THE DIGESTIBILITY, INTAKE AND FAECAL MARKER PATTERNS OF HEREFORD AND FRIESLAND BULLS CONSUMING KIKUYU (*Pennisetum clandestinum*) USING N-ALKANES

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Abstract

Kikuyu is an important summer pasture species in South Africa for animal production, and is seemly suitable for growing out dairy replacement heifers. Previous research by Horne (1996) and Fushai (1997) showed that Friesland heifers had disappointing growth performance on kikuyu and concluded that there was an intake problem. In this study, Friesland (FB) and Hereford bulls (HB) were compared (with respect to growth, intake digestibility, faecal marker excretion patterns and time spent grazing) to investigate the previously identified intake problem of Friesland heifers.

Growth parameters (weight, height and condition score) were measured (during summer and autumn) for five FB (remaining three Friesland bulls were excluded due to disease) and eight HB while on kikuyu pasture. The average daily gain was 0.66 kg per day with no significant difference between treatments. Average height and condition score gain were not significantly different. The alkane method was used (and was compared with Calan gate intake estimates) to determine intake and digestibility estimates (seven days). The alkane method compared favourably with the Calan gate estimation of feed intake (coefficient of variation was 22 %). No significant differences were found between the breeds for intake and the average intake was 93 g DM/kg $W^{0.75}$/day. Apparent dry matter digestibility (calculated by alkane method) was 6 % higher ($P < 0.05$) in the Friesland bulls over the Hereford bulls. Apparent dry matter digestibility estimates were measured (three FB and three HB; five days) while animals were confined to metabolic crates. Dry matter digestibility was not significantly different between treatments with the average estimate being 696 g/kg DM. However, intake was 11 % greater ($P < 0.05$) for the Friesland bulls when expressed on a metabolic basis (g DM/kg $W^{0.75}$/day). Amount of faeces produced and nutrient digestibility estimates (crude protein, NDF and ADF) were the same for the breeds. The dry matter of faeces varied in that the Friesland bulls produced faeces 25 % drier than the Hereford bulls. Faecal marker excretion patterns were plotted (four days) after oral administration of an alkane marker (three FB and three HB). The Grovum and Williams (1973) model indicated no significant differences in the digesta flow between treatments. Mean retention time was 45 hours for the alkane marker. QDQ curve analysis fitted two separate curves ($r^2 = 0.91$) but peak times were not significantly different. The average peak time was 23.7 hours. A gompertz curve ($r^2 = 0.97$) was fitted to accumulated marker concentration. Linear parameters were significantly different, the Hereford bulls having a greater accumulation of marker concentration over time. Animal activity (time spent grazing, ruminating and idling) was recorded over a 24 hour period (five FB and eight HB). The study was performed twice. There was no significant difference in animal activity between the breeds. The average bull spent 30 % of the day grazing, 34 % of the day ruminating and 36 % of the day was spent idling. At slaughter the heart, liver, lungs and spleen were weighed (five FB and five HB). No significant differences were found when organ weight was divided by metabolic weight.

No significant differences were found in the growth rate, feed intake and feed digestibility when comparing Friesland and Hereford bulls on kikuyu pasture, in contrast to the findings of Horne (1996) and Fushai (1997) using Friesland heifers.

Declaration

I declare that this dissertation is my own work, except for assistance that is acknowledged or where due reference is made in the text. The results contained in this dissertation have not been submitted, in whole or in part, for a degree at another University.

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Soli Deo Gloria

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List of Abbreviations

Abbreviation	Description
ADF	acid detergent fibre
ADG	average daily gain
CG	Calan gate
CP	crude protein
CV %	coefficient of variation percentage
d	day
DM	dry matter
DMI	dry matter intake
FB	Friesland bull
FS	Friesland steer
HB	Hereford bull
ME	metabolizable energy
NDF	neutral detergent fibre
RDP	rumen degradable protein
SE	standard error of the mean
UDP	rumen undegradable protein
$W^{0.75}$	metabolic weight (live weight raised to the power of 0.75)

Chapter 1

Introduction

1.1 Kikuyu - an important summer pasture for animal production in KwaZulu-Natal

Kikuyu (*Pennisetum clandestinum*) is one of the most important summer pasture species in South Africa (Miles *et al.*, 1995). Kikuyu comprises 24 % of the cultivated pasture area (123 000 ha) in KwaZulu-Natal, second only to *Eragrostis curvula* (32 %) which is generally used for hay (Fotheringham, 1981). Kikuyu is well adapted to the high rainfall areas of Natal, especially to the Natal Midlands, and forms the bulk of summer grazing for milk production (Dugmore & Du Toit, 1988; Marais *et al.*, 1990). Heard and co-workers found that in the Natal Midlands, 87 % of the kikuyu produced (the highest value in the survey) was used for summer grazing on dairy farms (Heard *et al.*, 1984).

