.48	0.65	0.44	4.98	7.29	12.18	42.39	21.60	14.44
4	2	11.56	1.08	0.43	3.99	7.11	14.39	42.41	23.30	14.67
4	3	12.85	0.85	0.45	4.80	7.32	12.32	37.73	19.03	15.49
4	4	12.01	0.67	0.44	4.22	7.71	18.42	45.12	24.56	14.60
4	5	10.85	0.82	0.40	3.98	8.42	13.58	40.54	21.68	15.66
4	6	11.53	0.81	0.43	4.19	8.07	17.74	39.87	21.99	16.06
4	7	11.77	0.97	0.40	4.42	7.81	18.25	44.12	24.21	15.80
4	8	11.74	1.08	0.43	4.81	8.67	16.62	43.26	23.17	13.95
4	9	13.14	1.09	0.43	3.91	9.16	13.35	41.42	22.06	13.78
4	10	13.96	0.85	0.47	4.00	8.94	11.85	37.91	19.40	16.29
4	11	15.11	1.12	0.50	3.96	8.63	13.21	42.80	21.32	14.72
4	12	14.47	0.81	0.46	4.66	8.81	14.93	41.07	19.29	16.71
4	13	11.85	0.89	0.42	4.05	7.99	13.80	54.28	20.94	15.01
4	14	12.63	1.07	0.40	3.80	8.50	13.99	43.81	22.20	13.95
4	15	13.76	1.11	0.48	4.50	8.74	10.92	35.20	16.78	11.70
4	16	14.18	0.76	0.48	3.84	7.77	12.57	40.51	20.77	14.41
5	1	13.18	1.10	0.54	5.32	8.61	13.74	36.54	20.33	15.21
5	2	12.94	1.42	0.47	5.76	8.96	14.16	39.43	22.81	15.68
5	3	13.45	1.05	0.47	6.05	8.36	13.25	38.06	21.70	14.81
5	4	13.18	1.11	0.46	5.23	9.67	14.54	39.07	22.45	14.41
5	5	14.03	1.54	0.51	5.16	10.53	12.69	35.85	19.23	16.01
5	6	13.27	1.40	0.52	5.70	9.85	13.85	35.29	21.17	15.94
5	7	13.29	1.33	0.54	5.47	9.53	15.29	36.01	19.87	16.04
5	8	12.35	1.38	0.51	5.54	10.85	14.40	38.57	21.89	14.30
5	9	14.48	1.19	0.51	4.79	9.68	12.37	34.93	18.98	13.33
5	10	13.89	1.46	0.52	4.80	11.24	11.54	34.67	19.41	17.09
5	11	14.95	1.40	0.54	3.83	9.69	12.25	36.82	19.13	15.25
5	12	14.41	1.41	0.45	4.36	10.57	12.68	34.92	17.27	14.19
5	13	12.89	1.61	0.51	3.61	11.47	11.95	31.71	19.48	15.47
5	14	13.95	1.59	0.51	4.10	10.87	12.50	37.64	20.62	14.99
5	15	15.37	1.52	0.55	3.92	10.19	11.84	34.56	17.34	15.89
5	16	15.27	1.47	0.57	2.97	9.79	14.23	35.30	20.76	13.25
6	1	16.23	1.66	0.66	4.92	10.31	11.57	35.78	19.94	16.85
6	2	14.33	1.75	0.61	5.00	10.22	10.73	30.33	19.13	16.24
6	3	14.00	1.54	0.58	5.68	10.34	12.68	34.85	19.74	15.37
6	4	15.61	1.54	0.60	5.52	10.75	12.52	34.64	20.02	14.97
6	5	13.70	1.57	0.58	5.43	11.32	13.23	35.09	19.79	17.32
6	6	15.50	2.03	0.65	5.65	12.18	12.19	34.54	20.22	17.90
6	7	13.72	2.06	0.60	5.21	12.40	12.28	34.07	19.16	17.05
6	8	14.27	1.65	0.62	5.33	11.66	11.78	34.08	18.97	17.48
6	9	15.25	1.83	0.62	3.06	12.78	10.64	32.69	17.79	16.81
6	10	17.17	1.53	0.65	5.50	10.67	11.17	30.97	17.66	16.64
6	11	14.22	1.78	0.59	2.61	11.54	12.06	36.47	19.95	16.62
6	12	14.29	2.00	0.59	3.10	13.98	12.71	34.47	20.35	16.23
6	13	13.32	2.23	0.63	2.89	13.15	12.25	43.25	21.17	14.64
6	14	15.65	2.02	0.61	2.70	13.18	12.46	36.49	19.64	15.78
6	15	14.83	2.37	0.60	2.73	13.26	12.76	34.17	19.58	15.97
6	16	15.46	2.13	0.64	2.86	11.68	10.42	32.14	17.66	15.70

Appendix 2.1.2 Metabolism study of diets Four, Five and Six

Diet	Refusals (g)	Faeces (g)	Urine (ml)	Crude protein (g)		Gross energy (MJ)		Organic matter (g)
				Faeces	Urine	Feed	Faeces	Faeces
4	0.00	1512.1	29800	184.63	306.94	84.91	27.90	1368.90
4	0.00	1668.7	16930	219.77	404.63	84.91	30.93	1493.15
4	0.00	1509.8	29150	217.71	253.61	84.91	27.33	1334.06
4	0.00	1328.8	15590	205.83	355.45	84.91	24.37	1177.05
4	0.00	1634.4	14020	234.21	382.75	84.91	29.73	1439.42
5	0.00	1547.8	34300	186.51	466.48	82.98	27.16	1329.71
5	0.00	1640.9	14710	195.60	353.04	82.98	29.26	1433.65
5	0.00	1576.2	21740	176.85	426.10	82.98	27.66	1370.03
5	0.00	1811.7	13010	220.48	408.51	82.98	31.88	1560.96
5	0.00	1691.8	18750	203.86	399.38	82.98	30.01	1465.44
6	0.00	1537.3	9270	190.32	467.21	85.33	27.44	1328.53
6	0.00	1773.8	18050	204.70	483.74	85.33	32.05	1558.64
6	0.00	1884.5	11240	210.88	520.41	85.33	33.42	1636.31
6	0.00	1694.2	12300	195.17	489.54	85.33	30.68	1476.50
6	0.00	1572.7	20060	179.60	423.27	85.33	27.98	1364.79

Appendix 2.2.1 Rectal temperatures °C (9.00 am) of individual animals over time (weeks)

				Week													
Diet	Maturity	Pen	ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13
4	Early	F	152	39.45	39.25	39.50	39.30	39.10	39.00	39.45	39.25	39.00	39.15	39.80	39.60	39.30	39.00
4	Early	F	181	39.10	39.20	39.30	39.55	39.30	39.80	39.20	39.50	38.85	38.85	38.80	39.00	39.40	
4	Early	F	313	40.00	39.00	39.30	39.40	39.50	39.05	39.40	39.50	39.30	39.05	39.30	39.50	39.60	
4	Early	F	322	39.35	39.20	39.65	40.10	39.50	38.90	39.35	40.00	38.75	39.30	39.30	39.80	39.30	39.40
4	Early	F	332	39.20	38.70	39.00	39.10	39.40	39.15	39.35	39.45	39.05	39.20	39.30	39.70	39.00	
4	Late	D	372	39.40	39.25	39.25	39.30	39.30	38.75	39.15	39.10	39.35	39.10	39.30	39.40	39.10	39.30
4	Late	D	403	39.10	39.15	39.40	39.65	39.30	38.80	39.15	39.00	39.30	39.10	39.30	39.20	39.00	39.10
4	Late	D	410	39.60	39.30	39.20	39.50	39.35	39.10	39.60	39.25	39.20	39.15	39.40	39.70	39.10	39.30
4	Late	D	420	39.30	39.45	40.05	39.55	39.30	39.55	39.30	39.45	39.30	39.50	39.80	40.00	39.20	39.20
4	Late	D	424	39.10	38.95	39.70	39.60	39.10	38.90	39.25	39.00	38.90	38.85	39.40	39.40	39.00	39.10

				Week													
Diet	Maturity	Pen	ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13
5	Early	A	183	39.00	39.60	38.90	39.10	39.45	38.85	39.00	39.25	39.10	38.80	39.10	39.20	39.20	39.00
5	Early	A	278	39.10	39.10	39.10	39.50	39.65	39.45	39.15	39.30	39.10	38.95	39.20	39.50	39.40	39.50
5	Early	A	282	38.90	39.45	38.90	39.70	39.75	39.20	38.95	39.20	39.00	39.00	39.30	39.40	39.10	
5	Early	A	293	39.50	39.55	39.30	39.25	39.60	39.45	39.60	39.25	38.90	39.55	39.40	39.70	39.30	39.30
5	Early	A	309	38.85	39.00	39.60	39.80	39.30	38.95	39.35	39.95	39.15	39.60	39.60	39.30	39.00	39.00
5	Late	B	155	39.25	39.45	39.35	39.60	39.35	39.15	39.15	40.95	39.45	38.95	39.10	39.50	39.10	39.00
5	Late	B	375	38.85	39.10	39.55	39.65	39.20	39.10	39.15	39.20	39.05	39.00	39.10	39.30	39.30	39.20
5	Late	B	378	39.55	39.50	39.70	39.80	38.90	39.20	39.30	39.30	39.05	39.00	39.20	39.70	39.20	39.00
5	Late	B	383	39.15	39.00	39.10	38.95	38.95	39.00	39.05	38.95	38.80	38.70	39.00	38.90	39.10	39.00
5	Late	B	445	39.25	39.35	39.25	39.25	39.20	38.95	39.10	39.00	38.95	38.90	39.10	39.50	39.00	39.30

Diet	Maturity	Pen	ID	Week 0	1	2	3	4	5	6	7	8	9	10	11	12	13
6	Early	E	249	39.65	39.00	39.30	40.20	39.60	39.05	39.25	39.60	39.10	38.60	39.50	39.90	39.50	
6	Early	E	254	39.20	39.20	39.30	39.40	39.50	39.90	39.60	39.45	39.50	39.10	39.30	39.40	39.60	39.40
6	Early	E	265	39.50	39.50	39.45	39.40	39.00	39.10	39.20	39.30	38.95	39.00	39.50	39.90	39.40	
6	Early	E	267	39.20	39.45	39.40	39.90	39.20	38.85	39.10	39.30	38.95	39.20	39.80	40.00	39.80	
6	Early	E	274	39.35	39.65	39.10	40.00	39.30	39.30	39.15	39.30	39.05	39.40	39.70	40.00	39.00	39.30
6	Late	C	398	40.00	39.90	39.50	39.70	39.70	39.05	39.25	39.80	39.65	39.40	39.50	39.60	40.00	39.30
6	Late	C	402	39.50	39.50	39.90	39.60	40.00	39.20	39.50	39.15	39.45	39.50	39.60	39.50	39.70	39.30
6	Late	C	409	39.00	39.10	39.00	39.60	40.00	38.90	39.30	39.30	39.15	39.20	39.40	39.70	39.60	39.80
6	Late	C	411	38.80	39.35	39.30	39.20	39.55	39.20	39.20	39.45	39.20	39.05	39.50	39.90	39.30	39.30
6	Late	C	463	39.10	39.90	38.55	39.35	39.00	38.85	38.55	39.05	38.90	39.05	39.50	39.90	39.10	39.20

Diet	Maturity	Pen	ID	Week 0	1	2	3	4	5	6	7	8	9	10	11	12	13
Control	Early	Pasture	154	38.80	38.80	38.80	39.25	39.00	38.85	38.90	38.95	39.15	38.60	38.80	38.60	38.90	38.60
Control	Early	Pasture	221	38.60	39.35	39.40	39.10	38.70	39.20	38.90	38.80	39.10	38.45	39.50	38.85	38.50	38.70
Control	Early	Pasture	246	39.20	38.90	39.10	39.20	39.10	38.70	38.75	39.30	39.35	38.60	39.10	39.00	38.35	38.75
Control	Early	Pasture	273	39.40	39.00	38.30	38.40	38.85	39.15	39.10	39.50	38.85	38.45	39.15	39.10	39.10	38.80
Control	Early	Pasture	324	39.10	39.05	38.75	38.80	38.85	38.80	38.70	38.95	38.90	38.65	39.15	38.75	38.80	39.30
Control	Late	Pasture	165	38.60	39.35	39.60	39.85	39.40	39.20	39.40	39.50	39.00	38.80	39.30	39.00	38.90	39.10
Control	Late	Pasture	385	39.15	39.45	39.70	39.40	38.90	38.70	39.60	39.60	39.30	38.90	39.80	39.50	38.90	39.45
Control	Late	Pasture	393	38.70	39.50	38.30	38.95	39.80	38.70	39.30	38.90	39.20	38.70	39.40	39.45	38.90	38.70
Control	Late	Pasture	100		38.85	38.90	38.50	38.50	38.86	38.25	38.60	38.70	38.05	38.40	38.60	38.20	38.55
Control	Late	Pasture	448	37.80	38.80	37.95	38.00	38.40	38.25	38.50	38.70	39.05	38.35	39.40	38.90	38.90	39.10

Appendix 2.2.2 Rectal temperatures °C (2.00 pm) of individual animals over time (weeks)

				Week										
Diet	**Maturity**	**Pen**	**ID**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
4	Early	F	152	39.50	39.55		39.70	39.35		39.80	39.90	39.20	39.20	39.70
4	Early	F	181	39.30	39.60		39.45	39.40		38.80	39.40	39.40	39.00	
4	Early	F	313	39.80	39.40		39.55	39.20		39.30	39.40	39.70	39.80	
4	Early	F	322	40.10	40.35		40.20	40.80		39.30	40.20	40.20	39.30	39.50
4	Early	F	332	39.65	39.35		39.70	39.30		39.30	39.40	39.50	39.40	
4	Late	D	372	39.30	39.15		39.20	39.20		39.30	39.40	39.50	39.30	39.30
4	Late	D	403	39.55	39.10		39.60	39.60		39.30	39.20	39.20	39.40	39.40
4	Late	D	410	39.65	39.50		39.50	39.45		39.00	39.60	40.70	39.30	39.40
4	Late	D	420	39.40	39.20		39.20	39.65		39.60	39.50	40.10	39.40	39.20
4	Late	D	424	39.55	39.30		39.35	39.50		39.00	39.20	39.50	39.20	39.30

				Week										
Diet	**Maturity**	**Pen**	**ID**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
5	Early	A	183	39.20	39.45		39.45	39.55		39.50	39.40	39.70	39.30	39.80
5	Early	A	278	39.40	39.70		39.70	40.00		39.70	39.60	39.40	39.30	39.50
5	Early	A	282	39.70	39.55		39.95	39.90		39.90	39.20	39.60	39.40	
5	Early	A	293	39.60	39.60		39.75	39.40		39.90	39.70	40.50	39.30	39.30
5	Early	A	309	39.80	39.40		40.50	41.05		39.60	39.70	39.50	39.30	39.20
5	Late	B	155	39.80	39.45		39.70	41.35		39.00	39.30	39.90	39.30	39.50
5	Late	B	375	39.45	39.40		39.35	39.75		38.80	39.30	40.20	39.20	39.80
5	Late	B	378	39.20	39.35		39.20	39.65		39.60	39.60	39.60	38.90	39.40
5	Late	B	383	39.10	39.50		39.10	38.95		38.90	39.20	39.00	39.40	39.30
5	Late	B	445	39.35	39.45		39.45	39.45		38.50	39.40	40.00	39.20	39.30

Diet	Maturity	Pen	ID	Week 3	4	5	6	7	8	9	10	11	12	13
6	Early	E	249	40.20	40.00		39.95	39.90		39.30	39.80	39.80	39.20	
6	Early	E	254	39.20	39.60		39.50	39.75		39.40	39.60	39.30	39.30	39.50
6	Early	E	265	39.15	39.50		39.75	39.60		39.50	39.50	39.40	39.00	
6	Early	E	267	39.75	40.00		39.70	39.85		39.40	40.00	39.90	39.30	
6	Early	E	274	40.00	39.55		39.90	39.95		39.60	39.80	40.20	38.90	39.40
6	Late	C	398	39.40	39.65		39.70	39.50		39.40	39.40	40.00	39.60	39.20
6	Late	C	402	39.70	40.10		39.60	39.55		39.60	39.50	39.20	39.30	39.80
6	Late	C	409	39.50	39.95		39.70	39.80		39.50	39.60	39.50	39.30	39.50
6	Late	C	411	39.50	40.10		39.40	39.70		39.30	39.90	40.60	39.20	39.00
6	Late	C	463	38.80	39.10		39.00	39.25		39.30	39.90	39.90	39.00	39.00

Appendix 2.2.3 Respiration rate (breaths / 30 seconds) of individual animals over time (weeks)

