A STUDY OF THE EFFICIENCY OF FEED UTILIZATION
IN YOUNG FRIESIAN BULLS FED CUT PASTURE

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ABSTRACT

An investigation was undertaken into the efficiency of feed utilisation of Friesian bulls. Of major interest was the comparison of efficiency of feed utilisation in two groups of bulls selected for extreme differences in liveweight gains at pasture.

Data for yearling, Friesian bulls run at pasture over a period of six months at the Awahuri and Newstead Artificial Breeding Centres were analyzed. Nine bulls with the highest liveweight gain were placed in a high (H) group, and nine bulls with the lowest liveweight gains were placed in a low (L) group.

A standardisation period of four weeks was used to measure the voluntary intake of cut pasture of the two groups of bulls. At the end of this period the bulls were assigned to blocks on the basis of liveweight and one of three intake levels randomly allocated within blocks. Intake levels one, two and three were designed to give liveweight gains of 0.1, 0.5 and 1.0 kg/day respectively. Each bull within intake level one or two was allocated cut pasture in direct proportion to their metabolic liveweight ($W^{\frac{3}{4}}$). During the eight week comparison period, a concentrate meal was offered at the rate of 3.6 kg/day to those bulls on intake level three, together with *ad libitum* cut pasture.

Digestible energy intake and liveweight gain were measured in the comparison period, and measures of total and partial efficiency calculated from the data.

In the selection period the mean liveweight gains of the high and low liveweight gain groups were 1.35 and 1.00 kg/day respectively. However, in the standardisation period there were no significant differences between the high and low liveweight gain groups in either, voluntary intake or liveweight gain.

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PREFACE

In recent years there has been a large increase in the number of dairy bred calves kept for beef production. In 1968-69 the estimated number of calves bred for beef on dairy farms was 187,000, by 1971-72 this had increased to 385,000 (N.Z. Dairy Board, Farm Production Division, 1972). Of these calves an estimated 60.1 per cent were from Friesian sires, 31.6 per cent from beef breed sires and 7.5 per cent from other dairy breed bulls.

The world demand for beef is expected to continue (Philpott, 1970); and as a consequence there could be a need to increase the efficiency of beef production. In cognizance of this, the New Zealand Dairy Board has been recording the liveweight gains of yearling Friesian bulls, kept at the Awahuri and Newstead Artificial Breeding Centres as part of their progeny test scheme for dairy merit. It was envisaged that the data obtained on liveweight gain would allow farmers to select semen from weight gain tested bulls for use on cows that were to produce calves for dairy beef.

It is often accepted that the genetic correlation between liveweight gain and the efficiency of feed utilisation is high. However, there is scant information on the interrelationships between appetite, liveweight gain and intrinsic differences in the efficiency of feed utilisation for cattle.

In the present study liveweight gain data for yearling Friesian bulls at the Awahuri and Newstead Artificial Breeding Centres were analysed. As a result of this analysis, nine bulls with the highest liveweight gain, and nine with the lowest liveweight gain over a selection period of six months were assigned to two experimental groups. The investigation was designed to study the differences in voluntary intake, liveweight gain and various efficiency measures when these two extreme groups were fed cut pasture indoors; and relate these to the differences observed in the selection period.

In the comparison period there were no differences between liveweight gain groups in either, liveweight gain, total efficiency, or partial efficiency on any of the intake levels. However, the *ad libitum* intake of the low liveweight gain bulls on intake level three was significantly ($P < 0.05$) higher than that of the high liveweight gain bulls.

The DE requirements calculated from the data using two different biological models, were compared with other requirements reported in the literature. The variation in predicted requirements, using the different models, suggested that meaningful requirements will only be obtained when the growth process of cattle is more fully understood, and when measurement errors are much less than they were in this experiment.

It was concluded that the experiment was too short to allow differences in efficiency to be detected, either between groups, or between individuals. To enable meaningful efficiency comparisons to be made, either much longer experiments are needed, or, more sophisticated methods of determining the energy content of liveweight gain.

It was suggested that future work in efficiency of feed utilisation should determine how strongly appetite is inherited in a grazing situation, and the magnitude of differences in the intrinsic efficiency of feed utilisation. There appears to be a need for research into increasing the efficiency of the whole, meat production system. An isolated attempt to improve liveweight gain in male offspring may fail to increase the efficiency of the whole system because of a correlated increase in the liveweight of female breeding stock.

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CHAPTER ONE

REVIEW OF LITERATURE

There is an extensive literature on the many facets of the efficiency of feed utilisation. This review does not attempt to cover the entire subject. It is limited to a consideration of the efficiency complex in growing cattle, although information from the growth of other species is used when the information on cattle is sparse. The review also contains discussion of the implications of genetic selection for certain efficiency parameters and the means of achieving this selection. The reasons for selecting this particular study, and for the experimental design and procedures used, are discussed.

The review contains six sections, the first deals with the intake of pasture and its chemical composition. The second section reviews aspects of cattle growth that are relevant to this study of efficiency of feed utilisation. Emphasis is placed on the problems associated with liveweight gain as a response parameter. The energy requirements for growth in cattle, and methods of estimating these are discussed in the third section. The problems of using multiple regression analysis in predicting energy requirements, and also in estimating individual differences in efficiency are reviewed.

The information on the efficiency of feed utilization relevant to the present study is considered in section four; attention is centred on the different efficiency measures, the correlations between them, and the problems associated with their use. The fifth section summarises information on performance testing, including factors affecting the accuracy of performance tests and systems of performance testing.

The final section enumerates the objectives of the study. The evidence for the experimental design and procedures chosen is also discussed.

1.1 SOME ASPECTS OF PASTURE INTAKE

In this section some information on the chemical composition of improved, New Zealand pastures is summarised. A few of the more important factors determining the voluntary intake of pasture are considered, together with estimates of the likely individual variation in voluntary intake. Finally, the effect of feeding a concentrate mixture on the intake of pasture offered ad libitum is considered. No attempt has been made to cover the large number of factors known to effect intake in ruminants, excellent discussions on these can be found in reviews by Balch and Campling (1962), Campling (1970), Baumgardt (1970) and Arnold (1970).

1.1.1 Chemical Composition

The chemical composition of dairy pastures at Ruakura has been analyzed by McIlroy and Bartrum (1940) and Hutton (1961); and at Massey by Davey (1964). Their results are summarised in Table 1.1.

TABLE 1.1 : Chemical composition of dairy pasture at different times of the year, expressed as per cent of DM (All figures are corrected to 100 per cent DM).

Period :	Author :	Crude Protein :	N-Free Extract :	Crude Fibre :	Ether Extract :	Ash :
13/6 - 13/7	McIlroy and Bartrum (1940)	20.8	39.1	17.6	4.6	17.9
14/7 - 25/7	"	19.5	40.0	18.0	N.D.*	17.3
26/7 - 15/8	"	17.8	44.0	18.0	N.D.	15.3
16/8 - 8/9	"	19.9	39.0	17.0	N.D.	19.4
9/9 - 19/9	"	20.1	43.0	17.0	N.D.	14.9
Oct. - Apr.	Hutton (1961)	19.2	46.9	24.5	2.5	6.7
Spring	Davey (1964)	15.2	41.9	29.3	4.3	9.4

* Not determined

McIlroy and Bartrum (1940) have shown distinctly lower values for crude fibre percentage and much higher ash percentage than either those reported by Davey (1964), or Hutton (1961). The high ash percentage could be due to soil contamination of pasture samples. In extensive trials at Ruakura, Hutton (1961) found that protein levels rose from 15.9 per cent in late October to 26.0 per cent in late April. In the same trials crude fibre levels ranged from 27 to 30 per cent from October to February and fell to 19 per cent by April. Ash and ether extract percentages were quite stable throughout the season. The values obtained by Hutton (1961) for ether extract were much lower than those reported by Davey (1964) and McIlroy and Bartrum (1940); however, the former agree with those given by McDonald, Edwards and Greenhalgh (1966). The variations in chemical composition might be expected to lead to variations in the gross energy content of the pasture mainly through the effect of differences in the ash content.

Lambourne (1957) analysed sheep pastures and found that the gross energy of pasture was extremely constant at 4.47 kcal/g DM, throughout the year. Hutton (1961) obtained a mean value of 4.50 kcal/g DM on dairy pastures, there being a seasonal trend from 4.37 kcal/g DM in late October to 4.55 kcal/g DM in late April. The increase was attributed to changes in botanical composition, with the higher clover component in April producing an increased protein percentage and hence a higher gross energy.

1.1.2 Physical regulation of intake

Campling (1969) has concluded that the limits within which physical regulation occurs are not yet clearly defined. However, Blaxter, Wainman and Wilson (1961), and Montgomery and Baumgardt (1965), have shown that the control of intake by physical factors appears to cease about the range of 65 to 70 per cent digestibility. Hutton (1963) was unable to show any clear relationship between intake and digestibility of DM for cut grass from 65 to 75 per cent digestibility.

There is conflicting evidence on the influence of large amounts of water ingested with pasture on the voluntary intake of cattle.

Holmes and Lang (1963) found DM intake was high when DM percentage was high, however, the observation was confounded by the fact that reduced DM was offered on days when DM percentage was low. The same paper reports an experiment using 450 kg Friesian steers to determine the effect of adding water to cut ryegrass or cocksfoot with DM percentage ranges from 17 to 28 per cent and 15 to 21 per cent respectively. There was a non-significant correlation of + 0.21 between DM intake and DM percentage for the pooled data. Similarly, Hood (1962) could find no consistent relationship between DM percentage and DM intake over a three year period.

Duckworth and Shirlaw (1958) obtained a significant ($P < 0.01$) correlation of + 0.96 between daily DM intake of fresh grass and DM percentage on the same day, when DM ranged from 19 to 28 per cent. However, it is possible that the high correlation obtained was due to variations in DM offered rather than to DM percentage. On a phalaris-subterranean clover pasture of 73.2 per cent digestibility, Arnold (1962) found a highly significant ($P < 0.001$) relationship between DM intake and DM percentage. This relationship applied to a period of three weeks; subsequent periods, when digestibility was lower, showed no such relationship.

It may be tentatively concluded that, while it may be possible for the DM content of pasture to influence voluntary intake in certain situations, it is by no means established that large variations in DM content will directly cause changes in DM intake.

Studies with monozygous cattle twins (Taylor and Young, 1964) show that differences in appetite are genetically controlled. Blaxter (1964) has reviewed evidence which suggests that the voluntary intake of feed varies from individual to individual by about ± 10 to ± 15 per cent. In a study of the variability in ad libitum forage intakes by sheep, Heaney, Pritchard and Pigden (1968) found that even when the same sheep were fed the same forage for several successive weekly periods, the animal variabilities, as well as intakes, were inconsistent from week to week. Coefficients of variation during continuous feeding of the same forage to the same animals over successive weekly periods were 8.1 and 18.0 per cent for the pelleted mixed hay and alfalfa hay respectively.

Campling (1969) has proposed that physiological processes, such as growth, can modify the capacity of the reticulorumen and possibly the factors responsible for the breakdown and removal of digesta from the rumen. Purser and Moir (1966) have shown that differences between individual sheep in voluntary intake and their propensity to eat were positively related to differences in the physiological volume of their reticulorumens. The increased amount of abdominal fat is associated with the restriction of voluntary intake of pasture by grazing cattle, Tayler (1959) has suggested that this is due to reduced rumen capacity, however, some form of metabolic control is also possible. On very limited evidence, Campling, Freer and Balch (1961) suggested that inherent differences between animals in the time of retention of food residues in the gut might be partly responsible for the individual animal variation in voluntary intake.

Caloric density, expressed as kcal/ml, has been suggested as an important factor in determining intake regulation by Baumgardt (1970). This concept was based on the assumption that at a given level of digestibility, a feed with a higher density will have : (1) a more rapid rate of digestion; (2) a more rapid rate of passage, and (3) occupy less space in the digestive tract per unit weight. If this model is correct it would appear that the addition of grain, (a high density feed), to pasture of greater than 70 per cent digestibility, (a low density feed), could lead to an increased DE intake even though the pasture digestibility exceeds the value where metabolic control is thought to become important.

Conrad, Hibbs and Pratt (1966) found that DM intake of rations below 67 per cent digestible DM was related to the exponent one of bodyweight. This was considered realistic because when the digestive tract is filled to maximum volume it represents a constant proportion of each cow's weight, and hence volume. However, for rations where fill did not limit intake the exponent was 0.73. This change will complicate attempts to predict a ruminant's intake from bodyweight unless a ration's characteristics are adequately known.

Major differences in the nutritional regimes of grazing and housed ruminants have been described by Macdonald (1968). The cutting of pasture for stall feeding may elicit a number of changes, few of which have been studied in detail. Arnold (1969) points out that the moisture content of cut herbage may change rapidly, changing the concentration of soluble plant constituent and perhaps leading to alterations in acceptability and intake. Volatile compounds are lost more easily from cut herbage and alteration in odour occurs. The intake of stall fed animals may be much lower than that of grazing animals because diet digestibility is often higher for the latter. Reid, Jung and Murray (1966) and Tayler and Deriaz (1963) have found that the intakes of grazing sheep on single species was up to 20 digestibility units higher than that of sheep in pens eating the cut pasture.

1.1.3 The effect of concentrate mixtures on the intake of pasture

In any consideration of this topic it must be remembered that the animals intake will reflect, not only the type of concentrate and pasture fed, but also the level of concentrate offered, and the physiological processes occurring in the animal. The interactions between concentrate and pasture with regards to their effects on digestive and metabolic functions are not well understood.

Campling, Freer, and Balch (1962) have demonstrated that marked increased in the voluntary intake of low quality roughages can occur when concentrates containing nitrogen are given. However, in the case of New Zealand pasture it is very unlikely that this effect will be manifest, because of the adequate protein content of the pasture, (see Table 1.1).

A more frequent occurrence is an increase in the total DM intake associated with a fall in the intake of roughage, when restricted amounts of concentrate are offered. The degree of substitution has been shown to vary over a wide range. Blaxter and Wilson (1961) found that in sheep the extent of the depression in voluntary intake of hay when restricted amounts of concentrate were given, varied inversely with the quality of the hay. Tayler and Wilkinson (1972) fed five combinations of concentrates and pasture, ranging from 100 per cent cut perennial ryegrass to 100 per cent concentrates, to growing steers. The decrease in grass organic matter intake was 0.87 and 0.95 gram per gram increase in concentrate organic matter intake for periods one and two of the experiment, respectively. This agrees well with the finding by Forbes, Raven and Robinson (1966) that a substitution rate of 1.02 occurred when barley comprised zero to 35 per cent of the diet. However, in a later experiment, Forbes, Raven, Irwin and Robinson (1967) reported a substitution rate of only 0.60. Working with lactating cows, Tapaira and Davey (1970) found a substitution rate of 0.66, and reported that digestive upsets occurred if the cows were offered more than 4.0 kg/day.

It has been demonstrated by Tayler and Wilkinson (1972), and Forbes _et al_. (1966), that the crude fibre digestibility of the pasture concentrate ration decreased as the proportion of concentrate rose. It was suggested by Tayler and Wilkinson (1972) that the reduced crude fibre digestibility might explain the depressed pasture intakes at all levels of concentrate feeding in their experiment.

As the level of intake increases, it is generally accepted that a fall in DM digestibility will occur, although the rate of this fall depends on the ration (Blaxter, 1962). The same author draws attention to the fact that, when mixtures of different feedstuffs are given to ruminants, the apparent digestibility of the mixture is not necessarily the same as the weighted sum of the apparent digestibilities of its components. Forbes _et al_. (1967) reported that treatments of grass alone, grass plus 0.5 kg barley per 100 kg body weight, and grass plus one kg barley per 100 kg body weight, gave total daily DM intakes of 4.0, 4.4 and 5.1 kg respectively. Despite the increased level of intake there was no significant effect on DM digestibility, presumably because of the associative effect of the increased concentrate levels.

1.2 ASPECTS OF CATTLE GROWTH RELEVANT TO THE STUDY OF EFFICIENCY OF FEED UTILISATION

This section does not attempt to review all the diverse information that exists on cattle growth. Its purpose is to review those aspects of growth in cattle which were of importance in planning the experiment and also those aspects which must be considered in its interpretation.

A study of the efficiency of feed utilisation should ideally use carcass weight gain or total energy gain as a response parameter. Unfortunately, neither of these parameters could be obtained because of the need to maintain the bulls for progeny testing of dairy merit. Liveweight gain was the only response parameter available, and the first subsection reviews the use of liveweight gain as a response parameter and the likely sources of error.

The bulls used in the experiment were subjected to a wide range of environmental conditions before they were assembled at either the Awahuri or Newstead Artificial Breeding centres at approximately 12 months of age. It is therefore essential to review some of the literature on compensatory growth, as this phenomenon may affect both feed requirements predicted from experimental data, and comparisons of efficiency of feed utilisation among groups of animals.

Growth patterns of cattle and the chemical composition of liveweight gain are discussed in the next two subsections because of their relevance to performance testing for efficiency of feed utilisation. These factors also influence the requirements for growth, which are discussed in the final subsection.

1.2.1 Liveweight gain as a Response Parameter

Bailey, Broster and Burt (1958) stated that a large number of published experiments have shown mean differences of 0.1 to 0.15 kg/day liveweight gain with 10 to 15 animals per treatment, but these differences have failed to reach statistical significance ($P < 0.05$). The same authors identify two sources of variation for any treatment, they are :

(i) variation in the inherent growth capacity of animals within a group due to age, genetic effects and differences in previous treatments; and

(ii) errors in the determination of individual changes in liveweight.

1.2.1.1 Group variation in liveweight gain

Inherent variation may be controlled to some extent by increasing the number of animals per treatment, the use of covariance analysis, or by using monozygous twins. In some cases, inherent, individual variation is of interest itself, this was the case in the experiment described later, although it was not as important as the comparison of high and low liveweight gain groups. Thomas, Clanton and Wilson (1953) used 70 animals per treatment to detect a statistically significant difference of 0.06 kg/day liveweight gain. For the present study facilities could be provided for only 18 animals, and hence resort to large numbers of animals per treatment could not be made.

The use of initial liveweight as the covariate in a covariance analysis design has been suggested by Ashton, Lucas and Sherwood (1955), however, Green and Burie (1953) could obtain no benefit from this procedure. Rate of gain in a standardisation period was also found to be ineffective by Green, Langer and Williams (1952), although Kincaid, Litton and Hunt (1945) found it to be of some use. Bailey et al (1958) suggest that covariance adjustment is of little value for short-term growth studies of less than 10 weeks. Success of the covariance design is dependent on the proportion of the error variance which is due to the between animal variability in inherent growth characteristics.

For purposes of studying individual variation, and also in the interests of maximum error control, the use of change-over designs has been suggested by Lucas (1959). In the present study the time available was limited, and this, coupled with the possibility of carryover effects from preceding treatments, rendered change-over designs unsuitable.

When limited numbers of animals are available, Lucas (1959) has suggested that balanced allotment to treatments be practised to minimize the variation between group means. Statistical considerations suggest that this method could lead to bias; furthermore, Meyer, Lofgreen and Garrett (1960) found randomised blocking to be more successful than balanced allotment in reducing error variance.

1.2.1.2 Individual variation in liveweight gain

Errors in individual changes of liveweight gain have been overcome to some extent by the use of extended experimental periods, standardised management and by repeated recordings of liveweight. Extended experimental periods usually increase liveweight gain relative to the errors of measurement, although this may not occur where feeding levels are close to maintenance. A doubling of the length of an experiment was shown by Bailey et al. (1958) to halve the standard deviation of error; this finding supports the contention that most of the experimental error is due to random fluctuations in liveweight. The major problem with lengthened experimental periods is usually the cost of extra feed.

Fasting before weighing will reduce error in liveweight gain estimation by reducing the variation in gut fill between treatments, (Meyer, Lofgreen and Garrett, 1960; Tayler, 1954). Gut fill has been found to account for 10 to 28 per cent of the total liveweight of adult cattle (Mott and Lucas, 1962), and over the course of one day may cause an average change in measured liveweight of 9-16 kg (Tayler, 1954). Day to day variations in the liveweights of individual cattle have been shown to vary up to 28 kg, (Hughes and Harker, 1950). The same authors suggest that liveweight gain is influenced some days afterwards by overnight fasting. The writer could find no sound evidence for this assertion in their report, and considers that it would be extremely difficult to experimentally determine the effect of fasting for short periods, on tissue gain. It is likely that the differences were due solely to gut fill. Withdrawal of water for periods of 16 hours may have deleterious effects on the animals when relatively dry feeds are fed in hot climates; however, Whitman, Loggin, Chambers, Pope and Stephens (1954) have shown that it is water rather than feed availability that is the major determinant of gut fill.

That fasting does not reduce all variability because of gut fill is strikingly demonstrated by Meyer et al. (1960), individuals from the same treatment had gut fills ranging from 13 to 48 kg after a 12 hour fast. Steers of 360 to 640 kg liveweight were still losing gut fill after 36 hours of fasting (Tayler, 1954). These reports emphasise the fact that the suggestion by Meyer and Garrett (1967) that animals be fasted for 16 to 18 hours before weighing is based largely on practical considerations.

Errors of liveweight determination are high during the first few days on a new feedstuff, or in new surroundings (Hughes and Harker, 1950; Whitemen et al, 1954). Unless adaptation to a new diet is complete the standard deviation of initial liveweights will be greater than for final liveweights and the difference required among treatments before statistical significance is reached will be inflated (Bailey et al., 1958).

A large volume of literature exists on the number of weighings made to determine a particular weight and the number of weights taken throughout an experiment to determine liveweight gain. However, the conditions under which these studies have been conducted were so diverse that they have not been able to adequately resolve the controversy which exists on this topic.

Evidence presented by Lush, Christensen, Wilson and Black (1928) suggests that there is a 42 per cent reduction in errors of bodyweight determination of weighings are made on three consecutive days and averaged, (three day weights), instead of one day only, (one day weights). Patterson (1947) has analyzed extensive data to test the accuracy of one day weights compared to three day weights; this author defines three sources of variation for three day weights, they are as follows :

(i) between-day variation, caused by average weights on one day being different from average weights on another day, this could be due to weather, management feed intake or time of weighing.

(ii) between animal variation (experimental error), this is a measure of genetic or age differences between animals and any differential environmental effects, and

(iii) residual variation due to interactions between days and animals, it includes differences in fill away from the average and also scale and operator error. If final weight or liveweight gain is considered, the difference due to treatment effects is another source of variation.

A very important point is the fact that residual variation is of major importance when interest centres on individual liveweights, in this case single day weights contain three times as much variation as three day weights. However, in testing for differences among groups of animals, the between-animal variation is used. Patterson (1947) showed that in all cases between-animal mean square values were very much larger than residual mean squares. In fact, three day weights increased accuracy by only 0.95 - 2.44 per cent for final liveweight compared to one day weights, when groups of animals were compared.

When liveweight gain, rather than liveweight, was the parameter of interest, Patterson (1947) showed that three day initial and final weights were only 2.27 per cent more efficient than one day initial and final weights in determining liveweight gain. The writer concludes that the efficiency of an experiment using liveweight gain as a response parameter, is best increased by decreasing between-animal variance. Residual variance may become an important component if the mean gains are small, or if the variability in gain among animals is small. A statistical approach similar to Patterson's was used by Koch, Schleicher, and Artaud (1958), to determine the effect of 6 to 12 hour fasting on between animal variation. Their findings suggested that fasting for this length of time could be an important aid to reducing between animal variation, especially in animals of one year or older.

1.2.1.3 Methods of estimating liveweight gain

Several methods have been used to estimate liveweight gain during an experiment. Three of the most common methods were examined experimentally by Bailey *et al* (1958), these were as follows :

(i) the regression of liveweight on time.

(ii) the difference between single, initial and final liveweights.

(iii) as in (ii) but with two weighings on two consecutive days.

Their results indicated a standard error of ± 0.12 kg/day for all three methods. Unfortunately, a comparison with fasted liveweights was not made and so the value of these findings is reduced.

In an experiment using 2 rumen-fistulated cows, Bath, Ronning, Lofgreen and Meyer (1966) estimated reticula-rumen fill by emptying the contents and calculating "fill corrected" weights. The liveweight change so obtained was considered to be the "true" weight change, however no account was taken of other parts of the alimentary tract. (see Section 1.2.1.4). The experimental results are summarised in Table 1.2.

TABLE 1.2 : A comparison of different methods of estimating liveweight losses (kg) in rumen-fistulated heifers, over a 42-day period

Method of liveweight change estimation :	Heifer A	Heifer B
'Fill corrected' weights	9.1	22.2
Three day means	18.5	15.6
Shrink weights	9.1	24.0
Regression of daily weights	12.7	20.4

Shrink weights give a better prediction than regression on daily, unshrunk weights, which in turn are better than three day means. From this data it would seem reasonable to assume that a regression on shrink weights taken at intervals throughout an experimental period, would be at least as accurate as taking initial and final shrink weights. The cyclical appearance of liveweight curves plotted against time, has been shown by Baker and Guilbert (1942) to be due to animals with above average fill on one day having above average fill on the next day. This finding led them to condemn the practice of weighing on consecutive days because of the correlation which exists between the deviations. No work has been done on how this correlation changes with time, although Koch et al (1958) assumed it to be zero after seven days. Obviously the longer the period between weighing the more closely the analysis will resemble a regression of liveweight on time.

In the present study a randomised block design was considered to be the most satisfactory. The selection criterion of either very high or very low liveweight gain, (see Section 1.6.1) meant that initial liveweights were quite variable, and consequently it was decided to use initial liveweight as a basis for blocking. In view of the importance of experimental length in determining the error variance, it was decided to extend the main comparison period to ten weeks; however, feed shortage meant that this period had to be terminated after eight weeks. The decision to estimate liveweight gain from a regression of shrunk weights taken at weekly or fortnightly intervals was based on the experimental evidence cited, and on practical considerations of labour availability.

1.2.1.4 The effect of alimentary tract fill on estimates of liveweight gain

By definition, gut fill is :

(Alimentary tract + contents) - (Alimentary tract empty).

A large proportion of the fill is usually water, and Makela (1956) has shown that 72.8 ± 3.6 per cent of the total gut fill contents are in the reticulorumen, on hay intakes ranging from 3 to 13 kg DM/day. The proportion appeared to change little with increasing levels of intake. This finding is important when total gut fill is to be estimated by total removal of the reticulo-rumen contents or by indirect methods using a marker. Three major determinants of gut fill appear to be : the quantity of the diet, its digestibility and physical nature, and the time after the last meal. The first two are often very closely related and will therefore be discussed together.

Hutton, Hughes, Newth and Watanabe (1964) have derived equations relating rumen DM to daily DM intake and percentage apparent digestibility. Their equations imply that lactating cows fed cut herbage of constant digestibility will increase rumen DM content by 0.6 kg for each 1.0 kg DM fed. Furthermore, at constant intake a fall of one digestibility unit will result in an increase of approximately 0.09 kg in rumen DM.

Gut fill determined at slaughter enabled Tayler and Wilkinson (1972) to develop equations relating gut fill to level of pasture and concentrate intake and liveweight. An equation including all three variables accounted for 75 per cent of the variation in gut fill. Fill progressively decreased as the proportion of concentrate in the total intake increased.

In his studies on grazing steers, Tayler (1954) showed that 520 kg steers lost an average of 50 kg fill per 24 hours if the fast was started at 2100 hours, but only 38 kg fill per 24 hours when the fast was started at 0900 hours. The weight difference of 21 kg in favour of the former group, decreased to 9 kg after 24 hours, indicating that animals with the greatest gut contents lost fill at a faster rate than their counterparts. Tayler (1954) has also developed equations that relate fasted weights after 12 and 18 hours to a 36 hour fasted weight. However, these equations do not allow for the differential weight loss that may occur when animals from different dietary treatments are fasted for the same length of time.

It was the writer's intention, in reviewing some of the work on gut fill in cattle, to develop a prediction equation that would make use of the liveweights, dry matter intakes and concentrate to pasture ratios measured in the present study. However, the equations developed by different workers appear to be only useful under the conditions in which they were derived, and it appeared likely that little increased accuracy of liveweight gain determination could be attained by using any one of them in the present study. This view is supported by the differences in gut fill of 13 to 48 kg between individuals under the same treatment after a 12-hour fast (Meyer et al., 1960). The complex interactions that exist between intake, digestibility and retention time with different diets also make it unlikely that a general equation relating gut fill to the quantity and quality of intake could be found.

1.2.2 Body composition

Even if liveweight gain is estimated accurately with no confounding effects of gut fill, there is still the possibility that a unit of liveweight gain may differ in calorific value from treatment to treatment, or from animal to animal. By far the major components of liveweight gain are fat, protein and bone. It has been unequivocally demonstrated that fat and protein account for almost all the energy contained in a carcass (Reid and Robb, 1971). Calorimetric determinations by Reid, Wellington and Dunn (1955) have resulted in bovine fat being assigned an energy value of 9.499 kcal/g and bovine protein a value of 5.447 kcal/g. Obviously, variation in the proportion of either fat or protein in a unit of liveweight gain will alter the calorific value of that unit.

In a study of efficiency, such as this, where liveweight gain is the only available output measure it is essential to determine to what extent age, liveweight, liveweight gain and quality of the diet effect the proportions of fat and protein in the carcass.

In many feeding systems age and liveweight are very highly correlated, and because of this their effects will be discussed together. However, when animals have been on different nutritional regimes, comparisons at equal ages often lead to different results than comparisons at equal weights. In a recent review on body composition, Reid and Robb (1971) concluded that heifers of dairy breeds ranging in age from one day to fourteen months increased the amount of body energy linearly with respect to increasing empty body weight. In dairy cows of 28 months to 15 years of age, relationships between body components and body weights were quite variable, in fact it appeared possible that body tissue gain or loss could range from as much as 100 per cent water to about 90 per cent fat.

The changes of body composition as liveweight increases have been adequately demonstrated in both sheep and cattle (see Fig. 1.1). However, the effect of different nutritional regimes over and above the effect of liveweight changes has not been clearly demonstrated. Studies in growing sheep (Bull, Reid, and Johnson, 1970; Paladines, Reid, Von Niekirk and Bensadoun, 1964) showed that within breed and sex, the relationship of fat and protein to empty body weight was capable of resisting nutritional alteration. In their review of body composition in dairy cattle, Reid and Robb (1971) concluded that more work was needed before the extent to which this was true for growing cattle could be determined.

In a study reported by Kelly, Fontenot, Graham, Wilkinson and Kincaid (1968), different levels of nutrition from maintenance to ad libitum feeding produced large differences in the carcass composition of steers slaughtered at 5, 10, 16 and 23 months of age. Unfortunately, no mention is made of the slaughter weights of the steers, and it appears likely that the nutritional effects are confounded with the effect of liveweight.