Some of the factors accounting for the popularity of kikuyu as a pasture grass for animal production in KwaZulu-Natal are:

* a yield potential of up to 18 tons of dry matter per hectare in the Natal Midlands (Heard & Wiseman, 1973);
* its vigour and hardiness make it tolerant to a wide variety of (sometimes harsh) management practices (Henning *et al.*, 1995);
* the favourable growth response of kikuyu to nitrogen fertilizers (Mears, 1970; Miles *et al.*, 1995); and
* it survives heavy frosting (although it has a zero growth rate during the winter).

Although kikuyu has many positive agronomic attributes as a pasture species, it does have limitations in terms of animal production with some poor results being reported (Van Ryssen *et al.*, 1976; Dugmore & Du Toit, 1988; Marais, 1990; Henning *et al.*, 1995; Miles *et al.*, 1995). These limitations are discussed in Chapter 2.

Dairy farmers are faced with the challenge of growing out replacement heifers as economically as possible. Most dairy farmers in the Natal Midlands make use of kikuyu as a summer pasture (Heard *et al.*, 1984) and the growing out replacement heifers on these pastures during the spring and summer months is a common practice. However, complaints of poor performance by Friesland heifers on kikuyu were experienced, unless supplemented (T.J. Dugmore, personal communication, 2000; R.I. Jones, personal communication, 2000; I.B. Stewart, personal communication, 2000; P.G. Stewart, personal communication, 2000). Du Plessis (1992) measured the average daily gain of Friesland heifers on kikuyu pasture at the Cedara research station over a period of three years and found that yearling Friesland heifers had an average daily gain of 0.45 kg (range: 0.35 to 0.61 kg) during the summer period. In contrast, Hereford animals had achieved growth rates up to one kg/day at the Cedara research station (I.B. Stewart, personal communication, 2000). Allwood (1994) recorded the growth rate responses of Friesland heifers grazing kikuyu to energy and protein supplementation at Baynesfield estates and found positive responses to supplementary energy. In an attempt to clarify the poor growth rates of Friesland heifers on kikuyu grazing, Horne (1996) and Fushai (1997) compared yearling Friesland (dairy breed) and Hereford (beef breed) heifers on kikuyu pasture (with and without energy supplementation) during the summer period. Friesland heifers were chosen since this is the most common dairy breed in KwaZulu-Natal (Animal Improvement Institute, 1998). Hereford heifers were chosen for comparison with the Friesland heifers, as there was an established Hereford herd at the Cedara research station where Horne (1996) and Fushai (1997) performed their investigations.

Horne (1996) found that the Hereford heifers gained significantly more weight than the Friesland heifers (0.81 versus 0.01 kg/day; $P < 0.05$) under rotational grazing of kikuyu pasture without supplementation (apart from the high calcium mineral lick). The average daily gain of the Friesland heifers increased from 0.01 to 0.60 kg/day with energy supplementation, while the Hereford heifer's average daily gain increased from 0.81 to 0.97 kg/day (not significantly different). Fushai (1997) had similar, although less pronounced findings than Horne (1996). The Hereford heifers in the study by Fushai had a greater average daily gain (1.2 versus 0.5 kg/d; $P < 0.05$) than the Friesland heifers when no energy supplementation was given. However, the Friesland heifers did not respond to energy supplementation (average daily gain decreased from 0.54 kg/day to 0.50 kg/day when energy supplementation was given). The difference in weight gain of the Hereford and Friesland heifers in both Horne (1996) and Fushai's research (1997) was ascribed to the dry matter intake of kikuyu herbage. Fushai (1997) found that the Hereford heifers, during both trial periods (with and without energy supplementation), had a greater intake than the Friesland heifers (111.05 versus 95.35 g DM/kg $W^{0.75}$/d; $P < 0.05$) while on a continuous kikuyu grazing system. Although the prospect of growing out dairy heifers on kikuyu pasture should be feasible, questions as to why Friesland heifers don't grow as well as Hereford heifers and why Friesland heifers consume less kikuyu still need to be answered.