				Week												
Diet	**Maturity**	**Pen**	**ID**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
4	Early	F	152	10.5	11.0	17.0	17.0	15.5	12.5	15.0	18.0	15.0	18.0	13.5	14.5	14.5
4	Early	F	181	10.0	9.5	16.0	24.5	20.0	15.5	15.0	34.0	28.5	12.0	17.0	17.0	21.5
4	Early	F	313	10.0	9.0	9.5	20.0	27.5	20.5	15.0	23.0	20.5	15.5	19.0	19.5	19.5
4	Early	F	322	9.5	14.0	18.5	33.5	30.5	17.5	14.5	45.0	29.5	14.5	17.5	18.0	21.0
4	Early	F	332	9.5	11.0	14.5	26.0	25.0	22.0	15.0	33.0	31.5	22.5	20.5	20.0	17.0
4	Late	D	372	13.0	12.0	16.0	14.5	15.5	12.5	14.5	24.0	21.5	20.0	13.0	16.5	16.0
4	Late	D	403	15.5	13.5	23.5	23.5	19.5	19.5	13.5	25.0	25.5	17.0	15.5	16.5	23.0
4	Late	D	410	17.0	16.0	17.0	22.0	22.0	15.5	15.5	20.5	23.5	22.5	17.0	18.5	16.5
4	Late	D	420	10.0	10.0	16.5	16.5	23.0	16.5	16.5	23.5	17.5	14.5	18.5	18.0	21.0
4	Late	D	424	11.5	10.5	17.0	29.5	24.5	16.5	13.0	29.0	29.0	23.0	17.5	20.0	34.0

				Week												
Diet	**Maturity**	**Pen**	**ID**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
5	Early	A	183	12.0	14.5	18.5	26.0	17.5	29.0	28.0	25.0	22.5	18.5	18.5	19.5	19.0
5	Early	A	278	10.0	11.5	16.0	20.0	17.5	15.5	15.0	20.5	21.0	16.0	17.0	18.0	22.0
5	Early	A	282	10.5	11.0	21.5	33.5	22.0	22.0	19.0	25.0	30.0	18.0	16.5	17.5	17.5
5	Early	A	293	11.0	9.5	14.0	21.5	18.0	21.5	17.5	21.5	29.5	17.0	16.5	17.0	22.0
5	Early	A	309	13.0	13.5	16.0	25.5	22.5	22.0	23.5	28.0	29.5	20.5	29.0	29.0	20.0
5	Late	B	155	14.0	14.0	20.5	27.5	20.0	18.0	19.5	27.5	19.5	18.5	19.0	18.5	22.5
5	Late	B	375	12.0	13.5	24.0	30.5	31.0	33.0	29.5	48.5	30.5	25.0	20.0	21.0	40.0
5	Late	B	378	15.5	10.5	16.0	20.0	19.0	14.5	16.0	34.0	16.0	16.0	13.0	13.0	18.0
5	Late	B	383	13.0	15.0	15.5	27.5	20.5	18.5	17.5	20.0	16.0	20.0	14.5	13.5	20.0
5	Late	B	445	17.0	13.0	15.5	21.0	16.0	19.5	15.5	22.0	20.0	14.0	17.5	18.0	18.0

Diet	Maturity	Pen	ID	Week 0	1	2	3	4	5	6	7	8	9	10	11	12
6	Early	E	249	11.0	13.0	21.0	24.0	27.5	27.5	25.5	37.5	29.5	23.0	19.5	19.5	19.5
6	Early	E	254	11.5	12.0	16.5	20.5	19.5	15.5	16.5	23.5	30.0	17.0	25.0	25.0	24.0
6	Early	E	265	10.0	10.0	16.0	26.0	20.0	20.5	21.5	31.5	28.5	20.0	22.0	22.0	22.0
6	Early	E	267	10.0	10.5	18.0	22.0	21.5	20.5	25.5	37.0	21.5	20.0	20.5	20.5	20.5
6	Early	E	274	10.0	9.0	20.5	41.5	20.0	25.0	26.0	34.5	25.0	19.5	21.5	21.0	27.0
6	Late	C	398	9.0	8.5	16.0	22.0	11.5	12.5	12.5	25.0	21.5	17.0	15.0	16.5	18.0
6	Late	C	402	12.0	14.5	18.0	22.0	16.5	16.5	12.5	22.5	19.0	17.5	17.5	18.0	18.0
6	Late	C	409		13.0	15.0	20.5	21.5	16.5	14.5	18.0	15.5	17.0	17.5	17.0	18.0
6	Late	C	411	8.0	9.5	15.5	22.0	13.5	15.5	11.0	18.0	21.5	18.0	18.0	18.5	19.0
6	Late	C	463	9.0	13.0	16.0	19.5	19.5	21.0	19.5	27.0	23.0	18.0	31.0	24.5	18.0

Diet	Maturity	Pen	ID	Week 0	1	2	3	4	5	6	7	8	9	10	11	12
Control	Early	Pasture	154	17.0	19.5	17.0	17.0	16.5	16.5	16.0	16.0	15.0	15.5	15.0	15.0	15.5
Control	Early	Pasture	221	15.5	13.5	17.5	13.5	16.5	16.5	16.0	17.5	18.0	12.0	14.0	14.0	13.0
Control	Early	Pasture	246	23.0	15.5	19.0	13.0	14.5	14.5	13.5	20.0	15.0	13.0	13.0	13.0	13.0
Control	Early	Pasture	273	13.5	8.0	12.0	19.0	13.0	14.0	14.0	22.0	20.0	16.0	16.0	16.0	15.0
Control	Early	Pasture	324	15.0	15.0	19.0	13.0	19.0	13.5	12.0	19.0	20.0	17.5	17.5	18.0	14.0
Control	Late	Pasture	165	21.5	19.5	14.5	17.5	19.5	19.0	17.5	15.5	21.0	12.0	12.0	12.0	12.0
Control	Late	Pasture	385	11.0	12.0	12.5	19.5	14.0	11.5	11.0	15.0	17.0	15.0	16.0	16.0	15.0
Control	Late	Pasture	393	11.0	10.0	15.0	15.5	13.5	15.5	14.5	14.0	16.0	12.0	12.5	12.5	19.0
Control	Late	Pasture	100	13.0	13.0	15.5	15.0	13.0	16.5	15.0	17.5	17.5	13.5	14.5	13.5	14.0
Control	Late	Pasture	448	8.5	9.5	7.5	14.5	16.0	16.5	16.5	18.0	19.0	15.0	16.5	15.5	15.0

Appendix 2.2.4 Weekly means of the maximum, average and minimum ambient temperatures °C for the weeks of rectal temperature and respiration rate recordings.

Week	Ambient temperatures for the days rectal temperature were recorded			Ambient temperatures for the days respiration rates were recorded			Mean (S.E.) of the weeks average ambient temperature
	Maximum	Average	Minimum	Maximum	Average	Minimum	
0	20.1	11.3	2.5	21.3	13.0	4.6	11.3 (0.57)
1	21.6	13.2	4.7	25.7	16.1	6.4	14.1 (0.61)
2	27.2	18.0	8.8	23.5	13.9	4.3	15.5 (0.81)
3	21.7	16.4	11.1	24.8	17.6	10.4	16.2 (0.53)
4	22.8	15.3	7.8	24.3	17.0	9.7	15.5 (1.07)
5	12.8	11.1	9.3	20.9	13.9	6.8	13.4 (0.91)
6	19.8	13.3	6.8	19.3	12.7	6.1	13.4 (0.85)
7	27.3	18.8	10.2	26.8	19.3	11.8	16.3 (0.79)
8	17.9	14.8	11.7	31.2	23.1	15	19.7 (1.27)
9	13.5	11.9	10.3	24.5	16.4	8.2	17.6 (2.61)
10	20.0	16.6	13.1	18.8	12.8	6.8	14.0 (0.98)
11	29.7	20.2	10.6	15.0	13.3	11.5	16.8 (1.00)
12	18.3	13.9	9.4	29.5	20.7	11.8	18.1 (1.31)

Appendix 2.3.1.1 An animal's dry matter feed-intake kg's (calan gates) over time (weeks)

				Week															
Diet	**Maturity**	**Pen**	**ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
4	Early	F	152	50	65	75	71	75	103	87	104	103	75	81						
4	Early	F	171	73	73	92	71	84	78	80	111	93	103	74						
4	Early	F	181	71	83	83	75	78	110	82	97	106	82	84	84	90	81	57		
4	Early	F	212	63	86	108	76	88	121	97	119	96	68	82						
4	Early	F	232	58	62	82	69	74	110	86	81	100	75	89						
4	Early	F	240	38	24	36	42	37	59	55	76	70	71	66	75	94	94	63		
4	Early	F	308	58	66	47	85	78	98	88	107	103	101	117	77					
4	Early	F	313	43	47	85	65	78	89	84	124	90	99	125						
4	Early	F	322	69	51	78	71	79	120	75	105	86	112	95	102					
4	Early	F	332	69	49	62	62	68	75	63	82	88	85	93	89	87	76	70		
4	Late	D	214	30	49	56	85	71	69	107	90	107	94	89						
4	Late	D	260	31	34	64	80	91	92	90	61	68	50	59	65	79	63			
4	Late	D	302	60	54	94	65	82	144	97	119	127	109	83						
4	Late	D	372	51	74	83	100	87	89	103	133	132	107	130	125	125	77			
4	Late	D	399	42	33	57	53	57	96	43	86	54	113	69	84					
4	Late	D	403	72	55	104	94	88	123	108	120	117	113	143	132	116	70			
4	Late	D	410	47	62	76	82	91	104	74	115	76	74	122	112	89	83	137		
4	Late	D	420	53	62	30	50	76	63	73	112	98	106	98	116	119	94	107	115	115
4	Late	D	424	53	74	86	66	68	74	67	126	113	84	71	114	78	74	115	102	102
4	Late	D	439	53	70	92	63	121	115	93	123	141	134	100	75	100	92			

				Week															
Diet	**Maturity**	**Pen**	**ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
5	Early	A	183	36	30	48	57	60	82	59	78	92	82	83	92	93	61			
5	Early	A	278	57	38	52	46	56	74	69	95	95	90	104	91					
5	Early	A	282	63	60	71	64	91	78	91	87	110	89	101						
5	Early	A	293	47	25	38	33	43	34	70	96	73	116	113	105	122	58			
5	Early	A	298	17	23	31	63	30	63	63	90	74	71	75	70	89	71	99	105	105
5	Early	A	299	26	26	86	82	84	99	98	115	93	75	83	80	76	94	58		
5	Early	A	309	64	65	57	66	77	99	79	66	88	94	90	108	75	67	91		
5	Early	A	310	37	23	38	56	84	72	62	64	52	47	77	84	80	92	100		
5	Early	A	329	49	80	69	64	67	82	85	132	113	120	91						
5	Early	A	330	19	24	31	55	66	70	78	73	92	91	68						
5	Late	B	155	90	56	87	66	99	94	86	105	113	113	82	56	72	100	105	90	90
5	Late	B	375	33	78	63	78	52	112	53	72	53	124	109	98	102	87	100	93	93
5	Late	B	378	46	32	38	48	70	107	86	112	100	126	85	80	109	108	92		
5	Late	B	383	71	66	85	72	63	86	84	108	88	117	98	91	151	97	94	107	107
5	Late	B	421	71	65	78	76	87	79	89	105	112	110	91	126	131	100	116	157	120
5	Late	B	441	43	52	66	55	94	79	76	97	92	124	102	116	73	107			
5	Late	B	445	53	58	94	73	92	88	92	119	126	132	109	125	100	83			
5	Late	B	452	45	67	78	81	91	113	122	129	118	92	104	107					
5	Late	B	459	32	53	91	36	110	117	90	83	102	89	99	115	111	95	132	110	110
5	Late	B	461	36	54	113	55	71	94	80	75	114	108	102	151	117	108	96	69	89

				Week															
Diet	**Maturity**	**Pen**	**ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
6	Early	E	160	59	65	75	54	82	106	83	73	92	107	76	117					
6	Early	E	177	73	71	99	77	99	101	96	109	71	115	114	110					
6	Early	E	186	66	63	65	71	82	100	83	92	99	108	83	93					
6	Early	E	249	51	50	78	71	91	135	94	96	88	108	76						
6	Early	E	254	43	54	80	63	68	77	63	91	67	97	75	73	105				
6	Early	E	265	64	41	63	73	91	86	84	92	88	120	81						
6	Early	E	267	60	60	59	74	56	106	80	79	91	77	78						
6	Early	E	271	62	66	65	69	86	112	96	90	140	150	100	68	75				
6	Early	E	274	59	52	62	67	84	108	100	85	98	111	92	90					
6	Early	E	319	46	42	64	59	66	92	69	88	87	86	89	88					
6	Late	C	217	60	63	83	77	111	114	75	81	108	77	107	94					
6	Late	C	388	57	61	93	79	104	122	93	98	127	123	126	110	94	81	114	102	102
6	Late	C	395	57	28	44	48	43	77	84	135	112	76	84	93	102	79	142	106	106
6	Late	C	398	55	38	51	51	41	36	35	108	81	84	83	70	59	86	86	82	82
6	Late	C	401	61	44	72	46	83	90	64	63	67	83	89	56	101	104	84	78	78
6	Late	C	402	69	56	73	69	87	105	90	97	81	73	97	99	103	85			
6	Late	C	409	51	59	70	74	101	87	87	92	106	110	99	99	100	72	114	103	103
6	Late	C	411	65	51	70	78	92	107	93	107	117	111	117	116	125	78	109	125	125
6	Late	C	422	58	66	81	71	92	112	86	110	103	96	100	119	117	96	127	111	111
6	Late	C	463	42	20	34	52	47	89	85	86	71	97	103	91	117	97	104	124	124

Appendix 2.3.1.2 An animal's dry matter feed-intake (kg's) per pen over time (weeks)

				Week															
Diet	**Maturity**	**Pen**	**ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
4	Early	7	251	65	75	75	75	75	105	115	100	105	70	108	8					
4	Early	8	261	65	80	75	85	90	110	115	95	105	80	106	56	106	13			
4	Late	3	287	65	75	75	85	100	100	115	102	105	105	115	97	107	60	69	13	
4	Late	4	294	65	80	70	85	90	110	120	110	110	100	115	98	122	88	117	98	100
5	Early	13	318	60	70	80	85	90	110	115	105	110	75	83	71	84				
5	Early	14	159	60	70	70	95	95	115	125	105	115	70	100	6					
5	Late	17	184	65	80	80	95	90	110	125	100	110	105	130	115	114	105	133	83	100
5	Late	18	206	70	75	80	90	95	125	125	105	120	105	140	95	99	55	63	51	100
6	Early	15	270	60	75	70	85	95	100	115	95	110	70	117	5					
6	Early	16	292	60	70	80	90	90	105	110	100	105	105	115	40	37				
6	Late	5	227	60	75	75	80	90	110	110	96	110	105	115	107	108	115	120	97	70
6	Late	6	241	65	70	80	100	105	105	125	110	115	105	115	110	118	100	131	63	100

Appendix 2.3.2.1 Individual animals live weights (kg's) over time (weeks) (calan gate feeding)

				Week																
Diet	**Maturity**	**Pen**	**ID**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
4	Early	F	152	227	236	255	273	290	303	320	334	354	365	375	389						
4	Early	F	171	221	237	248	264	280	287	306	309	321	342	344	351						
4	Early	F	181	202	212	223	244	254	265	280	290	299	312	316	316	330	336	345	359		
4	Early	F	212	265	281	297	323	330	347	362	370	397	401	407	417						
4	Early	F	232	221	229	244	262	272	286	300	312	329	346	357	370						
4	Early	F	240	182	192	204	211	224	232	228	238	252	258	280	297	299	323	343	356		
4	Early	F	308	188	196	214	212	232	249	262	276	290	308	327	342	358					
4	Early	F	313	197	222	237	266	272	286	304	311	326	350	351	369						
4	Early	F	322	209	222	236	258	261	286	290	305	313	332	346	351	373					
4	Early	F	332	169	185	200	211	218	226	247	250	270	279	290	310	321	332	347	361		
4	Late	D	214	209	215	238	256	265	274	289	293	311	331	344	364						
4	Late	D	260	201	206	230	236	262	273	285	293	294	308	319	339	339	348	354			
4	Late	D	302	253	265	280	310	316	323	352	362	377	397	404	413						
4	Late	D	372	263	270	286	309	326	340	367	375	390	418	426	439	459	469	487			
4	Late	D	399	192	202	218	228	239	261	279	289	304	327	347	361	377					
4	Late	D	403	249	255	279	308	317	338	365	370	396	416	424	437	449	461	478			
4	Late	D	410	222	230	246	270	285	291	322	324	349	374	380	399	407	429	439	455		
4	Late	D	420	223	227	225	244	257	274	295	313	333	361	369	390	404	420	436	448	458	474
4	Late	D	424	283	284	310	332	329	358	377	385	403	429	444	452	460	479	477	495	507	509
4	Late	D	439	174	187	200	215	222	244	261	274	291	303	319	327	327	339	359			

				Week																
Diet	**Maturity**	**Pen**	**ID**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
5	Early	A	183	166	177	184	207	214	224	239	252	266	284	289	305	311	329	336			
5	Early	A	278	184	196	208	217	224	239	256	273	280	299	303	327	340					
5	Early	A	282	204	223	244	261	278	290	305	324	338	351	355	385						
5	Early	A	293	200	201	212	215	218	230	244	256	260	285	292	305	321	333	348			
5	Early	A	298	174	175	190	201	201	223	236	236	265	246	276	294	301	319	337	350	357	377
5	Early	A	299	206	212	210	221	237	251	255	271	293	316	328	350	356	365	371	386		
5	Early	A	309	206	216	229	239	256	256	273	276	300	316	321	334	364	368	373	396		
5	Early	A	310	166	177	188	199	221	222	227	231	250	250	255	285	289	293	303	315		
5	Early	A	329	220	228	241	258	276	289	303	313	334	356	366	392	392					
5	Early	A	330	187	194	213	223	234	243	261	266	285	303	306	337						
5	Late	B	155	250	272	283	302	317	326	326	331	346	368	368	369	394	403	413	426	437	439
5	Late	B	375	292	311	333	346	364	378	395	407	437	447	454	480	484	508	523	542	544	571
5	Late	B	378	191	194	205	211	227	247	264	273	288	307	321	337	347	359	366	380		
5	Late	B	383	251	258	270	296	314	339	356	370	385	407	412	424	432	456	470	483	488	499
5	Late	B	421	209	228	245	254	264	285	296	308	320	344	353	359	363	376	389	408	410	414
5	Late	B	441	213	217	226	254	252	285	297	307	328	354	368	386	389	412	422			
5	Late	B	445	244	237	266	292	302	312	310	345	365	381	387	397	407	418	429			
5	Late	B	452	227	231	255	264	273	286	310	311	339	358	361	386	390					
5	Late	B	459	240	220	249	267	280	289	295	313	332	358	377	391	399	419	437	458	457	482
5	Late	B	461	174	189	197	208	211	220	237	247	262	279	282	293	294	308	324	339	336	340