In a more comprehensive study, Waldman, Tyler and Brungardt (1971) fed Holstein steers at either ad libitum intake, or, a restricted level set at 60 per cent ad libitum intake. Nutritional treatment did not influence fat deposition up to 227 kg liveweight,

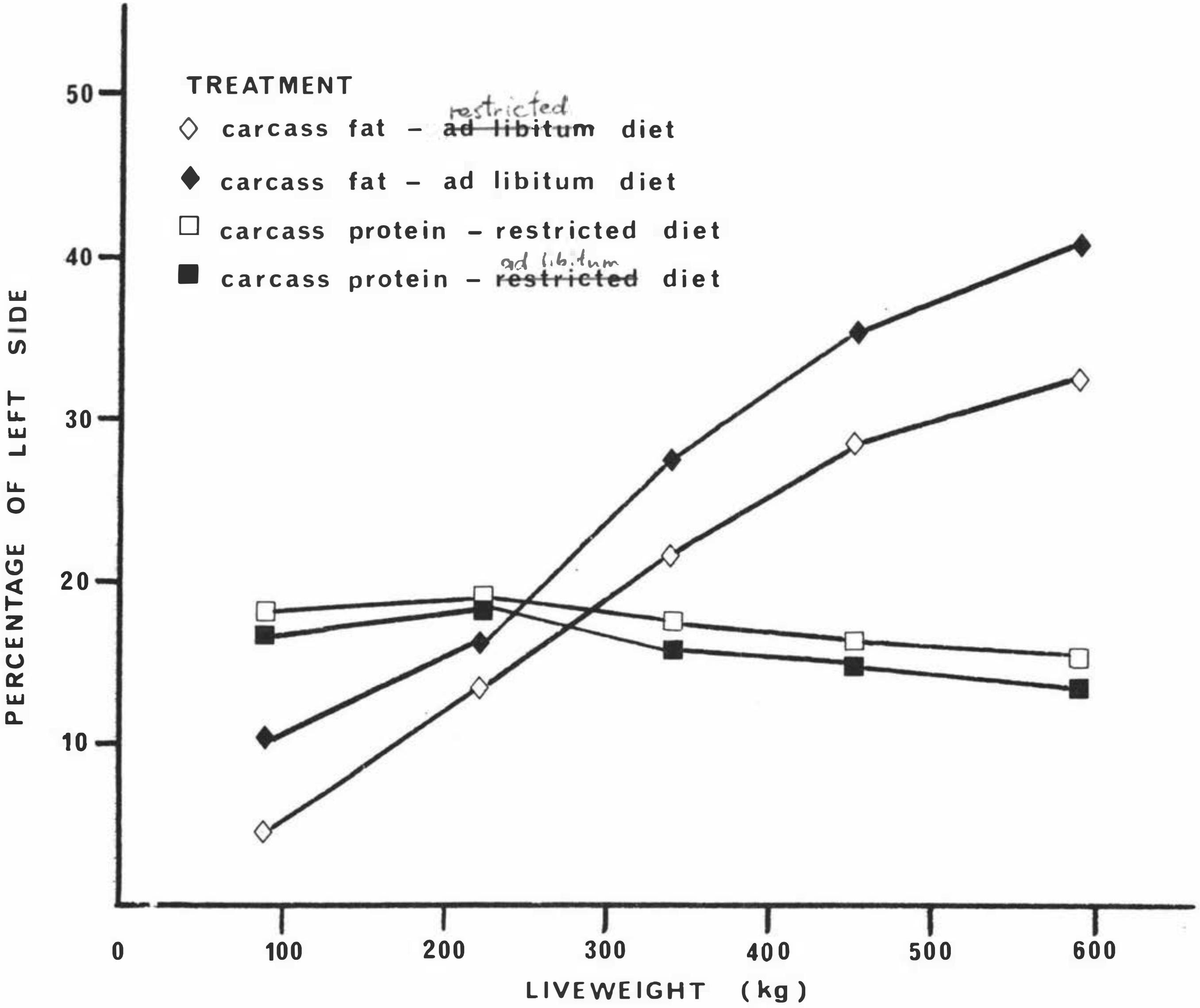

FIGURE 1.1: Changes in the fat and protein per cent. of Holstein steers from 90 to 590 kg liveweight for ad libitum and 60 per cent. ad libitum feeding (based on Waldman et al., 1970).

thereafter ad libitum feeding produced significantly greater ($P < 0.01$) amounts of carcass fat than the restricted groups at all slaughter weights (see Fig. 1.1). These findings support those of Hendrickson, Pope and Hendrickson, (1965) and Meyer (1962) who all showed a higher plane of nutrition to increase the proportion of fat in the carcass. Lofgreen (1965) fed the same ration at two levels of intake for 133 days; ad libitum feeding resulted in 3.4 times as much weight gain as the restricted group, but nine times as much energy gain. This is an indication that the ad libitum feeding resulted in a marked increase in fat percentage, although some of this would undoubtedly be due to the greater liveweight of the group fed ad libitum.

When an alfalfa-roughage ration and one with a high proportion of concentrate were fed to produce the same rates of gain, Lofgreen, Bath and Strong (1963) could find no difference in the energy content per kg of liveweight gain. More surprisingly, gains of 0.25 kg/day on alfalfa and 1.13 kg/day on the high concentrate ration gave energy contents of 4.4 and 4.8 Mcal/kg liveweight gain respectively, indicating very little difference in the fat content of the gains at these widely differing rates. It would appear that plane of nutrition has its greatest influence after fat deposition has accelerated, this occurred at approximately 227 kg liveweight in the study conducted by Waldman et al. (1971). However, there is still controversy over the magnitude of changes in the energy content of a unit of gain as the plane of nutrition increases.

It has been suggested, on the basis of theoretical considerations that the energetic cost of protein synthesis will be lower than the cost of fat synthesis (Blaxter, 1962; Baldwin, 1968). On the basis of experimental work, Thorbek (1967), considers that the reverse may be true for growing hogs. Experimental work with ruminants that were simultaneously synthesising fat and protein suggested there was little evidence for any difference in the energy cost of protein and fat synthesis (Blaxter, Clapperton and Wainman, 1966; Garrett, 1971; Graham, 1969; Lofgreen and Garrett, 1968).

Work by Bull et al. (1970) with Southdown lambs indicated that the efficiency of ME utilisation above maintenance was 57.6 and 65.5 per cent for rams and ewes respectively. Body fat varied from 17.5 to 33.6 per cent and from 23.0 to 43.2 per cent for rams and ewes respectively over an empty bodyweight range of 20 to 50 kg. There were no differences in the protein percentage for rams and ewes, combined with the other evidence, it suggested to the authors that the ewes were energetically more efficient despite the higher fat percentage deposited.

In a breed comparison of energy utilisation for tissue growth in Holstein and Hereford steers, Garrett (1971), reported that both breeds produced 24 g of protein per kg of feed consumed above maintenance, but fat production was 115 and 86 g of fat per kg feed above maintenance for the Herefords and Holstein steers respectively. Thus implying that Herefords were at least as efficient in energy utilisation as Holsteins despite greater fat deposition.

Obviously, more work is needed before the biochemical efficiencies of fat and protein synthesis in growing cattle can be accurately defined. The present evidence suggests that no difference exists in the two functions in growing cattle. This implies that there will be no difference in the efficiency of ME utilisation when gain is measured on an energy basis, even when differences in fat and protein percentages occur. However, if liveweight gain is used as a response parameter, the animal with the higher fat percentage will be penalised because the higher calorific value of the gain is not recognised.

In the present study the two groups of interest differed quite markedly in initial liveweight. The importance of liveweight per se on body composition has been demonstrated in all the work reviewed for liveweights of 400 - 600 kg. It is unfortunate that the information on the body composition of cattle does not allow correction factors for the effect of different liveweights to be calculated.

To obtain a broad basis for comparison of the two groups it was considered necessary to design the experiment to include three planes of nutrition : one close to maintenance, one giving approximately 0.5 kg liveweight gain/day, and one giving approximately 1.0 kg liveweight gain per day. The bulk of evidence suggests that the energy content of a unit of liveweight gain will increase as the level of intake increases for 400 - 600 kg animals; however, the evidence is not unequivocal (Lofgreen, et al., 1963), it is to be regretted that some of the most comprehensive experiments attempted in this field by Californian workers (Lofgreen, 1965; Lofgreen and Garrett, 1968) may be to some extent invalidated by technical difficulties associated with predicting carcass composition from measurement of specific gravity, (Reid and Robb, 1971).

The evidence for similarity between the efficiencies of protein and fat synthesis means that a plot of liveweight gain against ME (or DE) above maintenance could be used to determine if the calorific value of the gains was changing with increasing intake. A linear relationship would indicate no change whereas an asymptotic relationship would indicate an increasing calorific content per unit liveweight gain.

1.2.3 Growth in Bulls

In the present study interest is focussed on the growth patterns of Friesian bulls both on grazed pasture and freshly cut pasture fed in stalls. Although some important contributions have been made by New Zealand researchers, it has been necessary to include overseas work on both Friesian bulls and steers to characterise growth patterns more fully.

Seasonal growth patterns of bulls at pasture are reviewed in order to facilitate discussion of preliminary data used in the selection of bulls for the present experiment (Section 3.1). A comparison of the Friesian with other breeds used for beef purposes is made, with especial reference to New Zealand conditions. The final section summarises the growth patterns of bulls compared with steers, it is necessary to know how closely they correspond because much of the work reviewed in section (1.2.1 to 1.2.5) applies to experiments conducted on steers rather than bulls.

In a summary of liveweight data collected at the Newstead Artificial Breeding Centre, New Zealand; Carter (1969) reported a variation in liveweight between years which was apparently due to seasonal differences in pasture production. Growth patterns were considered sufficiently consistent to warrant a pooling of the data over a four-year period, for the purposes of comparison, birthweights of : 27.2, 36.3 and 40.8 kg were used for Jersey, Ayrshire and Friesian calves respectively. Table 1.3 indicates the average daily gain in specific periods along with the range, and some information from British Milk Marketing Board centres (Anon., 1966).

TABLE 1.3 : The average daily gain of dairy breed bulls at pasture.

Period	Breed					
	Jersey		Ayrshire		Friesian	
Milk Mkt. Board (3-12m)	0.74	(0.68-0.91)**	0.92	(0.75-1.17)	1.10	(0.60-1.41)
Birth - 13 (31 Aug.)	0.59	(0.45-0.78)	0.67	(0.43-0.82)	0.75	
13 - 16 (30 Nov.)	0.98		1.11		1.24	
16 - 20 (31 Mar.)	0.61		0.78		0.95	
13 - 20	0.75	(0.48-0.95)	0.90	(0.65-1.15)	1.05	(0.80-1.34)

** Range of average liveweight gain

Table 1.3 illustrates the liveweight gains of 1.24 kg/day achieved by Friesians from September to November when the bulls were 13 to 16 months of age, and the marked decrease in liveweight gain from December to April. Table 1.4 shows how these different liveweight gains result in breed differences in liveweight.

TABLE 1.4 : Mean liveweights (kg) and their ranges for dairy breed bulls at pasture

Age	Breed					
	Jersey		Ayrshire		Friesian	
13 mos. (31 Aug.)	262	(204-345)	304	(243-397)	343	(274-458)
20 mos. (31 Mar.)	424	(306-494)	499	(417-612)	570	(463-694)
56 mos. (26 Mar.)**	539	(442-658)	695	(606-821)	783	(640-876)

** Mature weight (one year's data only)

Although Carter (1969) assumed that the marked decrease in liveweight gain from December to April was caused by the decreased pasture production, another explanation is possible and may have been responsible for at least some of the decrease. By using data for Friesian bulls for Table 1.3 and 1.4, it can be shown that the average liveweight at 1 December would have been 455 kg, at 20 months (31 March) the average liveweight was 570 kg (Table 1.4). Table 1.5 summarises some of the relevant data from a trial by Waldman *et al* (1971). The point of major interest is the marked decrease in liveweight gain from 455 kg to 590 kg liveweight when the steers were on *ad libitum* feeding.

TABLE 1.5 : Liveweight, liveweight gain and age for Holstein steers fed *ad libitum* from birth to 590 kg liveweight

		Proposed slaughter liveweight				
Item	Birth	91	227	341	455	590
Liveweight (kg)	47.0	86.0	231.0	342.0	459.0	592.0
Liveweight gain (kg/d)	-	0.75	1.0	1.17	1.17	0.86
Age (days)	-	65.0	200	295	395	550
No. of steers	9	18	36	36	36	36

This decline was obviously not due to the restriction of feed available and most probably reflects the combined effect of increasing maintenance requirement and the increased calorific value of liveweight gain at higher liveweights. It is possible the same explanation applies to animals fed pasture. Work by Levy, Holzer and Volcani (1968) with intact Israeli-Friesian male calves demonstrated that the ability to gain liveweight was only slightly diminished up to a slaughter liveweight of 625 kg. Animals were slaughtered at 25 kg intervals from 350 to 625 kg, and through all intervals liveweight gain was close to one kg/day. The difference between the finding of Waldman *et al*. (1971) and that of Levy *et al*. (1968) may be due to either the different diets used, or to the difference between bulls and steers at heavier liveweights.

In an experiment designed to estimate the intake of grazing Friesian bulls and steers, Maclean, Joyce and Rattray (1970) found no significant difference in seasonal growth rates for animals stocked at 1.5, 2 and 2.5 beasts per acre. However, in two previous years the same workers found high growth rates in spring and much lower ones in autumn; this lends support to the idea that variations in growth rate may be due to variations in pasture availability and quality.

Information on different breeds for beef production in New Zealand has only become available in the last decade. However, the few experimental comparisons that exist indicate that the Friesian, a breed traditionally used for dairying purposes, has a potential for beef production equal to, or exceeding, that of the traditional beef breeds. In a comparison of 51 Friesian and 22 Angus bull calves reared under similar environmental conditions until 18 months of age, Dalton and Everitt (1972) reported that the Friesians were superior to the Angus in liveweight gaining ability. The meat yield was also higher for the Friesians, despite the fact that the best twelve Friesians were not slaughtered. Joblin (1970) fed freshly cut pasture to Friesian and Angus steers for six months, liveweight gains were 0.77 and 0.69 kg/day respectively. However, in a second experiment the same author could detect no significant difference in carcass weights between the two breeds.

Tables 1.3 and 1.4 indicate the superiority of the Friesian for liveweight gain over both the Ayrshire and the Jersey under similar pasture feeding conditions. Undoubtedly, the Friesian bulls would reach slaughter weights more rapidly if feeding approached *ad libitum* levels but with intensive pasture management this is unlikely at most times of the year. No comparisons of the three dairy breeds for feed conversion efficiency with pasture feeding could be found, although Joblin (1970) concluded that there was no difference between Friesian and Angus steers in feed conversion efficiency.

It has been well established that when bulls and steers are similarly fed the bulls will tend to outgain steers by 10-15 per cent

(Harte, Curran and Vial, 1965; Prescott and Lamming, 1964; Nichols, Ziegler, White, Kesler and Watkins, 1964). The superiority of bulls over steers may not exist until approximately 200 kg liveweight (Harte et al., 1965); Aitken, Preston, MacDearmid and Phillip (1963) found accelerated growth rates of bulls compared to steers after eight months of age. When Friesian bulls and steers were compared at pasture, no difference in growth rate could be detected by Maclean et al. (1970), despite the fact that slaughter weights were 320 - 450 kg and liveweight gains approximately 0.80 kg/day. The explanation for this unexpected result is not apparent since animals were allowed to grow well past 200 kg liveweight and liveweight gains were similar to those in other comparisons.

In an experiment comparing pasture fed bulls and steers slaughtered at 17 and 23 months of age, Harte (1969), found that bulls had 14 and 29 per cent more 'meat' in their carcasses at 17 and 23 months respectively. In a review on the growth patterns of bovine muscle, fat and bone, Berg and Butterfield (1968) present evidence for a delayed impetus to fatten in bulls compared to steers. A study of bulls and steers slaughtered at 364 kg and 454 kg by Nichols et al. (1964) showed that bulls were significantly ($P < 0.01$) less fat than steers at both slaughter weights. The steers were 3 and 5 per cent fatter at 364 and 454 kg respectively. It seems likely that if growth data are compared for bulls and steers at equal weights, the steers will be significantly fatter; however, if comparisons are made at the same age on an ad libitum feeding system it is likely that the increased growth rate of the bull will have led to heavier liveweights and hence a greater fat content.

The evidence suggests that Friesians have a definite potential as dual-purpose (beef and dairy) animals in New Zealand. The limited information on the growth patterns of Friesian bulls in New Zealand, and similar overseas breeds, indicates that animals in the 400-600 kg liveweight range could make liveweight gains of up to 1.0 kg/day, although this weight range might be beyond the optimum for studying maximum liveweight gains.

1.2.4 Compensatory growth

Aspects of this complex, and often controversial subject, have been extensively reviewed by Wilson and Osbourne (1960) and Allden (1970). The importance of considering compensatory growth in the present study will be acknowledged when it is realised that the bulls used were assembled at either the Awahuri or the Newstead Artificial Breeding Centre at approximately twelve months of age. The subsequent period of six months was used as a selection period. After approximately nine months the selected bulls were assembled at Awahuri for the experiment; thirteen were from Newstead and five from Awahuri. It is possible that some compensatory effects were manifested after one or both of the shifts mentioned.

Four topics will be reviewed because of their relevance to either the preliminary data collected, or the experimental design. Firstly, the correlations that exist between liveweight gain in one period and liveweight gain in a subsequent period, are reviewed. Secondly, some effects of early rearing treatment on subsequent growth performance are discussed. Thirdly, the review considers the efficiency of feed utilisation of animals fed ad libitum after a period of restricted feeding; and finally, the changes in appetite of re-alimentated animals are considered.

Compensatory growth has been defined by Bohman (1955) as, "abnormally rapid growth relative to age". This definition is based on the demonstration that growth, at least in the final stages, proceeds as if the normal condition were mature size, and that the rate of growth will be proportional to the growth needed to reach mature size, (Brody, 1945). Consequently, a restricted animal should show a rate of growth greater than that which is normal in animals of the same chronological age, when feed restriction is removed.

Grazing animals are often subject to periods of feed shortage, and many workers have documented the effect of these periods of shortage on subsequent liveweight gain. Correlations of - 0.64 and - 0.81 between summer and winter liveweight gain were demonstrated by Heineman and Von Keuren (1956) and Kincaid (1939) respectively, for range cattle in the United States. Literature on this subject has been reviewed by Lawrence and Pearce (1964). These authors used a 168-day winter feeding period to achieve liveweight gains of 0.73, 0.34 and 0.01 kg/day in three groups of cattle, in the following 140-day *ad libitum* pasture grazing period liveweight gains were 0.57, 0.98, 1.20 kg/day respectively. This gave a highly significant ($P < 0.01$) correlation of - 0.90 between summer and winter gain. With a more severe winter restriction, McCarrick, Harrington and Conway (1963) reported that summer liveweight gains were proportional to the degree of restriction during the winter.

In New Zealand, Scales and Lewis (1971) obtained a significantly negative regression for post-winter gain on winter gain in each year of a three year trial on improved clover-tussock pasture. However, Brumby, Walker and Gallagher (1963) could show no correlation between winter and summer gains for beef cattle. They suggested that this could be due, in part, to compensating growth and, in part, to appreciable errors in the estimates of liveweight gain, especially during the winter period. It is also possible that the lack of correlation could be due to an interaction between individual genotypes and the differing pasture environments in winter and summer. Of particular relevance to the present study is the regression coefficient of 0.87 between 20 month liveweight and 12 month liveweight, calculated by Carter (1969) for bulls bought into the Newstead Artificial Breeding Centre at twelve months of age. This implies that some compensatory growth is occurring, and might be expected in view of the widely different areas the bulls were brought from. The finding by Everitt, Evans and Franks (1969) that 54 per cent of the variation in liveweight at slaughter is due to between farm variation, further supports this idea.

Fitzhugh (1968) has issued a warning on "pseudo-compensatory growth". This may result when liveweight gains in two adjacent periods are calculated, a common liveweight term is used and any error in the estimation of this liveweight will automatically lead to a negative correlation. For example, an above average gut fill at one weighing will give inflated liveweight gains for the first period and depleted gains the second period.

It has been suggested that the older an animal is the more likely it is to demonstrate compensatory growth when feed restriction is lifted (Bohman, 1955). In an experiment involving 21 sets of identical twin steer calves, Everitt (1972), assigned one member of the set to ad libitum milk intake and the other was restricted to a growth rate of 0.15 kg/day, from birth until 112 days of age. The average liveweight difference between sets of twins of 42 kg at 112 days was reduced to 35 kg at 400 days after a common pasture grazing period. These results indicate that nutritional restriction for the first four months of life can markedly affect the liveweight achieved at 14 months of age. There is some evidence that the critical period for permanent stunting is in the first two to four weeks of life (Wardrop, 1966; Lonsdale and Tayler, 1969).

In a well designed experiment, Levy, Folman, Holzer and Drori (1971) examined the effect on compensatory growth of : three ages of starting a feed restriction - 90, 135, and 180 days of age; three durations of restricted feeding - 30, 75, and 120 days; two levels of nutrition during restricted feeding - maintenance and 125 per cent maintenance; and two slaughter weights - 450 and 525 kg. These workers examined liveweight and carcass component gain, but were unable to find evidence of compensatory growth for any of the treatments. This implies that the critical period for feed restriction may be up to nine months of age, while the duration of restricted feeding need only be as short as 30 days to have a significant effect on slaughter weights at either 450 or 525 kg liveweight.

However, Winchester and Howe (1955) and Winchester and Ellis (1953) restricted cattle from six to twelve months of age, and three to six months or four to eight months respectively, and were able to report that complete recovery occurred in all cases.

Meyer and Clawson (1964) were unable to confirm the assertion made by Blaxter and Wood (1951) that undernutrition resulted in a lowered basal metabolism, the former authors suggested that errors in liveweight determination due to gut fill and the lower heat production of undernourished animals is a result of lowered activity could account for the lower basal metabolism reported. Allden (1970) concluded in his review that the question is still unresolved.

In a series of digestibility determinations on growing cattle fed hay, Sheehy and Senior (1942) could find no significant differences in the apparent digestibility of energy during the restricted and re-alimentation periods. Wilson and Osbourne (1960) considered that it could not be definitely stated that an animal is more efficient at digesting food either during the period of restriction or re-alimentation. It would appear likely that, with some feeds, differences in levels of intake between the restricted and re-alimentation periods could result in differences in apparent digestibility and thus confound any effect of re-alimentation on digestibility.

Work by Meyer and Clawson (1964) with young sheep demonstrated an increased net energy utilisation for growth. There are many reports in the literature of animals subjected to considerable periods of energy restriction achieving the same weight as unrestricted animals without consuming significantly more food (Winchester and Howe, 1955; Sheehy and Senior, 1942; Meyer, Hull, Weitkamp, and Bonilla, 1965). However, other outcomes are possible, for example Meyer and Clawson (1964) found that when restricted sheep were fed until they equaled the bodyweight of the control group, the amount of feed required increased in direct proportion to the dietary restriction. Although net efficiency of liveweight gain was increased during refeeding, only the least restricted sheep reached the same total efficiency as the control sheep. The failure of the other groups to reach the same total efficiency is explained by the increased maintenance cost due to the extra time required to reach the final liveweight. In treatment comparisons involving different lengths of time, Allden (1970) stresses the need to maintain constant environmental conditions and a comparable feed supply to avoid confounding comparisons.

Increased relative feed capacity in cattle during re-alimentation has been demonstrated by Sheely and Senior (1942) Winchester and Howe (1955), Bohman (1955), and Meyer _et al_. (1965). It has been suggested that increased feed capacity may contribute to increased growth rates and total efficiency. That increased feed capacity is not always a feature of the re-alimentation period has been adequately shown by Meyer and Clawson (1964) and Allden (1970); sheep restricted in intake for 42 and 400 days respectively, did not show an increased feed capacity on the resumption of _ad libitum_ feeding. A similar effect has been observed in young cattle by Stuedemann, Guenther, Ewing, Morrison and Odell, (1968). Meyer _et al_. (1965) were able to demonstrate an increased feed capacity during concentrate feeding for animals previously fed on a low plane of nutrition on hay compared to those animals previously on a medium plane of nutrition . However, when animals previously fed on different planes of nutrition on pasture were subsequently fattened there was no significant difference in feed capacity.

In the present study a four week _ad libitum_ feeding period before the comparison period was considered desirable to determine differences in individual relative feed capacity, the _ad libitum_ feeding period would also allow differences in appetite between the two liveweight gain groups to be detected. The two levels of constrained feeding in the comparison were designed to detect any differences in feed conversion efficiency that the animal inherently possessed. Evidence from authors such as Everitt (1972) and Levy _et al_. (1971) suggests that rearing treatment before nine months of age will influence the liveweight at later ages, both these authors found that restricted and unrestricted animals grew at similar rates when a common feeding regime was imposed. However, detailed work by Meyer _et al_. (1965) suggests that increased partial efficiency of energy utilisation may result when animals re-alimentated. In the present study the pre-experimental liveweight gains were 0.3 kg and hence the lowest experimental plane of nutrition would represent a decrease in intake while the highest experimental plane of nutrition would represent a definite increase. It would thus be on the highest plane of nutrition where signs of compensatory growth, either an increased feed capacity or increased partial efficiency of energy utilisation would be manifested.

1.3 ENERGY REQUIREMENTS FOR GROWTH IN CATTLE

Aspects of this subject have been reviewed by Joyce (1971) his conclusion was that most cattle feeding experiments carried out in New Zealand had not led to any marked advance in defining the feed requirements of grazing beef cattle. Some of the major problems in establishing energy requirements for beef cattle lie in the difficulty of obtaining information on the composition of liveweight gain, the effect of environmental conditions and the voluntary intake and digestibility of different feeds or combinations of feeds. The dangers inherent in extrapolating results obtained with stall-fed animals to grazing animals has been adequately reviewed by Macdonald (1968).

One of the objectives of the experimental study reported here was to obtain estimates of the energy requirements for maintenance and growth of beef cattle. The limitations of one study or one breed of cattle covering a small range of liveweight will be readily appreciated, however, it was thought that it would provide some information and be useful in a comparison with the four other estimates derived in New Zealand with pasture feeding. A comparison with the U.S.A., NRC system (1970) and the U.K., ARC system (1965) was also planned.

A discussion on the use of multiple regression techniques to estimate energy requirements is followed by a short discussion of the factors that could be important in the estimation of requirements in the present study.

1.3.1 Energy Requirement estimation by Multiple regression analysis

Many New Zealand and overseas workers (Wallace, 1961; Hutton, 1962; Joblin, 1970; Maclean, Joyce and Rattray, 1970; Holmes, 1961; Hodgson and Wilkinson, 1967), have partitioned energy intake into requirements for maintenance and liveweight gain. Much of this work has not fully taken into account the assumptions implicit in multiple regression analysis. Langlands, Corbett, Macdonald and Pullar (1963) and Joblin (1970) have criticised the application of multiple regression analysis to data in order to obtain energy requirements for maintenance and liveweight gain. Some of the assumptions made in multiple regression analysis and the effect they have on the possible uses for regression equations, have been discussed by Snedecor and Cochran (1967).

In many studies involving the triple relationship of intake, liveweight and liveweight gain, intake has been taken as the dependent variable. Although a more useful function may often be that with liveweight gain as the dependent variable, (R. Townsley, pers. comm.). If intake is the dependent variable the following equation can be described :

$$I = f\ (W^x, G) \quad \ldots\ldots \qquad 1.1$$

where I = food intake

W^x = liveweight raised to some exponent, x .

G = liveweight gain.

The actual relationship : $I = B_oW^x + B_1G + e$ is estimated by :

$$I = b_oW^x + b_1G + e$$

The coefficients b_o and b_1, will be unbiased estimators of B_o and B_1 respectively only if measurements of liveweight and liveweight gain are substantially free from errors. If this is not the case they estimate some other regression coefficient, the size of which is dependent on the influence of unobserved, independent variables. In controlled experimentation, the process of randomisation will make the unknown variables independent of liveweight and liveweight gain; however, if the other variables are large the residual standard deviation will be large and the regression coefficients too imprecise to be useful.

In his discussion of the application of multiple regression analysis to the prediction of energy requirements of cattle, Joblin (1970) states that some criteria should be specified before a regression equation can be considered to satisfactorily express the relationship between intake, liveweight, and liveweight gain. He suggested a multiple regression coefficient of > 0.90, a constant term of ± 0.10 kg and a residual standard deviation of digestible organic matter intake of $\leqslant 0.20$ kg.

The discussion by Snedecor and Cochran (1967) on the subject, implies that bias in the estimated individual regression coefficients may be advantageous if the aim is to predict the independent variable. The least squares method will improve the prediction insofar as the unknown, independent variables are good predictors of the dependent variables and are stably related to the other, measured, independent variables.

Hutton (1962) has raised some objections to the use of multiple regression analysis in predicting energy requirements. He considers the heat disposal capacity of the body may be an important factor in the relationship between liveweight and food intake, although it is not directly related to maintenance requirements. Despite this objection, Joblin (1970) concluded that regression equations could be useful for predicting requirements as long as the criteria mentioned above were satisfied, and the knowledge applied to stock of similar liveweight and liveweight gain and fed the same food as those from which the equation was derived.

Two basic forms of regression equations have been used by research workers. Many workers (Hutton, 1962; Joblin, 1970; Taylor and Young, 1966; Hodgson and Wilkinson, 1967) have used the following form :

$$I = b_0 + b_1W^x + b_2G \pm R.S.D. \quad \ldots\ldots$$

R.S.D. = residual standard deviation.

This equation implies that the requirement for a unit of liveweight gain will be the same no matter what the value of liveweight. Some evidence has been presented (see Section 1.2.2) to suggest that this may be true when liveweight gain is measured in terms of energy. However, there is a great deal of evidence (see Section 1.2.2) to support the idea that the energy content of a unit liveweight gain increases as liveweight increases. If a wide range of liveweights is considered this may become an important source of error.

The second form of the equation has been used by Winchester and Hendrick (1953), Swanson (1971) and Garrett, Meyer and Lofgreen (1959). It can be described as follows :

$$\frac{I}{W} = A_0 + A_1 G \quad \ldots\ldots\ldots \quad 1.2$$

This equation implies that the requirement for a unit of liveweight gain will increase as liveweight increases. Swanson (1971) supported his decision to analyze growth data from a large number of experiments on dairy heifers, with evidence that the caloric density of liveweight gain increased as size increased. Further support for the use of the equation, when only liveweight gain data are available, is provided by evidence that as size increases gut contents as a percentage of the whole body decrease (Tayler and Wilkinson, 1972).