1.2 Breed history and maturity types

The Friesland breed (also referred to as Holstein-Friesland) in South Africa originated from the Dutch Friesland found in north Holland in the Netherlands but was greatly influenced by the Canadian Holstein-Friesland (Preston, 1989). The first Dutch Friesland animals were imported to South Africa during Jan van Riebeeck's time in the 1660's (Preston, 1989). This prolific milk breed from Holland became popular over the years and more animals were steadily imported. Frieslands were first officially imported by General Cuyler of Uitenhage in 1850 (Preston, 1989). Dutch Frieslands are an example of a dual purpose breed in that the breed can be used for both meat and milk production. Milk productivity was considered to be of primary importance during breeding and selection in Holland, however, a well-muscled conformation was also required (Rouse, 1970). In about 1880, a large shipment of pure Friesland cattle were exported from the Netherlands to the United States of America (Preston, 1989). The shipment was delayed at Rotterdam harbour so the cattle were sent overland to Schieswig-Holstein in Germany and then shipped from there to America. The American importers referred to the cattle from Schieswig-Holstein as the "Holstein cattle" and the name came into general use. The breed society of Canada insisted that the name Friesland should be used as well and the breed was called Holstein-Friesland. From 1895 onwards no further Dutch blood was imported into America (Fourie, 1963, cited by Preston, 1989) and the Canadian and American breeders started their own breeding program with the foundation stock from the Netherlands (Rouse, 1970). The Canadian and American breeders emphasized udder shape, teat placement, milk ability and milk production (Preston, 1989). In the quest to produce the ideal milk-producing cow, the selection process also lead to the extreme angular appearance of the Canadian Holstein-Friesland animal (Cook & Newton, 1979). In 1963, three registered Holstein-Friesland cows from Canada were imported to South Africa (Preston, 1989). A bull named Enterprise that was bred from one of these cows was purchased by the Baynesfield Artificial Insemination Station and his semen was distributed to many herds in Natal (Preston, 1989). The improvement in udders and milk production was considerable and the popularity of using Canadian Holstein-Friesland sires has increased to such an extent that most Friesland dairy herds in South Africa have a portion of Canadian Holstein-Friesland blood in the herd (Preston, 1989).

The Hereford breed originated on the western border of Herefordshire, central England. Literature states that Sir Benjamin Tonkims was the first to initiate "improvement" of the Hereford in the late 1700's and is often regarded as the founder of the breed (Köster & Köster, 1993). The type of animal he selected for was an early maturing compact animal that could fatten readily on pastures. The first importation of Hereford animals to South Africa recorded by the Stud Book Society was in 1892 (Köster & Köster, 1993). Hereford cattle were prominent in research programs during the early 1900's in southern Africa. As the consumer dictated the need for leaner meat, some Hereford breeders changed the maturity type and bred a later maturing Hereford animal.

From the description of the development of the breeds in South Africa, it is evident that the Hereford breed was selected to perform on a grass based system to produce beef while the Friesland breed was selected to produce a considerable amount of milk when fed a high quality/high concentrate diet. It is a moot point whether the long-term effects of breeding and selection for high milk production and the feeding of considerable amounts of concentrates to Friesland cows have favoured the mechanisms that influence concentrate digestion. In other words, could Friesland cows have a "superior" ability to process concentrates when compared with beef cows. Furthermore, could it be at the expense of fibre digestion? The Friesland heifers in Horne's trial had a zero growth rate when fed kikuyu *ad libitum*, but when supplemented with energy concentrates growth improved to 0.6 kg per day (Horne, 1996).