Diet	Maturity	Pen	ID	Week 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
6	Early	E	160	206	211	228	245	256	273	294	303	319	331	357	371	375					
6	Early	E	177	211	222	240	252	265	281	307	311	324	343	365	368	371					
6	Early	E	186	172	185	200	204	221	233	256	261	278	295	311	316	320			359		
6	Early	E	249	218	231	227	259	272	280	304	300	314	328	338	359						
6	Early	E	254	185	194	213	215	225	237	254	264	277	295	312	313	328	339	339			
6	Early	E	265	223	258	274	282	291	310	322	325	332	356	363	379				356		
6	Early	E	267	214	222	229	240	250	266	283	289	303	319	336	350						
6	Early	E	271	226	234	250	257	272	286	304	308	315	339	340	358	371	375	356			
6	Early	E	274	186	194	206	215	227	239	258	270	282	300	307	323	330					
6	Early	E	319	214	217	237	250	264	271	287	289	304	318	336	343	343			361		
6	Late	C	217	262	272	281	300	308	314	335	339	348	357	366	378	379					
6	Late	C	388	263	266	284	311	320	331	355	361	369	391	404	417	426	426	432	452	454	472
6	Late	C	395	169	182	181	189	197	199	220	224	232	245	252	272	275	294	304	317	324	333
6	Late	C	398	158	171	198	200	200	207	222	229	229	246	251	264	269	274	289	297	307	318
6	Late	C	401	205	207	214	240	250	269	280	286	300	322	333	352	356	373	387	402	402	434
6	Late	C	402	229	230	250	269	281	299	311	324	340	358	360	380	392	406	416			
6	Late	C	409	234	246	259	275	282	296	314	320	338	355	355	377	385	391	412	431	432	455
6	Late	C	411	224	228	234	247	267	273	301	310	325	348	358	386	393	406	421	450	459	575
6	Late	C	422	272	289	300	301	318	329	352	351	365	394	399	424	431	443	456	476	482	504
6	Late	C	463	184	190	201	212	220	235	253	250	268	271	290	299	312	320	337	337	351	372

Appendix 2.3.2.2 Individual animals live weights (kg's) over time (weeks) (group feeding)

				Week																
Diet	Maturity	Pen	ID	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
4	Early	7	251	215	224	232	243	265	273	286	294	308	328	334	341						
4	Early	7	261	238	254	271	292	298	304	326	334	350	374								
4	Early	7	287	198	221	233	252	263	270	295	305	321	343								
4	Early	7	294	179	206	210	227	229	250	266	284	296	313	321	332						
4	Early	7	318	216	224	240	258	267	280	301	312	323	353	366	370						
4	Early	8	159	240	254	274	273	297	314	334	342	347	359	371	376						
4	Early	8	184	200	215	235	244	265	277	301	307	320	337	343	360	371	378				
4	Early	8	206	207	223	235	250	262	277	289	301	317	337	343	354	367	387				
4	Early	8	270	201	225	240	251	265	278	296	311	322	347								
4	Early	8	292	173	195	206	214	231	247	260	271	286	312	320	337						
4	Late	3	227	256	274	284	300	317	332	339	322	362	378	388	401						
4	Late	3	241	263	302	310	322	340	350	369	381	403	419	426	449	461	475				
4	Late	3	391	218	231	243	248	273	279	306	297	326	346	356	368	388	396	413	416		
4	Late	3	428	187	196	212	220	232	245	262	267	286	308	318	333	348	358	371	384		
4	Late	3	432	243	255	267	286	307	321	353	366	382	396	416	436	447	456				
4	Late	4	377	217	234	248	264	284	302	318	330	341	365	370	380	387	400				
4	Late	4	419	254	290	301	324	344	367	381	398	415	437	448	465						
4	Late	4	434	220	242	251	264	291	316	328	342	355	384	391	413	426	437	449	465	485	500
4	Late	4	437	182	184	199	194	223	225	253	267	276	298	325	343	354	367	372	393	408	422
4	Late	4	449	237	251	273	286	318	319	328	358	380	405	423	432	446	457	481	487		

				Week																
Diet	**Maturity**	**Pen**	**ID**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
5	Early	13	172	191	206	221	230	239	264	276	288	305	321	330	344	348	360				
5	Early	13	262	212	236	255	267	282	295	316	324	340	356								
5	Early	13	300	200	220	239	252	262	278	280	287	308	307	317	336	347	348				
5	Early	13	304	195	208	232	242	247	274	295	309	326	343	356	364						
5	Early	13	327	232	248	277	294	292	314	346	343	367	368								
5	Early	14	242	181	198	209	218	230	248	264	275	291	311	329	332						
5	Early	14	263	190	212	221	243	247	264	284	294	306	325								
5	Early	14	279	232	243	265	279	291	314	325	343	354	370	384	385						
5	Early	14	307	220	231	253	267	279	301	316	334	351	375								
5	Early	14	325	200	214	225	246	255	275	292	308	321	335								
5	Late	17	418	242	244	280	290	308	320	346	356	348	388	389	409	418	435	442	453	459	470
5	Late	17	426	245	265	281	288	308	313	336	351	363	397	395	411	418	437				
5	Late	17	435	215	232	251	255	273	288	300	312	324	342	338	363	375	391	402	417		
5	Late	17	440	177	182	205	206	220	246	267	268	290	311	312	337	346	361				
5	Late	17	453	280	301	342	350	364	390	413	426	451	483	471	504	509	532	543	560	568	581
5	Late	18	208	210	229	250	251	265	289	301	306	325	354	353	376						
5	Late	18	405	208	233	246	261	276	293	308	317	337	357	358	370	384	389				
5	Late	18	414	197	210	227	230	242	266	282	293	302	330	339	357	364	378	386	398	418	431
5	Late	18	427	240	260	293	305	318	344	355	371	392	415	428	459	468	475	497	512	522	533
5	Late	18	433	252	278	312	309	333	358	375	382	403	404	405	437	445	459				

Diet	Maturity	Pen	ID	Week 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
6	Early	15	139	228	234	254	265	277	294	310	318	329	345	346	361						
6	Early	15	173	190	199	210	220	228	243	262	268	282	298	308	323						
6	Early	15	257	199	213	230	236	253	266	288	300	307	332	346	352						
6	Early	15	311	239	245	253	257	282	293	305	311	316	347								
6	Early	15	314	192	213	225	237	253	265	289	298	306	334								
6	Early	16	182	193	207	230	241	262	277	297	308	328	339	341	358						
6	Early	16	235	217	230	254	255	262	266	289	306	328	347	351	372						
6	Early	16	250	208	222	240	250	260	283	296	313	322	338	349	366						
6	Early	16	289	182	199	215	220	234	248	263	273	286	309	314	331	337	341				
6	Early	16	323	197	200	226	230	243	260	272	281	300	316	321	340	351	355				
6	Late	5	211	204	216	228	223	234	243	258	266	281	294	304	319	333	337	344	358	356	370
6	Late	5	407	188	193	212	220	227	248	263	277	286	309	318	323	328	329	345	354	362	370
6	Late	5	431	248	250	260	271	286	309	327	336	343	379	385	401	410	418	430	432	445	460
6	Late	5	446	234	256	266	285	292	311	338	346	363	388	400	416	422	438	454	461	472	490
6	Late	5	455	267	278	300	307	316	331	337	350	359	386	392	405	412	419	429	438	450	468
6	Late	6	381	226	240	254	269	286	293	321	335	353	374	382	406	406	419	433	443		
6	Late	6	416	171	184	200	219	229	244	261	280	284	304	310	326	334	333	346	364		
6	Late	6	451	233	245	253	271	282	294	330	332	335	358	367	382	383	383				
6	Late	6	458	260	272	282	309	324	332	352	368	382	404	411	420	436	436	452	462	465	475
6	Late	6	460	247	248	271	291	299	314	335	353	365	390	396	406	421	420	438	448	459	470

Appendix 2.3.3.1 Length of time in the feedlot (days) and carcass data for individual animals (calan gate feeding)

Diet	Maturity	Pen	ID	Days	Carcass weight (kg)	Fat score Overall	Hind quarter	Loin	Fore-quarter	Dressing Percentage
4	Early	F	152	78	205	2	2	2	2+	52.70
4	Early	F	171	78	195	3	2+	3	3-	55.56
4	Early	F	181	106	184	3	2+	3	3+	51.25
4	Early	F	212	78	224	2	2	2	2	53.72
4	Early	F	232	78	202	2	2-	2	2	54.59
4	Early	F	240	106	207	2	2+	2+	2	58.15
4	Early	F	308	85	186	2	2	2	2	51.96
4	Early	F	313	78	201	3	3	3	3	54.47
4	Early	F	322	85	200	3+	3+	3+	3	53.62
4	Early	F	332	106	192	3	3	3+	3	53.19
4	Late	D	214	78	192	2	2-	2+	2	52.75
4	Late	D	260	99	193	2+	3-	2+	2	54.52
4	Late	D	302	78	226	3	3	3	3	54.72
4	Late	D	372	99	269	2+	2	3	2+	55.24
4	Late	D	399	85	191	2	2	2	2-	50.66
4	Late	D	403	99	251	2	2-	2	2	52.51
4	Late	D	410	106	246	3	2+	3	3	54.07
4	Late	D	420	117	257	3	2	3	3-	54.22
4	Late	D	424	117	281	2	3	2-	2	55.21
4	Late	D	439	99	188	2-	2-	2-	2	52.37

Diet	Maturity	Pen	ID	Days	Carcass weight (kg)	Fat score Overall	Hind quarter	Loin	Fore-quarter	Dressing Percentage
5	Early	A	183	99	178	3	3	3	3	52.98
5	Early	A	278	85	172	2	2	2	2	50.59
5	Early	A	282	78	204	3	3	3	3	52.99
5	Early	A	293	99	186	3-	3-	3-	2+	53.45
5	Early	A	298	117	195	2	3-	3-	2	51.72
5	Early	A	299	106	207	2+	2+	2+	2	53.63
5	Early	A	309	106	215	2	2-	2	2	54.29
5	Early	A	310	106	161	2	2-	2	2-	51.77
5	Early	A	329	78	209	3	3+	3+	3+	53.32
5	Early	A	330	78	169	2	2-	2-	2-	50.15
5	Late	B	155	117	243	3	3-	3	3	55.35
5	Late	B	375	117	310	2	1+	2-	2	54.29
5	Late	B	378	106	221	3	2+	3	2+	58.16
5	Late	B	383	117	263	2	2+	2	2+	52.71
5	Late	B	421	117	216	2	1+	2-	2	52.17
5	Late	B	441	99	219	2	2-	2	2-	51.90
5	Late	B	445	99	232	3-	2+	3-	3-	54.08
5	Late	B	452	85	210	2	2-	2+	2	53.85
5	Late	B	459	117	251	2	2	2+	2	52.07
5	Late	B	461	117	181	2	1+	2-	1+	53.24

Diet	Maturity	Pen	ID	Days	Carcass weight (kg)	Fat score Overall	Hind quarter	Loin	Fore-quarter	Dressing Percentage
6	Early	E	160	85	209	2	2-	2	2	55.73
6	Early	E	177	85	203	3	3	3+	3-	54.72
6	Early	E	186	85	173	3	3	3+	3	54.06
6	Early	E	249	78	195	3	3	3	3-	54.32
6	Early	E	254	99	186	2+	2+	2+	2+	54.87
6	Early	E	265	78	201	3	3-	3	3-	53.03
6	Early	E	267	78	179	2	2+	2+	2	51.14
6	Early	E	271	99	196	3	3	3	3-	55.06
6	Early	E	274	85	170	2	2	2	2+	51.52
6	Early	E	319	85	189	2	3	2+	2	55.10
6	Late	C	217	85	205	2	2	3-	2	54.09
6	Late	C	388	117	250	2	2+	2+	2+	52.97
6	Late	C	395	117	168	1	1	1	1-	50.45
6	Late	C	398	117	157	1	1	1	1-	49.37
6	Late	C	401	117	215	1	1+	1+	1	49.54
6	Late	C	402	99	225	1	1	1	1	54.09
6	Late	C	409	117	239	2	1+	2-	2-	52.53
6	Late	C	411	117	244	1	1	2-	1+	51.37
6	Late	C	422	117	270	1	1	2-	1	53.57
6	Late	C	463	117	185	2	1+	2-	2-	49.73

Appendix 2.3.3.2 Length of time in the feedlot (days) and carcass data for individual animals (group feeding)

Diet	Maturity	Pen	ID	Days	Carcass weight (kg)	Fat score Overall	Hind quarter	Loin	Fore-quarter	Dressing Percentage
4	Early	7	251	78	179	2	2	2+	2-	55.94
4	Early	7	261	64	193	2+	2+	3	2+	54.21
4	Early	7	287	64	173	3	3	3	3	53.73
4	Early	7	294	78	183	3	3	3	3	57.55
4	Early	7	318	78	189	2	2	2	2	55.43
4	Early	8	159	78	178	3	3	3+	3+	50.28
4	Early	8	184	92	210	4-	3+	4-	2	56.60
4	Early	8	206	92	215	3-	3-	2+	2	57.03
4	Early	8	270	64	176	2	3-	2+	2	53.99
4	Early	8	292	78	171	3	3-	3-	3-	54.29
4	Late	3	227	78	210	1	1+	1+	1+	53.85
4	Late	3	241	92	254	2	2	2+	3-	55.82
4	Late	3	391	106	239	3-	3-	3	2+	58.72
4	Late	3	428	106	195	4	4-	4-	4	52.99
4	Late	3	432	92	253	4	3+	4+	4	57.63
4	Late	4	377	92	218	3-	3	3-	2	56.48
4	Late	4	419	78	254	2	2	2	2	56.44
4	Late	4	434	117	275	3	2+	3+	3	57.53
4	Late	4	437	117	225	2	2	2+	2-	55.28
4	Late	4	449	106	255	2	2+	2	2-	53.13

Diet	Maturity	Pen	ID	Days	Carcass weight (kg)	Fat score Overall	Hind quarter	Loin	Fore-quarter	Dressing Percentage
5	Early	13	172	92	207	2-	2-	2-	2-	59.65
5	Early	13	262	64	188	3+	3	3+	1-0	56.12
5	Early	13	300	92	191	3-	3-	3	2+	55.36
5	Early	13	304	78	189	2	2+	2	2	54.00
5	Early	13	327	64	196	3	3-	3	3	54.44
5	Early	14	242	78	188	2	2	2	2	59.31
5	Early	14	263	64	167	3	3+	3	3	53.87
5	Early	14	279	78	198	2	2-	2+	2	54.10
5	Early	14	307	64	191	3	3+	3	3	54.57
5	Early	14	325	64	169	3	3	3+	3	52.81
5	Late	17	418	117	254	3	3	3	3-	54.27
5	Late	17	426	92	222	2-	1	2-	2-	53.49
5	Late	17	435	106	209	2	2-	2	2	52.51
5	Late	17	440	92	190	1	1	1	1	54.91
5	Late	17	453	117	318	3	3-	3	3	55.40
5	Late	18	208	78	200	3	3	3	3	56.02
5	Late	18	405	92	211	4	3+	5-	3+	56.12
5	Late	18	414	117	230	2	2-	2+	2	55.69
5	Late	18	427	117	287	3	2	3-	2+	54.98
5	Late	18	433	92	254	3	2	3+	2-	57.60

Diet	Maturity	Pen	ID	Days	Carcass weight (kg)	Fat score Overall	Hind quarter	Loin	Fore-quarter	Dressing Percentage
6	Early	15	139	78	179	3	3	3	3	53.12
6	Early	15	173	78	179	2	2	2	2	57.74
6	Early	15	257	78	191	3	3-	3	3	56.68
6	Early	15	311	64	174	2	2+	2+	2+	55.06
6	Early	15	314	64	164	2+	2	3-	2+	53.59
6	Early	16	182	78	184	2	2-	2	2	54.76
6	Early	16	235	78	226	3	3-	3	3-	63.13
6	Early	16	250	78	215	3	3	4-	3+	62.68
6	Early	16	289	92	191	2	2+	2+	3-	57.36
6	Early	16	323	92	190	3	3-	3-	2+	55.39
6	Late	5	211	117	201	3	3-	3	3-	55.83
6	Late	5	407	117	206	1	1	1+	1+	56.13
6	Late	5	431	117	238	1	1	1	1	52.65
6	Late	5	446	117	268	2	2	2-	2	56.30
6	Late	5	455	117	250	2	2	2+	2	54.59
6	Late	6	381	106	232	2	2	2	2	54.98
6	Late	6	416	106	183	1	1+	1+	1+	53.82
6	Late	6	451	92	204	2-	1	2-	2-	54.84
6	Late	6	458	117	254	3	3	4	3+	54.74
6	Late	6	460	117	252	2	2-	2	2-	54.55