Taylor and Young (1966) have used both forms of the equation on the same data, and found that although equally good fits were obtained, equation 1.1 gave obviously erroneous maintenance requirements. However, they warned that with small numbers of animals it was futile to attempt a comparison of the two equations.

The decision on what exponent of liveweight to use has long concerned workers using regression analysis to describe growth data, (Hodgson and Wilkinson, 1967; Holmes et al., 1961; Brody, 1945). The resting metabolism of Jersey and Holstein cattle varied as the 0.56 and 0.60 power of bodyweight respectively in Brody's work (1945). Calculations by Winchester and Hendricks (1953) gave a value of 0.66 for the exponent. Holmes et al. (1961) found that exponents varying from 0.56 to 0.84 gave the most statistically satisfying equations at different stages of growth. A value of 0.61 was derived by Hodgson and Wilkinson (1967) in grazing experiments. Obviously, controversy exists on which value to use to describe liveweight in experiments with growing cattle. It appears unsatisfactory that the exponent should be manipulated to provide an equation of best fit and then be considered for general use, especially when measurements of intake and liveweight gain are subject to large errors. For older cattle the values of 0.75 (Kleiber, 1961) and 0.73 (Blaxter, 1962) appear to be well established, and could be used for growing cattle.

An exponent of 0.75 was chosen in the present study; firstly, to allow easy comparison with other work, and secondly, because in many cases no significant distinction could be made between exponents.

1.4 EFFICIENCY OF FEED UTILIZATION

The term "efficiency complex" was coined by Brody (1945) to signify the range of efficiency measures used to analyze and describe the production processes in all the economically important farm animals. Besides Brody, many other prominent scientists have reviewed some aspects of this vast subject. In an excellent and comprehensive review, Blaxter (1964) has examined pertinent research in different fields of animal nutrition and enumerated a series of useful generalisations concerning the efficiency of feed utilisation. Kleiber (1961) has presented a concise review of the relation of body size to food utilization and of total efficiency to partial efficiency. New concepts in performance and progeny testing for efficiency of feed utilisation have been developed by Taylor and his co-workers (Taylor and Young, 1962; Taylor, Watson and Young, 1962; Taylor and Young, 1966).

In this section the review will be concerned only with that part of the "efficiency complex" which includes growing cattle. The first three sections review information on total, partial and intrinsic efficiency. Fourthly, the use of statistical adjustments in estimations of feed conversion efficiency is considered. Finally, correlations between efficiency measures and other variables are discussed.

1.4.1 Total efficiency

Kleiber (1961) has defined total efficiency as :

$$\text{Total efficiency (T)} = \frac{\text{Liveweight gain}}{\text{Intake.}}$$

It is of course possible to express liveweight gain in terms of energy or mass, and likewise intake can be expressed on a DM, DE, or ME basis. Kleiber (1961) suggests that similar units should be used for both liveweight gain and intake, thus rendering the term dimensionless and capable of expression as a percentage. The same definition has been assigned the following names by different authors : "efficiency of feed utilization", (Blaxter, 1962); "desirable feed efficiency" (Magee, 1962);

and "observed efficiency" (Taylor and Young, 1966).

To be technically correct, an efficiency term should always be of the form : $\frac{\text{Output}}{\text{Input}}$. However, Blaxter (1962) has defined the reciprocal of total efficiency as :

$$\text{"Feed utilization"} = \frac{\text{Intake}}{\text{Liveweight gain}}$$

This term is widely used in farming circles in the United Kingdom and the United States, although its use is quite common in scientific literature and is the preferred efficiency measure in a review of efficiency of feed utilization by Byerly (1967). The same author emphasises that the term suffers from the same disadvantages as total efficiency.

Blaxter (1964) has asserted that if animals of the same size are given the same diet ad libitum the animal which eats the most is the most efficient convertor. This implies that one of the major determinants of total efficiency is the voluntary intake of feed. Contrary to this, Magee (1962) has reviewed some evidence that suggests total efficiency is improved in swine by limiting daily feed consumption. It is generally assumed that there will be a positive relationship between daily food consumption and total efficiency, because daily feed consumption is positively associated with total efficiency. In an experiment designed to study these relationships, Magee (1962) found that in all groups of swine, average daily food consumed was positively correlated with average daily gain, but negatively associated with total efficiency. In this, and in another experiment conducted by Biswas, Hunt, Chapman, First and Self (1966), pigs with the largest appetites did not have the highest total efficiency (see Section 1.4.5).

The use of total efficiency as a measure of biological efficiency has been criticised by Meyer and Garrett (1967). These authors consider that the measure of biological efficiency is more properly either liveweight gain, or food intake, because a ratio gives two unseparated response criteria which can only lead to uncertain conclusions. In a discussion of the use of ratios in scientific research, Weil (1962) has specified three conditions that must be satisfied to warrant their use.

Firstly, the two variables considered should increase or decrease together in a linear fashion. Secondly, the regression for the two variables should intercept at zero; and finally, the variance of the variables should increase with the increasing magnitude of the variables. When liveweight gain and food intake are the two variables considered the intercept of the regression of liveweight gain on intake is not zero. It is also unlikely that the relationship between the two variables could increase or decrease in a linear fashion. Koch, Swiger, Chambers and Gregory (1963) found that a quadratic regression relating gain, food intake, and liveweight was more accurate than a linear relationship, however, the improvement was only slight. These authors believed that the automatic correlation which exists between total efficiency and either food intake or gain, and its biological unreality, (it disregards maintenance requirements), precluded its use in most experimental work.

In an excellent paper on this subject, Sutherland (1965), agrees that the prediction of liveweight gain from feed intake may easily give fallacious results if a ratio is used. He argues that the ratio of each animal's liveweight gain to its own food intake is an entirely different proposition, and claims that total efficiency is a perfectly valid estimate of efficiency. The problem of "automatic" correlations is discussed in Section (1.4.4).

As liveweight increases total efficiency will decrease except in extremely young animals (Taylor and Young, 1962). The curve of diminishing increment has been used by Headly, Miller, Ullrey and Hoefer (1961) to describe the relationship between liveweight and feed intake in growing swine. They found that the decrease of total efficiency with increasing liveweight was not strictly linear because of the logarithmic relationship between feed consumed and liveweight. This is to be expected if maintenance requirements are proportional to W^x where $x \leqslant 1.0$.

Obviously, the requirement for maintenance represents feed unavailable for growth, and consequently any difference in maintenance requirements between individuals or groups of animals may effect liveweight gain, especially if the intake level is held constant. To enable accurate comparisons to be made between animals of different liveweights the term partial efficiency is used.

1.4.2 Partial efficiency

Partial efficiency has been defined by Kleiber (1961) as "the quotient of a part of liveweight gain and the corresponding part of the food consumed". When the changes are extremely small, partial efficiency becomes "differential efficiency". Conversely, changes in liveweight gain may become as large as total liveweight gain, in this case intake refers to total intake minus the intake required for maintenance functions. This has been termed "Net efficiency" by Brody (1945), however, because he also uses it to measure the efficiency of work, the following review will refer to it as partial efficiency. The review will only be concerned with this special case.

$$\text{Partial efficiency (P)} = \frac{G}{I - M} \quad \ldots\ldots \quad 1.3$$

where M = maintenance requirement.

Kleiber (1961) has made the assumption that the partial efficiency for maintenance is the same as that for production, so that the maintenance requirement (M), may be expressed in terms of the basal metabolism (B).

Therefore $B = P.M$ 1.4

using the relation $T = \frac{G}{I}$ it can be shown that :

$$T = P - \frac{B}{I} \quad \ldots\ldots\ldots\ldots \quad 1.5$$

Equation 1.5 implies that the total efficiency is the difference between the partial efficiency and the ratio of basal metabolic rate to energy intake. In cattle it is generally accepted that the basal metabolic rate may be estimated from body weight as follows :

$$B = 70W^{\frac{3}{4}} \quad \ldots\ldots\ldots\ldots \quad 1.6$$

When this relation is introduced into equation 1.5 it leads to :

$$T = P - \frac{70}{I/W^{\frac{3}{4}}} \quad \ldots\ldots\ldots\ldots \quad 1.7$$

The term $\frac{I}{W}\frac{3}{4}$ is the energy intake per unit of metabolic body size, defined by Kleiber (1961) as "relative feed capacity". The implications of equation 1.7 are embodied in Kleiber's law which states : "Since neither partial efficiency nor relative food capacity are consistently related to body size the total efficiency of food utilization is independent of body size", (Kleiber, 1961). Brody and his co-workers (1945) have verified this experimentally by comparisons of total efficiency of lactation in rats and cows. However, for growing animals within a species, total efficiency will decline as liveweight increases due to the decrease in relative feed capacity. Kleiber's law provides the basis for the supposition made by Blaxter (1962) that two animals will have equal total efficiencies as feed convertors if they consume the same multiple of their feed requirements for maintenance. Despite their equal efficiency the animal with the higher maintenance requirements will make the largest liveweight gains. Kleiber, (1961) has developed his concept of "relative production capacity" to allow for these differences in liveweight gains between equally efficient animals.

From equation 1.5 it can be derived that :

$$G = P.I - B \quad \dots\dots\dots\dots\dots \quad 1.8$$

Equation (b) can be divided by B to give :

$$\frac{G}{B} = P.\frac{I}{B} - 1 \quad \dots\dots\dots\dots\dots \quad 1.9$$

but since B = $70W^{\frac{3}{4}}$ equation 1.9 becomes :

$$\frac{G^{\frac{3}{4}}}{W} = P.\frac{I^{\frac{3}{4}}}{W} - 70 \quad \dots\dots\dots\dots\dots \quad 1.10$$

$\frac{G^{\frac{3}{4}}}{W}$ is known as the relative production rate, and can be readily seen to be a linear function of the relative feed capacity. Kleiber (1961) concludes that selection of animals for efficiency of feed utilisation should utilise the relative production rate. While this may be true for an *ad libitum* feeding system it will not necessarily be true for feeding systems other than *ad libitum* such as are used for maintaining breeding stock, or growing cattle in an intensive grazing ecosystem. In fact, Taylor and Young (1968) assert that selection for a high relative food capacity will result in higher feed costs when an animal is close to maintenance.

Meyer and Garrett (1967) have pointed out the necessity of assuming a maintenance term when partial efficiency values are being calculated. Blaxter (1962) suggests that DE required for maintenance can be estimated as 1.7 kcal DE/kcal of fasting metabolism in ruminants. The maintenance requirement for DE was calculated as twice the basal heat production by Brody (1945), while Lofgreen and Garrett (1968) have reported experimental data which suggest a maintenance requirement of 161 kcal DE/kg$^{\frac{3}{4}}$. These figures were obtained under widely different conditions and ~~and~~ any one figure will always be an approximation when applied to a group of animals because of the inherent, individual variation in the maintenance requirement of cattle. If partial efficiency is studied at a constant, restricted level it is likely that the animal or group of animals with the lowest maintenance requirements will be classified as the most efficient.

1.4.3 Intrinsic and potential efficiency

These two forms of efficiency are special cases of partial efficiency, they have been developed by Taylor and his co-workers to aid them in their interpretation of variations in growth and efficiency under different feeding systems (Taylor, Watson and Young, 1962; Taylor and Young, 1964; Taylor and Young, 1966). In their largely theoretical discussions, Taylor and Young (1964) used a linear model relating gain, feed intake and liveweight. However, for the purposes of comparison with work in Section 1.4.1 and 1.4.2, $W^{\frac{3}{4}}$ has been used instead of W in their equations. The basic equation expressing liveweight gain as a function of feed intake and $W^{\frac{3}{4}}$ is :

$$G_i = a_i I_i - b_i W_i^{\frac{3}{4}} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad 1.10$$

where i represents the ith animal.

a_i = intrinsic efficiency of growth.

$\frac{a_i}{b_i}$ = intrinsic efficiency of maintenance

This is analogous to equation 1.8 in Section 1.4.2

$$G = P.I. - 70\ W^{\frac{3}{4}}$$

since $B = 70\ W^{\frac{3}{4}}$

However, the intrinsic efficiency of growth is a more general term than partial efficiency. Each animal at a given weight will have a range of possible food intakes and thus a range of possible liveweight gains. A conceptual curve can be visualised for each individual covering all possible food intakes and liveweight gains, the slope of this curve represents the intrinsic efficiency of growth. However, in an experiment all that can be measured is liveweight gain at one particular feeding level, the values derived will give total efficiency and, if maintenance requirements are allowed for, partial efficiency.

Potential efficiency is defined as "the gain an individual animal would have made at the mean food intake of the experimental group divided by the mean food intake.

It is possible to write equation 1.10 as :

$$G_i = a_i (I_i - \bar{I}) - b_i (W^{\frac{3}{4}} - W^{\frac{3}{4}}) + (a_i \bar{I} - b_i W^{\frac{2}{4}}) \quad \ldots\ldots \quad 1.11$$

The first term represents gain or loss due to eating more or less than the mean amount of food intake; the second term represents gain or loss due to weighing more or less than average; the final term indicates gain or loss due to intrinsic efficiency.

Taylor and Young (1966) explain that the efficiency parameters will change with food composition, temperature, climate and housing although these are often experimentally controlled. The parameters are independent of any particular growth and food intake curves. The genetic variation in these efficiency parameters is much more constant than the genetic variation in food intake, liveweight and liveweight gain, which can be altered drastically by the feeding system imposed. The implications of this in performance testing will be discussed in Section (1.5.1).

1.4.4 Statistical Adjustment of Efficiency of feed utilization data

The evalution of efficiency of feed utilization data in either nutritional or genetic studies may often be complicated by differences in liveweights maintained, or food intake, or both. These differences may prejudice the comparison of individuals or groups, unless adjustments can be made to compensate for the differences. One such adjustment has been used by Koch *et al.* (1963), the efficiency of feed utilization is computed by holding either liveweight gain or feed consumption constant statistically. This results in the following expressions of efficiency :

(i) Feed consumption adjusted for differences in liveweight gain.

(ii) Liveweight gain adjusted for differences in feed consumption.

These two expressions comply with the requirement that the proper expression of efficiency of feed utilization is either liveweight gain, or feed consumption (Meyer and Garrett, 1967), (see Section 1.4.1).

Expression (ii) partitions lifeweight gain in to that expected on the basis of a groups average performance consuming a given amount of food. The deviation from the expected value based on regression is attributed to differences in efficiency of feed use. In fact, this is equivalent to potential liveweight gain defined by Taylor and Young (1964).

The proper liveweight to use in the determination of maintenance requirements may sometimes be difficult to decide upon. Mid-liveweight (initial liveweight + 0.5 liveweight gain) has been proposed by Koch *et al.* (1963), and could be important where large treatment differences exist. However, if liveweight gains in the experimental period are small, mid-weight may be subject to more error than a liveweight taken close to the middle of the experimental period, because the liveweight gain term used to compute mid-liveweight is subjected to greater errors (see Section 1.2.2).

A basic objection to the methods of estimating deviation of liveweight gains from the regression of liveweight gain on feed consumption has been raised by Sutherland (1965). Animals with identical deviations in liveweight gain are called identically efficient regardless of the feed consumption required to produce such a deviation from expected liveweight gain. A sample calculation to illustrate this point is presented in Table 1.6

TABLE 1.6 : Hypothetical total efficiencies and deviations from expected gain in two animals of the same liveweight

Animal	Intake (kg/DM/day)	Predicted LWG (kg/day)	Actual LWG (kg/day)	Deviation (kg/day)	Feed utilization :
A	7	1.66	2.16	+ 0.5	3.24
B	12	2.51	3.01	+ 0.5	3.98

Both A and B have the same deviations, but A has the highest total efficiency on account of its lower food intake. Sutherland (1965) proposes that some of the failings of B, may be overcome by calculating the regression of gain on intake on a log-log basis; animals with equal log deviations would then be of equal efficiencies. The relationship between the regression of liveweight gain on food intake and total efficiency is :

$$\frac{G}{I} = \frac{a + b.I + D}{I} = \frac{a}{I} + b + \frac{D}{I} \quad \ldots\ldots\ldots\ldots \quad 1.12$$

$$\text{and} \quad G = a + b.I + D \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 1.13$$

where a = interception of the regression line on the liveweight gain axis.

b = the slope of the regression of liveweight gain on feed intake.

D = the deviation of an animals liveweight gain from the regression of liveweight gain on food intake.

The above deviation (D) is the measure of efficiency used by Koch et al. (1963). The two methods differ principally in the fact that total efficiency weights D by the actual amount of feed consumed, whereas use of D alone makes no such allowance. D alone will give a fair picture of the relative advantage in efficiency of a particular animal at a given consumption rate, but it cannot be interpreted as representing the efficiency of that animal relative to the population at large without taking into consideration the shape of the curve from which it is a deviation.

Some of the assumptions involved in regression analysis and of the problems involved in its use in establishing maintenance and growth requirements for cattle have been discussed in Section (1.3). Some additional considerations are mentioned here because of their relevance to the determination of efficiency values. The relation of a regression line calculated from a number of experimental observations, to the average slope of the intrinsic efficiency of the animals involved, has been explained by Taylor and Young (1964). They argue as follows - "the regression line (of liveweight gain on food intake) will depend very largely on the shape and relative placings of the underlying individual curves i.e. on individual differences in potential efficiency, and on any association between these and differences in food intake." When animals are fed ad libitum or on a feeding scale dependent on age and liveweight there will usually be some association established between food intake and potential efficiency. In these cases, the slope of the regression line will be less or more steep than the average slope of the response curves, depending on whether animals that eat more are potentially less or more efficient. Therefore, the mean slope of the response curves will only be obtained from this regression when there is no association between potential efficiency and food intake. This can be achieved by either, random allocation of each individuals food intake, or, by ensuring that all the animals have very similar potential efficiencies. Unless it is possible to estimate the average intrinsic efficiency for the group of animals the deviations from regression, D, cannot be said to be the correct estimates of intrinsic efficiency for individual animals.

1.4.5 Correlations between Carcass characteristics, Liveweight gain, and efficiency of feed utilization

A knowledge of the correlations between carcass characteristics, liveweight gain and the efficiency of feed utilisation is useful when not all of the parameters can be measured. Carcass characteristics are difficult to obtain from bulls required for artificial breeding use, and when bulls are performance tested at pasture measures of intake are usually difficult to obtain. Knowledge concerning relationships between carcass characteristics and liveweight gain and the efficiency of feed utilisation is not so extensive, although it would be valuable in a selection programme for beef animals. This section will be discussed in two parts, firstly, the relation between liveweight gain and the efficiency of feed utilisation will be examined, and secondly, the relationship of liveweight gain and the efficiency of feed utilization to carcass characteristics will be discussed.

The correlation between total efficiency and liveweight gain in an ad libitum feeding period was found to be negligible by Guilbert and Gregory (1944); however, if gain was expressed as a function of metabolic liveweight ($W^{\frac{3}{4}}$) it became highly correlated to total efficiency. The correlation between total efficiency and liveweight gain generally rises when differences in liveweight are accounted for, (Winters and McMahon, 1933; Knapp and Baker, 1944; Grizzle and Kincaid, 1954).

Knapp and Baker (1944) suggested a low correlation between the rate of gain and total efficiency could be expected when all animals are fed for the same period of time, but that the corelation would be higher if weight constant periods were used.

This is supported by Willis and Preston (1970) who used a system that approached a weight-constant one and found correlations of -0.72 to -0.86 between "feed utilization" and liveweight gain.

In a theoretical discussion, Sutherland (1965) explains that whenever the coefficient of variation of feed intake is much smaller than that for liveweight gain the correlation between feed utilization (the reciprocal of total efficiency) and liveweight gain will be highly negative regardless of the correlation between feed intake and liveweight gain.

In an extensive study in U.S.A., Koch et al. (1963) concluded that selection for liveweight gain would lead to 81 per cent as much genetic gain in efficiency as would be achieved by direct selection for efficiency. Genetic correlations between feed conversion efficiency and liveweight gain of -0.69 and -0.41 have been reported by Lickley et al. (1960) and -0.34 by Brown and Gifford (1962). It is very important to realise that their data were corrected for differences in liveweight. On the basis of this high genetic correlation, Klosterman (1972) suggests that selection for relative liveweight gain should increase feed efficiency within all sizes of cattle. However, percentage growth rate has a coefficient of variation of 5 per cent (Taylor, 1971), and hence dramatic increases in efficiency would appear to be unlikely.

There is very little experimental information to support the proposal that selection for rate of liveweight gain will increase the efficiency of feed utilisation. Tallis et al. (1959) have reported significant differences in rate of liveweight gain between sire lines and a tendency for calves of sires from production tested lines to be more efficient. Horn (1967), cited by Klosterman (1972), is less optimistic about increasing efficiency by selection for rate of liveweight gain. When comparing average daily liveweight gains of 0.80 and 1.3 kg he suggests a conversion efficiency for protein of 16.6 and 18.8 per cent respectively. Horn also found that an increase of 0.1 kg daily liveweight gain of fattening bulls increased mature weight of female stock by 100 kg.

The problem of increasing rate of liveweight gain without increasing mature size has been discussed by Fitzhugh and Taylor (1968). These authors cite some evidence to suggest that the genetic correlation between mature size and maturing index is approximately -0.9, this implies that a genetic change in rate of liveweight gain and rate of maturing could be accomplished without changing mature size. It was concluded that deviations from the normal rate of liveweight gain associated with a particular mature size could arise from animals that were either intrinsically more efficient, or had greater appetites for mature size. Selection for rate of liveweight gain while restraining change in mature size could increase rate of liveweight gain, earliness of maturing, intrinsic feed efficiency or appetite (or some combinations of these). Lickley et al. (1960) reported that selection for rate of gain can be expected to increase efficiency and mature size in approximately equal proportions.

In conclusion it needs to be emphasised that the high genetic correlations that exist between liveweight gain and the efficiency of feed utilisation apply only when liveweight gain is expressed on a relative basis. It is also necessary to stress that the overall efficiency of beef producing systems depends to quite a large extent on the maintenance requirements of breeding stock; selection for increased liveweight gain may lead to increased mature size of breeding cows, and hence little or no improvement in the system's efficiency.

Genetic or phenotypic correlations between liveweight gain and carcass characteristics have not often been estimated. Performance tests in the U.S.A. use a fixed test period so that animals that grow faster reach heavier final liveweights and therefore have a fatter carcass (see Section 1.2.2). Coniffe and Harte (1967) have published an informative paper on the relationship of liveweight gain to a number of measures of food conversion efficiency in cattle. The efficiency criteria used were the ratios of intake to : liveweight gain, carcass weight, total lean weight in the carcass, and total fat weight in the carcass. Table 1.7 summarises the correlations calculated between liveweight gain and the efficiency criteria in two experiments.

TABLE 1.7 : The correlations between liveweight gain and various efficiency criteria under two different feeding systems

Efficiency criteria	Correlation between liveweight gain and efficiency criteria	
	Experiment (1)	Experiment (2)
Based on rate of LW gain	- 0.24	- 0.52**
Based on carcass weight	0.13	- 0.56**
Based on carcass "lean" weight	- 0.14	- 0.51**
Based on carcass "fat" weight	0.42*	- 0.14

Experiment one in Table 1.7 refers to a feeding system where concentrates were fed according to liveweight gain. The only significant ($P < 0.05$) correlation was between liveweight gain and carcass fat weight which might be expected because of the higher concentrate level in the ration of those animals gaining the most. In experiment two, Table 1.7, shows significant ($P < 0.01$) correlations between "feed efficiency", carcass weight, carcass lean weight and rate of liveweight gain. In this experiment grain silage was fed ad libitum and animals slaughtered at a constant age. This feeding system leads to a positive correlated response between carcass weight and carcass "lean" weight and liveweight gain when selection is applied for the latter. The data indicate that animals with a high rate of gain will not necessarily be above average in fat production per unit feed intake, this contention is supported by information from Cundiff, Stephens, Chambers and Willham (1964) and Willis and Preston (1967). On the basis of theoretical considerations and unpublished findings, Preston and Willis (1970) believe that selection for weight for age will bring about either no change, or an increase in percentage edible meat due to reduced fatness, if evaluation is at a constant weight.

In a comparison of progeny from a Hereford bull selected for high gain and efficiency and those from a bull poor in these traits, Cundiff, Bradley, Kemp and Greathouse (1966), found that the former has faster gains, less fat thickness, a lower percentage of fat and more lean. Melton, Brown, Lewis and Heck (1967) also found that bulls superior for feed efficiency had leaner carcasses. It is important to emphasise here that the above authors use liveweight gain in their calculation of efficiency values. The findings of Garrett (1971) (see Section 1.2.2) suggest that expression of efficiency on an energy basis may lead to different conclusions.

1.5 PERFORMANCE TESTING FOR LIVEWEIGHT GAIN AND EFFICIENCY OF FEED UTILIZATION

A performance test is a comparison of individual animals kept as a group in one environment. The performance of each animal is measured directly and its ranking in the group determined. Performance testing has been traditionally used for traits such as growth rate which have a medium or high heritability. The accuracy of a performance test is indicated by the correlation between a bulls own ranking and the ranking of his progeny. Very little work has been reported for such correlations. In New Zealand, Brumby, Walker, and Gallagher (1962) were able to demonstrate a good relationship between fast and slow growing beef bulls and the carcass quality of their progeny. However, Carter (1971) achieved very disappointing correlations between the performance of beef bulls and that of their progeny, although this could be blamed, at least partially, on groups being compared in different conditions.

Extensive U.S.A. work on factors influencing the accuracy of performance tests will not be reviewed here. Suffice to say that this work has shown that variation in the length of the test period, the initial liveweight and the age of the animals will affect the accuracy of a performance test. This is to be expected from the results of experiments reviewed in Section 1.2. The following section is confined to a discussion of the advantages and disadvantages of different systems of performance testing.

1.5.1 Systems of Performance Testing

The three major types of performance testing are : constant age - constant weight, constant weight-constant weight, and time constant. Biswas *et al.* (1966) has pointed out that the economically most realistic tests may not necessarily be the best for obtaining an understanding of the biological relationships that exist between changes in body composition during growth and efficiency of feed utilization.

The use of a constant age - constant weight performance test has been reported by Willis and Preston (1970). Animals were started at 90 days of age and finished the test at 400 kg liveweight. This system resulted in high correlations between total efficiency and liveweight gain; the reasons proposed were : a lack of initial weight differences, a decreased proportion of food used for maintenance, and the inability of animals to select between components of the diet. A similar system was used by Jones and Francis (1963) who considered that testing from an early age reduced the effect of the dam's milking ability on the animals growth, but if testing was delayed until weaning, calves of acceptable growth and conformation could be chosen. These authors decided on an initial age of 34 days for their performance tests.

Extensive studies on a constant weight-constant weight performance test were reported by Landers, Wheat and Bogart (1967), the initial weight was 227 kg and final weight 364 kg. These authors believed that a weight constant testing method makes associations of performance traits with weight changes valid because the associations are derived from all the animals at very similar weights. In a time constant test the associations are more difficult to observe because liveweights are usually more widely spread.

A time constant test, from weaning at six months of age, to at least 18 months of age, has been suggested by Dalton, Rae and Clarke (1970) for bulls grazing pasture in New Zealand. This method requires some form of correcting for pre-test environmental differences between animals, unless the whole test period is considered as adjustment for these differences.

In the present study the pre-experimental selection period can be considered as a performance test at pasture. It was a time constant test of approximately six months observation with animals varying quite widely in liveweight and age. A weight-for-age measure would have been complicated by different ages and by the assumptions that have to be made about birth weight, it was therefore thought best to use average daily liveweight gain as a measure of comparison in the selection period. It was considered that liveweight gain in this period should be positively correlated with growth up to the time the selection period began (see Section 3.1), if this was the case high liveweight gain animals would be significantly heavier than low liveweight gain animals in initial weight, this was so (see Section 3.1). However, this does not preclude the possibility that at least some of the animals selected in the high liveweight gaining group, were making compensatory growth during the selection period.

The actual experimental period in the present study can be thought of as a performance test for efficiency of feed utilization, although emphasis on individual differences in efficiency is not as great as on the comparison of efficiencies between the high and low liveweight gain groups.

In a series of publications (Taylor and Young, 1964; Taylor and Young, 1966; Taylor and Young, 1967) Taylor and his co-workers have discussed, in a largely theoretical framework, the evaluation of individual efficiency under widely differing feeding systems. The parameters of efficiency are those discussed in Section 1.4.3. Taylor and Young (1962) assert that when feed intake is recorded and information on liveweight, liveweight gain and food intake is combined, the best, least squares estimate of intrinsic liveweight gain is an individual's deviation from the mean, expected liveweight gain, namely :

$$\text{Intrinsic gain} = g - (I - \bar{I}) + b (W - \bar{W}) \ldots \quad 1.14$$

(symbols are as described in Section 1.4.3).

This estimate is independent of the feeding system, unless adaptation to a new diet is occurring. They conclude that unless there is detailed knowledge on the genetic characteristics of the population, the above phenotypic index for intrinsic efficiency will also be the best genetic selection index.

In a further paper, Taylor and Young (1966) show that genetic variance and covariance between food intake, liveweight and liveweight gain will depend largely on the feeding system under which they are estimated. They define "constrained" environments as those in which some variable is controlled at a different value in each individual. The decision on the particular value is often made on the basis of some other variable measured on the individual, for example intake may be set as some function of liveweight. The major advantage of constrained environments is that each constraint imposed reduces the number of variables to be examined by one.

In an ad libitum feeding system the growth and efficiency of animals can be specified by the general functional relationship expressed in equation 1.14 along with the intrinsic efficiency parameter values and the voluntary food intake curve. The magnitude of intrinsic differences in the appetite parameters has not been adequately examined, but Taylor and Young (1966) suggest that because there is a high correlation between voluntary food intake and weight of animals at the same age, it implies that either individual variation in the appetite parameters is small, or it is highly correlated with weight. They further postulate that the high correlation between weight and voluntary intake is consistent with either, very little variation in intrinsic efficiency parameters but considerable variation in appetite parameters, or vice versa.

The same authors urge that care be taken when data from restricted part life testing are subjected to regression analysis. This form of statistical analysis may give a biased functional relationship between intake, liveweight and liveweight gain, this bias may actually eliminate some of the individual differences that are being assessed.

It is generally accepted that performance tests should be conducted using feeding systems that are similar to those in which the offspring of tested animals will perform (Dalton, 1967; Falconer, 1960; Dalton, Rae and Clarke, 1970). However, Preston and Willis (1970) consider diets of high energy concentration should be fed ad libitum when performance testing bulls. In this system daily gain is limited only by the growth potential of the bull and the generation interval is minimized; selection of feed components is usually less than if roughages or roughage - concentrate mixtures are used. An equally important consideration was thought to be the reduction in labour costs and the increased accuracy of feed recording. The same authors make the important point that from an economic viewpoint genetic progress per unit time, not per generation, is what is required. To test accurately for growth rate or efficiency of feed utilization a given weight must be reached, this will take much longer if restricted feeding is practised and consequently the generation interval will be decreased and any advantage due to testing as close as possible to commercial conditions may be lost.