Besides the difference in purpose and origin, a comparison of the performance of the Friesland breed with the Hereford breed on kikuyu pasture is further complicated by the fact that the Hereford is an early maturing breed while the Friesland is a late maturing breed. The concept of maturity types has been well documented (Paterson, 1991). In summary, the late maturing animal will have a greater average daily gain, will grow for a longer period, will reach a greater mature size, will consume more food but will have the same efficiency of feed conversion as the early maturing animal. The breeds compared during this investigation (Hereford versus Friesland) are of a differing maturity type, theoretically favouring the growth rate of the Friesland breed, and as such it may be questioned whether the comparison is fair. Ideally, the Friesland breed should have been compared with a late maturing beef breed but due to practical and financial constraints this was not possible. To reduce the maturity type differences the results in this dissertation were converted, where possible, to metabolic weight ($W^{0.75}$), for example, intake (kg DM/d) was converted to intake (g DM) per kg metabolic weight (g DM/kg $W^{0.75}$/d).

1.3 Previous research done by Horne (1996) and Fushai (1997)

This investigation was a continuation of the work performed by Horne (1996) and Fushai (1997) and was to address their findings as to why yearling Friesland heifers performed so poorly on kikuyu pasture. The work of Horne (1996) and Fushai (1997) was critically examined during the planning of the research described in this thesis to ensure that the results obtained would be relevant, applicable and mistakes were not repeated.

Horne (1996) and Fushai (1997) concluded that the intake of the pasture was a problem for the Friesland heifers. Both researchers used the alkane method to estimate pasture intake in the field. The alkane method is one of the most practical methods for measuring pasture intake in the field since only a faecal sample taken once or twice daily per animal (Dove & Mayes, 1991) is required as opposed to total faecal collection methods. Although the alkane method is considered to measure intake accurately (Dove & Mayes, 1996), Horne (1996) reported that kikuyu intake had been overestimated in his study.

There is a positive relationship between feed intake and the passage of digesta through the digestive tract (McDonald *et al.*, 1988). Fushai (1997) investigated the nature of the faecal marker patterns between Hereford and Friesland heifers to see if it would account for the difference in intake (i.e. was rate of passage limiting?). Although Fushai (1997) reported that there was no significant difference between the faecal excretion patterns of the breeds, it was found that insufficient data points were collected during the ascending phase of the model (data was recorded every four hours for only two days). Fushai (1997) further recommended increasing the alkane dosage since there was a failure to detect the alkane in some of the samples.

Fushai (1997) proposed that the lower kikuyu intake by the Friesland heifers was due to a limited gut capacity and recommended that rumen volume or weight should be measured. Fushai (1997) postulated that if gut capacity was limiting, the grazing patterns of the Friesland heifers would be more frequent but of shorter duration than the Hereford heifers.

In planning a research project to quantify the relationship between intake, digestibility and rate of passage, and to measure gut weight it was decided that it would be more appropriate to use males instead of females, since males are more suited to collecting separate urine and faeces samples in metabolic crates. By using males there would be no potential loss of female breeding stock when the animals would be slaughtered to weigh their internal organs. Practically, there were no suitable female animals available for research at the time at the research institute.

1.4 Project objective

The objective of this investigation was to contribute to the knowledge base as to why Friesland heifers perform so poorly on kikuyu pasture in comparison with Hereford heifers. To achieve this objective and address all the research issues outlined in Section 1.3, the growth of Friesland yearling bulls would be compared with that of Hereford yearling bulls on kikuyu pasture from about 250 to 400 kg live weight.

The accuracy of the alkane technique of kikuyu intake would be assessed by comparison with intakes determined using electronic controlled individual feed gates (Calan gates).

A digestibility estimate to evaluate if the Hereford and Friesland bulls were extracting the same amount of digestible nutrients from kikuyu herbage would be obtained while animals were confined in metabolic crates.

Differences in faecal marker excretion patterns (rates of passage) of Hereford and Friesland bulls would be determined.

An observation study recording animal behaviour would be performed to investigate whether there were breed differences in the amount of time spent grazing.

Gut weight would be determined by weighing the digestive tract and internal organs of the animals upon slaughtering, following overnight fasting.