Appendix 2.4.1.1 Example model of the statistical analysis of rectal temperature °C (9.00 am)

```
  27  treatmentstructure Maturity type*Weeks*Diet
  28  anova[fprob=yes;uprint=aov,means,%CV;cprint=aov,means;\
  29        print=aov,means,%cv] Rectal temperature (9.00 am)

29.....................................................................

***** Analysis of variance *****

Variate: Rectal temperature (9.00 am)

Source of variation      d.f.(m.v.)      s.s.       m.s.     v.r.  F pr.
Maturity type                 1          0.04968    0.04968   0.52  0.472
Weeks                        12          8.31923    0.69327   7.23  <.001
Diet                          3         15.57900    5.19300  54.15  <.001
Maturity type.Weeks          12          0.87207    0.07267   0.76  0.694
Maturity type.Diet            3          0.08837    0.02946   0.31  0.820
Weeks.Diet                   36          4.84126    0.13448   1.40  0.066
Maturity type.Weeks.Diet     36          2.83966    0.07888   0.82  0.759
Residual                   415(1)       39.79600    0.09589
Total                      518(1)       71.96014

***** Tables of means *****

Variate: Rectal temperature (9.00 am)

Grand mean  39.214

     Maturity type        1        2
                     39.224   39.204

    Weeks        1        2        3        4        5        6        7
            39.155   39.254   39.218   39.386   39.271   39.053   39.163

    Weeks        8        9       10       11       12       13
            39.309   39.101   38.969   39.328   39.421   39.154

    Diet         1        2        3        4
            39.297   39.242   39.389   38.928

*** Standard errors of differences of means ***

Table                  TYPE       Weeks      RATION        TYPE
                                                            Weeks
rep.                    260          40         130          20
d.f.                    415         415         415         415
s.e.d.                0.0272       0.0692      0.0384      0.0979

Table                  TYPE       Weeks        TYPE
                      RATION      RATION       Weeks
                                               RATION
rep.                    65          10           5
d.f.                    415         415         415
s.e.d.                0.0543       0.1385      0.1959

(Not adjusted for missing values)
***** Stratum standard errors and coefficients of variation *****

Variate: Temp

   d.f.          s.e.          cv%
    415        0.3097          0.8
```

Appendix 2.4.1.2 Example model of the determination of correlations between rectal temperature °C (9.00 am) and ambient temperature °C

```
 31  matrix[rows=13;columns=40]M
 32  equate !p(temp[1...13]); M
 33  calc N=transpose(M)
 34  variate [nvalues=13] Ta[1...40]
 35  equate N;!p(Ta[1...40])
 36  variate [nvalues=13] Mintemp,Maxtemp,Avtemp;\
 37   values=!(2.5,4.7,8.8,11.1,7.8,9.3,6.8,10.2,11.7,10.3,13.1,10.6,9.4),\
 38   !(20.1,21.6,27.2,21.7,22.8,12.8,19.8,27.3,17.9,13.5,20.0,29.7,18.3),\
 39   !(11.3,13.2,18.0,16.4,15.3,11.1,13.3,18.8,14.8,11.9,16.6,20.2,13.9)
 40
 41  variate[nvalues=13] Gr[1...8]
 42  calc Gr[1...8]= vmean(!p(Ta[1...5]),!p(Ta[6...10]),!p(Ta[11...15]),\
 43      !p(Ta[16...20]),!p(Ta[21...25]),!p(Ta[26...30]),!p(Ta[31...35]),\
 44      !p(Ta[36...40]))
 45
 46  correlate[print=corr] Gr[1...8],Mintemp,Maxtemp,Avtemp

*** Correlation matrix ***

        Gr[1]     1.000
        Gr[2]     0.502     1.000
        Gr[3]     0.697     0.590     1.000
        Gr[4]     0.107     0.105     0.214     1.000
        Gr[5]     0.490     0.336     0.654     0.189     1.000
        Gr[6]     0.695     0.440     0.646     0.374     0.536     1.000
        Gr[7]     0.331     0.708     0.669     0.053     0.410     0.315     1.000
        Gr[8]     0.049     0.500     0.365     0.605     0.383     0.347     0.474
     Mintemp    -0.008     0.196     0.202     0.001     0.162    -0.051     0.117
     Maxtemp     0.667     0.489     0.576     0.287     0.659     0.821     0.543
      Avtemp     0.573     0.523     0.603     0.251     0.649     0.686     0.530

                Gr[1]     Gr[2]     Gr[3]     Gr[4]     Gr[5]     Gr[6]     Gr[7]


        Gr[8]     1.000
     Mintemp     0.328     1.000
     Maxtemp     0.495    -0.002     1.000
      Avtemp     0.596     0.501     0.864     1.000

                Gr[8]   Mintemp   Maxtemp    Avtemp
 47
 48  variate[nvalues=13] GR[1...4]
 49  calc GR[1...4]= vmean(!p(Ta[1...5,21...25]),!p(Ta[6...10,26...30]),\
 50                !p(Ta[11...15,31...35]),!p(Ta[16...20,36...40]))
 51  correlate[print=corr] GR[1...4],Mintemp,Maxtemp,Avtemp

*** Correlation matrix ***

        GR[1]     1.000
        GR[2]     0.713     1.000
        GR[3]     0.675     0.727     1.000
        GR[4]     0.249     0.449     0.364     1.000
     Mintemp     0.089     0.078     0.177     0.186     1.000
     Maxtemp     0.768     0.782     0.613     0.456    -0.002     1.000
      Avtemp     0.708     0.717     0.622     0.490     0.501     0.864     1.000

                GR[1]     GR[2]     GR[3]     GR[4]   Mintemp   Maxtemp    Avtemp
```

Appendix 2.4.2 Example model of the statistical analysis of the animals live weights (kg's)

```
 21  covariate Start mass
 22  for I=Final mass
 23  treatmentstructure Maturity type*Site*Diet
 24  anova[uprint=aov,means,%cv;\
 25        print=aov,means,%cv;fprob=yes;pfactorial=2] I
 26  endfor
```

***** Analysis of variance (adjusted for covariate) *****

Variate: Final mass
Covariate: Start mass

Source of variation	d.f.	s.s.	m.s.	v.r.	cov.ef.	F pr.
Maturity type	1	69531.2	69531.2	75.20	0.86	<.001
Site	1	457.9	457.9	0.50	0.98	0.483
Diet	2	4630.2	2315.1	2.50	1.00	0.087
Maturity type.Site	1	6425.5	6425.5	6.95	1.00	0.010
Maturity type.Diet	2	426.1	213.0	0.23	0.99	0.795
Site.Diet	2	282.8	141.4	0.15	1.00	0.858
Maturity type.Site.Diet	2	438.4	219.2	0.24	1.00	0.789
Covariate	1	120163.2	120163.2	129.96		<.001
Residual	107	98933.1	924.6		2.19	
Total	119	407815.6				

***** Tables of means (adjusted for covariate) *****

Variate: Final mass
Covariate: Start mass

Grand mean 387.4

Maturity type	1.00	2.00
	361.9	413.0

Site	1.00	2.00
	389.3	385.6

Diet	1.00	2.00	3.00
	388.8	394.3	379.2

Maturity type	Site	1.00	2.00
1.00		371.1	352.7
2.00		407.5	418.5

Maturity type	Diet	1.00	2.00	3.00
1.00		364.9	369.7	351.0
2.00		412.6	419.0	407.5

Site	Diet	1.00	2.00	3.00
1.00		389.2	398.3	380.3
2.00		388.3	390.3	378.2

*** Standard errors of differences of means ***

Table	Maturity type	Site	Diet	Maturity type Site
rep.	60	60	40	30
d.f.	107	107	107	107
s.e.d.	5.98	5.61	6.80	8.09

Table	Maturity type Diet	Site Diet
rep.	20	20
d.f.	107	107
s.e.d.	9.78	9.64

***** Stratum standard errors and coefficients of variation (adjusted for covariate) *****

Variate: Final mass
Covariate: Start mass

d.f.	s.e.	cv%
107	30.41	7.8

Appendix 2.4.3 Example model of the determination of prediction equations

```
 20  For I=ME
 21
 22  for J=ADG
 23  model J
 24  terms I+Start mass+Maturity type+Site
 25  add [nomes=l,r;tprob=yes] I
 26  add [nomes=l,r;tprob=yes] Start mass
 27  add [nomes=l,r;tprob=yes] Site
 28  endfor
 29  endfor

***** Regression Analysis *****

 Response variate: ADG
     Fitted terms: Constant + ME + Start mass + Site


*** Summary of analysis ***

              d.f.          s.s.          m.s.       v.r.
Regression       3         2.623       0.87419      17.16
Residual       116         5.909       0.05094
Total          119         8.531       0.07169

Change          -1        -0.364       0.36372       7.14

Percentage variance accounted for 28.9
Standard error of observations is estimated to be 0.226


*** Estimates of regression coefficients ***

                          estimate          s.e.    t(116)  t pr.
Constant                    -2.265         0.712     -3.18  0.002
ME                          0.3348        0.0691      4.84  <.001
Start mass                0.003454      0.000725      4.76  <.001
Site 2                      0.1111        0.0416      2.67  0.009
```

Appendix 3.1.1 Nutrient composition of diets Seven, Eight and Nine on a dry matter basis

Diet	Rep.	CP %	Ca %	P %	FAT %	ASH %	C.FIBRE %	NDF %	ADF %	MOISTURE %
7	1	13.74	1.02	0.50	5.58	8.20	11.28	33.54	15.92	14.84
7	2	13.36	1.01	0.52	5.77	8.17	11.36	32.52	15.88	14.84
7	3	14.15	0.80	0.48	6.09	7.77	15.04	40.12	18.42	13.89
7	4	13.93	0.81	0.48	5.58	7.76	14.88	38.76	19.44	14.54
7	5	14.90	0.80	0.53	3.59	7.77	13.42	40.76	18.92	11.86
7	6	14.51	0.77	0.55	3.71	7.41	13.42	43.08	20.12	11.78
7	7	16.04	0.81	0.48	6.88	7.77	14.22	42.16	20.00	10.81
7	8	16.16	0.81	0.50	6.94	7.65	14.72	41.60	20.10	10.73
8	1	14.24	0.75	0.48	3.75	7.41	13.87	40.16	20.02	13.27
8	2	13.67	0.76	0.52	3.79	7.19	13.40	40.56	20.00	13.54
8	3	13.80	0.73	0.52	4.73	7.43	15.15	41.28	19.74	12.70
8	4	13.68	0.72	0.51	4.76	7.42	15.68	41.36	21.04	13.83
8	5	13.63	0.84	0.50	3.71	8.25	13.43	40.72	19.60	12.89
8	6	13.75	0.85	0.51	3.62	8.23	14.18	40.76	19.04	12.88
8	7	14.16	0.90	0.53	3.51	8.16	15.92	43.08	18.90	11.66
8	8	14.24	0.90	0.50	3.51	8.21	15.47	41.48	20.12	11.01
9	1	14.24	0.79	0.55	1.48	6.56	10.44	40.10	16.04	13.20
9	2	13.67	0.77	0.59	1.48	6.67	10.63	40.40	16.70	13.16
9	3	14.40	0.72	0.61	1.55	7.06	11.38	40.96	16.78	12.68
9	4	14.52	0.73	0.59	1.61	7.15	12.10	39.00	16.84	12.17
9	5	15.58	0.78	0.58	1.90	7.37	10.94	40.56	16.36	12.06
9	6	14.82	0.79	0.57	1.68	7.14	10.93	40.44	16.86	12.68
9	7	14.06	0.78	0.57	1.72	7.57	14.11	42.32	18.72	12.59
9	8	14.17	0.78	0.58	1.66	7.61	14.25	42.84	18.74	12.63

Appendix 3.1.2 Metabolism study of diets Seven, Eight and Nine

Diet	Refusals			Faeces (g)	Urine (ml)	Crude protein (g)		Gross energy (MJ)		Organic matter (g)
	Dry matter (g)	CP (g)	GE (MJ)			Faeces	Urine	Feed	Faeces	Faeces
7				1938.4	14040	242.69	482.63	110.26	33.36	14.71
7	893.1	114.99	14.40	1859.2	4025	227.38	535.83	95.86	30.55	15.54
7	93.1	6.78	1.42	2083.1	10340	253.51	491.15	108.84	35.73	14.75
7				2397.6	10900	285.31	436.00	110.26	39.62	14.28
7	753.6	87.06	10.57	2160.1	4020	258.56	447.23	99.69	35.75	13.78
8				1929.6	9690	247.57	496.88	111.18	32.45	15.16
8				2036.2	6950	253.91	599.25	111.18	34.06	14.65
8				1815.2	8110	222.73	512.43	111.18	30.59	13.82
8				1646.3	13750	188.01	513.56	111.18	27.74	14.87
8	79.7	0.6	1.27	1739.2	12610	228.53	449.21	109.92	29.28	14.16
9				2340.3	5265	283.88	599.57	106.90	38.32	13.89
9				1861.7	10200	248.72	621.16	106.90	31.15	13.56
9				1828.9	7960	247.45	623.46	106.90	30.84	15.45
9				1803.4	14940	215.87	635.94	106.90	30.76	13.00
9				2361.9	10890	322.16	567.45	106.90	37.88	12.68

Appendix 3.2.1 Prime rib cut dissection weights (kg) and chemical composition (%)

Diet	ID	carcass (kg)	Prime Rib Cut (8-10th) (kg)				Prime rib cut chemical composition (%)		
			Whole	Subcutaneous Fat	Muscle	Bone	Protein	Chemical Fat	Mositure
Control	280	174	4.974	0.148	3.571	1.255	18.016	17.383	63.710
Control	192	161	4.621	0.096	3.475	1.050	17.821	13.464	67.600
Control	447	152	3.819	0.062	2.784	0.973	18.357	12.310	68.300
Control	158	140	4.011	0.065	2.874	1.072	18.537	9.410	71.160
Control	281	149	4.504	0.086	3.300	1.118	17.808	14.842	66.460
7	199	235	8.168	0.671	5.940	1.557	18.033	26.483	55.510
7	216	254	7.565	0.328	5.695	1.542	19.240	20.962	59.820
7	225	221	6.242	0.316	4.774	1.152	19.742	20.066	60.210
7	248	251	8.283	0.624	6.324	1.335	17.947	26.089	55.990
7	259	210	6.268	0.359	4.570	1.339	19.493	19.086	61.450
7	288	246	8.400	0.596	6.284	1.520	19.445	20.548	60.030
7	324	218	7.506	0.644	5.675	1.187	17.341	27.776	54.910
7	443	251	7.791	0.443	5.970	1.378	19.997	22.328	57.690
8	128	237	7.206	0.223	5.567	1.416	19.746	19.088	61.190
8	179	224	7.265	0.469	5.499	1.297	18.845	22.470	58.710
8	180	216	6.413	0.339	4.859	1.215	17.603	25.871	56.560
8	185	229	7.067	0.334	5.299	1.434	19.160	20.366	60.500
8	197	231	7.238	0.477	5.495	1.266	18.822	23.485	57.720
8	220	279	8.457	0.399	6.433	1.625	18.589	22.733	58.710
8	315	248	7.787	0.420	5.840	1.527	19.384	21.468	59.170
8	408	252	8.000	0.425	6.119	1.456	18.242	25.080	56.700
9	178	247	6.884	0.413	5.094	1.377	19.178	23.221	57.630
9	228	226	7.807	0.643	5.748	1.416	18.475	24.369	57.180
9	231	240	6.929	0.240	5.094	1.595	18.937	21.588	59.500
9	268	228	7.078	0.506	5.357	1.215	19.276	22.047	58.700
9	296	225	7.914	0.552	6.115	1.247	19.885	18.964	61.180
9	297	254	8.425	0.613	6.373	1.439	17.171	29.121	53.730
9	317	250	8.449	0.481	6.674	1.294	18.141	25.998	55.880
9	320	255	7.936	0.886	5.680	1.370	18.232	26.640	55.150

Appendix 3.3.1 Rectal temperatures °C (9.00 am) of individual animals over time (weeks)

			Week										
Diet	Pen	ID	0	1	2	3	4	5	6	7	8	9	10
7	H	243	39.5	39.1	38.9	39.2	39.1	39.3	39.1	38.8	38.8		
7	H	253	38.6	39.3	38.7	38.8	39.1	39.6	38.9	38.8	38.8		
7	H	295	38.2	39.2	38.7	39.2	39.4	39.2					
7	H	443	38.5	39.2	38.9	39.6	39.9	39.4	39.6	38.9	39.5	39.6	38.8
7	H	468	38.6	38.8	39.0	39.1	39.1	39.0	38.9	38.9	38.8		
7	J	163	38.6	38.9	38.0	39.4	39.2	39.1	39.2	38.9	38.8	38.9	
7	J	205	38.4	39.1	39.0	39.3	39.0	39.3	39.3	38.8	39.2	39.0	
7	J	225	38.4	39.1	39.3	39.0	39.0	39.0	39.0	38.9	38.9	39.0	
7	J	248	38.5	38.8	38.6	39.4	39.5	38.9	39.0	39.0	39.0	38.8	
7	J	288	39.1	38.8	39.0	39.1	39.1	39.1	38.9	39.0	39.1	38.8	39.3