Unfortunately, Preston and Willis (1970) do not discuss the problem of performance testing in relation to minimizing maintenance requirements of breeding cows. The lower levels of intake may reduce variation displayed in growth rate and hence make differentiation more difficult (Preston and Willis, 1967; Taylor and Young, 1966).

1.6 THE OBJECTIVES AND DESIGN OF THE EXPERIMENT

This section will firstly enumerate the objectives of the present experiment. Secondly, reasons for choosing particular procedures used in the experiment are discussed. Where necessary reference is made to evidence already presented in the review of literature.

1.6.1 Experimental Objectives

The objectives of the present study, in order of importance were :

1. To compare liveweight gain, total efficiency and partial efficiency and voluntary food intake of two groups of Friesian bulls selected on the basis of liveweight gain at pasture over a six month period.
2. To compare liveweight gain, total efficiency and partial efficiency between individual bulls of the two liveweight gain groups at one of three intake levels.
3. To estimate DE requirements for maintenance and growth of 400 to 600 kg liveweight bulls fed cut pasture.

1.6.2 Experimental Design

In this study a randomised block design was considered to be the most satisfactory. The selection criterion of either very high or very low liveweight gain, meant that initial liveweights were quite variable, (see Section 3.1). As a consequence it was decided to use initial liveweight as a basis for blocking.

To obtain a broad basis for comparison of the two liveweight gain groups it was considered necessary to design the experiment to include three planes of nutrition. This design would also enable

DE requirements for maintenance and growth to be predicted.

There was a likelihood that differences in voluntary food intake between the two liveweight gain groups could have caused some of the differences in liveweight gain observed in the selection period. A standardisation period of four weeks was planned to allow any differences in voluntary food intake to be expressed. This was to be followed by a ten-week period for the comparison period when three levels of intake would be used to compare the two liveweight gain groups. Information in Section (1.2.1.3) demonstrates the importance of having as long an experimental period as possible when differences in liveweight gain are to be detected.

The decision to estimate liveweight gain from a regression of shrunk weights taken at weekly or fortnightly intervals was based on the experimental evidence cited in Section (1.2.1.3), and on practical considerations of labour availability. Some of the literature on gut fill was reviewed in the hope of finding a general equation to predict fill given food intake, quality of the diet and liveweight. However, the information available was too imprecise to allow this to be done.

The two lower feeding levels during the comparison period were devised so that individual feeding was proportional to metabolic liveweight ($W^{\frac{3}{4}}$). This meant that each bull on a particular intake level should have the same amount of food available for growth and that differences in growth rate would be due solely to differences in the efficiency of maintenance and growth, (see Section 1.4.3). The ad libitum feeding level was designed to give further information on the voluntary intake characteristics of the two liveweight gain groups. The inclusion of a concentrate mixture was considered necessary to avoid the situation where the feed quality and quantity are limiting growth rather than the genetic potential of the animal being the limiting factor.

CHAPTER TWO

METHODS AND MATERIALS

This chapter describes the nature of the feeds and animals used in the experiment and the methods of analysis. The first section explains the experimental design and the order of experimental events. The second section describes the collection of pasture and the feeding levels used. In the third section the selection and treatment of the animals is explained.

The chemical analysis of feed, the determination of pasture, apparent digestibility and the measurement of liveweight gain are described in the fourth section. Finally, the methods of statistical analysis of the results are described.

2.1 EXPERIMENTAL DESIGN

A 3 x 2 factorial arrangement was used for this continuous experiment with three replicates in a randomised block framework. Bulls were blocked on the basis of initial liveweight and randomly allocated to treatments. This was done immediately prior to the comparison period. The number of bulls in each block was six, with the restriction that three be from the high liveweight gain group and three from the low liveweight gain group.

A pre-experimental period of four weeks began on 17/4/72 when bulls from Newstead arrived at Awahuri and all eighteen experimental bull plus the two reserve bulls were kept on lines outside. A standardisation period of four weeks ran from 15/5/72 to 12/6/72; this was immediately followed by a comparison period which continued until the experiment concluded on 4/8/72. The comparison period was planned to be 10 to 12 weeks, however a shortage of harvestable pasture reduced this to eight weeks. Further information on the calendar of operations can be found in Appendix 1.

The standardisation period was actually a comparison of *ad libitum* pasture intake between the high and low liveweight gain groups. The comparison period consisted of three levels of feed intake and two liveweight gain groups. The three levels of food intake will be designated as follows : low (1), medium (2) and high (3). The management, feeding and design are summarised in Table 2.1.

TABLE 2.1 : A calendar of the experimental periods and the management and feeding procedures adopted during these periods

Period	Date	Management
Selection		
Awahuri Newstead	(16/8/71 to 20/1/72) (5/8/71 to 21/1/72)	Bulls grazed as part of a group at Awahuri or Newstead.
Pre-experimental	17/4/72 - 14/5/72	All experimental bulls assembled at Awahuri and grazed on lines. Subjected to frequent handling as a prelude to the experiment.
Standardisation	15/5/72 - 12/6/72	All bulls fed in covered stalls on _ad libitum_ diet of cut pasture.
Comparison	13/6/72 - 4/8/72	Three intake levels used as follows : low (1) - restricted cut pasture to gain 0.1 kg/day. medium (2) - restricted cut pasture to gain 0.5 kg/day. high (3) - _ad libitum_ cut pasture plus a concentrate meal to gain 1.0 kg/day.

2.2 EXPERIMENTAL FEEDS

2.2.1 Pasture feeding

Economical considerations meant that cut pasture had to be the major feed used during the experiment. Pasture was harvested each day between 0800 and 0900 hours with a single chop forage harvester and trailer attachment. The cutting height was adjusted to avoid contamination by soil and dung, strips of soil accidentally collected were discarded together with any badly soiled pasture. It was initially proposed to obtain estimates of botanical composition to characterise the pasture more fully. However, the problems of obtaining a representative sample, either from the pasture, or from the harvested material were many, and the time available did not allow this sampling to be carried out.

2.2.2 Feeding Levels

In the standardisation period all bulls were offered cut pasture *ad libitum* (10 per cent to 15 per cent refusals). In almost all cases this level of refusal was met each day. During the comparison period bulls on the low and medium intake levels were fed cut pasture only. The experimental design required an equal amount of each animal feed intake to be available for liveweight gain. The proposed liveweight gains were 0.1 and 0.5 kg/day for the low and medium intake levels respectively. The details of intake calculations are shown in Appendix IX.

The bulls on the high intake level during the comparison period were offered *ad libitum* cut pasture together with a concentrate mixture (see Appendix V).

The concentrate was offered at the rate of 3.6 kg/day although this was reduced if successive refusals occurred. Concentrate feeding was used to increase the voluntary intake of DE, and hence increase liveweight gain to provide a wide base for comparison between the high and low liveweight gain groups. The decision to feed concentrates was based largely on the voluntary intakes of pasture achieved in the standardisation period (see Section 3.3.2) and the estimated requirements for growth (see Section 1.3.1).

2.3 EXPERIMENTAL ANIMALS

Experimental bulls were selected from groups of 23 and 76 Friesian bulls at the Awahuri and Newstead Artificial Breeding Centres respectively. Selection was based on data collected during the period from 16/8/71 to 20/1/72 at Awahuri and from 5/8/71 to 21/1/72 at Newstead. The selection procedure is described in Section 2.5.1. Twelve bulls from Newstead and six from Awahuri were selected; this decision being based on the numbers present at each centre and the availability of transport from Newstead to Awahuri.

Unfortunately, it was necessary to discard five of the bulls originally selected from the Awahuri group. They were discarded for the following reasons : aggressive temperament, tuberculosis test reaction, leptospirosis test reaction, undiagnosed sickness and excessive age. An age limit was arbitrarily set at 450 days at the beginning of the selection period to avoid too large a spread in the experimental groups.

Discarded bulls were replaced by animals with the next largest deviations from the regression of liveweight gain on age and liveweight (see Section 2.5.1). Two reserve bulls were selected, one for each liveweight gain group. These two bulls were kept on overhead lines at pasture and periodically weighed during the course of the experiment (see Appendix II). They were not required to replace any of the original experimental animals. A summary of relevant data on the bulls finally selected is presented in Appendix II.

Individual feeding stalls were erected in a semi-enclosed covered haybarn with a wood shaving floor. The drainage in this area proved to be inadequate during the standardisation period. As a consequence the bulls spent much of this period in a completely closed barn on wooden slats over concrete. The modifications to the feeding area were made during the standardisation period. Prior to the standardisation period the bulls were allocated at random to permanent positions in the barn.

The health of the bulls remained very good throughout the experiment. However, they suffered from bloat on a number of occasions and when this occurred the most severely affected were drenched.

2.4 EXPERIMENTAL PROCEDURES

The experimental conditions meant that only simple techniques could be used to evaluate the bulls performance. The major response parameter was liveweight gain, while the determination of apparent digestibility meant that food intake could be expressed on a DE basis. The voluntary intake of pasture or the pasture and concentrate mixture was used as an indicator of appetite variation between animals. The chemical composition of pasture was determined for descriptive purposes and for comparison with data obtained by other New Zealand workers.

2.4.1 Chemical analysis

Cut pasture was grab sampled from the feed trailer every day and dried in a forced air oven at 90°C for 24 hours, to obtain the DM content. All refusals for the previous day were weighed immediately prior to the morning feeding and samples taken for DM determination on all but the smallest refusals. For these an average refusal DM percentage was used to calculate DM content.

Samples of pasture were bulked on a weekly basis and stored in plastic bags. The concentrate mixture was sampled for DM content at intervals through the comparison period; a subsample was stored for later chemical analysis.

Samples of pasture and concentrate were ground through a Wiley Mill (one mm sieve) and a proximate analysis, (AOAC, 1965) carried out on ground, duplicate subsamples of each feed to determine ash, crude protein, crude fibre and ether extract content. Duplicate samples of the feeds were used to determine gross energy content (Adiabatic Bomb Calorimeter).

Ground faecal samples collected during the digestibility trial were re-dried and duplicate 0.5 g subsamples taken for chromium sesquioxide analysis by a wet digestion method (Stevenson and de Langen, 1960; Stevenson, 1962), modified by Ruakura workers (Newth, pers. comm.). Chromium sesquioxide is oxidized to the dichromate ion which can be estimated colorimetrically by use of a calibrated curve derived from a standard solution of potassium dichromate. A Beckman

SP500 spectrophotometer was used to measure the optical density of the oxidised samples. If duplicates failed to agree by greater than four per cent the determination was repeated.

2.4.2 Digestibility of Rations

The digestibility trials were conducted during the experiment, both were for a period of ten days. The apparent digestibility of DM was determined using chromium sesquioxide as a marker. In both, a check on the marker technique was provided by using faecal collection harnesses to enable total collection of faeces from four bulls during the standardisation period, and three bulls during the comparison period. It was not possible to determine the apparent digestibility of the diet for each bull and results had to be extrapolated to those bulls unable to be tested. It was also necessary to assume that equivalent digestibilities occurred throughout the experimental periods in order to calculate DE intake.

The first digestibility trial was conducted during the standardisation period from 31/5/72 to 9/6/72. Ten bulls, five from the high liveweight gain group and five from the low liveweight gain group were randomly selected. They were dosed with 20 g/day of chromium sesquioxide; this was given as 10 g at 0800 hours and 10 g at 1630 hours. The chromium sesquioxide was suspended in arachis oil contained within a gelatine capsule.

An equilibration period of seven days was used to allow steady state conditions for chromium sesquioxide to be attained, this was followed immediately by the ten-day collection period. Approximately 250 g of wet faecal matter was obtained from a well mixed sample of the previous days faeces taken from the floor. The faeces were dried for two to three days at 90°C until constant weight was reached; they were then carefully ground, to avoid dust loss, using a Wiley Mill (one mm sieve), and stored in air-tight jars until further analysis.

The second digestibility trial was conducted during the comparison period, from 23/7/72 to 1/8/72 while the bulls were on the wood shavings pad. Two bulls from each of the six treatment groups were selected at random and subjected to an equivalent dosing schedule described for the standardisation period. One bull from each feed intake level was selected on the basis of temperament and size, for total collection of faeces.

2.4.3 Liveweight gain

The bulls were weighed in random order between 0800 and 1000 hours at weekly or fortnightly intervals. A weekly interval was not strictly adhered to during the comparison period, because the sixteen hour total fast imposed before weighing reduced intakes and on the medium intake level these could not be easily recovered.

A set of Donald scales employing an hydraulic system whereby the displaced hydraulic fluid registered the bulls weight on a vertical scale was used. A pre-experimental check on the accuracy of the scales was carried out during weighing of the animals, the result of these tests are presented in Appendix III.

Liveweight gain for each animal was estimated separately for the standardisation period and the comparison period by a regression of liveweight on time (see Section 1.2.1.3). Mean liveweight for the purposes of estimating maintenance requirements was derived from the predicted liveweight on the regression line midway through the priod under consideration.

2.5 STATISTICAL PROCEDURES

2.5.1 Selection Period

Experimental bulls were initially selected on the basis of deviations from the group average liveweight gain during the selection period. However, Townsley, (pers. comm.) suggested that age and liveweight during the selection period might have exerted some effect on the liveweight gain deviations from a simple average. To account for this, data were analysed by the multiple regression of liveweight gain on age and liveweight (Snedecor and Cochran, 1967). The bulls were selected on the size of their liveweight gain deviation from the liveweight gain predicted by the multiple regression analysis. The Newstead and Awahuri data were analysed separately. The six bulls from Newstead and three bulls from Awahuri with the largest deviations above their predicted liveweight gains were placed in the high liveweight gain group. Similarly, six bulls from Newstead and three bulls from Awahuri with the largest deviations below their predicted liveweight gains were assigned to the low liveweight gain group (see Appendix ii).

2.5.2 Standardisation Period

The response parameters of interest during this period were those of apparent digestibility of energy, *ad libitum* intake, liveweight gain and liveweight. A simple t test (Snedecor and Cochran, 1967), was used to test for differences between the high and low liveweight gain groups during this period. A comparison between the chromium sesquioxide method of calculating digestibility and the digestibility predicted from total collection, was made by means of a t test.

The relationship between DE intake and either liveweight or metabolic liveweight ($W^{\frac{3}{4}}$) was determined by simple regression analysis (Snedecor and Cochran, 1967) using a t test to determine if the slopes of the regression line were significantly different from zero.

2.5.3 Comparison Period

The response parameters in this period were those of apparent digestibility of energy, *ad libitum* intake, liveweight gain and liveweight together with measures of efficiency derived from these fundamental responses. The measures of efficiency included total efficiency, logarithmic total efficiency, partial efficiency and logarithmic partial efficiency.

Data on these variables were analyzed in a two-way classification analysis of variance within a 3 x 2 factorial experiment. A comparison of differences between treatment means was conducted with the least significant difference test with the safeguard that these comparisons would only be made when the value for F in the overall analysis of variance was significant at ($P < 0.05$). A fixed effects model of the form in equation 2.1 was used.

$$Yijkl = \mu + ai + b_j + \gamma k + eijkl \quad \ldots\ldots \quad 2.1$$

where

$Yijkl$ = Observed value for any of the response parameters or measures of efficiency

μ = an overall mean

ai = the effect due to blocks, $i = 1, 2, 3$

bj = The effect due to liveweight gain treatments, $j = 1, 2.$

γk = the effect due to intake treatments.

$eijkl$ = $N (0, \sigma)$.

In order to derive estimates of the energy requirements for maintenance and growth it was necessary to use multiple regression analysis (Snedecor and Cochran, 1967). Two models were used in estimating energy requirements, these were :

Model 1 : $Y = a + b_1 X_1 + b_2 X_2 + e$ 2.2

where Y = liveweight gain
a = value of liveweight gain when X, and X_2 are zero.
b_1 = partial regression coefficient of liveweight gain on metabolic liveweight.
b_2 = partial regression coefficient of liveweight gain on DE intake
X_1 = metabolic liveweight ($W^{\frac{3}{4}}$)
X_2 = DE intake
e = $N (0, \sigma)$.

Model 2 : $Y = a + b_1 \frac{X_2}{X_1} + e$ 2.3

where Y = liveweight gain
a = value of liveweight gain when $\frac{X_2}{X_1}$ is zero.
b_1 = partial regression coefficient of liveweight gain on DE intake per kg metabolic liveweight
$\frac{X_2}{X_1}$ = De intake per kg metabolic liveweight.
e = $N (0, \sigma)$

A simple regression model was used in both the standardisation and comparison periods to estimate liveweight gain. The model was :

$Yij = a + b_1 X_1 + eij$ 2.4

where Yij = liveweight
a = liveweight when $x_1 = 0$.
b_1 = regression coefficient of liveweight on time (represents liveweight gain).
e_{ij} = $N (0, \sigma)$.

The analysis of variance and the regression analysis of the response variables adequately described the differences between treatment group and the relationships of the more important variables to each other. However, an analysis of correlations between intake, metabolic liveweight, liveweight gain, partial efficiency and total efficiency was conducted

(Snedecor and Cochran, 1967), to allow comparisons to be made with the findings of other workers.

CHAPTER THREE

RESULTS

This chapter presents only those data which are necessary to accurately describe the results obtained. The results of statistical analysis have been included in Tables, but the details of the statistical analysis have been given in the appendices. Error variability is expressed in the form of standard error unless otherwise stated.

The overall presentation of results follows a chronological order. The results of the selection and pre-experimental periods are reported first, followed by the standardisation and comparison period results. The results for the major response parameters are given in separate Tables and Figures within these main sections.

The high and low liveweight gain groups have been designated as high (H) and low (L) respectively. In the comparison period results it was also necessary to differentiate intake levels within a liveweight gain group. The lowest intake level is designated as 1, the intermediate, 2, and the highest level, 3. For example, bulls in group H1 are those from the high liveweight gain group, on the lowest plane of nutrition.

3.1 SELECTION AND PRE-EXPERIMENTAL PERIOD RESULTS

The mean initial liveweight and age, final liveweight and liveweight gain of Awahuri and Newstead Friesian bulls during the selection period, are presented in Table 3.1. The comparison of these parameters for the two populations was analysed using a simple t - test, the results of which are also presented in Table 3.1. Error variability is expressed as standard deviation to facilitate comparison with the results obtained by Carter (1969) in previous years.

TABLE 3.1 : Mean initial liveweight, age, final liveweight and liveweight gain for all Friesian bulls at Awahuri and Newstead, and the statistical significance of differences between bulls at the two centres, during the selection period (df = 71).

Item	Awahuri[a] (n = 21)	Newstead[b] (n = 52)	t	P
Initial mean LW (kg)	287.2 ± 54.2	285.3 ± 43.9	0.15	NS
Final mean LW (kg)	449.5 ± 42.1	498.7 ± 50.3	3.71	0.001
Initial age (days)	371.7 ± 47.6	382.9 ± 53.2	0.84	NS
L.W.G. (kg/day)	1.051 ± 0.125	1.258 ± 0.127	6.3	0.001

a Selection period was from 16/8/71 - 21/1/72 (158 days)

b Selection period was from 5/8/71 - 20/1/72 (168 days)

The main point of interest in Table 3.1 is the lack of any statistically significant difference between the Awahuri and Newstead bulls in either initial age or initial liveweight. However, during the selection period the Newstead bulls had significantly higher ($P < 0.001$) liveweight gains, and consequently higher ($P < 0.001$)

liveweights at the end of the selection period. The distribution of liveweight gain for the Newstead and Awahuri bulls during the selection period is shown in Figure 3.1 and Figure 3.2. Of especial interest is the wide variation about the mean for both groups of bulls.

The method of selecting the experimental animals has been fully described in Section 2.3.1. Information on the regression analysis used is given in Appendix II, while individual data on the eighteen bulls finally chosen can also be found in Appendix II. The purpose of Table 3.2 is to compare the initial and final liveweight; initial age, and liveweight gain during the selection period of the high and low liveweight gain groups selected for the experiment.

TABLE 3.2 : A comparison of initial and final liveweights, initial ages, and liveweight gains for the high and low liveweight gain groups over the selection period (df = 16)

Item	High (H) group (n = 9)	Low (L) group (n = 9)	t	P
Initial LW (kg)	291.4 ± 21.52	272.2 ± 15.00	0.73	NS
Final LW (kg)	516.2 ± 25.57	439.8 ± 16.82	2.50	0.05
Initial age (days)	364.6 ± 8.06	372.3 ± 10.37	0.59	NS
LWG (kg/day)	1.350 ± 0.045	1.00 ± 0.024	6.88	0.001

The similar liveweights and ages at the beginning of the selection period, of those bulls selected for the high and low liveweight gain groups, is shown in Table 3.2. The method of selection accounts for the significantly higher ($P < 0.001$) liveweight gain of the high group during the selection period, which in turn has caused this group to be heavier ($P < 0.05$) than the low liveweight gain group.

Table 3.3 compares equivalent items to Table 3.2 but with reference to those bulls selected from Awahuri and those selected from Newstead.

TABLE 3.3 : A comparison of initial and final liveweights, initial age, and liveweight gains for the selected Awahuri and Newstead groups over the selection period (df = 16)

Item	Awahuri (n=5)	Newstead (n=13)	t	P
Initial LW (kg)	260.8 ± 20.72	289.9 ± 15.90	1.01	NS
Final LW (kg)	432.2 ± 28.06	495.6 ± 20.12	1.71	NS
Initial age (days)	349.4 ± 7.76	375.8 ± 7.57	1.99	NS
LWG (kg/day)	1.082 ± 0.064	1.216 ± 0.062	1.24	NS

The data summarised in Table 3.3 indicate that the bulls selected from Awahuri were not significantly different in either age, or initial and final liveweight during the selection period, from the selected Newstead bulls. Despite the significantly higher mean liveweight gains of the entire population of Newstead compared to the Awahuri population (see Table 3.1); there was no significant difference between the selected bulls. However, the grouping of the high and low liveweight gain bulls for the comparison meant that the standard error of the mean was inflated.

There was an intervening period (called the pre-experimental period) between the end of the selection period and the beginning of the experiment. The liveweight gain of the Awahuri and Newstead selected animals and of the high and low liveweight gain groups has been statistically analyzed for differences during this pre-experimental period, and for the selection and pre-experimental periods combined. The results of these analyses are shown in Table 3.4.

TABLE 3.4 : A comparison of liveweight gains of Awahuri and Newstead bulls, and of the high and low liveweight gain groups during the pre-experimental and combined, selection and pre-experimental periods (df = 16)

Item	High group (n=9)	Low group (n=9)	t	P
Pre-experimental LWG (kg/day)	0.141 ± 0.085	0.399 ± 0.073	2.30	0.05
Combined LWG (kg/day)	0.931 ± 0.026	0.801 ± 0.030	3.33	0.01

Item	Awahuri (n=9)	Newstead (n=13)		P
Pre-experimental LWG (kg/day)	0.374 ± 0.041	0.230 ± 0.084	0.25	NS
Combined LWG (kg/day)	0.871 ± 0.034	0.864 ± 0.032	0.11	NS

A reversal of liveweight gain occurred during the pre-experimental period. The high liveweight gain group had a significantly lower ($P < 0.05$) liveweight gain during this period than the low liveweight gain group. Despite this reversal of liveweight gain the high group still had a significantly higher ($P < 0.01$) liveweight gain over the combined selection and pre-experimental periods than the low group. There was no significant difference in liveweight gain between the Awahuri and Newstead bulls during the pre-experimental period.

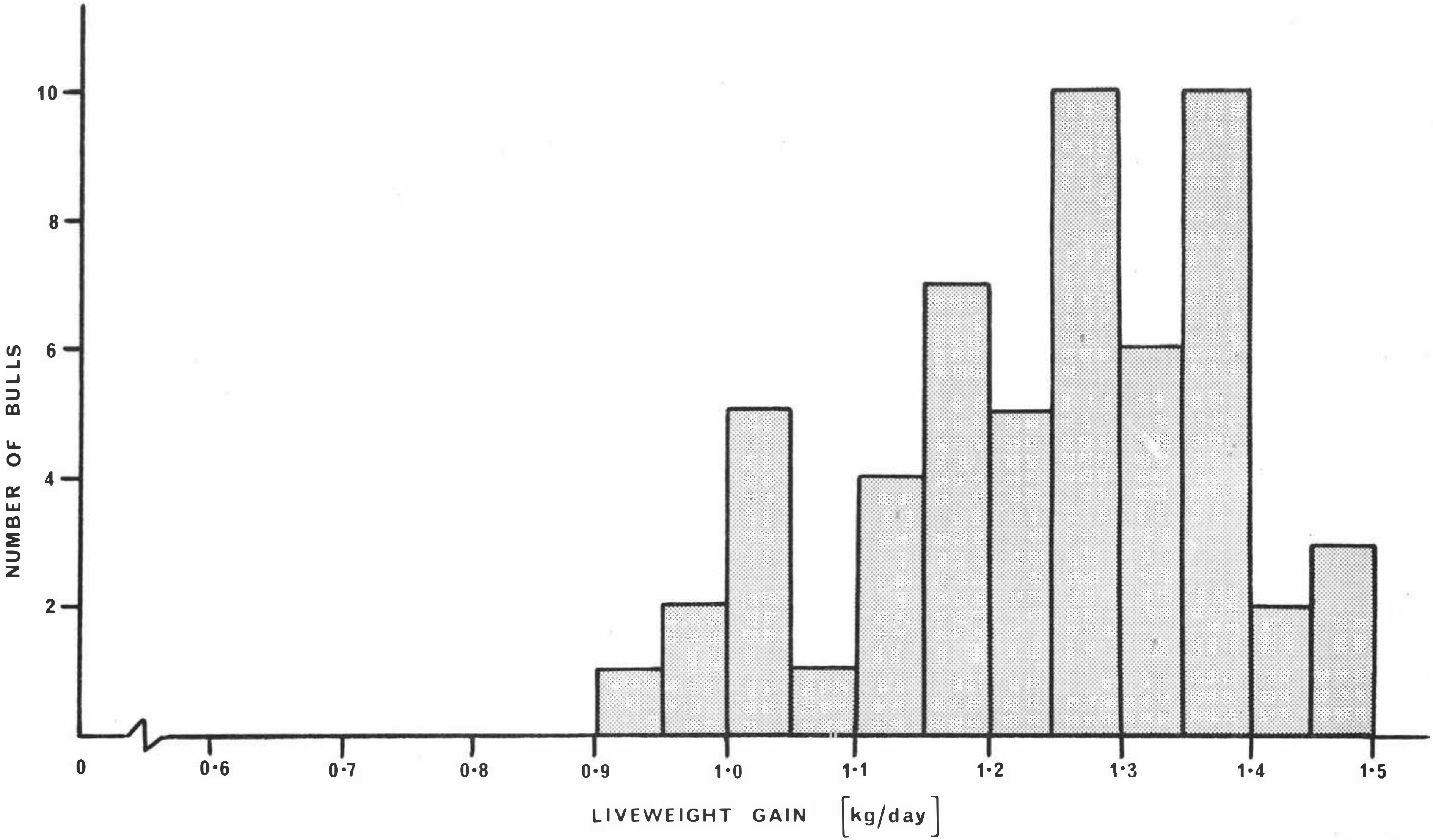

FIGURE 3.1: The number of bulls in each liveweight gain interval for the Newstead group, during the selection period.

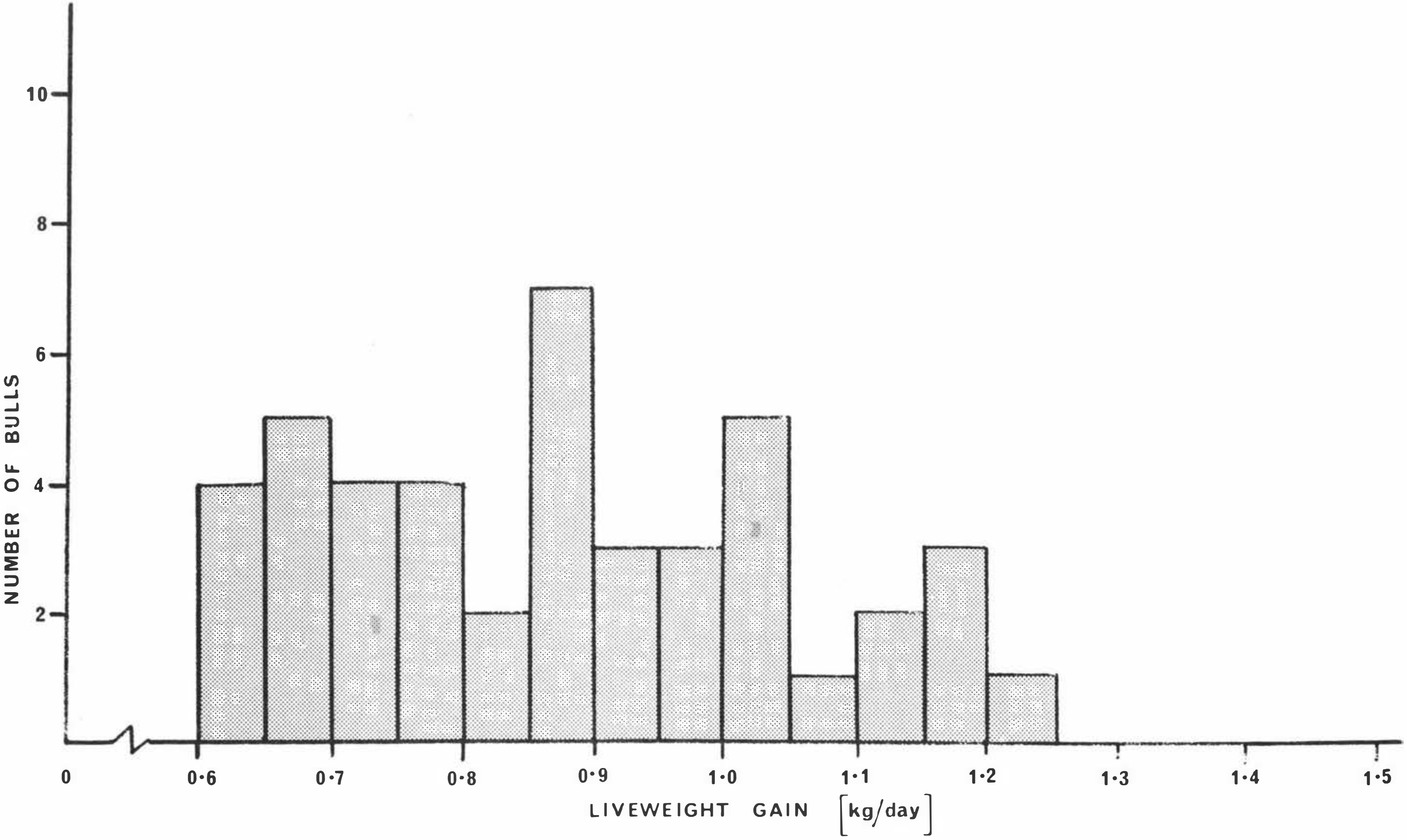

FIGURE 3.2: The number of bulls in each liveweight gain interval for the Awahuri group, during the selection period.