1.5 Thesis outline

The need to grow out replacement heifers as economically as possible and the importance thereof to industry is highlighted in Chapter 1. The nutritive value of kikuyu for growing cattle is presented in Chapter 2 by addressing the following topics: characteristics of kikuyu, the nutrient requirements of growing cattle, the nutritive value of kikuyu and the factors affecting the intake and digestibility of kikuyu. The growth performance of the experimental bulls is detailed in Chapter 3. Intake measured by electronic feed gates and the alkane estimation are compared and presented in Chapter 4. The digestibility estimate of kikuyu from metabolic crates is discussed in Chapter 5. The passage of indigestible markers through the digestive tract is detailed in Chapter 6. The behaviour observation study is presented in Chapter 7 and the findings of the internal organ mass investigation is reported in Chapter 8. Conclusions and recommendations are presented in Chapter 9.

Chapter 2

The nutritive value of kikuyu for growing cattle

2.1 Introduction

Kikuyu, *Pennisetum clandestinum* Hochst. ex. Chiov. (Skerman & Riveros, 1990), is well adapted to the Natal Midlands and yields up to 18 tons of dry matter per hectare per season (Heard & Wiseman, 1973). Kikuyu is popular due to it's adaptability, vigour and hardiness which makes it tolerate a wide variety of (sometimes harsh) management practices (Henning *et al.*, 1995).

Intensive pastures form a key component of animal production systems in South Africa, with kikuyu being one of the most important summer pasture species (Miles *et al.*, 1995). The use of kikuyu does have some limitations. Poor animal production has been reported (Van Ryssen *et al.*, 1976; Marais, 1990) even though kikuyu is equivalent to Italian Ryegrass (*Lolium multiforum*) in chemical composition (Dugmore & Du Toit, 1988).

2.2 Characteristics of kikuyu

2.2.1 Introduction of kikuyu to South Africa

Kikuyu grass was named after the Kikuyu people who live in Kenya (east of the Aberdare Mountains) where the grass thrives (Mears, 1970; Skerman & Riveros, 1990;). Kikuyu's natural habitat is at an elevation of between 1950 and 2700 m in the East and Central Africa highlands (Ethiopia, Kenya, Tanzania, Uganda and Zaire) on highly weathered well drained soils (Mears, 1970; Skerman & Riveros, 1990). From Zaire and Kenya, kikuyu has been introduced widely in tropical areas such as southern Africa, Colombia, Hawaii, Australia, Brazil and the northern areas of New Zealand (Langer, 1990; Skerman & Riveros, 1990).

Kikuyu was introduced to South Africa from East Africa in 1913. A small root cutting was given to Dr. Burtt Davy who propagated it at the Groenkloof Botanical Station (Hall *et al.*, 1959).

2.2.2 Morphology of kikuyu

Kikuyu is a prostrate perennial which may form a loose sward of up to 460 mm high when ungrazed, but under grazing or mowing assumes a dense turf (Skerman & Riveros, 1990). It spreads vigorously from rhizomes and stolons which root at the nodes and are profusely branched as illustrated in Figure 2.1 (Chippindall, 1959; Skerman & Riveros, 1990; Van Oudtshoorn, 1992).