			Week										
Diet	Pen	ID	0	1	2	3	4	5	6	7	8	9	10
8	I	128	38.7	38.8	38.6	39.4	39.2	39.2	39.1	38.8	38.9	39.0	39.0
8	I	180	37.9	39.3	39.3	39.0	39.3	39.8	39.4	39.4	39.3		
8	I	197	37.9	39.4	38.5	39.0	39.5	39.0	39.2	39.9	39.7	38.7	
8	I	331	37.9	38.7	38.0	39.1	39.1	39.0	38.8	39.1	39.1	38.8	39.1
8	I	397	39.0	39.2	38.9	38.5	39.2	38.9	39.0	38.9	38.9	39.2	38.9
8	L	185	38.7	39.1	39.2	39.0	39.0	39.2	39.1	39.0	39.0		
8	L	385	38.3	38.9	39.4	39.1	39.1	39.8	39.7	39.0	39.2	38.8	39.0
8	L	415	38.0	38.8	38.9	38.5	38.9	39.0	39.1	38.7	38.8	39.0	39.3
8	L	425	39.1	39.1	38.9	39.2	38.9	39.1	39.0	38.9	38.8		
8	L	444	38.9	39.0	39.2	39.3	39.2	39.5	39.2	39.0	39.1	39.2	38.8

			Week										
Diet	Pen	ID	0	1	2	3	4	5	6	7	8	9	10
9	G	228	38.5	39.0	38.8	39.1	39.0	39.0	38.9	38.9	38.8	38.8	
9	G	230	37.9	39.0	38.5	39.1	38.8	39.0	39.0	38.8	38.7		
9	G	231	38.9	38.8	38.6	38.8	38.7	39.1	39.0	39.0	38.9		
9	G	268	37.9	39.2	38.6	39.0	38.9	38.9	39.0	38.9	38.7	39.2	
9	G	321	39.1	38.1	38.8	39.1	38.1	38.9	39.0	39.1	38.9		
9	K	245	38.4	38.4	38.9	39.5	39.8	39.2	39.3	39.2	39.3	38.8	38.8
9	K	291	39.0	39.0	39.3	39.0	39.1	39.0	39.2	39.4	39.1	39.9	
9	K	305	39.4	39.0	39.1	39.2	39.4	39.1	39.2	39.0	38.9	38.5	38.8
9	K	317	39.1	39.0	39.1	39.3	39.3	39.0	39.4	39.0	39.2	38.9	
9	K	320	39.0	39.1	39.3	38.7	39.6	39.5	39.5	39.7	39.4	38.5	39.1

			Week										
Diet	Pen	ID	0	1	2	3	4	5	6	7	8	9	10
Control	Pasture	27		38.8	39.2	38.5		38.8	38.5	38.7	38.6	38.7	38.7
Control	Pasture	150		38.9	39.0	38.7		38.3	38.6	38.9	38.9	38.8	38.5
Control	Pasture	157		39.3	38.6	38.7		38.9	38.8	39.3	38.8	39.3	38.9
Control	Pasture	224		38.8	38.4	38.2		38.1	38.2	38.6	38.3	39.0	38.5
Control	Pasture	238		39.2	38.6	38.5		38.9	39.1	39.1	39.0	39.5	38.7
Control	Pasture	244		39.5	39.1	38.8		39.0	38.5	38.6	38.9	38.9	38.9
Control	Pasture	256		38.9	39.3	38.6		39.0	38.8	39.0	38.8	39.1	39.0
Control	Pasture	272		39.5	38.9	38.4		39.0	38.8	38.6	38.6	39.1	38.8
Control	Pasture	284		39.2	38.7	38.5		38.9	38.7	38.6	38.5	39.0	38.7
Control	Pasture	303		39.1	39.1	38.5		38.7	38.6	38.6	38.8	38.8	38.8

Appendix 3.3.2 Rectal temperatures °C (2.00 pm) of individual animals over time (weeks)

			Week										
Diet	Pen	ID	0	1	2	3	4	5	6	7	8	9	10
7	H	243	39.7	39.5	39.5	39.5	39.1	39.3	39.1	39.9	39.1		
7	H	253	39.5	39.3	39.2	39.5	39.2	39.0	39.2	39.1	39.1		
7	H	295	39.0	39.5	39.1	39.5	39.5	39.6					
7	H	443	38.9	39.4	38.9	39.0	40.1	39.7	40.0	39.2	39.5	39.1	39.0
7	H	468	39.0	38.1	39.4	39.5	39.5	39.3	39.3	39.1	39.1		
7	J	163	38.6	39.1	39.0	39.6	39.4	39.3	39.7	39.2	39.5	39.5	
7	J	205	39.0	39.3	39.0	39.5	39.3	39.2	39.3	39.4	39.5	39.3	
7	J	225	38.8	39.3	39.1	39.3	39.2	39.1	39.2	39.1	39.2	39.0	
7	J	248	39.1	39.5	39.1	39.0	40.3	39.4	39.7	39.4	39.1	39.0	
7	J	288	39.1	39.4	39.0	40.2	40.0	39.4	39.5	39.1	39.3	39.5	38.8

			Week										
Diet	Pen	ID	0	1	2	3	4	5	6	7	8	9	10
8	I	128	39.2	39.8	38.9	40.2	40.5	39.9	40.3	39.7	39.3	39.3	39.0
8	I	180	39.3	39.8	39.1	39.4	39.4	39.9	39.7	39.1	39.1		
8	I	197	37.9	39.6	39.0	39.4	39.6	39.4	39.5	39.2	39.5	39.0	
8	I	331	39.3	39.4	39.0	39.6	39.8	39.4	39.4	39.0	39.7	38.8	39.3
8	I	397	39.6	39.3	39.0	40.5	39.6	39.2	39.5	39.0	39.0	39.5	39.3
8	L	185	39.2	39.2	39.0	39.5	39.3	39.4	39.5	39.3	39.5		
8	L	385	38.5	39.3	39.6	40.8	39.4	40.0	41.0	39.4	39.5	40.2	38.9
8	L	415	38.5	39.4	38.9	39.2	40.2	39.6	39.9	38.9	39.8	39.8	38.3
8	L	425	39.2	39.1	39.5	39.8	39.2	39.6	39.4	39.0	39.0		
8	L	444	39.7	39.5	39.2	40.5	39.9	40.2	39.9	39.1	39.9	39.3	39.0

			Week										
Diet	Pen	ID	0	1	2	3	4	5	6	7	8	9	10
9	G	228	39.0	39.3	39.1	39.2	39.4	39.3	39.2	39.3	39.2	39.5	
9	G	230	38.7	39.2	39.0	39.2	39.9	39.5	39.3	39.1	39.2		
9	G	231	39.1	39.6	38.7	39.2	39.6	39.5	39.2	39.1	39.0		
9	G	268	38.9	39.4	39.2	40.5	40.0	39.4	39.4	39.2	39.2	39.3	
9	G	321	39.3	38.8	39.0	40.5	40.5	39.8	39.8	39.7	39.5		
9	K	245	39.1	39.5	38.5	40.3	40.1	39.3	39.6	39.5	39.3	38.8	39.0
9	K	291	39.5	39.4	39.2	39.3	39.2	39.3	39.2	39.3	39.3	39.7	
9	K	305	39.5	40.0	39.0	39.6	39.7	39.8	39.4	38.9	39.1	39.9	38.8
9	K	317	39.5	39.3	39.0	39.5	39.6	39.6	39.6	39.0	39.1	39.9	
9	K	320	39.4	39.5	38.8	39.7	39.6	39.4	39.5	39.1	39.8	39.7	39.3

Appendix 3.3.3 Respiration rate (breaths / 30 seconds) of individual animals over time (weeks)

Diet	ID	Week 0	1	2	3	4	5	6	7
7	243	19	30	17	31	28			28
7	253	17	31	21	24	22			21
7	295	16	20	17	23	21			
7	443	17	29	21	19	19			18
7	468	15	20	13	37	33			32
7	163	13	21	16	28	26			26
7	205	17	31	18	27	24			22
7	225	12	21	14	18	16			16
7	248	16	26	17	24	21			20
7	288	14	35	17	25	23			23
8	128	14	36	17	24	22			21
8	180	18	28	23	33	31			30
8	197	21	34	20	26	24			23
8	331	14	22	11	20	18			17
8	397	19	36	20	32	29			28
8	185	15	33	14	30	27			26
8	385	12	25	18	26	22			21
8	415	15	24	12	23	20			18
8	425	21	42	15	34	31			28
8	444	30	34	20	27	23			21
9	228	16	16	15	24	17			17
9	230	13	15	16	19	18			19
9	231	15	28	21	20	19			19
9	268	17	30	22	24	20			20
9	321	18	22	14	23	20			19
9	245	13	34	20	31	29			28
9	291	15	30	17	30	27			26
9	305	18	21	18	34	31			30
9	317	14	27	19	20	20			18
9	320	15	32	21	26	24			23
control	27	17	20						
control	150	22	21						
control	157	21	20						
control	224	12	18						
control	238	12	16						
control	244	14	24						
control	256	22	20						
control	272	15	22						
control	284	13	16						
control	303	13	22						

Appendix 3.3.4 Weekly means of the maximum, average and minimum ambient temperatures °C for the weeks of rectal temperature and respiration rate recordings.

Week	Ambient temperatures for the days rectal temperature were recorded			Ambient temperatures for the days respiration rates were recorded			Mean (S.E.) of the weeks average ambient temperature
	Maximum	Average	Minimum	Maximum	Average	Minimum	
0	25.9	21.2	16.5	25.6	21.2	16.8	20.57 (0.41)
1	25.8	18.9	12.0	19.9	18.5	17.0	20.09 (0.81)
2	31.8	22.4	13.0	23.9	18.4	12.8	17.69 (0.99)
3	17.3	16.2	15.0	28.3	20.1	11.8	19.39 (0.78)
4	28.6	21.4	14.2	22.5	19.1	15.7	19.69 (0.55)
5	27.8	20.6	13.4	27.3	20.8	14.2	19.81 (0.57)
6	28.5	20.9	13.3	25.3	17.4	9.4	17.99 (0.88)
7	23.4	17.1	10.7	26.0	18.4	10.7	18.00 (0.44)
8	27.9	19.7	11.5	20.0	16.5	13.0	18.71 (0.42)

Appendix 3.4.1 An animal's dry matter feed-intake kg's (calan gates) over time (weeks)

			Week											
Diet	Pen	ID	1	2	3	4	5	6	7	8	9	10	11	12
7	H	114	85	93	92	91	99	142						
7	H	189	98	138	86	94	120	92	97	94				
7	H	243	91	63	79	92	101	116	83	118				
7	H	253	91	98	67	87	113	110	94	95				
7	H	259	94	99	96	94	137	127	82	108				
7	H	295	84	92	91	123	109	95						
7	H	306	81	91	100	118	124	76	76	96	117	100		
7	H	328	84	90	93	79	99	93						
7	H	443	68	81	86	95	110	87	114	139	139	125	81	124
7	H	468	35	94	87	118	88	87	92	93				
7	J	151	99	103	77	100	114	85	105	96	125	137	108	
7	J	163	59	72	78	111	104	111	100	89	63	87		
7	J	199	84	95	85	98	73	89	107	100				
7	J	205	87	96	104	124	89	89	94	84	83	86		
7	J	216	48	70	82	68	94	95	93	84	62	98	95	69
7	J	225	64	88	63	101	109	89	90	93	96	128		
7	J	248	86	93	94	97	96	93	93	98	92	110		
7	J	285	96	92	114	98	84	88	117	104	92	122		
7	J	288	69	90	93	133	86	88	98	95	87	113	94	
7	J	324	102	107	133	114	77	56	89	90	79	124		

			Week											
Diet	Pen	ID	1	2	3	4	5	6	7	8	9	10	11	12
8	I	22	56	66	79	97	89	121	81	79	117	90	100	
8	I	169	85	118	96	113	96	81	95	112	136	125	91	
8	I	180	81	92	90	69	116	63	139	120				
8	I	193	101	77	95	97	94	110						
8	I	197	52	71	78	79	98	108	90	63	135	110		
8	I	239	83	62	69	78	92	124	95	80	93	108		
8	I	315	70	86	66	90	96	81	84	91	79	92	114	
8	I	331	30	90	67	87	77	127	99	80	103	117	88	86
8	I	397	95	74	62	112	71	84	85	90	93	90	101	
8	L	179	68	105	90	117	109	123	96	117	105	99		
8	L	185	77	85	91	101	116	117	83	73				
8	L	220	91	67	97	84	130	123	104	99				
8	L	286	83	120	102	87	127	93	110	116				
8	L	408	67	102	82	99	113	89	107	107	118	116		
8	L	415	65	61	49	88	52	65	63	80	86	137	73	106
8	L	425	43	104	115	103	129	59	98	112				
8	L	444	57	84	84	73	90	112	91	122	110	110	125	106

Diet	Pen	ID	Week 1	2	3	4	5	6	7	8	9	10	11	12
9	G	160	65	66	91	87	97	124	92	88	92	98	73	
9	G	195	96	105	90	109	108	117						
9	G	202	34	62	93	94	82	101	77	98	70	86		
9	G	228	68	75	99	124	105	90	87	90	102	86		
9	G	230	65	92	90	94	112	111	77	99				
9	G	231	53	66	58	85	81	94	94	123				
9	G	252	75	93	42	106	91	108	91	87	95	98	90	
9	G	268	39	73	84	73	94	114	83	82	69	81		
9	G	275	91	112	103	75	150	120						
9	G	321	78	105	107	101	108	121	90	122				
9	K	178	79	113	105	106	85	102	96	107	72	81	99	69
9	K	207	71	71	78	56	74	96	88	78	137	132	111	
9	K	245	59	66	73	158	107	59	78	84	113	125	90	90
9	K	291	95	95	68	59	84	103	68	85	96	90		
9	K	296	83	114	141	86	104	103	116	120	108	117	114	
9	K	297	68	88	62	94	106	90	91	91	87	90		
9	K	305	70	64	94	81	75	100	91	71	84	85	71	
9	K	317	80	86	93	60	98	70	78	91	114	92		
9	K	320	54	77	68	79	89	146	79	84	102	122	79	
9	K	448	83	78	76	132	105	102	84	80	102	76	94	101

Appendix 3.4.2 Individual animals live weights (kg's) over time (weeks) (calan gate feeding)

			Week												
Diet	Pen	ID	0	1	2	3	4	5	6	7	8	9	10	11	12
7	H	114	309	326	341	361	367	387	404						
7	H	189	360	368	382	405	413	428	451	460	467				
7	H	243	299	320	335	347	365	379	387	404	416				
7	H	253	331	343	361	373	385	410	423	435	453				
7	H	259	299	307	317	340	346	364	378	385	406				
7	H	295	361	367	389	409	420	445	465						
7	H	306	286	293	313	332	347	367	390	383	414	428	444		
7	H	328	330	350	362	387	393	415	431						
7	H	443	283	293	306	331	357	369	385	420	434	448	467	471	488
7	H	468	365	378	386	405	432	443	467	470	470	481			
7	J	151	332	344	363	368	394	396	411	420	435	440	460	472	
7	J	163	326	360	379	390	408	419	433	436	446	462	476		
7	J	199	327	347	358	375	392	412	428	438	452				
7	J	205	353	364	382	393	411	431	454	460	468	484	499		
7	J	216	273	272	299	313	327	352	375	381	397	411	423	433	448
7	J	225	290	308	323	344	360	374	404	409	419	430	449		
7	J	248	315	344	360	371	393	405	428	437	442	456	482		
7	J	285	370	391	401	417	429	452	462	468	484	501	515		
7	J	288	279	310	332	349	358	377	393	413	418	437	444	467	
7	J	324	318	323	330	350	355	379	390	403	412	418	447		

Diet	Pen	ID	Week 0	1	2	3	4	5	6	7	8	9	10	11	12
8	I	22	302	337	343	354	360	369	376	402	415	426	433	443	
8	I	169	316	334	342	352	367	383	382	383	413	423	427	448	
8	I	180	293	320	331	353	345	381	399	402	427				
8	I	193	355	382	389	410	428	450	468						
8	I	197	270	293	306	317	342	353	383	394	420	439	462		
8	I	239	255	276	280	297	309	325	339	357	362	392	409		
8	I	315	298	308	316	319	346	360	380	399	410	435	454	459	
8	I	331	306	314	333	352	351	364	372	380	423	435	455	446	470
8	I	397	342	360	382	397	404	412	427	438	450	469	485	488	
8	L	179	298	332	338	359	365	385	405	410	420	435	456		
8	L	185	315	333	348	369	386	394	415	419	435				
8	L	220	382	411	421	443	461	483	503	514	529				
8	L	286	329	343	361	373	379	403	420	432	440				
8	L	408	330	340	368	376	391	407	420	431	439	446	478		
8	L	415	301	314	316	325	362	364	385	398	422	432	452	456	476
8	L	425	291	304	335	357	373	383	406	408	423				
8	L	444	304	311	327	346	360	376	396	401	409	433	439	452	476