3.2 CHEMICAL ANALYSIS OF FEEDS

The proximate analysis (AOAC, 1965) of the daily samples of pasture, bulked on a weekly basis, is presented in graphical form in Figure 3.3. The physical composition and proximate analysis of the concentrate mixture, fed to one treatment group in the comparison period, has been included in Appendix V.

The information on the chemical composition of pasture summarised in Figure 3.3 shows that the crude fibre fraction fell from 25 per cent during the first three weeks of the standardisation period to 19 per cent for weeks four to eight of the comparison period; during the last four weeks of the comparison period the crude fibre level rose to 22 per cent. The crude protein level rose from 23 per cent during the first three weeks of the experiment to a mean value of 27 per cent for the following nine weeks. Figure 3.3 indicates that very little change occurred in the ash or ether extract proportions during the experimental period.

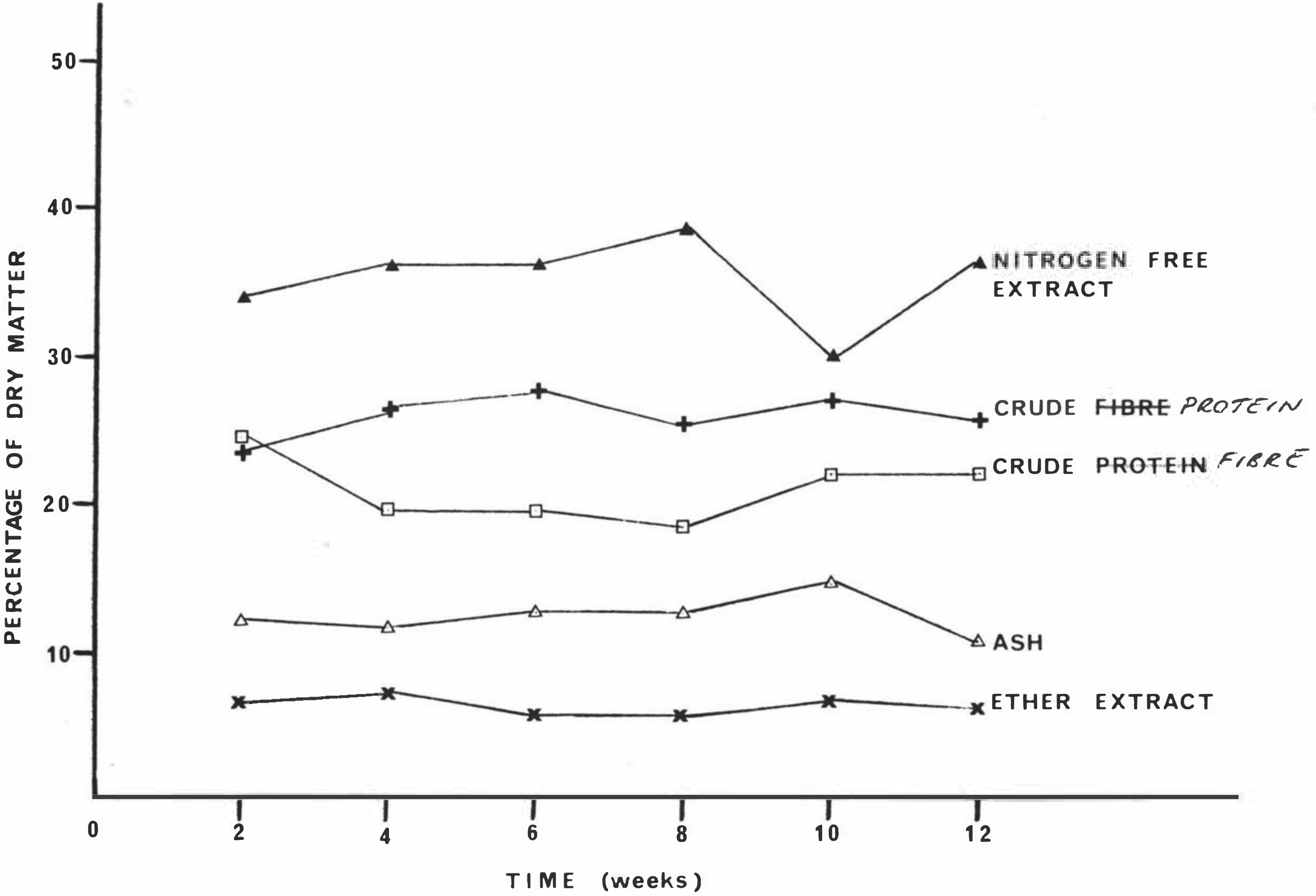

FIGURE 3.3: The changes in the crude fibre, crude protein, nitrogen-free extract, ether extract and ash for cut pasture over the entire experimental period.

3.3 STANDARDISATION PERIOD

Results presented in this section describe the digestibility of the pasture, the voluntary intake of pasture, and the liveweight gains of the high and low liveweight gain groups. The lack of uniform management during this period has been mentioned in Section 2.3, for this reason efficiency parameters were not calculated. This point should be borne in mind when the voluntary intake of pasture and the liveweight gains of the two groups are being considered.

3.3.1 Digestibility of Pasture

The apparent digestibility of energy of the pasture was determined for members of the high and low liveweight gain groups, and for two sub-periods each of five days. The results, and the statistical significance of differences are presented in Table 3.5. Further information, comparing total collection methods to the indirect chromium sesquioxide technique can be found in Appendix VII.

TABLE 3.5 : Mean apparent digestibilities of energy in pasture for the high and low liveweight gain groups, and the two five-day sub-periods (df = 18)

Item	High group (n = 5)	Low group (n = 5)	t	P	df
Mean apparent digestibility of energy %	73.03 ± 0.423	71.10 ± 0.412	1.59	NS	
Item	Sub-period 1	Sub-period 2	t	P	df
Mean apparent digestibility of energy (%)	71.60 ± 0.334	72.52 ± 0.524	0.72	NS	18

The information in Table 3.5 suggests that there was no difference in the apparent digestibility of energy either between the liveweight gain groups or between the five day sub-periods used.

3.3.2 Voluntary Intake of Pasture

The comparison of mean daily DM and DE intake, and intake of DE per kg metabolic liveweight of the high and low liveweight groups over the standardisation period is given in Table 3.6. There were no differences in any of these parameters between the two groups.

TABLE 3.6 : Mean daily DM intake, DE intake and DE per kg metabolic liveweight of the high and low liveweight gain groups fed *ad libitum* pasture during the standardisation period (df = 16)

Item	High group	Low group	t	P
DM intake (kg/day)	10.46 ± 0.425	9.88 ± 0.303	1.11	N.S.
DE intake (Mcal/day)	34.13 ± 1.466	32.11 ± 0.750	1.23	N.S.
DE intake ($Mcal/kg^{\frac{3}{4}}$. day)	0.310 ± 0.0075	0.317 ± 0.0073	0.68	N.S.

The weekly mean intakes of DE per kg metabolic liveweight for the high and low liveweight gain group are plotted in Figure 3.4. Although variation between weeks existed, there is no evidence for a group x week interaction in DE intake.

The mean daily DE intakes of each bull were plotted against metabolic liveweight during the standardisation period. The results are illustrated in Figure 3.5. The following regression equations were calculated, relating daily DE intake to either metabolic liveweight or liveweights :

$$Y = 8.2084 (\pm 5.1334) + 0.0488 (\pm 0.0100) X \qquad 3.1$$

$Sy.x = 2.339$

$R = 0.596$

$F = 23.63 \quad P < 0.001 \quad df = 16$

$$Y = 0.1638 (\pm 6.9777) + 0.3101 (\pm 0.0648) X^{\frac{3}{4}} \qquad 3.2$$

$Sy.x = 2.344$

$R = 0.590$

$F = 22.89 \quad P < 0.001 \quad df = 16$

In both equation Y = digestible energy (Mcal/day)

X = liveweight (kg).

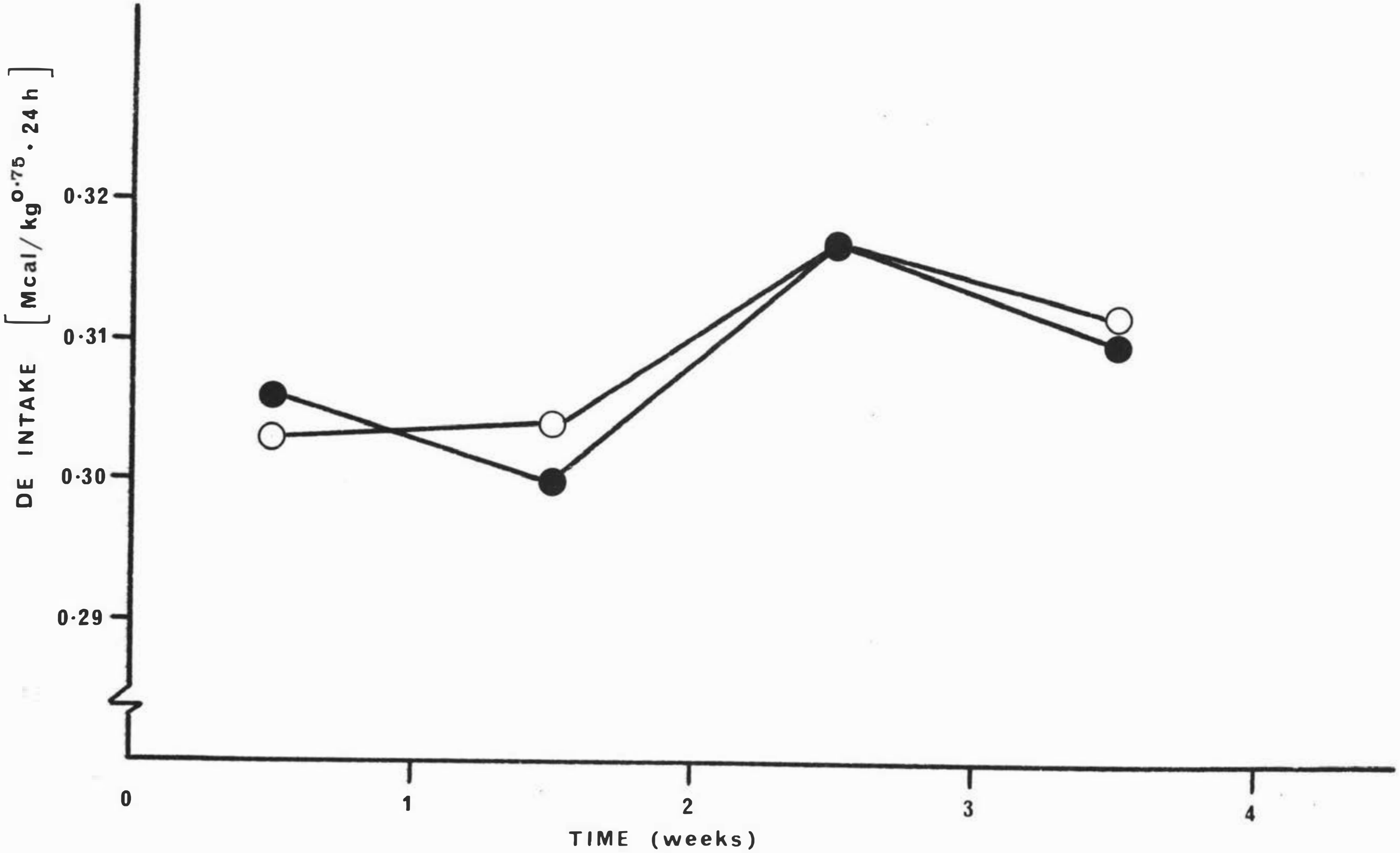

FIGURE 3.4: Weekly mean intakes of DE (Mcal/kg $^{3/4}$ day) of the high and low liveweight gain bulls over the standardisation period.

TREATMENT

○ L ● H

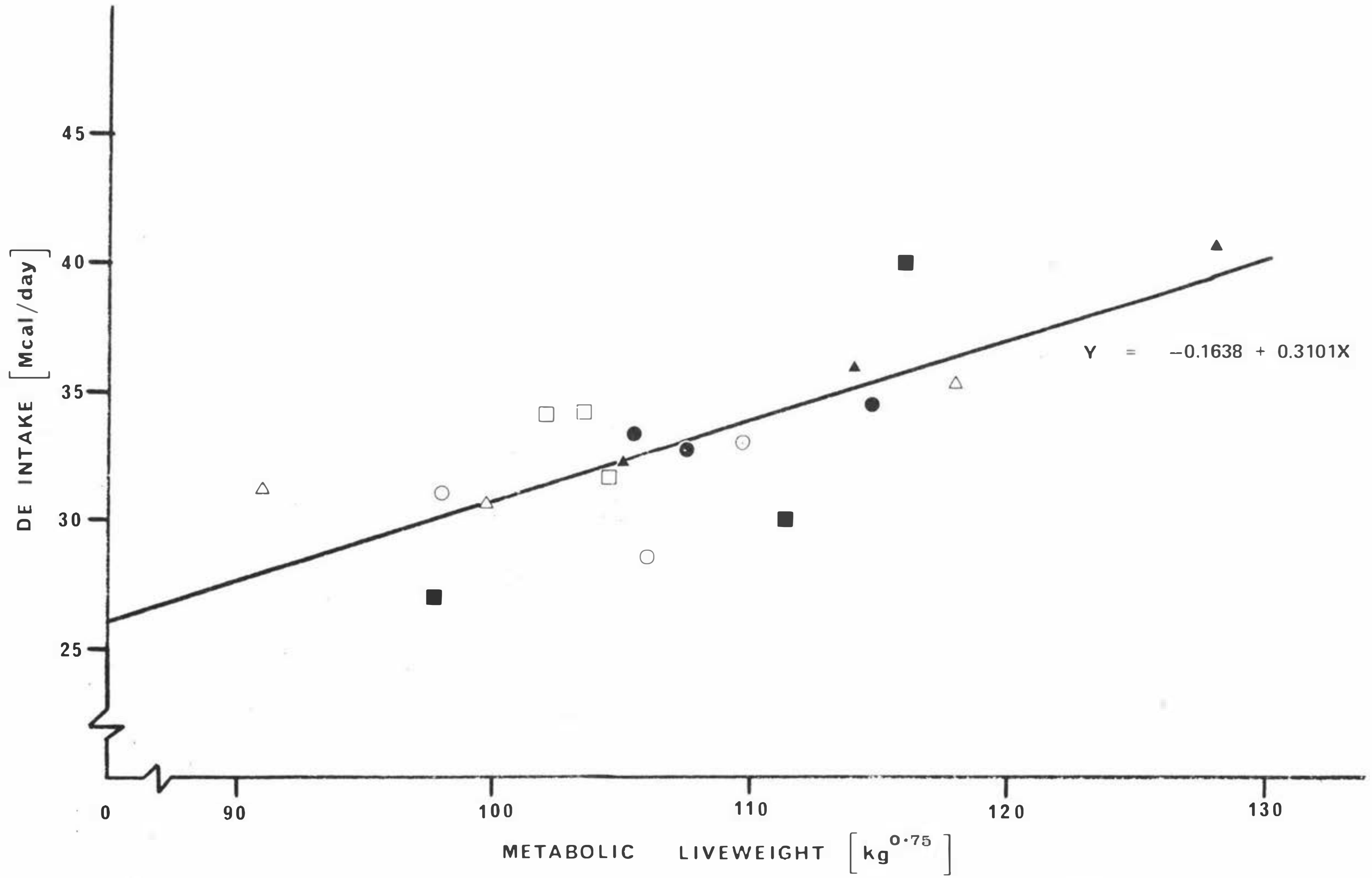

FIGURE 3.5: Mean intakes of DE (Mcal/day) for each bull, plotted against mean metabolic liveweight in the standardisation period.

TREATMENT

○ L1 ● H1

△ L2 ▲ H2

□ L3 ■ H3

Both equation 1 and 2 explain 59 per cent of the variation in *ad libitum* intake during the standardisation period. However, it makes no difference to the predictive value of these equations whether liveweight or metabolic liveweight is used.

3.3.3 Liveweight Gain

The mean mid-liveweight, mid metabolic liveweight, and liveweight gain during the standardisation period, of the high and low liveweight gain groups, are presented in Table 3.7. See Appendix XI for information on the two different methods of estimating liveweight gain.

TABLE 3.7 : Mean mid-liveweight, mid metabolic liveweight and liveweight gain of the high and low liveweight gain groups fed *ad libitum* pasture during the standardisation period (df = 16).

Item	High group (n = 9)	Low group (n = 9)	t	P
Mid-LW (kg)	533.4 ± 18.74	487.5 ± 15.84	1.87	0.10
Mid-$LW^{\frac{3}{4}}$ (kg)	111.01 ± 2.89	103.65 ± 2.53	1.92	0.10
LWG (kg/day)	0.204 ± 0.135	0.315 ± 0.078	0.71	NS

3.4 COMPARISON PERIOD

The digestibility of the pasture, DE intake and liveweight gain, during the comparison period, are presented in the first three sections. From this data total and partial efficiencies were calculated and the results of these calculations are given in the fourth and fifth sections. In the final section the results of the correlation analysis between liveweight gain and the efficiency parameters are summarised.

3.4.1 Digestibility of Pasture

The apparent digestibility of energy of the pasture, or the pasture-concentrate rations, depending on the treatment, was analyzed, for differences between the high and low liveweight gain groups. The mean values of the apparent digestibility of energy and the statistical significance of the differences are given in Table 3.8. A subsequent Table, Table 3.9 presents the apparent digestibility of energy on the three intake levels. Appendix VII provides further information on the statistical significance of the digestibility differences.

TABLE 3.8 : Mean apparent digestibility of energy of rations during the comparison period for the high and low liveweight gain groups, and for the two, five-day sub-periods averaged over three levels of intake (df = 5).

Item	High (n = 6)	Low (n = 6)	t	P
Mean app. dig. of energy(%)	73.80 ± 1.45	74.32 ± 1.18	1.00	NS

Item	Sub-period 1	Sub-period 2	t	P
Mean app. dig. of energy (%)	71.97 ± 2.26	76.16 ± 2.12	7.9	0.001

TABLE 3.9 : Mean apparent digestibility of energy of rations at the three intake levels in the comparison period; for bulls fed restricted levels of pasture on intake levels one and two and *ad libitum* pasture-concentrate ration on intake level three.

Intake level	Mean apparent digestibility (%)	Treatment comparison	P	t
1	72.54 ± 1.59	1 < 3	0.05	3.78
2	73.66 ± 0.63	1 = 2	0.05	1.23
3	75.98 ± 0.56	2 < 3	0.10	2.61

The information in Table 3.8 suggests that there was no difference in the digestive ability of bulls from the high or low liveweight gain groups over three levels of intake. The significant difference ($P < 0.001$) between the two, five-day sub-periods in the comparison period did not occur in the standardisation period and the reasons for this are not obvious.

The significant ($P < 0.05$) rise in digestibility from intake level one to intake level three, shown in Table 3.9 may be attributed to the inclusion of a concentrate meal at the higher intake level. There was no significant difference in the digestibility of pasture fed at the two different intake levels.

3.4.2 DE intake

The mean daily DE intakes, and DE intake per kg metabolic liveweight of the treatment groups is given in Table 3.10. The statistical significance of differences between these treatments is shown in Table 3.11. Data have been pooled in order to compare the overall difference between the two liveweight gain groups and the three intake groups. The mean daily DE per kg metabolic liveweight plotted against time for each of the six treatment groups is illustrated in Figure 3.6.

TABLE 3.10 : Mean daily DE intake per kg metabolic liveweight and daily DE intake during the comparison period for bulls of two liveweight gain groups and receiving different levels of pasture or pasture and concentrate.

Treatment	DE intake (Mcal/kg$^{\frac{3}{4}}$.day)	DE intake (Mcal/day)
L1	0.211 ± 0.005	22.68 ± 0.158
L2	0.257 ± 0.005	27.44 ± 1.712
L3	0.383 ± 0.001	41.82 ± 0.722
H1	0.200 ± 0.010	22.42 ± 0.695
H2	0.266 ± 0.006	31.18 ± 2.325
H3	0.325 ± 0.007	37.18 ± 2.325
L	0.284 ± 0.026	30.65 ± 2.93
H	0.264 ± 0.018	30.26 ± 2.28
1	0.206 ± 0.006	22.55 ± 0.324
2	0.262 ± 0.004	29.31 ± 1.259
3	0.354 ± 0.013	39.50 ± 1.504

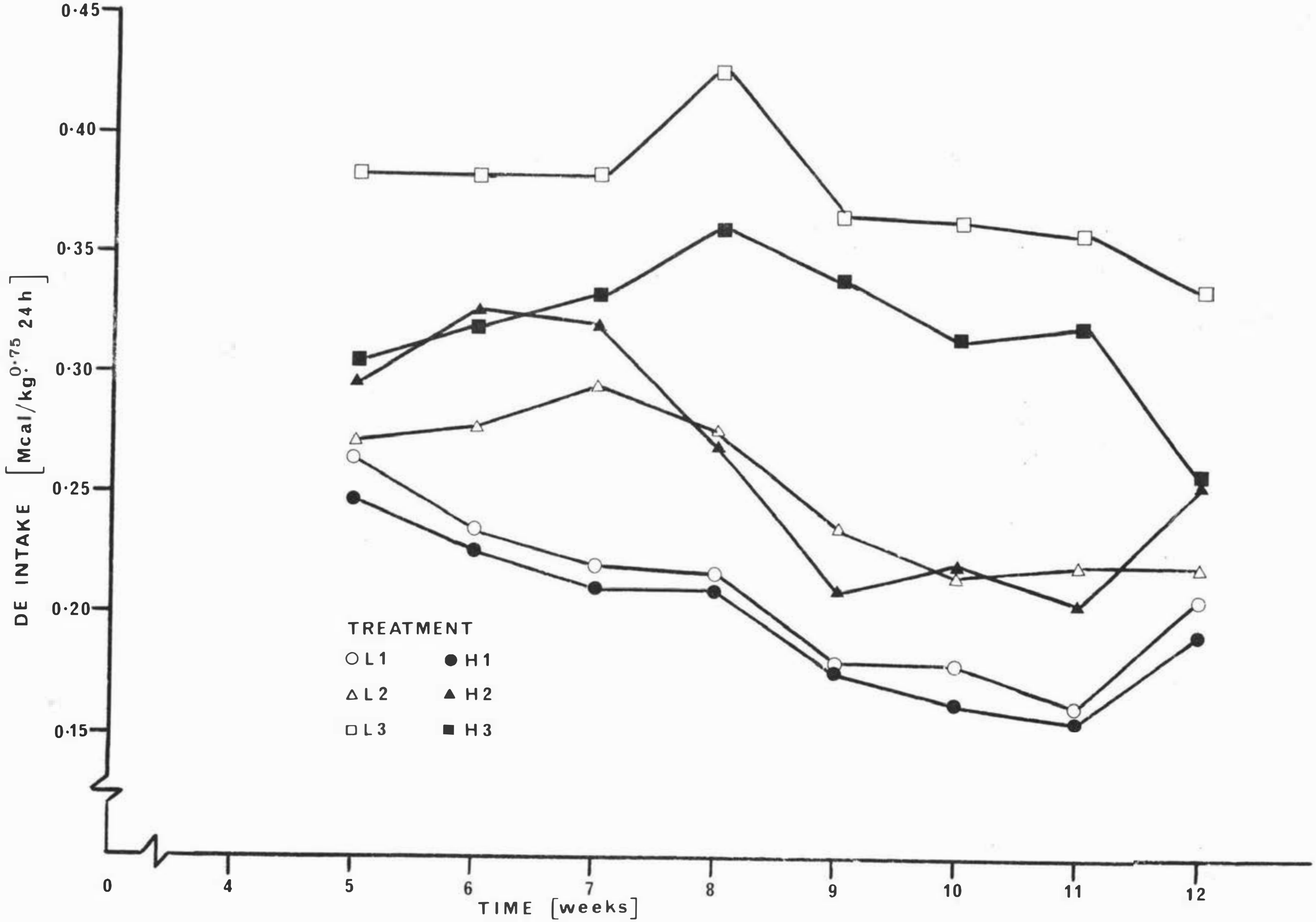

FIGURE 3.6: Weekly mean DE intake (Mcal/kg ¾·day) for each treatment group in the comparison period.

TABLE 3.11 : Statistical analysis of differences in daily DE intake per kg metabolic liveweight during the comparison period, for the three intake levels and two liveweight gain groups (df = 10)

Treatment comparison			P	t
L1	=	H1	NS	~~1.03~~ 1.20
L2	=	H2	NS	~~0.86~~ 1.00
L3	≠	H3	0.001	~~5.85~~ 6.80
L		H	0.01	4.08
1		2	0.001	~~1.70~~ 9.30
1		3	0.001	~~2.80~~ 15.3
2		3	0.001	~~4.48~~ 24.7

The statistical analysis of treatment differences in Table 3.11 indicates that the experimental design successfully ensured that there was no difference in Mcal DE/kg $^{\frac{3}{4}}$.day between the high and low liveweight gain groups on intake levels one and two. However, on ad libitum feeding the low liveweight gain group ate significantly ($P < 0.001$) more than the high liveweight gain group.

Figure 4.5 shows that the weekly intakes of DE were quite variable through the comparison period, but generally declined for those animals on intake levels one and two. On ad libitum intake the low liveweight gain animals ate consistently more than the high liveweight gain animals, throughout the period.

3.4.3 Live-weight gain

Liveweight gain during the comparison period was estimated from a regression of liveweight on time. The determination of mid-liveweight during the comparison period was also determined from a regression of liveweight on time; further details may be found in Appendix XI. The experimental design used in this study gives particular importance to liveweight gain as a measure of efficiency;

because feed intake, is experimentally controlled to provide a constant amount of food available for growth at any particular intake level (see Section 1.4.3).

The mean liveweight gain, mid-weight, and metabolic mid-weight, are presented for each of the six treatment groups in Table 3.12, along with pooled, mean estimates for the high and low liveweight gain groups and the intake levels. The statistical significance of treatment comparisons can be found in Table 3.13. Liveweight changes with time are plotted in Figure 3.7 for the six treatment groups. The two way analysis of variance for liveweight gain is presented in Appendix XI.

TABLE 3.12 : Mean daily liveweight gain, mid-liveweight and mid-metabolic liveweight during the comparison period for bulls of two liveweight gain groups and receiving different levels of pasture or pasture and concentrate.

Treatment	Daily liveweight gain (kg/day)	Mid-liveweight (kg)	Mid-liveweight ($\text{kg}^{\frac{3}{4}}$)
L1	0.380 ± 0.166	518.8 ± 24.96	107.8 ± 3.38
L2	0.715 ± 0.120	509.0 ± 50.97	106.9 ± 8.21
L3	0.953 ± 0.120	525.8 ± 12.25	109.1 ± 1.69
H1	0.348 ± 0.162	542.7 ± 12.65	112.1 ± 2.48
H2	0.479 ± 0.011	589.5 ± 44.00	117.4 ± 6.16
H3	0.965 ± 0.095	559.2 ± 37.98	114.3 ± 5.71
L1	0.683 ± 0.108	523.7 ± 17.13	107.9 ± 2.63
H 1	0.597 ± 0.113	560.8 ± 18.02	114.6 ± 2.64
1	0.364 ± 0.104	530.8 ± 13.60	109.9 ± 2.11
2	0.597 ± 0.090	544.7 ± 34.10	112.2 ± 5.16
3	0.959 ± 0.068	542.5 ± 19.35	111.7 ± 2.91

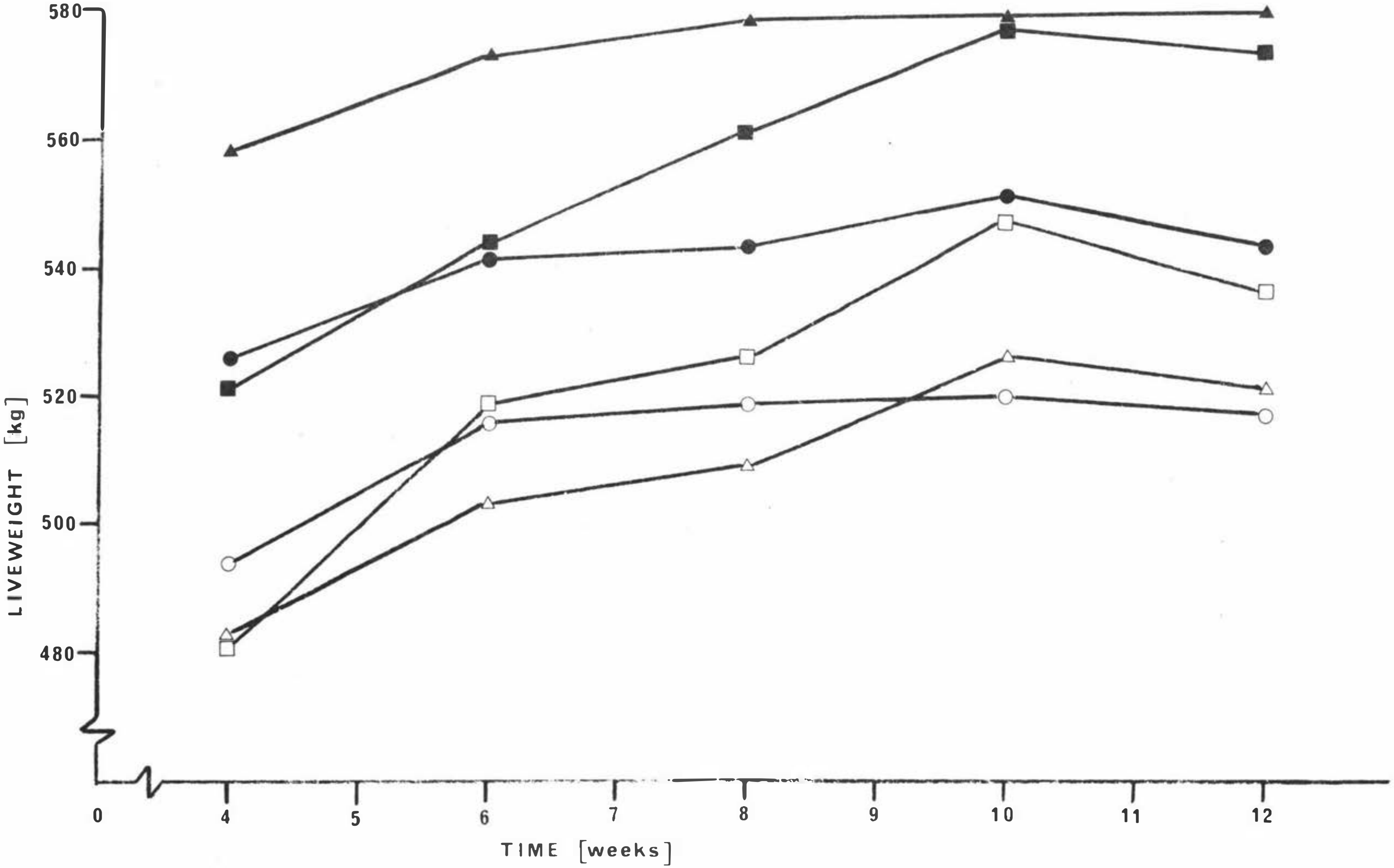

FIGURE 3.7: Treatment mean liveweights during the comparison period, plotted against time; showing the maintenance of liveweight differences between the high and low liveweight gain groups throughout this period.