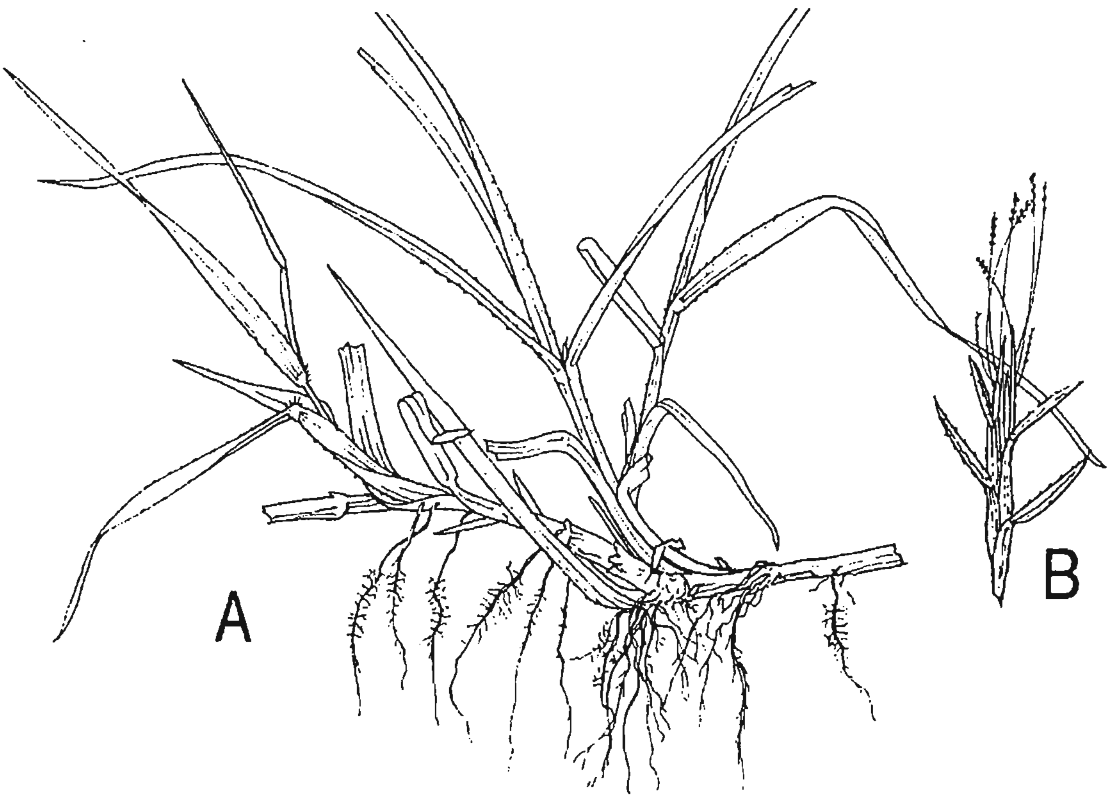

Figure 2.1: Kikuyu. A - Growth habit and B - Flower (Skerman & Riveros, 1990).

Short leafy branches (as illustrated in Figure 2.1-A) are produced from stolons, the leaf blades are up to 7 mm wide, they are initially folded in the bud, and later flatten along the leaf (Chippindall, 1959; Skerman & Riveros, 1990; Van Oudtshoorn, 1992). The inflorescence is small, consisting of 2 to 4 spikelets which are either bisexual or functionally unisexual. When bisexual - the stamens (Figure 2.1-B) and pistils do not usually mature at the same time (Chippindall, 1959; Mears, 1970; Skerman & Riveros, 1990; Van Oudtshoorn, 1992). The feathery stigma emerges from the flower first and has usually withered by the time the anthers appear (Quinlan *et al.*, 1975). The yellow anthers are carried on fine filaments up to 45 mm long (Quinlan *et al.*, 1975).

2.2.3 Ideal growth conditions for kikuyu

In the natural habitat of kikuyu at elevations above 2250 m, the mean minimum temperatures range from 2 to 8 °C and the mean maximum temperatures range between 16 and 22 °C (Mears, 1970). Kikuyu grows at sea level and up to an altitude of 3500 m (Skerman & Riveros, 1990). The mean annual rainfall of the native area of kikuyu ranges from 1000 to 1600 mm (Mears, 1970). Although kikuyu has been found growing in area's with rainfall as low as 500 mm, it is most suited to area's with rainfall above 1000 mm (Quinlan *et al.*, 1975). Kikuyu is fairly drought tolerant because of its deep root system (Tainton, 1998). Sporadic frosts occur in kikuyu's natural habitat, however, it does not survive sustained winter frosting (Mears, 1970). Heavy frost will completely kill the top growth but the plant will regrow quickly with favourable soil moisture and temperature conditions (Quinlan *et al.*, 1975; Skerman & Riveros, 1990). Kikuyu grows best on deep, fertile well drained soils (Skerman & Riveros, 1990) and does poorly on shallow, drought prone, infertile heavy clays (Tainton, 1998). Kikuyu requires moderate to high levels of soil fertility (Quinlan *et al.*, 1975). The Cedara Fertilizer Advisory Service (Manson *et al.*, 1993) recommend applying between 110 and 350 kg of nitrogen (dependent on rainfall); a soil potassium content of between 100 and 140 mg/l; a soil phosphorus content of between 7 and 18 mg/l (dependent on soil texture); sulphur applications of 30 to 40 kg per annum (dependent on soil type); and a permissible acid saturation of 40 %, to ensure a kikuyu pasture in optimal condition.

2.3 Nutrient requirements of growing cattle

The nutrient requirements of growing animals (250 to 400 kg) is presented in Table 2.1.