Diet	Pen	ID	Week 0	1	2	3	4	5	6	7	8	9	10	11	12
9	G	165	292	301	304	326	342	359	365	382	395	400	416	427	
9	G	195	333	352	361	380	397	405	423						
9	G	202	313	321	337	362	374	386	396	396	391	428	437		
9	G	228	292	306	318	342	355	366	381	393	407	420	437		
9	G	230	338	343	357	374	397	407	427	444	462				
9	G	231	377	364	391	405	413	428	440	460	474				
9	G	252	306	329	349	362	374	385	401	409	427	436	454	458	
9	G	268	294	313	322	340	361	365	384	400	411	418	435		
9	G	275	314	335	349	367	382	395	421						
9	G	321	346	354	373	395	404	415	430	442	467				
9	K	178	359	368	384	394	413	433	446	451	466	477	488	502	510
9	K	207	354	356	370	391	388	397	427	435	445	457	474	485	
9	K	245	295	311	325	338	338	356	369	380	395	403	414	427	438
9	K	291	341	355	355	381	393	407	428	429	450	463	484		
9	K	296	298	314	326	340	360	367	386	398	415	426	446	451	
9	K	297	347	357	372	391	401	422	438	448	456	469	492		
9	K	305	291	306	306	324	338	358	365	373	396	408	420	418	
9	K	317	329	340	353	371	388	405	423	425	446	467	484		
9	K	320	330	311	336	355	372	386	401	420	439	443	459	464	
9	K	448	324	331	347	360	376	387	406	413	434	453	468	489	501

Appendix 3.4.3 Length of time in the feedlot (days) and carcass data for individual animals (calan gate feeding)

Diet	Pen	ID	Days	Carcass weight (kg)	Fat score Overall	Hind quarter	Loin	Fore-quarter	Dressing Percentage
7	H	114	43	203	3	2+	2+	3-	50.248
7	H	151	78	252	4	3	4-	4	53.390
7	H	163	70	238	3	3+	3+	3	50.000
7	H	189	57	245	3	3+	3+	3	52.463
7	H	199	57	235	3	3+	3	3	51.991
7	H	205	70	264	2	2	2+	2	52.906
7	H	216	85	254	2	2	2-	2	56.696
7	H	225	70	221	3	2+	3	3	49.220
7	H	243	57	221	2	2	2	2	53.125
7	H	248	70	251	4	4	4	3	52.075
7	J	253	57	224	2	2	2	2	49.448
7	J	259	57	210	3	3	3	3	51.724
7	J	285	70	263	4	4+	5-	4	51.068
7	J	288	78	246	3	3	3	3	52.677
7	J	295	43	236	3	3	3	3	50.753
7	J	306	70	222	3	3	3	3	50.000
7	J	324	70	218	3	4-	3+	3+	48.770
7	J	328	43	217	3	3-	3	2+	50.348
7	J	443	85	251	2	2-	2+	3-	51.434
7	J	468	57	257	2	2-	2	2	53.430

Diet	Pen	ID	Days	Carcass weight (kg)	Fat score Overall	Hind quarter	Loin	Fore-quarter	Dressing Percentage
8	I	22	78	244	3	3	3	3	55.079
8	I	169	78	243	4	4	4+	3	54.241
8	I	179	70	224	3	3	3	3	49.123
8	I	180	57	216	2	2-	2	2-	50.585
8	I	185	57	229	2	3-	2	2	52.644
8	I	193	43	236	3	2+	3-	3-	50.427
8	I	197	70	231	3	3	3+	3	50.000
8	I	220	57	279	3	3	3+	3	52.741
8	L	239	70	201	2	3-	2+	2+	49.144
8	L	286	57	229	3	3+	3+	3	52.045
8	L	315	78	248	3	3	3	3+	54.031
8	L	331	85	241	3	3	3	3	51.277
8	L	397	78	255	3	3-	3	3	52.254
8	L	408	70	252	3	3-	3-	3+	52.720
8	L	415	85	283	4	3+	4+	4-	59.454
8	L	425	57	217	2	2-	2+	2+	51.300
8	L	444	85	244	3	3	4+	3+	51.261

Diet	Pen	ID	Days	Carcass weight (kg)	Fat score Overall	Hind quarter	Loin	Fore-quarter	Dressing Percentage
9	G	165	78	225	4	3-	4	4	52.693
9	G	178	85	247	3	3-	3+	3	48.431
9	G	195	43	208	3	3	3	3-	49.173
9	G	202	70	226	2	3-	2+	2+	51.716
9	G	207	78	248	3	3	3	3	51.134
9	G	228	70	226	2	2-	2	2+	51.716
9	G	230	57	241	3	2+	3	3	52.165
9	G	231	57	240	2	2-	2-	2-	50.633
9	G	245	85	227	3	3-	3-	3	51.826
9	G	252	78	247	4	4-	5-	4+	53.930
9	K	268	70	228	3	3	3+	3	52.414
9	K	275	43	205	3	3	3	3	48.694
9	K	291	70	252	4	3+	5	4	52.066
9	K	296	78	225	3	3	3	3-	49.889
9	K	297	70	254	3	3	3+	3+	51.626
9	K	305	78	215	4	4+	5-	4+	51.435
9	K	317	70	250	4	3	4	4	51.653
9	K	320	78	255	3	3	3+	4-	54.957
9	K	321	57	236	3	3+	3	3	50.535
9	K	448	85	250	2	1+	2	2	49.900

Appendix 3.5.1 Example model of the statistical analysis of prime rib cut composition

```
 15  factor [levels=4; values=(8(7),8(8),8(9),5(Control))] Diet
 16
 17  factor [levels =4;nvalues=29] Q2,Q3,Q4
 18  calc Q2=newlevels (Diet;!(2,1,3,4))
 19  calc Q3=newlevels (Diet;!(3,2,1,4))
 20  calc Q4=newlevels (Diet;!(4,3,2,1))
 21
 22  for I= Prime rib cut subcutaneous fat (PRsf)
 24
 25  for J=Treat,Q2,Q3,Q4
 26  model I
 27  terms J
 28  add  [tprob=yes] J
 29  endfor
 30  endfor

30.....
.....


***** Regression Analysis *****

 Response variate: PRsf
     Fitted terms: Constant, Diet 7


*** Summary of analysis ***

              d.f.          s.s.          m.s.       v.r.
Regression       3        0.7125       0.23750      12.85
Residual        25        0.4619       0.01848
Total           28        1.1744       0.04194

Change          -3       -0.7125       0.23750      12.85

Percentage variance accounted for 55.9
Standard error of observations is estimated to be 0.136
* MESSAGE: The following units have large standardized residuals:
                  11       -2.37
                  16        2.71
* MESSAGE: The error variance does not appear to be constant:
           large responses are more variable than small responses


*** Estimates of regression coefficients ***

                 estimate         s.e.      t(25)  t pr.
Constant           0.4976       0.0481      10.35  <.001
Diet  8            0.0441       0.0680       0.65  0.522
Diet  9           -0.1119       0.0680      -1.65  0.112
Control           -0.4062       0.0775      -5.24  <.001
```

Appendix 3.5.2.1 Example model of the statistical analysis of rectal temperature °C (9.00 am)

```
  25  treatmentstructure Weeks*Diet
  26  anova[fprob=yes;uprint=aov,means,%CV;cprint=aov,means;\
  27        print=aov,means,%cv] Temp

27.....................................................................
.....

***** Analysis of variance *****

Variate: Temp

Source of variation     d.f.(m.v.)      s.s.        m.s.     v.r.  F pr.
Weeks                        8          8.61951    1.07744   12.14  <.001
Diet                         3          4.41764    1.47255   16.59  <.001
Weeks.Diet                  22(2)       4.56005    0.20728    2.34  <.001
Residual                   303(21)     26.89178    0.08875
Total                      336(23)     40.87840


***** Tables of means *****

Variate: Temp

Grand mean  38.940

    Weeks         1         2         3         4         5         6         7
           38.538    39.010    38.873    38.960    39.086    39.068    39.018

    Weeks         8         9
           38.965    38.945

   Diet           1         2         3         4
           39.011    38.993    39.008    38.749

    Weeks   Diet           1         2         3         4
        1              38.640    38.720    38.440    38.353
        2              39.030    38.860    39.030    39.120
        3              38.810    38.900    38.890    38.890
        4              39.210    39.080    39.010    38.540
        5              39.240    39.070    39.140    38.895
        6              39.190    39.070    39.250    38.760
        7              39.100    39.150    39.160    38.660
        8              38.889    39.100    39.070    38.800
        9              38.989    38.990    39.080    38.720


*** Standard errors of differences of means ***

Table                  Weeks        Diet       Weeks
                                                 Diet
rep.                      40          90          10
d.f.                     303         303         303
s.e.d.                0.0666      0.0444      0.1332

(Not adjusted for missing values)
***** Stratum standard errors and coefficients of variation *****

Variate: Temp

   d.f.          s.e.          cv%
    303        0.2979          0.8
```

Appendix 3.5.2.2 Example model of the determination of correlations between rectal temperature °C (9.00 am) and ambient temperature°C

```
 16  variate min_temp; \
 17  values=!(40(16.5,12.0,13.0,15.0,14.2,13.4,13.3,10.7,11.5))
 18
 19  variate max_temp;\
 20  values=!(40(25.9,25.8,31.8,17.3,28.6,27.8,28.5,23.4,27.9))
 21
 22  variate av_temp;\
 23  values=!(40(21.2,18.9,22.4,16.2,21.4,20.6,20.9,17.1,19.7))
 24
 29  matrix[rows=9;columns=40]M
 30  equate !p(temp[1...9]); M
 31  calc N=transpose(M)
 32  variate [nvalues=9] Ta[1...40]
 33  equate N;!p(Ta[1...40])
 34  variate [nvalues=9] Mintemp,Maxtemp,Avtemp;\
 35   values=!(16.5,12.0,13.0,15.0,14.2,13.4,13.3,10.7,11.5),\
 36   !(25.9,25.8,31.8,17.3,28.6,27.8,28.5,23.4,27.9),\
 37   !(21.2,18.9,22.4,16.2,21.4,20.6,20.9,17.1,19.7)
 38  variate[nvalues=9] Gr[1...4]
 39  calc Gr[1...4]= vmean(!p(Ta[1...10]),!p(Ta[11...20]),!p(Ta[21...30]),\
 40      !p(Ta[31...40]))
 41  correlate[print=corr] Gr[1...4],Mintemp,Maxtemp,Avtemp

*** Correlation matrix ***

        Gr[1]    1.000
        Gr[2]    0.458    1.000
        Gr[3]    0.623    0.604    1.000
        Gr[4]   -0.482   -0.795   -0.269    1.000
     Mintemp    0.656    0.220    0.004   -0.515    1.000
     Maxtemp   -0.505   -0.344    0.017    0.420   -0.314    1.000
      Avtemp   -0.322   -0.289    0.017    0.273   -0.007    0.952    1.000

                Gr[1]    Gr[2]    Gr[3]    Gr[4]  Mintemp  Maxtemp   Avtemp
```

Appendix 3.5.3 Example model of the statistical analysis of the animals live weights (kg's)

```
 69  factor[levels=3;values=(20(7),20(8),17(9))]Diet
 70
 71  factor[levels=3;nvalues=57] Q8,Q9
 72  calc Q8=newlevels(Diet;!(8,7,9))
 73  calc Q9=newlevels(Diet;!(9,8,7))
 74
 75  For I= Final mass
 79
 80  for J=Diet,Q8,Q9
 81  model I
 82  terms Start mass+J
 83  add [nomes=l,r;tprob=yes] J
 84  add [nomes=l,r;tprob=yes] Start mass
 85  endfor
 86  endfor

86.....................................................................
.....


***** Regression Analysis *****

 Response variate: Final mass
     Fitted terms: Constant + Diet 7


*** Summary of analysis ***

              d.f.          s.s.          m.s.       v.r.
Regression       2            1.           0.7       0.00
Residual        54        44548.         825.0
Total           56        44549.         795.5

Change          -2           -1.           0.7       0.00

Residual variance exceeds variance of Y variate
Standard error of observations is estimated to be 28.7


*** Estimates of regression coefficients ***

                              estimate          s.e.      t(54)  t pr.
Constant                        458.10          6.42      71.33  <.001
Diet  8                           0.30          9.08       0.03  0.974
Diet  9                          -0.04          9.47       0.00  0.997
```

Appendix 3.5.4 Example model of the determination of prediction equations

```
 34  For I=ME
 35
 36  for J=ADG
 37  model J
 38  terms I
 39  add [nomes=1,r;tprob=yes] I
 40  endfor
 41  endfor

41.....
.....


***** Regression Analysis *****

 Response variate: ADG
     Fitted terms: Constant, ME


*** Summary of analysis ***

              d.f.          s.s.          m.s.       v.r.
Regression       1         0.457       0.45674       7.88
Residual        55         3.187       0.05795
Total           56         3.644       0.06507

Change          -1        -0.457       0.45674       7.88

Percentage variance accounted for 10.9
Standard error of observations is estimated to be 0.241


*** Estimates of regression coefficients ***

                  estimate          s.e.      t(55)  t pr.
Constant             0.718         0.486       1.48  0.145
ME                  0.1285        0.0458       2.81  0.007
```

Appendix 4.1.1 Nutrient composition of diets Ten, Eleven, Twelve and Thirteen on a dry matter basis

Diet	Rep.	CP %	Ca %	P %	FAT %	ASH %	C.FIBRE %	NDF %	ADF %	MOISTURE %
10	1	13.83	1.10	0.69	3.78	8.35	8.59	30.24	13.48	16.34
10	2	13.81	0.97	0.68	3.64	8.11	8.68	29.80	13.12	16.27
10	3	15.34	2.11	0.71	3.39	11.81	9.31	25.04	11.30	13.46
10	4	15.22	2.13	0.72	3.39	11.71	9.13	25.28	10.60	13.36
10	5	15.69	0.82	1.03	3.78	9.06	10.75	33.52	14.18	20.92
10	6	15.10	0.86	0.96	3.58	9.12	10.44	33.48	13.72	21.15
10	7	15.28	1.10	0.88	4.16	8.95	10.69	34.56	14.72	18.84
10	8	15.43	1.12	0.97	4.09	8.85	10.89	32.76	14.18	18.37
10	9	15.27	0.98	1.01	4.17	8.17	11.75	35.48	14.26	15.12
10	10	15.29	0.97	0.97	4.17	8.22	11.76	36.20	13.94	15.71
10	11	17.04	1.01	1.05	3.30	9.05	10.34	30.04	14.44	16.95
10	12	17.07	0.99	1.03	3.37	9.04	10.60	32.16	14.12	16.93
11	1	14.54	1.24	0.73	3.18	9.39	8.92	29.38	12.28	16.76
11	2	14.58	1.22	0.70	3.03	9.38	8.66	28.48	12.60	16.64
11	3	15.75	1.70	0.77	3.66	10.24	10.00	27.78	12.42	14.51
11	4	15.50	1.69	0.74	3.57	10.18	9.75	26.74	12.46	14.20
11	5	16.60	1.14	1.06	3.97	9.11	11.16	33.56	14.36	21.09
11	6	16.72	1.11	1.01	3.65	9.11	11.04	34.52	13.80	21.01
11	7	16.18	0.77	1.07	3.89	7.84	12.98	38.56	15.78	19.16
11	8	16.12	0.78	1.08	3.70	7.92	12.49	37.20	16.24	19.09
11	9	17.11	1.08	1.08	4.05	9.02	11.06	38.12	13.72	16.63
11	10	17.10	1.09	1.08	4.01	9.01	11.51	34.92	13.96	16.73
11	11	18.32	1.16	1.09	3.10	9.75	10.75	31.6	14.60	17.24
11	12	18.31	1.15	1.09	2.92	9.66	10.83	34.04	15.14	17.36
12	1	12.70	1.03	0.56	5.53	8.42	8.33	27.94	11.64	14.63
12	2	12.74	1.05	0.58	5.64	8.32	7.96	27.90	10.68	14.80
12	3	13.33	1.78	0.67	5.28	10.40	8.38	27.44	11.12	15.13
12	4	13.26	1.76	0.67	5.41	10.39	7.96	25.50	11.54	14.86
12	5	15.36	1.06	0.93	6.59	8.76	10.19	37.24	12.78	23.12
12	6	14.49	1.08	0.86	6.55	8.78	10.56	35.68	12.42	23.11
12	7	14.26	1.00	0.78	3.56	8.25	10.03	29.60	12.52	18.95
12	8	14.63	1.02	0.82	3.57	8.35	10.27	28.68	11.94	19.25
12	9	14.47	0.96	0.81	5.97	8.31	9.41	30.72	11.78	18.32
12	10	14.54	0.98	0.79	5.88	8.37	9.28	29.76	11.92	18.30
12	11	15.94	1.07	0.81	4.50	8.76	9.21	28.40	12.32	17.73
12	12	15.97	1.07	0.81	4.39	8.66	9.26	26.40	12.58	17.82
13	1	13.23	1.39	0.66	3.33	9.89	9.37	30.16	13.94	15.47
13	2	13.27	1.32	0.68	3.45	9.86	9.77	30.60	13.68	15.50
13	3	13.96	1.86	0.68	3.95	11.09	8.69	26.10	11.98	15.67
13	4	13.83	1.93	0.69	4.17	11.04	8.34	25.62	12.26	15.16
13	5	15.05	1.19	0.93	3.75	9.18	11.31	41.88	14.48	23.64
13	6	14.50	1.19	0.87	3.84	9.08	10.54	45.00	14.44	23.56
13	7	14.55	1.19	0.77	3.74	8.84	10.93	31.56	13.14	19.92
13	8	14.91	1.21	0.79	3.96	8.60	11.11	29.96	13.34	19.94
13	9	13.98	1.35	0.76	4.08	9.20	9.74	27.56	11.88	17.96
13	10	13.93	1.34	0.74	4.08	9.29	9.36	28.08	12.00	18.39
13	11	16.37	1.26	0.85	3.13	9.02	10.42	28.44	14.50	18.42
13	12	16.30	1.27	0.85	3.15	9.16	9.94	30.28	14.34	18.36