TABLE 3.13 : Statistical analysis of differences in daily liveweight gain and mid-liveweight during the comparison period for the bulls of the three intake levels and two liveweight gain groups (df = 10)

Daily liveweight gain :

Trt. Comp.	P	t
L1 = H1	NS	0.19
L2 = H2	NS	1.38
L3 = H3	NS	0.07
L = H	NS	0.75
1 = 2	NS	1.68
1 < 3	0.01	4.28
2 < 3	0.05	2.61

Mid-liveweight :

Trt. Comp.	P
L1 = H1	NS
L2 = H2	NS
L3 = H3	NS
L = H	NS
1 = 2	NS
1 = 3	NS
2 = 3	NS

Table 3.12 demonstrates the reduction of standard error of liveweight gain as the liveweight gain increases from intake level one to intake level three. The large standard errors on the lowest intake level explain the failure of the differences in liveweight gain between bulls on intake levels one and two to reach significance. The lack of any significant difference between the low and high liveweight gain groups at any of the three intake levels is shown in Table 3.13.

3.4.4 Total Efficiency

In this section the information on liveweight gain and DE intake is combined to give expressions for total efficiency, the logarithm of total efficiency, and the deviation of individual animals from the regression of liveweight gain on total DE intake.

The mean values for total efficiency and the logarithmic total efficiency are presented for each of the six treatment groups in Table 3.14, together with pooled data for the two liveweight gain and three intake groups. The statistical significance of the differences between treatments is given in Table 3.15, and further information on the analysis of variance is presented in Appendix XII.

The results expressed in Table 3.14 and 3.15 indicate that there were no significant differences in total efficiency or logarithmic total efficiency either between the low and high liveweight gain groups or among the three intake levels.

TABLE 3.14 : Mean total efficiency and logarithmic total efficiency during the comparison period for bulls of two liveweight gain groups, and receiving different levels of pasture or pasture and concentrate.

Treatment	Total efficiency (kg LWG/Mcal/DE)	Log. Total Efficiency (Log LWG/~~kg~~ Mcal DE)
L1	0.0167 ± 0.0072	1.8514 ± 0.1729
L2	0.0259 ± 0.0036	1.5963 ± 0.0660
L3	0.0227 ± 0.0025	1.5863 ± 0.1073
H1	0.0151 ± 0.0070	1.9973 ± 0.3253
H2	0.0157 ± 0.0042	1.8384 ± 0.0683
H3	0.0257	1.5457
L	0.0218 ± 0.0028	1.6780 ± 0.2602
H	0.0189 ± 0.003[illegible]	1.7938 ± 0.3965
1	0.0159 ± 0.0045	1.8693 ± 0.2185
2	0.0208 ± 0.0034	1.7173 ± 0.3632
3	0.0243 ± 0.0016	1.5661 ± 0.0599

TABLE 3.15 : Statistical analysis of differences in total efficiency and logarithmic total efficiency during the comparison period for bulls of two liveweight gain groups, and receiving different levels of pasture or pasture and concentrate (df = 10).

Total Efficiency				Log. Total Efficiency			
Trt. Comparison			P	Trt. Comparison			P
L1	=	H1	NS	L1	=	H1	NS
L2	=	H2	NS	L2	=	H2	NS
L3	=	H3	NS	L3	=	H3	NS
L	=	H	NS	L	=	H	NS
1	=	2	NS	1	=	2	NS
1	=	3	NS	1	=	3	NS
2	=	3	NS	2	=	3	NS

The regression equation calculated for the relationship between daily liveweight gain and daily digestible energy intake was :

$$Y = -0.3224 \ (\pm 0.3135) + 0.0316 \ (\pm 0.0100) \ X \quad .. \ 3.3$$

$Sy.x = 0.2233$

$R = 0.554$

$F = 23.32 \ (P < 0.001) \quad .. \quad d.f. = 16$

Y = liveweight gain per day (kg/day)

X = digestible energy intake (Mcal/day)

Equation 3.3 is expressed graphically in Figure 3.8, deviation of individuals from this regression could be taken as indicators of total efficiency. In this case, however, the multiple correlation coefficient of 0.554 means that over 44 per cent of the variation in liveweight gain is not explained by DE intake and it appears likely that much of this variation is due to errors in estimating liveweight gain rather than to differences in individual efficiency.

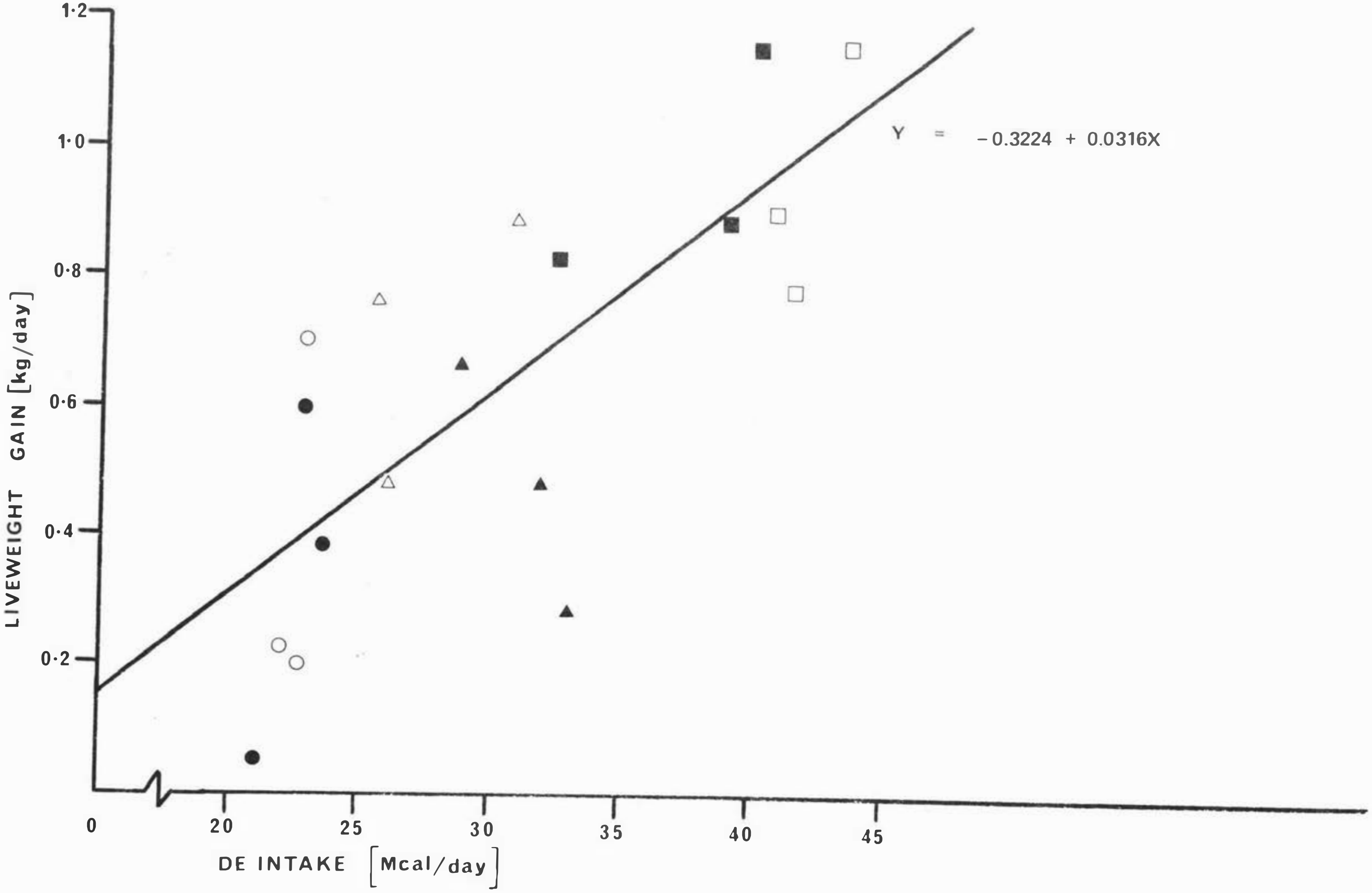

FIGURE 3.8: Daily liveweight gain plotted against daily DE for each individual in the comparison period.

TREATMENT

○ L 1	● H 1
△ L 2	▲ H 2
□ L 3	■ H 3

3.4.5 Partial Efficiency

In this section experimental results are expressed in forms that correct treatment comparisons for differences in the liveweight maintained during the comparison period. These forms are partial efficiency, logarithmic partial efficiency and deviation of individual animals from the regression of liveweight gain on digestible energy intake available for growth.

The review of literature (Section 1.4.2) suggests that another measure of individual partial efficiency would be the individual deviations of actual liveweight gain from that predicted by a regression of liveweight gain on DE intake (Mcal/kg$^{\frac{3}{4}}$.day). Figure 3.10 graphically describes this relationship while the regression equation is presented in the text (equation 3.5).

To calculate partial efficiencies it is necessary to assume some value for the maintenance requirement. Firstly, it was assumed that maintenance requirements were not altered by the plane of nutrition. Secondly, a value of 0.170 Mcal DE/kg$^{\frac{3}{4}}$. day was assumed on the basis of evidence presented in Section 1.4.2. It must be emphasised that any error in this assumption will have a greater relative effect on the partial efficiency of those animals closest to maintenance intake, than on those making rapid growth.

The mean values for partial efficiency and logarithmic partial efficiency are presented for each of the six treatment groups in Table 3.16. The statistical significance of treatment differences is given in Table 3.17, and the associated analysis of variance is tabulated in Appendix XIII. The regression of liveweight gain on the intake of DE available for growth is illustrated in Figure 3.9. The deviation of each individuals actual liveweight gain from that predicted by the regression, can be considered as another measure of partial efficiency.

TABLE 3.16: Mean partial efficiency and logarithmic partial efficiency during the comparison period for bulls of two liveweight gain groups and receiving different levels of pasture, or pasture and concentrate.

Treatment	Partial efficiency (kg LWG/Mcal DE)	Log. Partial Efficiency Log kg LWG/log Mcal DE)
L1	0.085 ± 0.038	1.152 ± 0.0960
L2	0.075 ± 0.010	1.134 ± 0.0596
L3	0.040 ± 0.004	1.338 ± 0.1079
H1	0.088 ± 0.035	1.132 ± 0.1841
H2	0.043 ± 0.011	1.397 ± 0.1126
H3	0.054 ± 0.003	1.229 ± 0.0602
L	0.067 ± 0.013	1.208 ± 0.0650
H	0.061 ± 0.013	1.253 ± 0.0771
1	0.086 ± 0.023	1.142 ± 0.0099
2	0.059 ± 0.010	1.265 ± 0.1315
3	0.047 ± 0.004	1.283 ± 0.0543

TABLE 3.17: Statistical analysis of differences in partial efficiency and logarithmic partial efficiency during the comparison period for the six treatment groups (df = 10).

Partial Efficiency		Log. Partial Efficiency	
Trt. Comparison	P	Trt. Comparison	P
L1 = H1	NS	L1 = H1	NS
L2 = H2	NS	L2 = H2	NS
L3 = H3	NS	L3 = H3	NS
L = H	NS	L = H	NS
1 = 2	NS	1 = 2	NS
1 = 3	NS	1 = 3	NS
2 = 3	NS	2 = 3	NS

The regression equation relating the mean daily liveweight gain to daily digestible energy intake available for growth is as follows:

$Y = 0.2448\ (\pm\ 0.0957) + 0.0337\ (\pm\ 0.0069)\ X$ ... 3.4

$Sy.x = 0.0453$

$R = 0.595$

$F = 23.50$ $P < 0.001$ $df = 16$

Y = liveweight gain (kg/day)

X = digestible energy available for growth (Mcal/day)

Equation 3.4 was calculated using total DE intake minus a value of 0.170 Mcal DE/$kg^{\frac{3}{4}}$. day. This figure was the one assumed to be correct for the purpose of allocating intake levels to bulls of different liveweight during the comparison period.

The equation calculated for the mean daily liveweight gain regressed upon daily DE intake per $^{\frac{3}{4}}$. day is expressed as follows for the pooled high and low liveweight gain groups:

$Y = -0.3934\ (\pm\ 0.2198) + 3.7753\ (\pm\ 0.7817)\ X$ ... 3.5

$Sy.x = 0.2120$

$R = 0.592$

$F = 23.92$ $P < 0.001$ $df = 16$

Y = liveweight gain (kg/day).

X = digestible energy (Mcal/$kg^{\frac{3}{4}}$. day).

High liveweight gain group:

$Y = 0.7855\ (\pm\ 0.3200) + 5.2439\ (\pm\ 1.1901)\ X$ ... 3.6

$Sy.x = 0.1902$

$R = 0.725$

$F = 19.41$ $P < 0.01$ $df = 7$

Y = liveweight gain (kg/day)

X = digestible energy (Mcal/$kg^{\frac{3}{4}}$. day).

Low Liveweight gain group:

$Y = 0.1649\ (\pm 0.3205) + 2.9876\ (\pm 1.0934)\ X$ ... 3.7
$Sy.x = 0.2297$
$R = 0.552$
$F = 7.47 \quad P < 0.05 \quad df = 7$
Y = liveweight gain (kg/day)
X = digestible energy (Mcal/kg $^{\frac{3}{4}}$. day)

As expected equations 3.5, 3.6 and 3.7, all show a significant relationship between liveweight gain and DE intake per kg $^{\frac{3}{4}}$. Although there is less error in the regression for the high liveweight gain groups there is no significant difference either between the slopes or intercepts of the regression lines for the high and low liveweight gain groups (see Appendix XIV).

3.5 Correlations among liveweight gain and efficiency measures

For the purpose of comparing relationships between measured variables and calculated efficiencies in this experiment, with those obtained by other workers, a table of correlation coefficients has been prepared. The severe limitations of correlations coefficients in providing adequate interpretation of cause and effect relationships are realised. However, some of the correlations provide an indication of the success of the experimental design in partitioning food intake. Correlation coefficients between important variables are given in Table 3.18.

TABLE 3.18 Correlation coefficients between liveweight gain, metabolic liveweight, partial efficiency, total efficiency, total DE intake and DE available for growth. Data have been pooled for all bulls during the comparison period.

Item	Metabolic LW	DE total intake	DE intake for growth	LWG	Part. eff.	Total eff.
Metabolic LW	-	0.24	-0.05	-0.03	-0.14	0.22
Total DE intake		-	0.75**	0.74**	-0.44	0.33
DE intake for growth			-	0.77**	-0.42	0.38
Liveweight gain				-	0.15	0.86**
Partial efficiency					-	0.58*
Total efficiency						-

** denotes significance at the 1 per cent level.
* denotes significance at the 5 per cent level.

3.6 Energy requirements for maintenance and growth

The two methods discussed in section (1.3.1) for the estimation of energy requirements have been used in analysing the experimental results obtained during the comparison period. The information from the standardisation period was not used because of the lack of a stable environment during this period, (see section 2.3).

The multiple regression equations derived from the data on metabolic liveweight, liveweight gain and DE intake are presented, along with the standard errors of the regression coefficients and the coefficients of determination. Tables 3.19 and 3.20 are estimates of energy requirements for Friesian bulls weighing from 350 to 600 kg and gaining 0, 0.5, and 1.0 kg liveweight per day, derived from equations 3.8 and 3.9 respectively.

The data were first analysed to fit an equation of the form:

$$Y = a + b_1 x_1^{\frac{3}{4}} + b_2 x_2$$

The equation predicted by multiple regression analysis was:

$$Y = 0.554 - 0.0085\ (\pm\ 0.0063) X_1^{\frac{3}{4}} + 0.0338\ (\pm\ 0.0073) X_2 \quad \ldots\ 3.8$$

$R = 0.530$

$F\ (b_1 \neq 0) = 1.88$ NS

$F\ (b_2 \neq 0) = 21.50\ (P < 0.001)$

Y = liveweight gain (kg/day)

X_1 = liveweight (kg)

X_2 = digestible energy (Mcal/day)

The same data were further analysed to fit an equation of the form:

$$Y = a + bX$$

where Y = liveweight gain (kg/day)

X = digestible energy (Mcal/ $kg^{\frac{3}{4}}$. day)

The equation predicted by linear regression analysis was:

$$Y = -0.3934\ (\pm\ 0.2198) + 3.7753\ (\pm\ 0.7817) X \quad \ldots\ 3.5$$

~~This is equivalent to equation 3.5~~. The substitution of actual values of metabolic liveweight and liveweight gain into equations 3.8 and 3.9 will allow the DE requirements for particular liveweight and growth levels to be predicted. Requirements for liveweights and liveweight gains close to those found in the experiment have been calculated and are tabulated in Tables 3.19 and 3.20.

TABLE 3.19: Predicted DE requirements for maintenance and growth of 350 to 600 kg Friesian bulls making daily liveweight gains from zero to one kg. Predictions are derived from equation 3.8.

Metabolic LW ($kg^{\frac{3}{4}}$)	Liveweight (kg)	Liveweight gain (kg/day)	DE requirement (Mcal/day)
80	347	0.0	7.24
		0.5	18.76
		1.0	33.55
100	465	0.0	9.05
		0.5	23.84
		1.0	36.09
120	596	0.0	14.14
		0.5	28.93
		1.0	43.73

TABLE 3.20: Predicted DE requirements for maintenance and growth of 350 to 600 kg Friesian bulls making daily liveweight gains from zero to one kg. Predictions are derived from equation 3.5. Values from ARC (1965) and NRC (1966) are included for comparison.

			DE requirement (Mcal/day)		
Metabolic LW ($kg^{\frac{3}{4}}$)	Liveweight (kg)	Liveweight gain (kg/day)	Present study	ARC (1965)	NRC (1970)
80	347	0.0	8.34	9.4	11.7
		0.5	18.93	14.4	20.2
		1.0	29.53	19.4	28.7
100	465	0.0	10.42	10.6	13.1
		0.5	23.66	16.6	23.6
		1.0	36.91	22.6	34.1
120	596	0.0	12.50	11.8	14.6
		0.5	28.39	19.3	26.6
		1.0	44.29	26.8	38.6

The following values were used in calculating DE requirements for the ARC (1965) and NRC (1970) columns.

Maintenance requirements:

ARC (1965)	0.118 McalDE/$kg^{\frac{3}{4}}$. day.
NRC (1966)	0.146 McalDE/$kg^{\frac{3}{4}}$. day.

Growth requirements (McalDE/kg liveweight gain) :

Metabolic liveweight ($kg^{\frac{3}{4}}$)	ARC (1965)	NRC (1970)
80	10	17
90	12	21
100	15	24

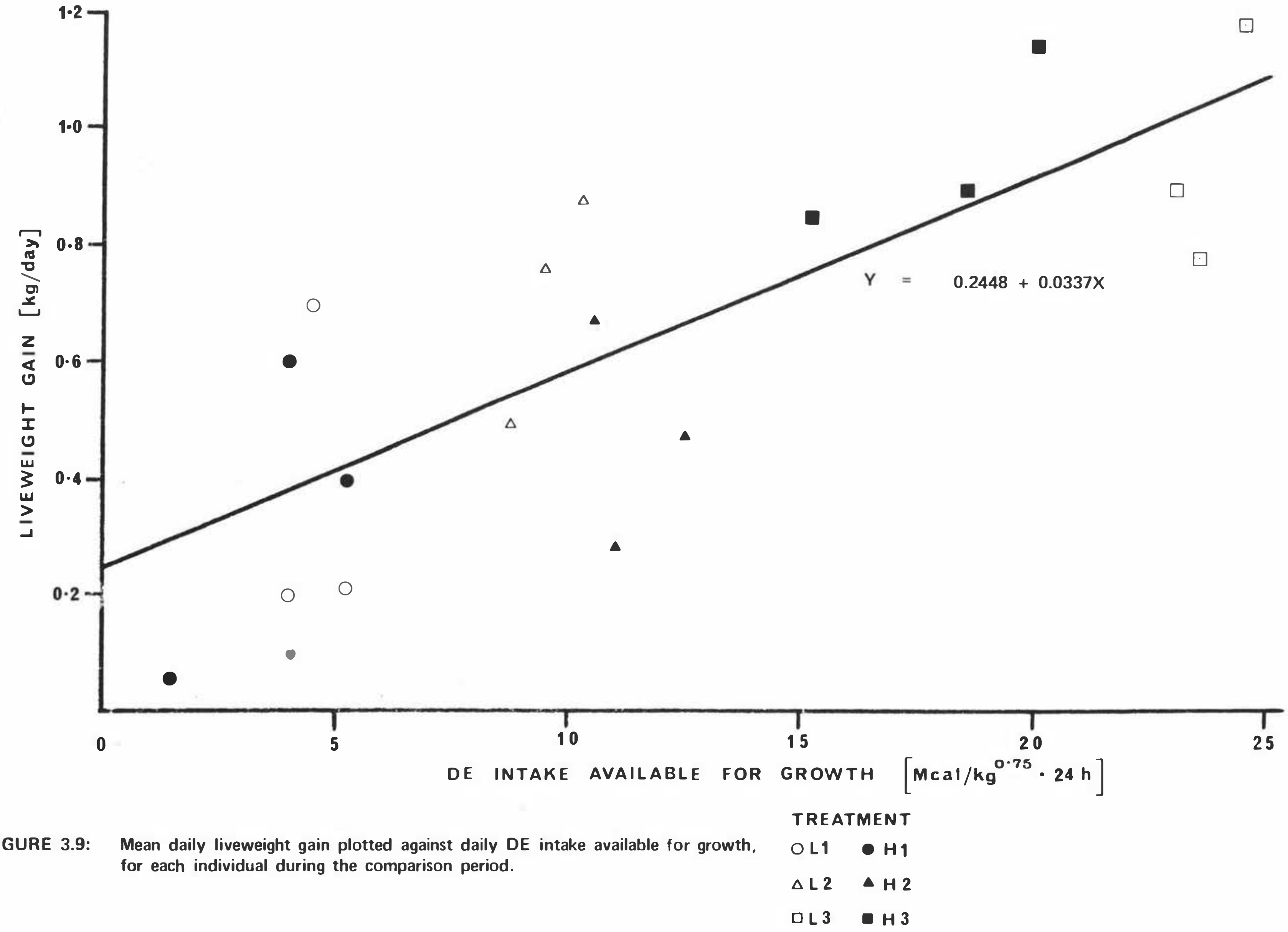

FIGURE 3.9: Mean daily liveweight gain plotted against daily DE intake available for growth, for each individual during the comparison period.

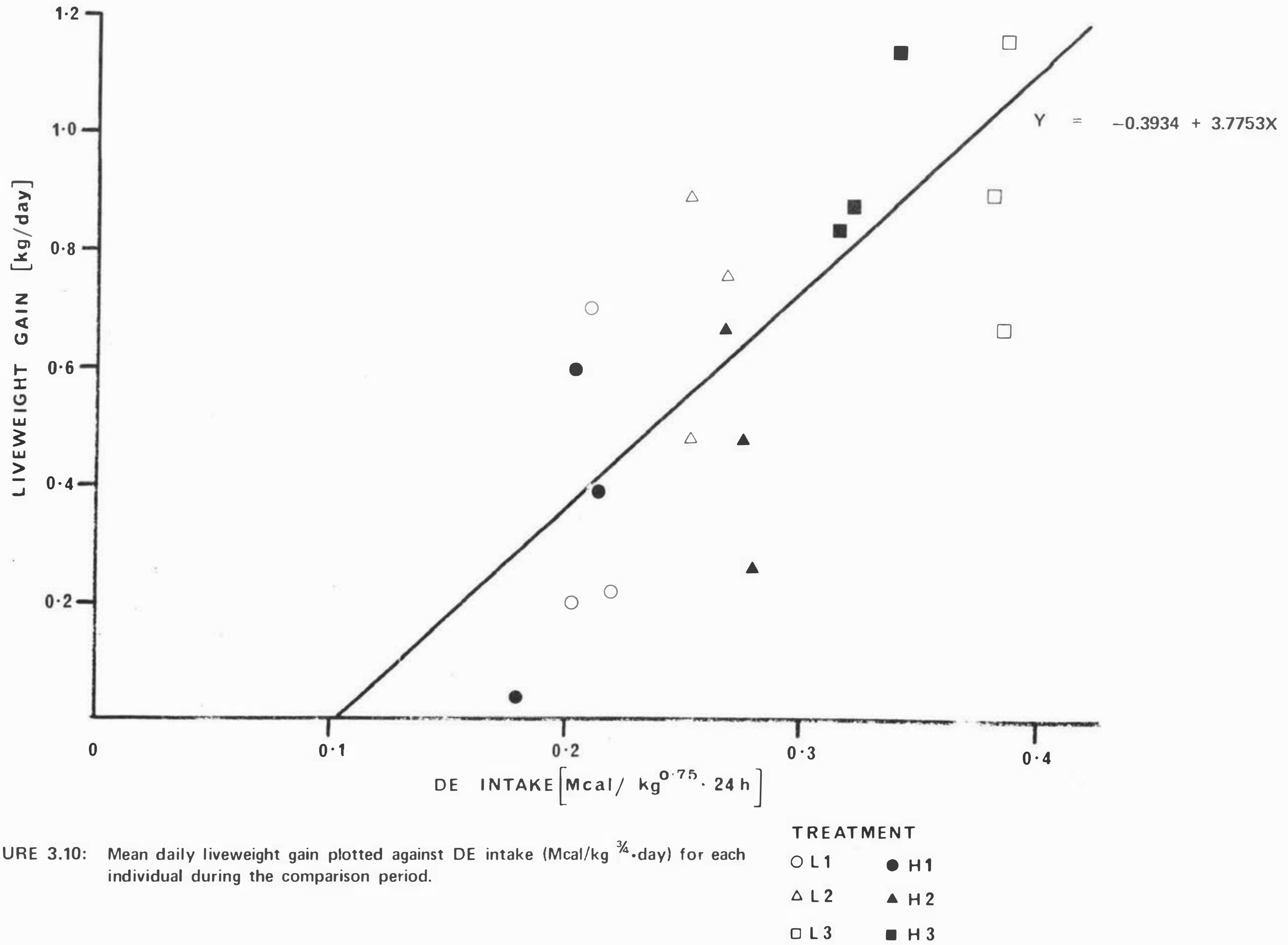

FIGURE 3.10: Mean daily liveweight gain plotted against DE intake (Mcal/kg $^{3/4}$·day) for each individual during the comparison period.

CHAPTER FOUR

DISCUSSION OF RESULTS

The discussion is divided into nine parts, as follows : The first discusses the results from the selection and pre-experimental periods. The parameters of voluntary intake, live-weight gain, total efficiency and partial efficiency for the standardisation and comparison periods are discussed in sections two (2) to five (5). The correlation analysis between these values is discussed in section six (6). The estimates of DE requirements for maintenance and growth are considered in section seven (7).

The overall success of the experimental design is discussed in section eight (8); and some recommendations for future work made on the basis of knowledge gained from the experiment and from the review of literature, in the final section.

4.1 SELECTION AND PRE-EXPERIMENTAL PERIOD

This section discusses the reversal of liveweight gain for the high and low liveweight gain groups from the selection period to the pre-experimental period. The lack of any significant difference in liveweight between the two liveweight gain groups at the beginning of the selection period; and the significant difference ($P < 0.001$) in liveweight gain between the Awahuri and Newstead bulls during the selection period are also discussed.

The high liveweight gains (> 1.0 kg/day) made by bulls of both liveweight gain groups during the selection period, imply that intake was close to _ad libitum_ throughout this period. If this was the case the differences in liveweight gain would have resulted, not only, from differences in the intrinsic efficiency of growth and maintenance, but also from differences in the maximum relative food capacity of the bulls. The likelihood of error in the estimates of liveweight gain is reduced, in this instance, because of the large gains made (see Table 3.3).

The liveweight gains made by the high and low groups during the pre-experimental period, immediately following the selection period, were the complete opposite of those during the selection period. The mean daily liveweight gains during the pre-experimental period were significantly different ($P < 0.05$) at 0.14 and 0.40 kg/day for the high and low liveweight gain groups respectively. These gain comparisons are from the pooled Awahuri and Newstead data; there being no significant difference between the Awahuri and Newstead bulls selected for the experiment, in liveweight gain during the pre-experimental period (see Table 3.3). The liveweight gains during the pre-experimental period were also much lower than those during the selection period, implying a reduced supply of pasture. Negative correlations between liveweight gain in one period and that in an immediate, subsequent period have been demonstrated by Carter (1969) and Calo, McDowell, Van Vleck and Miller (1973).

The latter authors could find no definite relationship between liveweight gain in different periods for Holstein-Friesian bulls fed in stalls, but they point out that the observed co-variance includes both the true covariance in growth rate and the negative covariance from weighing errors (see Section 1.2.4).

In a review of information on genotype - environment interactions for different species, Preston and Willis (1970) reported confusing and conflicting reports on this subject. Reynolds, De Rouen, Temple and Meyerhoeffer (1967) have presented data on two Breeds wintered at two levels of nutrition followed by a summer feeding period, that purport to show such an interaction. However, Preston and Willis (1970) consider that the interactions observed were more likely to be due to compensatory growth. In the present study the higher liveweight gains of the low liveweight gain group were expressed during a period of quite marked feed shortage. Work by Heaney, Pritchard and Pigden (1968) has highlighted the variability of weekly _ad libitum_ intake of sheep fed the same forage over several months. Such variability might result from the ineffectiveness of short term voluntary intake control (Baumgardt, 1970). The ability of ruminants to control intake very finely over long periods (Baumgardt, 1970) may be responsible for this reversal of liveweight gain patterns, and presumably intake patterns from the selection to the pre-experimental period. It is unlikely that the heavier liveweights maintained by the high liveweight gain group in the pre-experimental period would be sufficient to reduce liveweight gain from 0.40 to 0.14 kg/day. The influence of alimentary tract fill may have been important during the pre-experimental period when mean total liveweight gains were 6.9 and 48.0 kg for the high and low liveweight gain groups respectively.