Table 2.1: Nutrient requirements of growing cattle (NRC, 1988)

Mass kg	ADG kg	DMI kg DM	ME MJ/kg DM	CP g/kg DM	UIP [1] g/kg DM	DIP [2] g/kg DM	Ca g/kg DM	P g/kg DM
Large breed growing males								
250	0.8	5.27	10.6	147.6	57.9	61.7	4.6	3.2
300	0.8	6.13	10.4	125.8	45.8	66.6	4.1	3.1
350	0.8	7.02	10.2	120.1	37.2	69.8	3.7	2.8
400	0.8	7.96	9.9	120.0	30.7	71.9	3.3	2.6
Small breed growing males								
250	0.7	5.66	10.3	120.0	43.3	63.8	4.1	3.0
300	0.7	6.68	10.0	119.9	33.1	67.8	3.6	2.7
350	0.7	7.76	9.8	120.1	26.2	70.5	3.2	2.4
400	0.7	8.94	9.5	120.0	21.1	72.0	2.9	2.2
Large breed growing females								
250	0.6	5.31	10.3	120.0	43.1	61.4	4.1	3.0
300	0.6	6.26	10.1	120.1	33.4	66.0	3.7	2.7
350	0.6	7.29	9.8	119.9	26.5	68.7	3.3	2.5
400	0.6	8.39	9.5	120.0	21.7	70.6	3.0	2.3
Small breed growing females								
250	0.6	6.12	9.9	120.1	34.2	63.6	3.6	2.6
300	0.6	7.4	9.5	120.0	25.9	66.9	3.1	2.3
350	0.6	8.85	9.1	120.0	20.7	68.7	2.7	2.0
400	0.6	10.52	8.7	120.1	17.4	69.4	2.4	1.8

[1] UIP = UDP = the proportion of the dietary nitrogen fraction (protein) not degraded in the rumen at a particular rate of passage (Ørskov & McDonald, 1979)

[2] DIP = RDP = the proportion of the dietary nitrogen fraction (protein) degraded in the rumen at a particular rate of passage (Ørskov & McDonald, 1979)

As an animal grows and becomes heavier so feed intake increases and the required nutrient concentration (g/kg DM) in the diet decreases. From Table 2.1 it is evident that bulls have higher nutrient requirements and higher growth rates than heifers of the same maturity type until puberty. A further fundamental principle is that bulls have a greater feed conversion efficiency than heifers (Galbraith & Topps, 1981). The greatest requirements in Table 2.1 are for a large breed growing male gaining 0.8 kg/day weighing 250 kg. These nutrient requirements are: a crude protein requirement of 148 g/kg DM, a rumen degradable protein (RDP) requirement of 62 g/kg DM, a rumen undegradable protein (UDP) requirement of 58 g/kg DM, a calcium requirement of 4.6 g/kg DM and a phosphorus requirement of 3.2 g/kg DM.

2.4 Nutritive value of kikuyu

Animal performance of beef weaners on kikuyu pasture (no supplementation) varies between 0.41 and 0.81 kg/d (Sclanders, 1997; Mappledoram, 1998; Meaker, 1998). The nutrient content of kikuyu as presented in literature is summarised in Table 2.2.

Table 2.2: Nutritive values of kikuyu (on a DM basis) from literature

Reference	CP g/kg	ADF g/kg	NDF g/kg	Ash g/kg	Ca g/kg	P g/kg	K g/kg	Mg g/kg	Na g/kg	Ca:P
1	150									
2					4.2	1.8	8.6	3.2		2.3:1
3	178			124	4.6	3.6	39.8	2.5	0.07	1.3:1
4	138	330		109	4.7	3.8	20	2.9	4.1	1.2:1
5	150				3.5	3.1	36.6	4	0.3	1.1:1
6	224			109						
7	194									
8	179	346								
9	165				2.4	3.3	4.1			0.7:1
10	187									
11	130				3.5	2.2	22.5	2.3	0.3	1.6:1
12	190				3.8	2.9	24.1	2	0.8	1.3:1
13	216				2.8	3.4	36.5	3	0.4	0.8:1
14	166		581							
15	208	231	603		3.1	3.1	30.7	2.2	0.15	1:1
16	200	350	650		2.4	3.3	3.6	3	0.3	0.7:1
Mean (±SE)	**178 (±7)**	**314 (±28)**	**611 (±20)**	**114 (±5)**	**3.5 (±0.3)**	**3.1 (±0.2)**	**22.7 (±4)**	**2.8 (±0.2)**	**0.9 (±0.5)**	**1.2:1**