Appendix 4.1.2 Metabolism study of diets Ten, Eleven, Twelve and Thirteen

Diet	Refusals (g)	Faeces (g)	Urine (ml)	Crude protein (g)		Gross energy (MJ)		Organic matter (g)
				Faeces	Urine	Feed	Faeces	Faeces
10	0.00	827.4	7080	118.81	269.04	52.64	15.50	742.51
10	0.00	888.9	30050	122.22	348.58	52.64	16.65	815.12
10	0.00	887.6	23300	124.71	351.83	52.64	16.43	799.99
10	0.00	769.5	13440	102.88	322.56	52.64	14.31	702.32
10	0.00	786.8	12520	108.97	336.79	52.64	14.55	707.73
11	0.00	879.0	46180	133.34	350.97	53.23	16.49	790.48
11	0.00	637.5	13180	94.99	271.51	53.23	11.77	563.17
11	0.00	782.4	9130	111.96	367.03	53.23	14.57	694.69
11	0.00	890.3	15220	117.43	368.32	53.23	16.63	812.04
11	0.00	874.7	9620	117.21	316.50	53.23	16.05	772.45
12	0.00	822.0	11180	126.51	326.46	53.65	14.63	705.93
12	0.00	675.1	9520	102.28	282.74	53.65	12.00	586.05
12	0.00	841.6	19000	120.69	362.90	53.65	15.34	744.23
12	0.00	847.4	16610	126.18	343.83	53.65	15.68	751.81
12	0.00	719.9	14400	105.32	289.44	53.65	13.04	627.97
13	0.00	738.6	7460	110.57	253.64	52.10	13.06	623.75
13	0.00	879.8	12460	108.74	299.04	52.10	15.77	765.87
13	0.00	758.6	11710	111.51	262.30	52.10	13.82	661.58
13	0.00	765.3	10810	122.14	233.50	52.10	13.78	670.10
13	0.00	700.3	15410	113.17	241.94	52.10	12.63	604.36

Appendix 4.2.1.1 An animal's dry matter feed-intake kg's (calan gates) over time (weeks)

		Time																					
Diet	ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
10	30	45	57	62	67	57	80	71	71	104	85	98	85	73	107	66	81	82	95	81	95		
10	58	44	38	52	56	61	67	73	72	95	92	100	78	96	90	80	109	85	95				
10	90	31	16	45	50	49	64	72	60	77	96	81	75	76	95	77	75	84	71	82	84		
10	117	34	47	53	64	46	66	80	83	99	72	98	84	93	99	73	95	82	97	87	97	90	121
10	233	51	45	54	61	66	68	70	100	80	80	86	82	72	86	78	77	73	126				
10	268	52	44	50	78	49	87	66	71	101	101	86	80	77	109	88	80	97	78	97	82		
10	308	47	57	50	64	72	73	77	78	96	81	122	71	84	92	95	102	108	84	91	104		
10	314	44	35	41	47	87	62	89	73	95	86	71	72	95	84	77	80	85	101	105	99	67	75
10	319	39	31	48	86	78	83	94	65	80	89	89	81	84	79	91	75	80	85	80	108	104	121
10	31	35	41	43	83	95	93	63	81	76	80	92	106	90	88	92	109	106	110	110	110		
10	39	53	29	77	67	56	79	70	94	59	102	92	102	83	97	80	95	117	110	102	111		
10	151	42	29	37	83	91	59	97	65	80	99	62	85	87	75	91	92	105	113	82	72	62	92
10	156	47	38	45	76	49	86	100	64	103	86	74	77	73	83	67	94	86	110	90	70		
10	184	32	40	45	60	59	71	69	76	80	82	82	95	74	80	78	87	91	106	87	96	97	100
10	244	47	26	33	68	63	93	67	69	82	90	89	86	78	75	85	67	86	111	94	96	62	55
10	316	47	39	49	91	45	85	67	72	77	92	95	105	95	71	89	73	93	80	100	94	61	106
10	318	53	47	50	59	78	97	81	93	63	81	71	82	90	83	87	99	119	98	103	132	56	81
10	320	49	37	73	89	58	73	73	95	95	93	114	88	114	97	103	89	101	101	111	121	57	121

		Time																					
Diet	**ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
11	55	54	78	58	67	68	97	63	93	70	79	74	68	79	78	107	105	104	89	81	89	46	72
11	296	37	54	52	51	63	68	80	89	87	104	81	93	85	101	113	101	98	107				
11	83	7	25	32	49	46	81	87	73	86	90	69	76	82	91	81	84	114	86	118	98		
11	198	18	35	39	80	55	91	78	67	97	100	95	91	83	80	110	106	77	107				
11	263	53	52	42	61	66	79	105	69	99	109	76	96	82	87	76	116	80	84	90	97		
11	283	34	47	34	78	42	49	73	86	99	79	70	99	68	85	74	87	72	83	94	93	75	84
11	295	25	48	51	52	66	76	63	73	103	99	114	98	89	108	115	79	110	111	113	76		
11	56	52	51	61	72	57	79	84	60	99	88	117	123	93	108	126	98	84	84	89	111	96	129
11	98	59	61	63	74	73	95	77	65	127	98	75	116	99	80	117	119	110	80				
11	103	47	56	31	74	104	63	83	90	98	97	79	118	96	107	112	117	116	81	96	111		
11	104	43	57	46	70	49	67	70	78	86	87	83	82	91	99	126	131	113	85				
11	108	53	42	52	72	58	82	64	87	65	83	92	84	82	75	76	98	88	95	80	96		
11	136	36	65	33	56	61	78	79	98	62	89	116	122	110	81	118	133	114	86	86	87		
11	147	56	63	55	66	65	83	64	96	82	107	98	101	97	99	128	92	103	82	81	89		
11	166	41	45	43	74	72	87	77	90	68	73	89	94	116	90	101	93	118	115	82	110	107	59
11	309	69	61	58	95	68	87	80	66	84	91	83	96	101	90	110	88	110	91	78	92		

		Time																					
Diet	**ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
12	22	26	52	60	58	63	82	92	92	85	98	84	90	82	85	109	104	106	94				
12	24	47	66	36	58	66	103	74	94	74	104	90	82	78	93	88	74	80	75	87	82		
12	94	10	21	33	52	48	63	56	98	69	95	76	90	72	88	104	88	88	70	80	76		
12	164	31	58	18	67	53	93	66	83	80	83	82	90	82	80	88	71	86	87	86	112		
12	170	25	58	54	69	69	64	90	82	68	84	89	73	81	94	101	100	95	101	79	94	64	121
12	211	34	54	47	72	69	89	85	69	84	100	93	107	90	80	95	102	92	91	74	86	92	128
12	231	53	49	55	57	58	62	73	76	82	98	96	87	99	86	103	95	98	96				
12	236	34	17	31	57	64	52	73	70	100	61	100	70	91	76	92	66	84	92	102	89	54	73
12	243	46	46	54	52	56	67	77	79	92	96	84	86	97	94	80	84	116	103	88	79	66	87
12	266	43	61	40	54	72	77	69	105	65	79	110	72	82	76	84	89	78	78	91	88		
12	23	46	75	39	93	82	72	65	74	60	81	80	84	120	82	112	89	84	93	81	106		
12	201	39	39	36	57	64	80	85	54	73	81	81	77	86	85	104	66	84	84				
12	216	59	21	34	37	45	62	54	80	86	87	61	99	75	93	110	79	84	98	88	89		
12	267	45	30	35	63	96	89	100	65	88	76	87	72	81	73	71	86	95	85				
12	292	25	28	37	71	52	68	79	85	88	83	74	94	80	66	88	84	79	91	111	76	37	75
12	301	39	52	25	68	82	79	103	73	78	81	80	92	66	87	73	83	78	93	74	76	45	97
12	315	43	55	50	48	67	68	76	98	80	80	107	109	88	106	105	92	81	80	94	96		

Appendix 4.2.1.2 An animal's dry matter feed-intake(kg's) per pen over time (weeks)

		Time																
Diet	Pen	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
10	7	39	47	51	70	64	80	96	100	88	80	112	96	88	80	103	70	90
10	8	46	52	59	54	64	88	104	74	80	72	102	88	88	75	112	70	70
10	15	40	56	63	53	64	88	96	102	104	96	112	112	96	87	99	80	80
10	16	38	47	55	53	64	96	96	103	112	104	112	96	104	94	118	80	100
11	9	37	55	58	64	72	96	112	80	72	88	112	104	104	94	131	107	93
11	10	37	47	61	57	64	88	96	80	72	72	104	96	104	74	107	80	93
11	3	40	54	53	71	64	88	112	110	112	104	104	110	88	117	89	80	100
11	4	48	48	50	72	72	88	104	112	112	104	112	96	104	78	101	100	60
12	17	38	54	50	75	64	80	64	96	96	96	104	96	72	89			
12	18	38	48	61	52	72	80	88	88	96	88	104	88	96	60	144	80	60
12	19	39	56	64	80	72	88	96	85	104	96	112	80	96	108			
12	20	37	56	56	59	64	72	80	86	88	72	81	88	80	77	87	67	67
13	5	39	55	56	57	64	80	80	89	88	88	96	96	80	93	126	60	100
13	6	37	39	53	51	53	64	72	79	88	80	88	73	64	56	107	80	80
13	13	46	48	50	56	64	88	80	97	88	88	100	80	80	41			
13	14	40	56	56	58	64	80	88	93	96	96	82	96	88	67			

Appendix 4.2.2.1 Individual animals live weights (kg's) over time (weeks) (calan gate feeding)

		Week																						
Diet	ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
10	30	230	231	238	245	257	272	285	302	307	312	333	346	353	370	377	380	396	399	410	421	427		
10	58	244	244	247	256	267	276	291	303	312	329	344	354	363	375	384	401	411	416	422				
10	90	228	229	237	243	251	255	275	284	299	312	323	333	340	354	359	365	381	414	404	410	429		
10	117	230	233	245	246	249	258	282	289	300	304	309	309	312	325	331	361	369	378	390	403	414	416	439
10	233	243	243	253	261	273	279	292	298	300	304	307	322	325	347	357	358	373	391	398				
10	268	242	256	262	269	276	293	311	322	337	349	351	373	382	396	400	410	422	428	438	437	460		
10	308	262	269	270	274	290	307	313	326	336	337	355	369	376	378	389	392	402	409	410	413	427		
10	314	242	245	247	247	252	264	282	300	306	310	324	343	347	347	349	355	362	364	363	370	380	393	382
10	319	248	248	249	250	251	252	254	257	259	262	268	282	287	293	297	314	318	335	341	355	368	362	386
10	31	251	252	257	263	279	288	296	316	326	338	355	371	376	393	404	411	431	444	452	440	452		
10	39	244	251	254	256	272	285	290	298	302	308	327	344	347	360	370	377	402	417	419	414	423		
10	151	200	204	205	207	220	233	238	247	250	254	275	275	297	300	304	306	317	325	329	350	358	357	362
10	156	214	220	225	239	244	257	269	295	296	307	320	331	353	367	367	373	375	394	395	410	413		
10	184	241	243	241	247	260	267	276	286	313	314	327	348	350	380	384	389	403	414	418	419	443	449	468
10	244	273	271	273	287	300	317	327	340	346	367	384	390	399	399	408	410	424	436	433	440	450	464	464
10	316	227	227	228	230	235	245	252	257	271	278	286	298	301	310	317	330	338	354	359	363	371	363	392
10	318	266	270	278	282	290	294	310	324	339	340	355	356	366	371	380	388	392	409	403	419	432	435	463
10	320	244	245	251	262	271	285	295	306	321	328	345	359	361	380	388	391	403	414	420	428	448	451	448

		Time																						
Diet	**ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
11	55	250	259	264	267	277	293	307	311	316	316	320	325	328	343	348	354	363	384	380	367	377	379	404
11	296	228	229	234	244	250	254	272	278	291	305	321	339	340	347	360	366	377	388	383	383			
11	83	229	229	230	233	235	238	243	255	259	270	290	301	306	309	325	333	350	360	361	359	374		
11	198	238	241	243	247	259	271	288	298	300	304	315	328	334	355	367	378	385	400	404				
11	263	236	238	252	261	274	276	289	293	299	305	316	322	330	348	360	366	368	384	385	382	390		
11	283	214	217	218	221	225	235	237	248	262	274	285	297	309	320	321	331	341	350	362	370	382	378	389
11	295	270	272	281	283	294	304	320	330	341	341	373	377	380	393	396	413	421	441	433	439	453		
11	56	249	250	259	273	282	295	305	321	334	337	351	358	366	369	379	384	392	410	409	413	429	429	440
11	98	255	262	275	291	302	304	325	340	347	350	366	379	392	396	407	419	432	448	453	453			
11	103	259	273	275	276	278	278	292	303	317	332	341	358	366	368	370	385	403	400	399	414	418		
11	104	218	220	221	223	229	230	242	252	260	270	288	314	321	326	336	348	349	361	353				
11	108	220	226	226	227	230	231	245	265	273	285	300	315	326	326	331	349	353	357	365	375	393		
11	136	267	267	277	281	289	295	320	326	338	356	371	374	392	400	409	427	438	441	453	462	470		
11	147	243	244	253	264	266	275	300	315	321	342	352	366	373	383	383	403	410	420	426	421	437		
11	166	232	239	242	251	264	269	289	296	310	321	330	361	365	369	371	386	404	411	401	419	427	432	426
11	309	246	246	249	256	272	279	304	318	321	326	342	367	371	397	399	423	429	435	440	455	462		

		Time																						
Diet	**ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
12	22	274	274	284	295	306	321	336	354	360	371	386	399	410	425	430	435	445	456	460				
12	24	251	252	271	272	276	297	314	319	324	335	358	361	363	372	380	384	389	401	396	399	405		
12	94	219	220	221	224	224	226	228	230	236	247	252	261	281	287	297	306	314	317	335	347	361		
12	164	227	235	242	251	259	264	270	294	301	318	331	342	357	358	360	383	395	401	402	416	428		
12	170	266	266	267	271	279	287	307	315	317	320	325	344	353	367	377	379	393	396	401	399	411	430	433
12	211	236	241	254	257	261	278	292	306	313	332	345	345	349	367	377	378	385	401	413	421	428	431	450
12	231	237	237	238	247	259	265	274	289	298	307	322	326	334	351	357	367	375	384	391				
12	236	201	201	184	185	188	193	204	215	217	238	245	253	267	273	281	296	306	318	322	332	337	358	365
12	243	236	239	248	250	263	275	294	312	317	324	352	355	366	380	389	397	412	420	432	423	448	461	471
12	266	265	266	267	271	273	288	296	312	333	340	361	367	382	392	405	408	418	436	442	450	467		
12	23	233	235	248	256	262	272	285	297	300	304	308	313	331	340	354	366	383	408	401	401	414		
12	201	244	254	255	256	259	261	269	285	288	306	318	335	345	348	371	374	396	405	415				
12	216	250	244	244	245	246	246	249	250	254	260	276	292	301	320	331	349	373	389	402	414	435		
12	267	200	200	209	213	220	235	244	256	277	288	301	318	327	331	345	370	386	406	413				
12	292	230	230	218	224	222	237	241	250	258	272	282	299	303	315	328	330	344	340	347	354	370	378	383
12	301	224	228	237	240	249	261	273	284	286	286	289	296	301	308	316	333	341	346	351	363	370	392	380
12	315	227	227	228	231	242	253	262	277	289	299	315	332	341	356	376	384	403	419	424	438	457		

Appendix 4.2.2.2 Individual animals live weights (kg's) over time (weeks) (group feeding)

		Time																	
Diet	ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
10	72	222	220	229	235	246	254	273	285	284	278	290	307	318	328	337	349		366
10	167	246	237	255	256	256	262	286	296	302	301	321	334	334	348	361	367		386
10	188	215	216	225	240	245	254	282	291	302	313	341	337	346	355				
10	221	244	252	256	266	277	275	299	300	339	357	370	389	394	414	431	438		462
10	273	239	248	258	259	278	287	307	317	343	355	370	372	381	392	414	418		450
10	92	255	265	270	285	289	300	320	327	301	310	328	344	351	364	374	375		394
10	176	230	235	242	252	263	267	292	307	298	303	324	334	345	351	381			
10	209	243	230	243	253	262	269	281	303	293	301	325	332	340	352	360	361		386
10	235	216	216	221	234	246	253	271	287	306	315	329	341	353	363	379	387		402
10	289	250	245	249	248	254	264	290	300	323	333	349	353	366	366	385	391		402
10	20	226	223	241	246	256	264	294	304	326	335	355	363	364	385	390			
10	52	207	210	213	217	229	232	253	265	278	285	300	310	318	329	340	347		364
10	95	242	247	261	280	293	305	331	346	353	365	392	403	410	410				
10	119	224	218	226	232	234	238	261	277	304	310	320	329	350	351	369	376		382
10	256	246	252	250	265	273	276	296	310	329	337	360	371	388	405	425	428		446
10	50	237	230	230	249	265	267	292	305	319	332	352	365	380	395	414	414		436
10	121	226	233	233	247	260	270	292	304	318	338	352	353	360	377	400			
10	202	250	250	258	275	281	296	314	337	361	371	386	395	396	419				
10	252	215	217	220	231	241	245	258	270	288	308	320	330	334	344	366	371		388
10	271	257	268	268	280	295	308	326	332	350	368	386	395	404	424				