The important result of this reversal in liveweight gain from one period to the next, was that the selection period mean difference in liveweight gain in favour of the high group was 0.35 kg/day for the selection period but was only 0.13 kg/day for the combined periods. However, the liveweight gains of 0.93 and 0.80 kg/day for the high and low groups respectively, over the combined periods, were still significantly different ($P < 0.01$).

The absence of any significant difference in liveweight or age at the beginning of the selection period (see Table 3.2), suggests that the bulls in both liveweight gain groups grew at approximately the same rate from birth until the start of the selection period. The work by Everitt (1972) and Reardon and Everitt (1972) implies that differences in liveweight manifested during the pre-weaning period will not be made up by compensatory growth at a later stage up to eighteen months of age. However, work by Winchester and Howe (1955) and Winchester and Ellis (1953) suggests that compensatory growth can occur. It is likely that differences in rearing systems were not of sufficient magnitude to effect yearling liveweights; or, that the management systems were such that the high liveweight gain bulls could not assert their superiority.

If both maximum relative feed capacity and intrinsic efficiencies of growth and maintenance were responsible for the large differences in liveweight gain during the selection period, reasons for the lack of any significant difference in growth rate during the first year of life must be sought. It is possible that grazing management prior to the selection period was such that differences in relative food capacity were not exhibited, if so, then the contribution to growth rate from differences in intrinsic efficiency must have been small. Conversely, the intrinsic efficiency parameters could have been quite important but their effect diminished through an associated decrease in relative feed capacity.

Evidence reviewed in Section 1.2.2 shows that acceleration of fat deposition occurs at approximately 230 kg liveweight in steers, and at slightly heavier weights in bulls. This liveweight coincides with the liveweight of the bulls at the start of the selection period. If rates of fat deposition differed between bulls it is likely that those with the highest fat content in their liveweight gain would be classified as the low liveweight gaining bulls. However, if this was the case the difference in rates of fat deposition should still have existed in the experimental periods and been manifested by a lower partial efficiency for the low liveweight gain group.

The third important result to be considered is the difference in liveweight gains between all the Awahuri ($n = 25$) and all the Newstead bulls ($n = 52$) during the selection period. At the beginning of the selection period there was no significant difference in mean liveweight between the Awahuri and Newstead Friesian bulls (see Table 3.1). During the selection period however, the Newstead bulls had a significantly higher ($P < 0.01$) liveweight gain than the Awahuri bulls. This difference between centres was presumed to be due largely to differences in grazing management and feed supply. In selecting bulls for the experiment it was considered that ranking bulls, within centres, for liveweight gain was a more important indicator of liveweight gaining ability than absolute values of liveweight gain. The selected Newstead bulls had higher liveweight gains than the Awahuri bulls in both the selection and pre-experimental periods, although these differences were not significant as a result of the much smaller sample size (see Tables 3.3 and 3.4).

4.2 VOLUNTARY INTAKE

The major results of interest discussed in this section are as follows : Firstly, the absence of a significant difference in voluntary intake between the high and low liveweight groups during the standardisation period. Secondly, the significantly higher voluntary intakes of three bulls from the low group compared to three bulls from the high group, receiving a pasture-concentrate ration _ad libitum_ during the comparison period.

The DE intakes were 0.310 ± 0.007 and 0.317 ± 0.007 Mcal/kg$^{\frac{3}{4}}$.day for the high and low liveweight gain groups respectively during the standardisation period. These figures are comparable to the values of 0.332 and 0.296 McalDE/kg$^{\frac{3}{4}}$.day calculated by the writer from data reported by Tayler and Wilkinson (1972) and Forbes _et al._ (1967) respectively. These intakes refer to animals of 200 to 250 kg liveweight fed grass only. However, they are only approximate because data were reported as organic matter or dry matter and a digestibility of 75 per cent and gross energy of 4.4 Mcal/kg DM was assumed by the writer in calculating digestible energy. When feeding a mixed roughage-concentrate diet, Almquist, Brungardt, Tyler and Waldman (1971) reported intakes of 0.36 McalDE/kg$^{\frac{3}{4}}$.day for steer calves of 45 kg, falling to 0.30 McalDE/kg$^{\frac{3}{4}}$.day for steers of 160 to 400 kg with a further drop to 0.22 McalDE/kg$^{\frac{3}{4}}$.day for steers of 520 kg. However, the same authors noted that 520 kg animals fed at 60 per cent of _ad libitum_ from 160 kg had intakes of 0.290 Mcal DE/kg$^{\frac{3}{4}}$.day.* Obviously, the rate of decline in relative feed capacity with increasing liveweight can be modified by previous nutrition and, presumably, by the quality of the diet (Levy, Holzer and Volcani 1968). On this evidence it is likely that the bulls in the experiment did not suffer reduced intakes from the management disturbances during the standardisation period. An examination of individual intakes satisfied the writer that no individual bulls were grossly affected by the change in feeding conditions. Evidence

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* when returned to _ad libitum_ feeding

reviewed in Section 1.1.2 suggests that factors of bulk or DM content of the pasture were unlikely to be imposing limits on the bull's intake.

In the comparison period the *ad libitum* intakes of 0.383 ± 0.001 and 0.325 ± 0.007 Mcal $DE/kg^{\frac{3}{4}}$. day for the low and high liveweight gain groups respectively were significantly different ($P < 0.001$). However, only three bulls from each group were fed *ad libitum* during this period and it was possible that, although randomly selected for the intake level, the three low liveweight gain bulls had higher intakes than the three high bulls in the standardisation period. Examination of the data (see Appendix X) showed, however, that there was no difference between these sets of bulls in the standardisation period. It is possible that the low liveweight gain animals were exhibiting the increased appetite proposed to account for the significantly higher liveweight gains of the low group in the experimental period. There was no difference in the ratio of pasture to concentrate consumed by the two groups, and this, coupled with the higher total DM intake of the low liveweight gain group leads to the conclusion that an increase in both pasture and concentrate intake occurred.

An increase in *ad libitum* intake has often been reported when pasture and concentrate meals are offered together. An increase from 0.296 to 0.366 Mcal $DE/kg^{\frac{3}{4}}$. day was reported by Forbes *et al.* (1967) when grass and grass plus one kg of barley per 100 kg liveweight was offered respectively. When grass only and grass plus concentrate were offered *ad libitum* a rise in intake from 0.332 to 0.473 Mcal $DE/kg^{\frac{3}{4}}$.day was reported by Tayler and Wilkinson (1972). However, at high levels of concentrate, intake substitution rates close to one may occur. Tapaira and Davey (1970) found that despite the care taken to introduce concentrates gradually to lactating cows on pasture, serious declines in total intake occurred if concentrate intake rose above 4.0 kg/day. This evidence, together with the persistent refusal of some meal by all but one bull, implies that truly *ad libitum* conditions were achieved for the pasture and concentrate mixture.

4.3 LIVEWEIGHT GAIN

The main result discussed in this section is the lack of any significant difference in liveweight gain between the high and low liveweight gain groups at any of the three intake levels. The failure of the low liveweight gain group to demonstrate a higher rate of gain than the high group on intake level three, despite a significantly higher DE intake by the former is also discussed.

The experiment was designed to give every animal on a particular intake level, the same amount of food available for growth. It was planned to achieve this in the comparison period by offering feed at an amount proportional to metabolic liveweight (see Section 1.4.3). Difficulties were encountered in achieving this objective, because of the wide daily fluctuations in DM percentage of the pasture. The coefficients of variation of DE intake per kilogram metabolic liveweight were 5, 3, and 3 per cent, for intake levels one, two and three respectively. These are much lower than those associated with liveweight gain (see Appendix XI).

Differences in liveweight gain between the two liveweight groups can be attributed to differences in intrinsic efficiency of maintenance and growth, because allowance has been made for maintenance requirements. Liveweight gain has the added advantage that it meets the criterion, set by Meyer and Garrett (1967), that a valid measure of biological efficiency should be a single, measurable response variable. There is the disadvantage that differences in body composition and alimentary tract fill can influence liveweight gain.

Although there was no significant difference between the mean mid-period liveweights of the two liveweight gain groups, during the comparison period there was a large range from 438 to 658 kg. Information presented in Section 1.2.3 indicates that heavier animals will require more DE per kg liveweight gain, even when allowance has been made for the greater maintenance requirements of these animals. It is therefore possible that animals differing in liveweight but having the same energetic efficiency may differ in liveweight gain at equal DE intakes, because of differences in body composition.

The equivalent liveweight gains for the high and low liveweight gain groups on intake level three, despite the significantly higher DE intake of the low group cannot be explained in terms of differences in liveweight of the two groups. The liveweights of 559 and 542 kg for the high and low groups respectively were not significantly different. It is thus not possible to explain this result with the information available from this experiment.

In conclusion, the experimental evidence does nothing to refute the hypothesis that there is no difference in intrinsic efficiency between the high and low liveweight gain groups. However, the widely different intake levels and liveweights used, in conjunction with the short experimental time, would increase the chance of errors due to gut fill and body composition occurring. It is suggested that this occurred and rendered the experiment too insensitive to detect small differences in intrinsic efficiency.

The *ad libitum* nature of the highest feeding level and the interest in other measures of efficiency leads next to a discussion of total efficiency.

4.4 TOTAL EFFICIENCY

The comparison in Table 3.15 shows that there was no significant difference in total efficiency between the low and high liveweight gain groups, although the total efficiency of 0.0189 ± 0.003 kg LWG/Mcal DE for the high group was lower than that of 0.0218 ± 0.003 kg LWG/Mcal DE for the low group (see Table 3.14). In this experiment the high liveweight gain group was significantly heavier ($P < 0.05$) at the end of the selection period (see Table 3.2), and maintained this difference until the end of the experiment.

The maintenance of a heavier liveweight by the high liveweight gain animals explains to some extent the trend observed in the total efficiency values for the two groups. There is much evidence to suggest that heavier liveweights will reduce total efficiency (Preston and Willis, 1970; Levy, Holzer and Volcani, 1968; Headley et al., 1961). It is also likely that differences in body composition would lead to either no change, or a decrease in total efficiency for the heavier group (see Section 1.4.1). A failure to detect a difference in total efficiency could be due to either a greater intrinsic efficiency of the high liveweight gain group, or an inability of the experimental design to detect differences in liveweight gain accurately enough.

Blaxter (1964) has generalised that if maintenance requirements are equivalent then the higher the liveweight gain the higher will be the total efficiency. This trend is quite evident in Table 3.14 but the differences are not statistically significant due to the large variation in liveweight gain within intake levels (see Appendix XI). It is therefore concluded that the major reason for failing to detect a significant difference in total efficiency between the two liveweight gain groups is the inability of the experimental design to determine liveweight changes accurately enough.

The use of total efficiency for comparative purposes is only strictly valid where there are no differences in liveweight maintained between the groups of animals being compared. In the present study this was not so, (see Table 3.12) and other measures of efficiency were sought. The method suggested by Sutherland (1965) (see Section 1.4.4) uses logarithmic values for both DE intake and liveweight gain. It was proposed as an alternative to the regression of liveweight gain on DE intake, because the latter method assigns equal efficiencies to groups if they have equal deviations from the regression line, regardless of the amount of feed required to produce the deviation. Although this method allows comparisons at different levels of intake to be made, it does not correct for any differences in liveweight between groups.

There were no significant differences either between liveweight gain groups or intake levels in logarithmic total efficiency (see Table 3.15). It is interesting to note that the high liveweight gain group has a higher absolute efficiency than the low liveweight gain group; this is the reverse of the situation for total efficiency. The logarithmic transformation means that the highest intake group has to have larger absolute liveweight gain deviations from the regression of liveweight gain on DE intake than groups at lower intakes before it will be considered equally efficient. No information could be found in the literature on the validity of comparing individuals or groups with widely differing intakes by this logarithmic method. However, it is likely that the chemical composition of liveweight gain will change as intake levels (and hence liveweight gains) change. The logarithmic relationship may be of less use for comparative purposes if energetic efficiency is considered to be more important than efficiency derived from liveweight gain alone.

4.5 PARTIAL EFFICIENCY

There were no significant differences between the high and low liveweight gain groups for partial efficiency during the comparison period (see Table 3.17). There were also no significant differences in partial efficiency between the three intake levels, although there was some evidence that partial efficiency decreased as intake level rose. Partial efficiencies were 0.086 ± 0.023, 0.059 ± 0.010 and 0.047 ± 0.004 kg LWG/Mcal DE for intake levels one, two and three respectively.

To derive these values it was necessary to subtract the requirements for maintenance from the total DE intake of each animal. A maintenance requirement for DE of 0.170 Mcal/$kg^{\frac{3}{4}}$. day was assumed after a consideration of other workers results (Blaxter, 1962 and Joblin, 1970).

There is some evidence (Blaxter and Wood, 1951) that maintenance requirements change with the level of food intake, although more confirmatory evidence on this point could not be found. Allden (1970) has suggested that animals undergoing re-alimentation may have lower maintenance requirements, however, this is unlikely to be the case in this experiment, because of the high plane of nutrition in the pre-experimental and selection periods (see Table 3.4). The work by Van Es (1961) and Blaxter (1964) has suggested a coefficient of variation of ± 10 per cent for the mean maintenance requirement of cattle. As a consequence of this it is likely that differences in partial efficiency will arise simply as a result of differences in the intrinsic efficiency of maintenance if a common maintenance requirement is used.

The other factor capable of influencing partial efficiency, when liveweight gain is used, is the chemical composition of that gain. To test for an increased energy content of a unit of liveweight gain a regression of mean daily liveweight gain on logarithmic DE intake/$kg^{\frac{3}{4}}$. day was fitted (see Appendix XV). The coefficient of determination was increased from 0.606 for the regression of mean daily liveweight gain on DE intake (Mcal/kg$^{\frac{3}{4}}$. day) to 0.613 for the logarithmic regression. This increase is non-significant and it is concluded that no difference in the energy content of liveweight gain occurred as liveweight gain increased.

However, the above relationship assumed an increasing energy content in a unit of liveweight gain as liveweight increases. Lofgreen and Garrett (1968) showed that body weight accounted for some, but not all, of the increase in energy concentration of the weight gain as rate of gain increased. This can also be implied from the results of Waldman *et al.* (1971); contrary to this, Lofgreen, Bath and Strong (1963) were able to show little increase of the energy concentration of weight gain as the rate of gain increased from zero to 1.0 kg/day.

The failure of a curvilinear regression of daily liveweight gain on DE intake (Mcal/kg$^{\frac{3}{4}}$. day) to increase the proportion of variation that could be explained in this experiment should not lead to the dismissal of changes in energy concentration as a possible complicating factor in future studies on partial efficiency.

4.6 CORRELATION ANALYSIS

The significant correlation ($P < 0.01$) of + 0.86 between liveweight gain and total efficiency agrees with the high correlations obtained by many other workers (see Section 1.4.5). The relationship between a ratio and one of its components has been theoretically calculated by Sutherland (1965) for different ratios of the coefficients of variation for liveweight gain and food intake. In the present study the coefficient of variation of liveweight gain was much greater than that for food intake (see Appendix XI). In this case Sutherland's equation predicts a high positive correlation between liveweight gain and total efficiency.

The lack of significant correlations between partial efficiency and total intake, or, intake available for growth, further supports the proposal that partial efficiency was not dependent on the level of food intake.

The significant correlations ($P < 0.01$) between liveweight gain and total intake ($r = +0.74$), and between liveweight gain and intake available for growth ($r = +0.77$); reflect the well defined relatiionship between intake and liveweight gain. That the relationship between total intake and liveweight gain is almost as close as that between intake available for growth and liveweight gain is a reflection of the experimental design. It was envisaged that a correlation of +1.0 would exist between total intake and intake available for growth on intake levels one and two, however this correlation would be lowered by the *ad libitum* nature of intake level three, and further lowered by the failure of the feeding regime to be exactly proportional to the metabolic weight of each individual.

4.7 ENERGY REQUIREMENTS FOR MAINTENANCE AND GROWTH

Equation 3.8 (see Section 3.6) regresses liveweight gain on metabolic liveweight and DE intake, and is of the same general form used by Hutton (1962), Joblin (1970) and Taylor and Young (1966). When the animal is allowed to determine its intake as has occurred in many of these studies, it has been found that both metabolic liveweight and DE intake determine the amount of liveweight gain made. However, in the present study two of the three intake levels were designed to offer feed in proportion to the animals metabolic weight so that equivalent amounts would be left for growth within an intake level. It is therefore not surprising that the regression coefficient associated with metabolic liveweight was not statistically significant, in equation 3.8.

Taylor and Young (1966) have explained that when regression equations relating liveweight, liveweight gain and food intake are calculated from experiments where the animals alone control their intake, widely varying estimates of the requirements for maintenance and growth may result. The shape and slope of the regression line will be determined by both the intrinsic efficiency characteristics of the animals and the relation of food eaten to metabolic liveweight. However, if the relation of food eaten to metabolic liveweight can be controlled at some particular level, and a series of such levels used, then a more satisfactory estimate of the requirements for maintenance and growth can be obtained. Individual animal variation around the regression line represent differences in intrinsic efficiency of maintenance and growth, and error.

The present study established a reasonable control between intake and metabolic liveweight, however the failure to measure liveweight gain accurately meant that 47 per cent of the variation in liveweight gain could not be accounted for by DE intake, a value much in excess of that expected if variation was due to individual differences in efficiency alone. The constant term of 0.554 kg/day in equation 3.8 is well outside the value of ± 0.10 kg/day suggested by Joblin (1970) as being an acceptable figure if a regression equation is to be used to derive feed requirements.

The effect that inaccurate measurement of one parameter, in this case liveweight gain, can have on the derived requirements for maintenance and growth is seen in Table 3.20. Equation 3.8 leads to values of 0.09 Mcal/$kg^{\frac{3}{4}}$. day of DE intake for maintenance and a DE intake requirement of 29.58 Mcal/kg liveweight gain. The maintenance requirement is much lower than any cited in the summary by Joyce (1971) of beef cattle requirements, while the requirement for growth is much higher than any mentioned in the same paper. If the errors involved are random ones it might be expected that the regression equation would have approximately the right slope but with a large amount of variation about it. However, with small numbers of animals it is possible that quite wide fluctuations in slope could result from purely random errors. The possibility of different amounts of gut fill for the different intake levels should not be ruled out as a contributing factor to changes in the slope of the regression line.

Equation 3.5 (see section 3.6) regresses liveweight gain on DE intake per unit metabolic liveweight. This equation differs from equation 3.8 in that the requirements for growth continually increases as liveweight increases. The maintenance requirement of DE derived from equation 3.9 is 0.104 Mcal/$kg^{\frac{3}{4}}$. day, slightly higher than that of 0.090 Mcal/$kg^{\frac{3}{4}}$. day derived from equation 3.8.

Both these values are considerably lower than those reported from grazing trials. Requirements of DE for maintenance range from 0.290 Mcal/$kg^{\frac{3}{4}}$. day (Holmes, 1961) to 0.340 Mcal/$kg^{\frac{3}{4}}$. day (Wallace, 1956) in the grazing situation. In a stall feeding experiment using cut pasture to maintain dry cows at a constant weight, Hutton (1962) derived a value for maintenance of 0.205 Mcal DE/kg $^{\frac{3}{4}}$. day. A lower estimate of 0.172 Mcal DE/kg $^{\frac{3}{4}}$. day was derived by Joblin (1970) with steers fed hay, maize silage and a variable amount of pasture indoors.

All these published values are higher than those recommended in the NRC (1970) and ARC (1965) feeding standards. The NRC (1970) and ARC (1965) values for maintenance requirements are 0.150 and 0.123 Mcal DE/kg $^{\frac{3}{4}}$. day respectively. Although these standards are now widely used they are not beyond criticism. An informative paper by Levy and Holzer (1971) shows that there were significant differences between observed daily gain and expected daily gain when the NRC (1970) or SE systems were used, but no difference when the ARC (1965), or TDN systems were used.

The DE requirements for liveweight gain derived from equation 3.5 are: 21.2, 26.5 and 31.8 Mcal.kg liveweight gain at 350, 450 and 600 kg liveweight respectively. The bulls in the present study were much heavier than those used in most New Zealand experiments. It is therefore expected that requirements for growth will be higher (see section 1.2.2).

In a grazing study, Holmes (1961) obtained an estimate of 12.2 Mcal DE/kg liveweight gain, however, this is probably too low an estimate because of the excessively high maintenance requirements derived from the same study. In stall feeding experiments, Hutton (1962) and Joblin (1970) derived estimated of 14.3 and 8.8 Mcal DE/kg liveweight gain, respectively. The requirements for growth in an animal of 400 kg liveweight are set at 8.8 Mcal DE/kg liveweight gain by ARC (1965), and at 15.9 Mcal DE/kg liveweight gain by NRC (1970). The large difference between the two standards arises because the ARC (1965) requirements rise by 9.5 kcal/kg liveweight gain . kg liveweight, while those for NRC (1970) increase at a rate of 22 to

33 kcal/kg liveweight gain . kg liveweight depending on the quality of the diet.

Equation 3.8 and 3.5 give quite similar DE requirements despite the different models of the growth process which are used. Equation 3.5 gives a more realistic maintenance requirement than Eqation 3.8, although both are below the ARC (1965) value which is the lowest generally accepted standard. Equation 3.5 explains 60.6 per cent of the variation in liveweight gain compared to 53.0 per cent for equation 3.8, and the former equation is based on increasing requirements for growth as liveweight increases when liveweight gain rather than energy retention is used as a response parameter. This agrees with the assumptions made in both the ARC (1965) and NRC (1970) standards.

However, the large amount of experimental error in this study, together with the higher liveweights than are usually examined, means that it is not possible to state that equation 3.5 is more biologically correct than equation 3.8. These same factors also reduce the value of the estimates for more general application. The bias evident is these estimates indicates, once again, that extreme care is needed in deriving estimates from data when large errors are associated with one or more variables.

4.8 SUCCESS OF THE EXPERIMENTAL DESIGN

The experiment failed to answer adequately the three questions posed in section 1.6.1. The major reason for this can be attributed to the very high coefficients of variation associated with liveweight gain. The management immediately prior to weighing, and the method of determining liveweight gain from the liveweight data were considered to be the best that could be achieved within the experimental framework. It was considered that nine animals in the high and nine in the low liveweight gain groups were the maximum that could be handled by the labour and facilities available, and undoubtedly, increased numbers would have increased the sensitivity of the experiment. Information from Bailey et al. (1958) suggest that the length of time available for the experiment is more important than increasing the number of animals per treatment. In their experiment increasing the experimental period from three to six weeks had more effect on accuracy than doubling the number of animals.

That the shortness of the comparison period was the major failing is supported by work reported by Knapp and Clark (1947). These authors found that genetic influences accounted for 10, 54, and 84 per cent of the variation in the total liveweight gains of beef calves, in three successive 84-day periods, after the age of six months. If random error in the measurement of liveweight gain remains approximately constant then it will become progressively less important as liveweight gain increases. In the present study the choice of three intake levels meant that those on the lowest level gained only 20 kg during the comparison period. Gut fill may often represent 20 per cent of the liveweight of the animal, or 100 kg in a 500 kg animal. Consequently, a slight variation in gut fill could drastically change the estimated liveweight gain. The wide range of liveweight covered by the small number of experimental animals could not be avoided if high and low liveweight gain animals were to be studied. Unfortunately, this same variation would most likely be associated with differences in the composition of liveweight gain between animals, and thereby reduce the sensitivity of the experiment.

The use of a pasture and concentrate in a mixed ration to study ad libitum intake can be criticised because it differs from the pasture ration used in the standardisation period. Preston and Willis (1970) believed that mixed rations should not be used in performance tests because of the opportunity for different animals to select different components of the diet.

The determination of the energy requirements for maintenance and growth was also hindered by the inaccuracy of the liveweight gain measurement. As a consequence they served more to illustrate the nonsensical results that can be obtained by the use of multiple regression analysis on inappropriate data, than to supply useful DE requirements for the maintenance and growth of 400 to 600 kg Friesian bulls.

It is concluded that estimates of the efficiency of food utilisation, using widely different intake levels, and a wide range of liveweights, cannot be satisfactorily made unless an experimental period of much longer than eight weeks can be used. If estimates over a limited time period, such as eight weeks, are to be made, it appears that indirect measures of body composition and some method of determining gut fill would be necessary.

4.9 FUTURE WORK ON THE EFFICIENCY OF FEED UTILISATION

Although the efficiency of feed utilisation is of fundamental importance to the livestock industry, it obviously requires more resources to select for it than for liveweight gain. Koch et al. (1963) reached the conclusion that selection for liveweight gain would lead to 81 per cent as much genetic gain in efficiency as would be achieved by direct selection for efficiency. Their methods of obtaining genetic correlations has been criticised by Sutherland (1965), and therefore their conclusions cannot be considered to be completely satisfactory. Even if a high genetic correlation exists between liveweight gain and the efficiency of feed utilisation it still leaves the problem of selecting for liveweight gain alone will increase the mature weight of the female breeding stock (Fitzburgh and Taylor, 1968).

Dalton, Rae and Clarke (1970) consider that bulls should be performance tested under grazing conditions in New Zealand, if this is accepted then liveweight gain must be the major criterion of selection until more accurate ways of measuring grazing intake are developed. However, Taylor and Young (1967) emphasise that feeding systems employed by commercial operators will rarely be the same as those employed by performance testing centres. This difference arises because the commercial operator has the objective of maximising profit, while the testing centres must maximise the genetic gain per year. In New Zealand more information is needed on the effect of herd interactions on grazing behaviour and hence food intake. If these interactions arise more from environmental than from genetic factors, a grazing environment may not be the best one in which to evaluate animals.

If stall feeding is used to measure individual efficiency of feed utilisation there must be a decision on whether to feed pasture or some concentrate mixture. Pasture has the advantage that it will be the feed the bull's progeny will consume but it has the following disadvantages. Firstly, large areas of land near to the testing centre are required to provide the pasture. Secondly, variation of pasture quantity and quality through the year make the measurement and control of energy intake more difficult. Thirdly, the weighing of feed offered and refused requires much more labour than the distribution of concentrates. Finally, wide variation in the DM of feed make daily determinations of DM necessary. A suitably pelleted diet would reduce the problems associated with variations in quality, supply, and fluctuation in DM content, and reduce the labour required to test a given number of bulls. The disadvantage is that the bull's progeny will not usually be consuming this type of feed. However, Preston and Willis (1970) believe that the genetic gains per year possible with a concentrate ration would outweigh those obtained from roughage because of the greater liveweight gains possible on the former diet (Calo et al. 1973, Levy, Holzer and Volcani, 1968); and the greater number of bulls capable of being tested. If efficiency of feed utilisation is to be selected for, the question of which is the best feeding system to adopt for maximum genetic gain per year must be answered.

Another question to be answered is what is the best time period or weight range over which to test the efficiency of feed conversion. The New Zealand Dairy Board at present has a policy of buying in bulls for progeny testing for dairy production characteristics at approximately twelve months of age. If these same bulls are to be performance tested for meat production, as was envisaged in this study, it may be necessary to assemble them for testing at a much earlier age and test them up to normal slaughter weight (400 - 500 kg). This would have the advantage of reducing both the feed required for maintenance and the possible effects of differences in pre-weaning nutrition (Everitt, 1972; Reardon and Everitt, 1972), if bought early enough. This method of testing would cover a long enough period to reduce errors associated with liveweight gain to a low level.

If the present Dairy Board policy of buying bulls at twelve months of age is continued, it will be necessary to use a much longer period than eight weeks to estimate efficiency. This will increase the amount of feed needed in a performance test, and reduce the relevance of the results to the farming industry. If animals are assessed from a few days of age until slaughter weight any differences in body composition may cease to be of importance in terms of an economic interpretation. When testing occurs at a later age, as in the present study, the wide variation in liveweight means that heavier animals will be discriminated against if liveweight gain is the response parameter. These animals will have a higher fat percentage solely as a result of their higher liveweights. Bulls being progeny tested for dairy production can obviously not be slaughtered, and hence the only way to correct for these different liveweights would be to use indirect estimates of body composition. While techniques for this exist, it requires more sophisticated equipment and more skilled personnel than in a performance test based on liveweight gain.

The question of what level of feeding to adopt must also be answered in any large scale testing scheme for the efficiency of feed utilisation. *Ad libitum* intake has been suggested by Preston and Willis (1970) to be by far the most desirable level to use. It is true that this level will measure both the animal's appetite and it's ability to grow. However, pre-experimental results presented in section 3.1, suggest that at pasture, an animal's appetite ranking within a group can change quite drastically. Blaxter (1964) has presented limited evidence which suggests that *ad libitum* intake may be directly proportional to maintenance requirements, so that two animals may have equal total efficiencies and yet the one with the highest *ad libitum* intake will have the higher liveweight gain. This has important implications for the New Zealand pastoral industry where breeding animals spend much of their life close to maintenance, while growing animals are very often not on *ad libitum* feeding. As soon as feeding is less than *ad libitum* the animals with the highest maintenance requirement are at a disadvantage if the feeding level is constant for each animal. It is therefore important to know whether "intake drive" is still directly proportional to maintenance requirements at the restricted intakes that occur under intensive grazing.

To summarise, the following questions need to be answered before any large scale testing of dairy animals for efficiency of beef production occurs.

1. How much genetic improvement per unit time can be achieved by using liveweight gain rather than the efficiency of feed utilisation as a selection criterion?
2. Is cut pasture economically the most feasible feed to use when the efficiency of feed utilisation of individuals is estimated under stall feeding conditions?

3. How strongly inherited are the grazing intake patterns of bulls?
4. What is the correct time period or weight range over which bulls should be tested to allow optimum genetic improvement per unit time to occur?
5. If older bulls have to be used, then how does performance at this stage relate to performance from birth to slaughter weight?
6. What level of feeding should be used when estimating the efficiency of feed utilisation?
7. If liveweight gain is used as the major selection criterion, how will this affect the maintenance requirements of the female progeny, who will form the future breeding herd?
8. What emphasis should be placed on meat, as against milk production if a dual purpose breed, such as the Friesian is used?

Some work has already been done towards answering these questions both overseas and in New Zealand. However, more complete answers are needed before effective selection for meat production in New Zealand can occur.

CHAPTER FIVE

CONCLUSIONS

The markedly superior liveweight gain of the high group during the six month selection period led to the hypothesis that voluntary intake, efficiency of feed utilisation or a combination of both were responsible.

The four week standardisation period, however, failed to show any difference in either the voluntary intake of cut pasture, or of liveweight gain between the two liveweight gain groups. No differences in total or partial efficiency between the two liveweight gain groups at two restricted levels of intake were manifested in the eight week comparison period. However, during this period the *ad libitum* intakes of three bulls from the low liveweight gain group were significantly higher than those of three bulls from the high group, surprisingly, these higher intakes did not lead to increased total efficiency.

The lack of any significant differences of efficiency between the liveweight gain groups at any of the three intake levels, meant that any further analysis for individual differences in efficiency was not warranted.

The final objective of the study was to determine the DE requirements for maintenance and liveweight gain of Friesian bulls of 400 to 600 kg liveweight. Unfortunately, the presence of error in the liveweight gain measurements is almost certainly the reason for the biased estimates of DE requirements that were obtained by multiple regression analysis. Two types of equations were fitted to the data. The equation that considered requirements for liveweight gain to increase as liveweight increased, explained seven per cent more of the variation than the equation which considered the requirement for liveweight gain constant as liveweight increased. However, both equations gave estimates of maintenance that were biased below the ARC (1965) and NRC (1970) estimates.

It is concluded that the experimental design based on feeding in proportion to maintenance requirements could be useful in future experiments to elucidate the nature of the relationship between liveweight, liveweight gain and feed intake. However, the experimental period was too short to counteract the effects of random fluctuation in liveweight, on the liveweight gain measured. Future experiments concerned with the efficiency of feed utilisation should either, use longer experimental periods, or more accurate ways of estimating energy retention.

Firm conclusions are made impossible by the presence of error, but the results suggest that, within a group, the relative ranking of a bull's voluntary intake is unstable through time. With this in mind, it appears that more work need to be done before liveweight at any age can be taken as reflecting either a genetically superior voluntary intake or a superior efficiency of feed utilisation in any bull grazed with a group on pasture.

APPENDIX I

A calendar of Important Experimental Events

Date	Experimental Event
5.8.71	Selection period started for Newstead bulls.
16.8.71	Selection period started for Awahuri bulls.
20.1.72	Selection period for the Newstead bulls concluded.
21.4.72	Newstead bulls trucked to Awahuri.
25.4.72	All experimental animals and spares grazed on overhead lines.
15.5.72	Commencement of the standardisation period.
22.5.72	All animals moved to the main barn to allow the installation of drainage pipes under the sawdust pad.
30.5.72	Standardisation period digestibility trial commenced.
8.6.72	Standardisation period digestibility trial finished.
12.6.72	All animals returned to the sawdust pad.
12.6.72	Commencement of the comparison period.
23.7.72	Comparison period digestibility trial commenced.
1.8.72	Comparison period digestibility trial finished.
4.8.72	Experiment concluded.

APPENDIX II

Table II.i: Preliminary information on each bull used in the experiment.

This information indicates the Artificial Breeding Centre the bull was selected from, its age and liveweight at the beginning of the selection period, and the liveweight gain made by each bull during this period. The deviation of each bull from both the average liveweight gain and from the regression of liveweight gain on liveweight and age is given.

LWG Group	Bull No.	Origin (a)	Initial Age (days) (b)	Initial LW (kg) (c)	Final LW (kg) (d)	LWG (kg/ day)	Weight-for-age (kg/day)	Regression deviation	Simple Deviation
H	51	N	349	237	490.0	1.50	0.679	+0.2497	+0.24
	01	N	379	325	575.0	1.48	0.858	+0.1989	+0.22
	17	A	357	286.0	480.7	1.23	0.801	+0.1600	+0.18
	74	N	406	232	470.5	1.41	0.571	+0.1923	+0.15
	33	N	367	417	665.0	1.47	1.136	+0.1340	+0.21
	65	A	321	324	512.5	1.19	1.009	+0.0360	+0.14
	06	N	359	335	570.0	1.39	0.933	+0.1982	+0.13
	68	N	386	245	480.0	1.39	0.635	+0.1549	+0.13
	87	A	357	222	401.4	1.13	0.622	+0.1204	+0.08
L	03	N	362	295.0	450.5	0.92	0.815	-0.3541	-0.34
	45	N	448	340.0	505.0	0.89	0.759	-0.2728	-0.28
	12	N	340	222.0	410.5	1.11	0.653	-0.1371	-0.15
	76	N	364	252.0	420.5	0.99	0.692	-0.2603	-0.27
	31	N	380	332.0	520.5	1.11	0.874	-0.1742	-0.15
	71	A	346	211.0	358.3	0.93	0.610	-0.0840	-0.12
	54	N	373	250	425.0	1.04	0.670	-0.2046	-0;22
	07	N	372	287	460.0	1.02	0.772	-0.1396	-0.24
	64	A	366	261	408.2	0.93	0.713	-0.1043	-0.12
H	70	N	371	257	490.0	1.38	0.693	+0.1370	+0.12
L	57	A	406	320	460.0	0.89	0.788	-0.1464	-0.16

(a) A = Awahuri bulls, N = Newstead bulls.

(b) Age at the beginning of the selection period.

(c) Liveweight at the beginning of the selection period.

(d) Liveweight at the end of the selection period.

(e) Weight-for-age is based on liveweight at the beginning of the selection period divided by age at this time. Birthweight has been considered to be zero.

Table II.ii: Regression analysis of liveweight gain on age and liveweight for Awahuri and Newstead bulls during the selection period.

<u>Awahuri bulls</u>:

$$Y = 1.278\ (\pm 0.221) - 0.00134\ (\pm 0.00019) X_1 + 0.00094\ (\pm 0.00080) X_2$$

<u>Newstead bulls</u>:

$$Y = 1.308\ (\pm 0.1458) - 0.00052\ (\pm 0.00037) X_1 + 0.00053\ (\pm 0.00044) X_2$$

In both equations:

Y = liveweight gain (kg/day)

X_1 = age (days)

X_2 = liveweight at the start of the selection period (kg)

Newstead data		Awahuri data	
$a = 1.308$	$P < 0.0001$	$a = 1.278$	$P < 0.001$
$b_1 = 0.00052$	$P = 0.16$ NS	$b_1 = 0.00134$	$P = 0.16$ NS
$b_2 = 0.00053$	$P = 0.24$ NS	$b_2 = 0.00094$	$P = 0.25$ NS
RMS = 0.127		RMS = 0.124	
d.f. = 51		d.f. = 20	

APPENDIX III

Table III.i: Pre-experimental calibration check on the Donald scales used to obtain liveweight over the experimental period.

A standard 10 kg. weight was added to the scales each time an animal was weighed on two separate occasions. The expected increase in recorded weight was tested against that actually observed.

Weighing on 28.4.72	Weighing on 5.5.72
$n = 20$ $\bar{X}o = 9.86$ kg. $\bar{X}e = 10.00$ kg. $S^2 = 1.10$ $t = 0.86$ NS	$n = 20$ $\bar{X}o = 9.89$ kg. $\bar{X}e = 10.00$ kg. $S^2 = 0.66$ $t = 0.93$ NS

$\bar{X}o$ = mean of the observed weight increase

$\bar{X}e$ = mean of the expected weight increase

APPENDIX IV

The Blocking of the Experimental Animals and their random allocation to Treatment Groups

Table IV.i: Individual bull liveweights taken immediately prior to the comparison period, together with block means and their standard errors.

Blocks(a)											
1		2		3		4		5		6	
Bull No.	L.W.	Bull No.	L.W.	Bull No.	L.W.	Bull No.	L.W.	Bull No.	L.W.	Bull No.	L.W.
12	459.1	03	498.3	45	527.2	51	492.5	17	513.4	01	566.3
71	410.5	76	467.6	31	577.9	74	496.9	65	551.0	33	631.9
84	471.2	54	483.4	07	500.4	87	457.5	68	539.0	06	569.2
Mean LW±SE	446.9		483.1		535.2		482.3		534.5		589.1
	±18.55		± 8.86		±18.55		±12.47		±11.09		±21.40

(a) Blocks 1, 2, and 3 contain bulls from the low liveweight gain group while blocks 4, 5, and 6 contain bulls from the high liveweight gain group. All liveweights are in kilograms.

Table IV.ii: Two way analysis of variance of liveweight at the time of blocking, for blocks and intake treatments; together with a comparison of blocks and intake treatment differences.

Source	d.f.	SS	MS	F	
Blocks	5	38825.5	7765.1	8.73**	
Treatments	2	1155.1	577.5	0.65 NS	
Error	10	8896.5	889.6		
Total	17	48877.1			
Block Comparison		L.W. difference (kg)		t	d.f.
(1 and 4)<(2 and 5)		44.2		2.57*	10
(1 and 4)<(3 and 6)		97.5		5.66**	10
(2 and 5)<(3 and 6)		53.3		3.10*	10

APPENDIX V

The chemical and physical nature of the concentrate meal fed to the fulls on intake level three during the comparison period.

Table V.i: The chemical composition of the pelletted meal mixture used in the experiment.

Chemical Components	Percentage composition (corrected to 100 % DM)
Crude fibre	9.75 ± 0.04
Crude protein	16.70 ± 0.04
Ether extract	4.80 ± 0.10
Ash	4.68 ± 0.02
Nitrogen free extract	64.07 ± 0.20
Gross energy (Mcal/kg)	4.704 ± 0.005

Table V.ii: The feed components, total digestible nutrients and digestible crude protein content of the meal mixture used in the experiment.

Feed components of the meal mixture	Per cent Composition of meal	Per cent TDN value of each feed	Per cent Digestible crude protein of each feed
Coarse ground barley	60	70	10
Coarse ground oats	7	72	7
Wheat bran	18	66	13
Linseed meal	7.5	75	30
Lucerne meal	7.5	54	12
Mean value		71.5	12.0

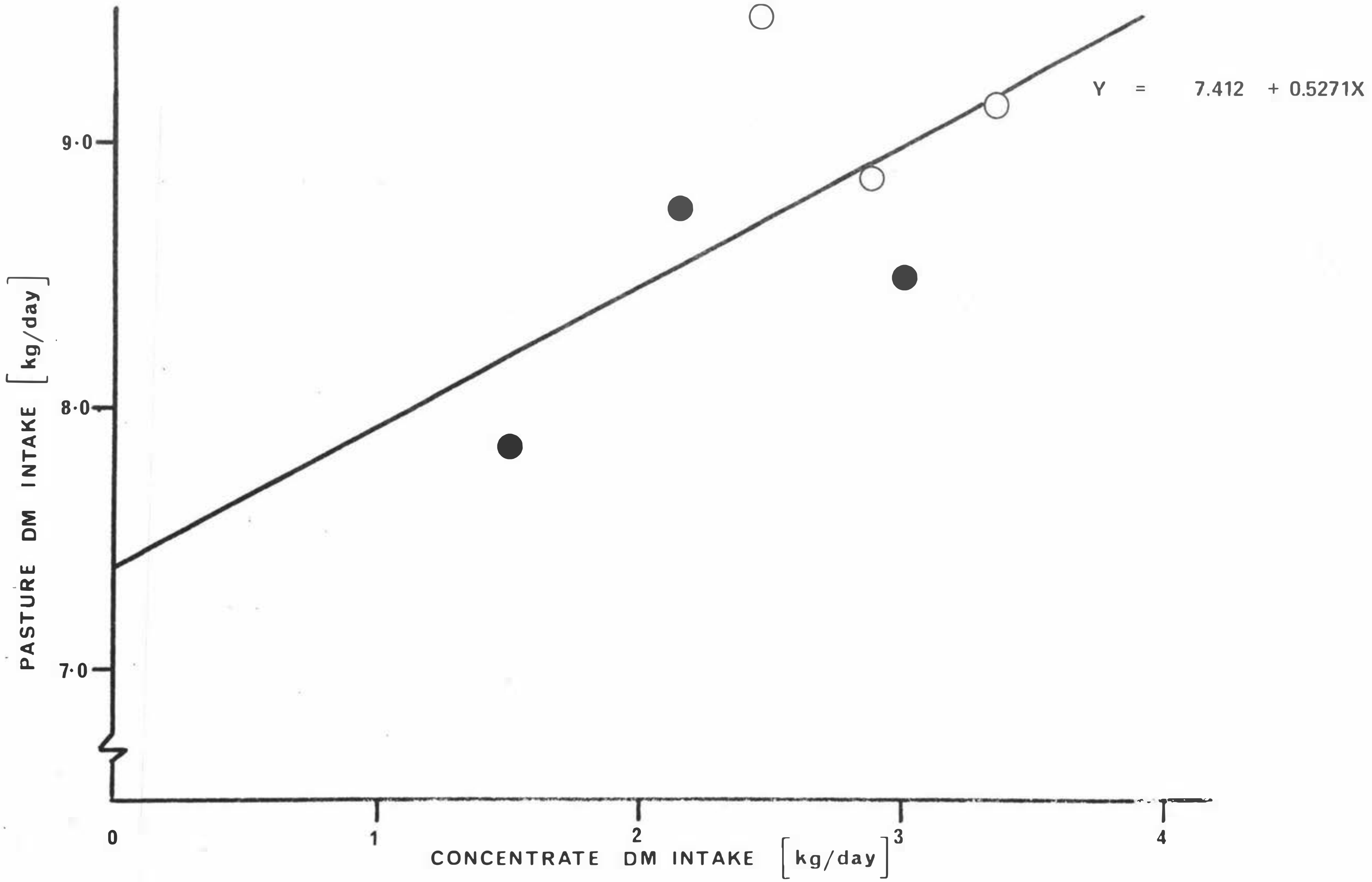

FIGURE V.i: Pasture DM intake plotted against concentrate DM intake for the six bulls on intake level three during the comparison period.

APPENDIX VI

Sample calculation of the estimation of DM digestibility by the use of chromium sesquioxide marker.

Daily dose of chromium sesquioxide = 20 gm.

Daily DM intake = 10 kg.

Faecal DM sample = 0.5 gm.

Chromium sesquioxide concentration in the faecal sample from a standard curve = 5 mg. per 0.5 gm. of faeces

$$\therefore \text{ 20 gm. of } Cr_2O_3 \text{ in } \frac{20}{5\text{x}10^{-3}} \text{ x } 0.5 = 2 \text{ x } 10^3 \text{ gm. of faeces}$$

$$\text{DM digestibility \%} = \frac{I - F}{I} = 100 = \frac{10-2}{100} \text{ x } 100$$

where I = DM intake = 80%

F = DM faeces

Table VI.i: A comparison of the estimates of energy digestibility obtained by either the total collection, or, the chromium sesquioxide indirect marker method, during the standardisation period.

Method	D.E. percent Mean = S.E.	Method comparison	t	p	d.f.
Total	76.68±1.03	T > Cr_2O_3	4.21	0.01	6
Cr_2O_3	72.17±0.28				

APPENDIX VII

Table VII.i: A comparison of the estimates of energy digestibility obtained by either the total collection, or the chromium sesquioxide indirect marker method, during the comparison period

Method	DE per cent	Comparison	t	p	d.f.
Total	71.86±2.52	T = Cr_2O_3	0.19	NS	4
Cr_2O_3	72.50±2.16				

Table VII.ii: Analysis of variance of digestible energy percentage in the comparison period, using data derived from the indirect chromium sesquioxide method.

Source	d.f.	SS	MS	F
Total	11	97.44		
Subperiods	1	52.50	52.50	31.6***
Treatment	5	36.64	7.33	4.4 ($P<0.10$)
Error	5	8.30	1.66	

APPENDIX VIII

Regression analysis relating DE intake during the standardisation period to liveweight and metabolic liveweight.

Table VIII.i: The regression of DE intake on metabolic liveweight.

$y^2 = 213.54$	$sy.x = 2.344$
$x^2 = 1306.9$	
$xy = 405.19$	$F = 22.89^{***}$ (d.f. = 16)
$b = 0.310 \pm 0.0648$	$r = 0.767$
$\alpha = 0.1638 \pm 6.9777$	$R = 0.590$

Table VIII.ii: The regression of DE intake on liveweight.

$y^2 = 213.54$	$sy.x = 2.339$
$x^2 = 52843.9$	
$xy = 2580.8$	$F = 23.63^{***}$ (d.f. = 16)
$b = 0.0488 \pm 0.0100$	$r = 0.772$
$\alpha = 8.2084 \pm 5.1334$	$R = 0.596$

APPENDIX IX

A sample calculation of the method used to predict DM intake for bulls of different weights and at different intake levels during the comparison period.

Assume liveweight = 465 kg
∴ metabolic liveweight ($W^{\frac{3}{4}}$) = 100 kg
Assume maintenance requirement of DE = 0.170 Mcal/kg$^{\frac{3}{4}}$·day
∴ Maintenance requirement of a 465 kg bull = 0.170 x 100
= 17 Mcal/kg$^{\frac{3}{4}}$·day

Assume a growthrate of 0.1 kg/day is required
and that the DE requirement for growth = 10 Mcal/kg LWG
∴ DE requirement for growth = 1 Mcal/day
∴ Total DE requirement = 10 Mcal/day
Or, if 1 kg DM = 2.6 Mcal DE
Then total DM requirement = $\frac{18}{2.6}$ kg DM
= 6.92 kg DM

The above calculations were used to estimate the approximate requirement at each intake level. However, in practice it was found to be more convenient to attempt to keep DM intakes in direct proportion to each animals metabolic liveweight.

APPENDIX X

Table X.i: Analysis of variance of daily digestible energy intake per $W^{0.75}$ in the comparison period, and the statistical significance of the differences in treatment effects.

Source	d.f.	SS	MS	F
Blocks	2	0.0006	0.0003	2.72 NS
Treatments	5	0.0729	0.0146	132.7***
Error	10	0.0011	0.00011	
Total	17	0.0746		

(1) Comparison of intake levels (No. of replicates = 3)

$\therefore$ Standard error of difference $= \sqrt{\frac{2s^2}{3}} = 0.01$

(2) Comparison of liveweight gain groups (No. of replicates = 9)

$\therefore$ Standard error of difference $= \sqrt{\frac{2s^2}{9}} = 0.0049$

Treatment comparison	Mcal DE/W .75/day Difference	t	d.f.
L1 = H1	0.0103	1.20 ~~1.03~~ NS	10
L2 = H2	0.0086	1.00 ~~0.86~~ NS	
L3 > H3	0.0585	6.80 ~~5.85~~***	
L > H	0.0200	4.08**	
1 < 2	0.056	9.30*** ~~1.70*~~	
1 < 3	0.092	15.3*** ~~2.80*~~	
2 < 3	0.148	24.7*** ~~4.48**~~	

Table X.ii: An analysis of differences in DE intakes in the comparison period with those in the standardisation period, for bulls on intake level three during the comparison period.

	n	Mcal DE /kg $^{\frac{3}{4}}$ · day	Comparison
Standardisation period			
L.W.G. group H	3	0.2983	L = H NS
L	3	0.3235	t = 0.95 d.f.= 4
Comparison period			
Trt. group H3	3	0.3248	L3 > H3 P 0.005
L3	3	0.3833	t = 7.13 d.f.=4

APPENDIX XI

Analysis of the methods of estimating liveweight gain during the comparison period

Table XI.i: A 't' test comparison of the 'regression' method and the 'difference' method of estimating liveweight gain during the comparison period.

Method	Mean LWG (kg)	Diff.(1)-(2) (kg)	$s\bar{x}_1-\bar{x}_2$	t	d.f.
Regression(1)	35.84	0.53	6.134	0.53 NS	34
Final-Initial L.W. (2)	35.31				

Table XI.ii: Analysis of variance of liveweight gain for all treatment groups over the comparison period, and the statistical significance of difference between treatments.

Source	d.f.	SS	MS	F
Blocks	2	0.0425	0.0212	0.37 NS
Treatments	(5)	1.1653	0.2331	4.01*
Intake	2	1.0801	0.5400	9.37***
LWG	1	0.0328	0.0328	0.56 NS
Interaction	2	0.0524	0.0262	0.45 NS
Error	10	0.5806	0.0580	
Total	17	1.7884		

Table XI.iii: The coefficients of variation (C.V.) of liveweight gain for the treatment groups over the comparison period.

Treatment group		Mean LWG (kg)	S.D. (kg)	C.V. (%)
Intake group	1	0.3639	0.2543	69.9
	2	0.5969	0.2209	37.0
	3	0.9593	0.1673	17.4
Liveweight gain				
Group	H	0.5873	0.3392	56.8
	L	0.6827	0.3231	47.3

Table XI.iv: Regression analysis relating daily liveweight gain to daily DE intake for the comparison period.

$y^2 = 1.7884$

$x^2 = 992.6$

$xy = 31.348$

$b = 0.0315 \pm 0.0100$

$\alpha = -0.3224 \pm 0.3135$

$sy.x = 0.2233$

$F = 20.0^{**}$ (d.f. = 16)

$r = 0.744$

$R = 0.554$

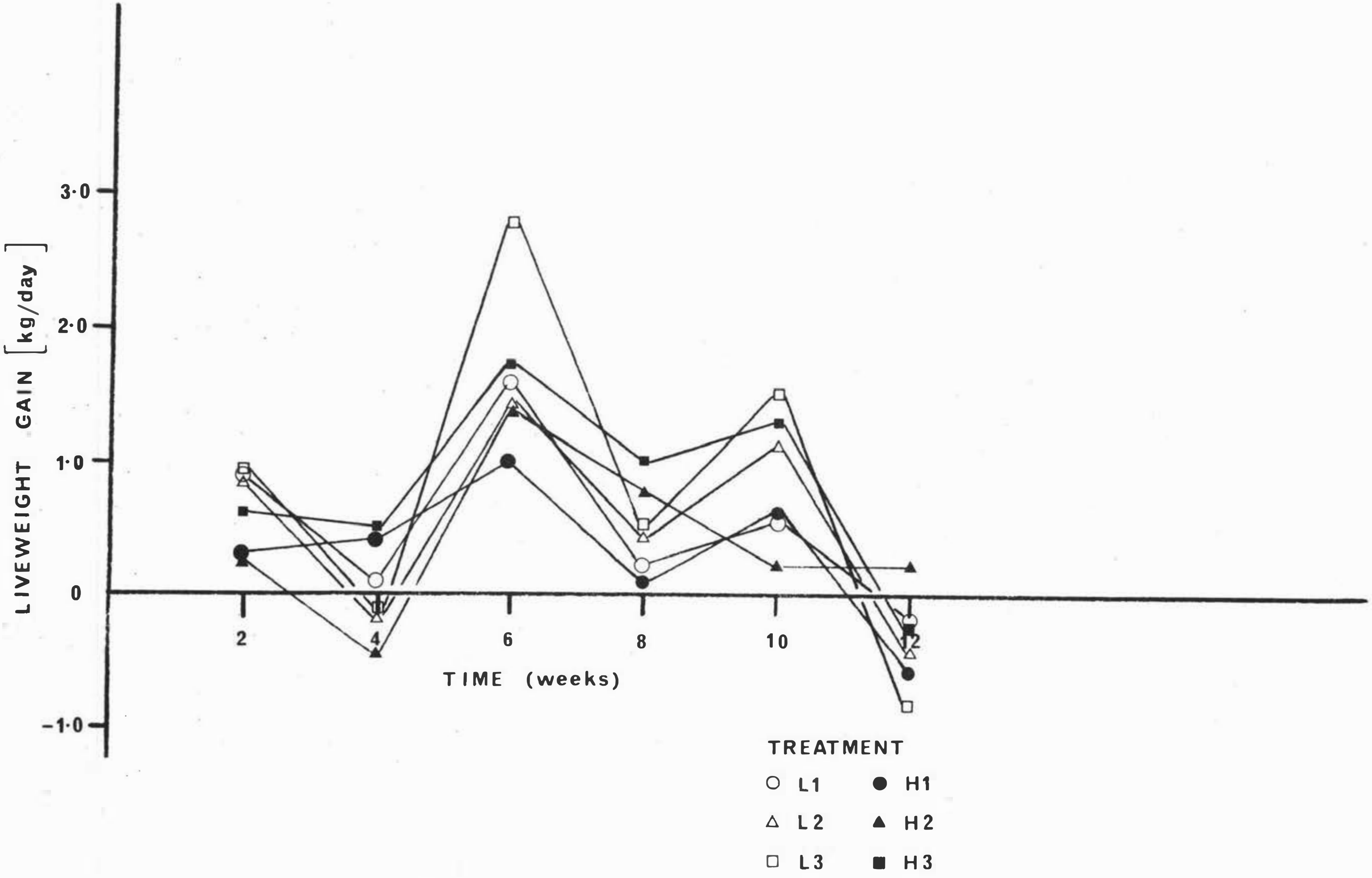

FIGURE XI.i: Mean fortnightly liveweight gain for each of the six treatment groups over the entire experiment, showing the large fluctuations in liveweight gain when calculated over a short time interval.

APPENDIX XII

Table XII.i: Analysis of variance of total efficiency of all treatment groups in the comparison period.

Source	d.f.	SS	MS	F
Blocks	2	0.000141	0.00007	1.00 NS
Treatments	(5)	0.000392	0.000078	1.10 NS
Intake	2	0.000219	0.00011	1.55 NS
LWG	1	0.000037	0.000037	0.52 NS
Interaction	2	0.000140	0.00007	1.00 NS
Error	10	0.000711	0.000071	
Total	17	0.001244		

Table XII.ii: Analysis of variance of logarithmic total efficiency all treatment groups in the comparison period.

Source	d.f.	SS	MS	F
Blocks	2	0.2084	0.1042	1.27 NS
Treatments	(5)	0.5105	0.1021	1.24 NS
Intake	2	0.3882	0.1941	2.36 NS
LWG	1	0.0604	0.0604	0.74 NS
Interaction	2	0.0618	0.0309	0.38 NS
Error	10	0.8216	0.0822	
Total	17	1.5405		

APPENDIX XIII

Details of the analysis of variance of partial efficiency and logarithmic partial efficiency data from the comparison period.

Table XIII.i: Analysis of variance of partial efficiency of all treatment groups in the comparison period.

Source	d.f.	SS	MS	F	
Blocks	2	0.00360	0.00180	1.31	NS
Treatments	(5)	0.00667	0.00133	0.97	NS
Intake	2	0.00485	0.00230	1.68	NS
LWG	1	0.00012	0.00012	0.12	NS
Interaction	2	0.00170	0.00086	0.62	NS
Error	10	0.01372	0.00137		
Total	17				

Table XIII.ii: Analysis of variance of logarithmic partial efficiency of all treatment groups in the comparison period.

Source	d.f.	SS	MS	F	
Blocks	2	0.0773	0.0387	0.76	NS
Treatments	(5)	0.1935	0.0387	0.76	NS
Intake	2	0.0712	0.0356	0.70	NS
LWG	1	0.0088	0.0088	0.17	NS
Interaction	2	0.1135	0.0568	1.12	NS
Error	10	0.5082	0.0508		
Total	17	0.7790			

APPENDIX XIV

Regression analysis of liveweight gain (kg/day) on DE (Mcal/kg $\frac{3}{4}$ day) during the comparison period for the low and high liveweight gain groups, and for both groups combined.

Table XIV.i: The regression of liveweight gain (kg/day) on DE (Mcal/kg $\frac{3}{4}\cdot$day) during the comparison period, for the low liveweight gain group.

$y^2 = 0.8353$
$x^2 = 0.0483$
$xy = 0.1443$
$b = 2.9876 \pm 1.0934$
$\alpha = 0.1649 \pm 0.3205$

$sy.x = 0.2400$
$F = 7.47^{*}$ D.F. = 7
$r = 0.718$
$R = 0.515$

Table XIV.ii: The regression of liveweight gain (kg/day) on DE (Mcal/kg $\frac{3}{4}\cdot$day) during the comparison period, for the high liveweight gain group.

$y^2 = 0.9204$
$x^2 = 0.0246$
$xy = 0.1290$
$b = 5.2439 \pm 1.1901$
$\alpha = 0.7855 \pm 0.3200$

$sy.x = 0.1830$
$F = 19.41^{***}$ D.F. = 7
$r = 0.857$
$R = 0.734$

Table XIV.iii: The regression of liveweight gain (kg/day) on DE (Mcal/kg 0.75·day) during the comparison period, for both liveweight gain groups.

$y^2 = 1.7884$	$sy.x = 0.2120$
$x^2 = 0.0744$	$F = 23.22^{***}$ D.F. = 16
$xy = 0.2809$	$r = 0.770$
$b = 3.775 \pm 0.7817$	$R = 0.592$
$\alpha = -0.3934 \pm 0.2198$	

Table XIV.iv: A comparison of regressions of liveweight gain on DE intake (Mcal/kg $\frac{3}{4}$·day) for the high and low liveweight gain groups during the comparison period.

						Deviations from Regression		
	df	x^2	xy	y^2	b	df	SS	MS
Within L	8	0.0483	0.1443	0.9353	2.9876	7	0.4042	0.0577
groups H	8	0.0246	0.1290	0.9204	5.2439	7	0.2439	0.0348
						14	0.6481	0.0463
Pooled, W	16	0.0729	0.2733	1.7557	3.7753	15	0.7311	0.0487
		Difference between slopes				1	0.0830	0.0830
Between, B groups	1	0.0015	0.0076	0.0327				
W + B	17	0.0744	0.2809	1.7884		28	0.7278	
		Difference between means				1	0.0033	0.0033

Comparison of slopes : F = 1.79 (df = 1,15) NS

Comparison of elevations : F = 0.07 (df = 1,16) NS

APPENDIX XV

Details of the analysis of variance of the regression of liveweight gain on metabolic liveweight and D E intake during the comparison period

Table XV.i: Analysis of variance of the regression of daily liveweight gain on metabolic liveweight and daily DE intake, for all animals during the comparison period

Source	d.f.	SS	MS	F
Regression	2	1.073	0.536	11.26**
Deviation	15	0.715	0.0476	
Total	17	1.788		

Table XV.ii: A further analysis of variance of the regression of daily liveweight gain on metabolic liveweight and daily DE intake, to test the individual effect of one independent variable after the effect of the other has been removed.

Source[(a)]	d.f.	SS	MS	F
X_1 and X_2	2	1.073		
X_1 alone	1	0.0019		
X_2 after X_1	1	1.071	1.071	22.5** $(\therefore B_2 \neq 0)$
X_2 alone	1	0.990		
X_1 after X_2	1	0.083	0.083	1.74 NS
Deviation	15	0.715	0.048	$(\therefore B_1 = 0)$

(a) X_1 is metabolic liveweight (kg), and X_2 is DE intake (mcal/day).

Table XV.iii: Regression analysis of liveweight gain on the logarithm of DE available for growth for all bulls in the comparison period.

$Y = -0.0778 (\pm 0.1533) + 0.7435 (\pm 0.1503) X_1$

$EMS = 0.044$

$R^2 = 0.61$

$F = 24.51$ $P < 0.001$ d.f. = 16

$a = 0$ $t = -0.5$ NS

$b \neq 0$ $t = 4.95$ P 0.001 d.f. = 16

Y = liveweight gain (kg/day)

X_1 = logarithm of DE available for growth (Mcal/day)

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