		Time																	
Diet	**ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
11	17	230	228	248	246	263	270	299	315	330	334	351	356	377	380	392	400		436
11	35	265	274	283	286	296	311	338	346	318	308	329	346	359	376	393	415		422
11	74	263	260	273	275	285	289	308	336	343	348	362	370	387	392				
11	96	231	230	235	244	258	261	282	300	308	315	327	340	346	366	376	380		400
11	265	214	218	226	230	249	247	278	295	290	307	325	337	346	364	380			
11	89	265	272	275	290	300	319	344	354	329	319	336	355	378	390				
11	206	230	226	232	229	241	247	269	279	303	322	329	336	340	345	362	363		384
11	181	221	228	236	239	256	263	287	297	321	287	314	331	347	360	380			
11	248	215	223	230	244	255	261	283	301	292	297	318	332	344	356	370	379		402
11	312	226	226	230	231	240	245	265	277	310	310	320	328	339	350	360	372		386
11	63	258	264	270	282	284	303	326	344	350	359	369	381	391	394				
11	161	245	244	253	256	272	278	296	314	327	324	337	347	361	378	378	386		408
11	215	238	234	244	252	256	265	290	303	318	325	341	344	362	364	376	387		386
11	219	215	216	213	227	245	250	277	283	297	310	332	333	354	361				
11	258	224	226	234	250	269	264	297	299	328	339	364	381	397	407				
11	60	257	262	267	269	288	294	314	333	342	352	367	381	384	391	407			
11	91	216	218	220	232	245	252	270	300	305	318	328	344	357	354				
11	99	225	228	230	225	238	242	260	279	287	297	314	319	327	334	343	342		370
11	242	228	238	256	261	278	280	302	309	335	338	366	376	390	396	403	424		432
11	261	250	265	269	283	300	307	335	355	374	382	408	405	416	427				

		Time																	
Diet	**ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
12	10	226	226	234	239	252	262	283	294	310	321	331	338	349	354	369			
12	118	220	210	228	231	242	243	274	284	300	323	339	346	352	369	390			
12	245	248	250	263	267	278	285	312	327	347	361	381	391	387	406	422			
12	255	236	231	246	253	270	277	301	306	338	348	370	378	390	394	415			
12	304	231	228	234	243	256	259	286	292	318	327	341	358	354	365	387			
12	18	222	212	219	227	245	259	279	297	308	323	341	346	354	369	386			
12	81	222	219	224	237	250	268	292	307	335	357	373	378	388	409	431	440		462
12	305	253	237	244	252	268	269	278	299	316	338	343	353	366	382	392	398		408
12	310	230	212	220	222	232	238	257	274	287	302	316	325	328	341	346			
12	321	255	240	258	265	276	290	309	330	349	369	384	392	395	406	431			
12	34	235	225	236	255	258	267	287	307	333	338	366	352	346	366	379			
12	88	245	238	259	272	287	299	323	336	353	371	389	393	410	416				
12	247	238	232	250	258	270	278	303	320	339	349	376	387	396	411				
12	250	222	222	231	244	262	262	283	303	322	330	350	362	368	384	404			
12	307	262	268	284	296	300	313	338	353	376	395	403	411	416	441				
12	93	240	253	261	271	281	284	305	329	349	355	375	386	398	414				
12	126	222	220	232	244	254	266	292	303	325	332	352	361	367	380	390	400		418
12	153	227	215	220	224	231	242	254	271	290	300	322	327	326	340	362	366		386
12	259	224	220	236	252	255	266	297	307	336	348	363	371	379	401				
12	260	269	259	263	274	284	289	312	320	345	357	378	372	374	394	411	417		432

		Time																	
Diet	**ID**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
13	76	235	236	247	249	266	280	297	306	319	330	347	352	361	368	384			
13	234	219	219	224	219	229	244	259	269	286	298	312	314	324	334	345	356		382
13	241	223	212	221	221	234	240	257	274	285	302	311	321	320	333	344	358		380
13	285	244	248	259	268	281	297	314	326	344	358	376	390	401	415				
13	293	246	246	260	267	278	294	310	325	342	357	371	380	398	409				
13	154	248	242	249	247	260	264	279	289	314	318	333	343	337	341	351	363		392
13	205	231	230	226	232	242	246	267	283	296	314	331	331	334	349	351			
13	227	242	242	250	254	262	267	289	294	309	320	339	343	353	370	378	389		412
13	281	263	260	261	271	282	299	318	321	344	362	388	406	414	433	430			
13	262	214	210	208	208	217	229	234	242	257	263	276	280	290	302	314	306		324
13	44	246	240	248	239	256	268	287	304	322	341	358	374	380	400				
13	53	220	223	237	242	252	265	284	300	317	331	340	342	348	357				
13	155	233	240	245	248	262	268	291	303	330	345	365	365	381	396	396			
13	191	239	230	219	237	245	248	265	274	286	307	315	320	318	317	331			
13	313	261	263	272	285	291	304	333	339	365	380	401	405	405	430				
13	38	213	217	223	232	244	254	275	288	312	326	341	359	367	380	388			
13	210	260	250	256	263	269	285	305	320	337	359	374	378	391	403				
13	223	226	225	229	234	241	254	269	282	307	317	334	339	345	356				
13	279	236	235	241	243	247	259	272	298	315	331	357	360	362	376	391			
13	294	243	236	244	260	272	288	309	325	348	369	384	393	402	423				

Appendix 4.3.1 Length of time (days) in the feedlot and carcass data for individual animals (calan gate feeding)

Diet	ID	Days	Carcass weight (kg)	Fat Score				Dressing percentage
				Overall	Hind-quarter	Loin	Fore-quarter	
10	30	140	231.08	2	2+	2+	2+	54.12
10	31	140	250.58	2	2	2	2-	55.44
10	39	140	225.23	2	2+	2+	2	53.24
10	58	126	215.48	2	2	2	2	51.06
10	90	140	235.95	2	2+	2	2	55.00
10	117	154	224.25	2	2	2	2-	51.08
10	151	154	192.08	2	2	2	2-	53.06
10	156	140	219.38	3	3	3	3	53.12
10	184	154	235.95	2	2	2-	2	50.42
10	233	126	210.60	2	2	2+	2	52.91
10	244	154	232.05	3	3	3-	3	50.01
10	268	140	250.58	2	2	2	2	54.47
10	308	140	218.40	2	2+	2	2	51.15
10	314	154	206.70	2	2-	2	2	54.11
10	316	154	197.93	2	2-	2-	2-	50.49
10	318	154	234.00	2	2	2	2	50.54
10	319	154	206.70	2	2+	2+	2	53.55
10	320	154	236.93	2	2-	2	2	52.89

Diet	ID	Days	Carcass weight (kg)	Fat Score				Dressing percentage
				Overall	Hind-quarter	Loin	Fore-quater	
11	55	154	206.70	2	2	2-	2	51.16
11	56	154	232.05	3	3	3	3	52.74
11	83	140	203.78	2	2	2	2	54.49
11	98	126	222.30	2	2+	2	2	49.07
11	103	140	234.98	2	2	2	2	56.21
11	104	126	185.25	3	3	3	2+	52.48
11	108	140	198.90	2	2+	2+	2	50.61
11	136	140	251.55	3	3	3	3	53.52
11	147	140	236.93	2	2	2	2	54.22
11	166	154	231.08	2	2-	2	2	54.24
11	198	126	211.58	3	3	3	2+	52.37
11	263	140	208.65	2	2-	2-	2-	53.50
11	283	154	212.55	2	2	2	2	54.64
11	295	140	242.78	3	3+	3	3	53.59
11	296	126	200.85	3	3	3	3	52.44
11	309	140	256.43	2	2	2	2	55.50

Diet	ID	Days	Carcass weight (kg)	Fat Score				Dressing percentage
				Overall	Hind	Loin	Fore	
12	22	126	243.75	2	3	2	2	52.99
12	23	140	208.65	2	2+	2	2	50.40
12	24	140	215.48	3	3	3	3-	53.20
12	94	140	200.85	3	3	3	3	55.64
12	164	140	218.40	2	2+	2	2	51.03
12	170	154	219.38	3	2+	3	3	50.66
12	201	126	221.33	3	3	3	2	53.33
12	211	154	232.05	3	3	3	3	51.57
12	216	140	223.28	2	2	2	2	51.33
12	231	126	216.45	3	2+	3	3	55.36
12	236	154	200.85	2	2+	2	2	55.03
12	243	154	243.75	3	3	3	3+	51.75
12	266	140	246.68	3	3	3	3	52.82
12	267	126	218.40	3	3	3	2+	52.88
12	292	154	197.93	2	2	2	2	51.68
12	301	154	202.80	2	2	2	2	53.37
12	315	140	243.75	3	3+	3	3	53.34

Appendix 4.3.2 Length of time in the feedlot (days) and carcass data for individual animals (group feeding)

Diet	ID	Days	Carcass weight (kg)	Fat Score				Dressing percentage
				Overall	Hind-quater	Loin	Fore-quarter	
10	20	105	212.55	3	2+	3	3	54.50
10	50	119	251.55	2	2	2	2	57.69
10	52	119	202.80	2	2-	2-	2	55.71
10	72	119	197.93	2	2-	2	2	54.08
10	92	119	209.63	2	2-	2+	2+	53.20
10	95	98	209.53	3	3	3	3-	51.10
10	119	119	213.53	2	2	2+	2	55.90
10	121	105	210.60	2	2	-3	2	52.65
10	167	119	205.73	3	3+	3	3	53.30
10	176	105	214.50	3	3	3	3	56.30
10	188	98	193.25	4	3	4	3	54.44
10	202	98	212.36	3	3	3+	3+	50.68
10	209	119	217.43	2	2-	2	2	56.33
10	221	119	247.65	2	2-	2	2	53.60
10	235	119	221.33	3	3+	3+	3+	55.06
10	252	119	217.43	3	3	3	3	56.04
10	256	119	250.58	3	3	3	3+	56.18
10	271	98	227.76	3	3-	3	3	53.72
10	273	119	252.53	4	4	4+	4	56.12
10	289	119	210.60	3	3+	3+	3	52.39

Diet	ID	Days	Carcass weight (kg)	Fat Score				Dressing percentage
				Overall	Hind-quarter	Loin	Fore-quarter	
11	17	119	225.23	2	2	2	2	51.66
11	35	119	226.20	2	2-	2	2	53.60
11	60	105	205.73	2	2	2	2	50.55
11	63	98	226.20	3	3	3+	2+	57.41
11	74	98	204.75	2	2	2	2	52.23
11	89	98	214.50	3	2	3	3	55.00
11	91	98	193.05	4	3	4	3+	54.53
11	96	119	220.35	2	2	2	2	55.09
11	99	119	195.98	2	2	2	2	52.97
11	161	119	203.78	2	2-	2	2	49.94
11	181	105	198.90	3	2+	3	2+	52.34
11	206	119	205.73	4	3	4+	4	53.57
11	215	119	221.33	3	3	3+	3-	57.34
11	219	98	196.95	3	2+	3	3	54.56
11	242	119	241.80	2	2	2+	2+	55.97
11	248	119	222.30	3	3+	3+	3+	55.30
11	258	98	209.63	3	3	3	2	51.50
11	261	98	229.13	4	3+	4	3+	53.66
11	265	105	205.73	3	2+	3	3	54.14
11	312	119	227.18	2	2	2	2	58.85

Diet	ID	Days	Carcass weight (kg)	Fat Score				Dressing Percentage
				Overall	Hind-quarter	Loin	Fore-quarter	
12	10	105	213.53	3	3	3	2	57.87
12	18	105	223.28	2	2	2	2	57.84
12	34	105	207.68	3	3	3	2+	54.80
12	81	119	263.25	2	2+	2	2	56.98
12	88	98	231.08	4	3+	4+	3	55.55
12	93	98	220.35	3	3	3	2	53.22
12	118	105	193.05	2	2	2+	2	49.50
12	126	119	240.83	2	2	2+	2+	57.61
12	153	119	216.45	2	2+	2	2	56.08
12	245	105	244.73	3	2+	2+	3	57.99
12	247	98	230.10	4	3	4	3+	55.99
12	250	105	201.83	2	2	3-	2	49.96
12	255	105	245.70	4	3	4	4	59.20
12	259	98	218.40	3	3	3+	3	54.46
12	260	119	256.43	2	2	2	2	59.36
12	304	105	207.68	3	3	3	3	53.66
12	305	119	229.13	2	2-	2+	2+	56.16
12	307	98	245.70	3	3	3+	3	55.71
12	310	105	189.15	2	2	2	2	54.67
12	321	105	241.80	3	2+	3	3	56.10

Diet	ID	Days	Carcass weight (kg)	Fat Coverage				Dressing percentage
				Overall	Hind-quarter	Loin	Fore-quarter	
13	38	105	210.60	3	3	3	3	54.28
13	44	98	213.53	3	2	3	3	53.38
13	53	98	191.10	3	2+	3	2+	53.53
13	76	105	210.60	3	3	3	2+	54.84
13	154	119	217.43	3	3-	3+	3	55.47
13	155	105	228.15	3	3	3	3	57.61
13	191	105	182.33	3	3	3+	3	55.08
13	205	105	176.48	1	1	1	1	50.28
13	210	98	225.23	3	2+	3	3	55.89
13	223	98	192.08	3	2	3+	2	53.95
13	227	119	226.20	2	2	2	2	54.90
13	234	119	211.58	2	2-	2	2+	55.39
13	241	119	205.73	3	3	3+	3	54.14
13	262	119	173.55	1	1+	1+	2	53.56
13	279	105	224.25	3	3	3	2+	57.35
13	281	105	236.93	3	3	3	2+	55.10
13	285	98	227.18	3	3	3+	2+	54.74
13	293	98	225.23	2	3-	2	2	55.07
13	294	98	230.10	3	2+	3+	2+	54.40
13	313	98	222.30	3	3-	3	3	51.70

Appendix 4.4.1 Example model of the statistical analysis of the animals live weights (kg's)

```
  25  vcomponents [fixed=Start mass+Diet] random=Site
  26  REML [print=model,components,effects,wald,means] Final Mass
  27  endfor
27.....................................................................
***** REML Variance Components Analysis *****
Response Variate : Final mass

Random model     : Site
Fixed model      : Constant+Start mass+Diet
Number of units  : 111
No absorbing factor

*** Estimated Variance Components ***

Random term                Component        S.e.
Site                            94.0       149.6
*units*                        639.0        87.8

*** Wald tests for fixed effects ***
   Fixed term              Wald statistic      d.f.

   Start mass                      41.2            1
   Diet                             3.7            2
* All Wald statistics are calculated ignoring terms fitted later in the
model

*** Table of effects for Constant ***
                       1
                   413.7

Table has only one entry: standard error       7.989

*** Table of effects for Start mass ***
                       1
                  0.9258

Table has only one entry: standard error      0.1418

*** Table of effects for Diet ***
      Diet          1.00          2.00          3.00
                   0.000        -9.829         0.000

Standard error of differences:     Average            5.887
                                   Maximum            5.932
                                   Minimum            5.840
Average variance of differences:                      34.65

*** Table of predicted means for Constant ***
                       1
                   410.4

Table has only one entry: standard error       7.989

*** Table of predicted means for Diet ***
      Ration        1.00          2.00          3.00
                   413.7         403.9         413.7

Standard error of differences:     Average            5.887
                                   Maximum            5.932
                                   Minimum            5.840
Average variance of differences:                      34.65
```

Appendix 4.4.2 Example model of the statistical analysis of the animals returns (R)

```
  38  covariate Start mass
  43  treatmentstructure Diet
  44  anova[uprint=aov,means,%cv;\
  45        print=aov,means,%cv;fprob=yes;pfactorial=2] Return
  46  endfor
46.....................................................................
.....

***** Analysis of variance (adjusted for covariate) *****

Variate: Return
Covariate: Start mass

Source of variation     d.f.       s.s.       m.s.    v.r. cov.ef.  F pr.
Diet                       3     169993.     56664.    3.23    1.00  0.027
Covariate                  1     313578.    313578.   17.90          <.001
Residual                  75    1313886.     17518.             1.22
Total                     79    1789409.


***** Tables of means (adjusted for covariate) *****

Variate: Return
Covariate: Start mass

Grand mean  1755.

   Diet       1.00      2.00      3.00      4.00
              1773.     1724.     1821.     1701.


*** Standard errors of differences of means ***

Table                  Diet
rep.                     20
d.f.                     75
s.e.d.                 41.9


***** Stratum standard errors and coefficients of variation
     (adjusted for covariate) *****

Variate: Return
Covariate: Start mass

   d.f.          s.e.          cv%
     75         132.4          7.5
```

Appendix 4.4.3 Example model of the determination of prediction equations

```
 19  For I=ME
 20
 21  for J=ADG
 22  model J
 23  terms ME+Site
 24  add [nomes=l,r;tprob=yes] ME
 25  add [nomes=l,r;tprob=yes] Site
 26  endfor
 27  endfor

27.....................................................................
.....


***** Regression Analysis *****

 Response variate: ADG
     Fitted terms: Constant + ME + Site


*** Summary of analysis ***

              d.f.          s.s.          m.s.       v.r.
Regression       2         1.894       0.94683      22.19
Residual       108         4.608       0.04267
Total          110         6.502       0.05911

Change          -1        -1.714       1.71418      40.18

Percentage variance accounted for 27.8
Standard error of observations is estimated to be 0.207


*** Estimates of regression coefficients ***

                              estimate          s.e.     t(108)  t pr.
Constant                         0.337         0.443       0.76  0.449
ME                              0.0847        0.0402       2.11  0.037
Site 2                          0.2494        0.0393       6.34  <.001
```