[1] Gomide *et al.* (1969a)
[2] Gomide *et al.* (1969b)
[3] Said (1971)
[4] Joyce (1974)
[5] Kaiser (1975)
[6] Van Ryssen *et al.* (1976)
[7] Aii & Stobbs (1980)
[8] Dugmore *et al.* (1986)
[9] Bredon *et al.* (1987)
[10] Dugmore & Du Toit (1988)
[11] Pastrana *et al.* (1990)
[12] Evans & Hacker (1992)
[13] Miles *et al.* (1995)
[14] Jackson *et al.* (1996)
[15] Reeves *et al.* (1996)
[16] Dugmore (1998)

2.4.1 Protein content

Kikuyu crude protein levels range from 150 to 224 g/kg DM (Table 2.2), and has an average crude protein content of 178 g/kg DM (±7), although nitrogen fertilization effects this value (Gomide *et al.*, 1969a). The Kjeldahl procedure of calculating protein content, nitrogen multiplied by 6.25, provides an estimate of the quantity of nitrogen present but does not provide an indication of quality (Kellems & Church, 1998). Assuming a crude protein degradability of 0.75 (Dugmore, 1998; Van der Merwe, 1998) the RDP would be 134 g/kg DM and the UDP (calculated by difference) would be 44 g/kg DM. Comparing Table 2.1 and Table 2.2, kikuyu (has a CP of 178 g/kg DM) is able to meet the required 148 g/kg DM of a large breed growing male (250 kg and gaining 0.8 kg/d). Likewise, RDP requirements (59 g/kg DM) can be met by kikuyu's value of 134 g/kg DM. However the UDP requirement (58 g/kg DM) is not met by kikuyu's 44 g/kg DM. The remaining UDP requirements of the larger animals in Table 2.1 can be met by the average UDP value of 44 g/kg DM.

The relationship between crude protein and intake is complex. It would be expected that as the crude protein content increases, up to a critical point, so the grass becomes more digestible and intake should increase. Dugmore *et al.* (1991) found that steers selected for more fibrous material at the expense of high crude protein levels (CP > 150 g/kg DM) to consume a diet of approximately 140 g/kg DM. Moir *et al.* (1979) reported a crude protein content of 223 g/kg DM for leaves and 132 g/kg DM for stems. Like-wise, Tayler et al. (1976) reported 173 g/kg DM for leaves and 107 g/kg DM for stems. Cattle generally select for the more nutritious leaves but are able to select for older stem material if the crude protein content exceeds 140 g/kg DM.

2.4.2 Carbohydrate content

The non-structural carbohydrate content in kikuyu is low, ranging from 30 to 80 g/kg DM, which explains why supplementation with highly digestible carbohydrates have favourable animal responses (Dugmore, 1998). However, energy supplementation on kikuyu pasture was found not to be economically justifiable for beef production (Kaiser, 1975; Van Niekerk *et al.*, 1990).

The structural carbohydrate content is determined by the neutral detergent fibre (NDF) content. NDF is a measure of the cell wall content of a plant (hemicellulose, cellulose and lignin components). The neutral detergent fibre levels cited in Table 2.2 were on average 611 g/kg DM (±20). Moir *et al.* (1979) reported average NDF values for kikuyu leaves of 530 g/kg DM and 690 g/kg DM for kikuyu stems. The acid detergent fibre (ADF) is similar to the neutral detergent fibre except the hemicellulose is not measured. The acid detergent fibre levels cited in Table 2.2 were on average 314 g/kg DM (±28). As the fibre component in the plant increases so the voluntary intake declines with an increasing negative slope (Van Soest, 1965).

2.4.3 Mineral content

It is commonly accepted that ruminants require a specific calcium to phosphorus ratio for growth and maintenance. However, Minson (1990) and NRC (1996) state that this ratio has been over-emphasised. NRC (1996) maintains that Ca:P ratios ranging from 1:1 to 7:1 will result in a similar animal performance provided that phosphorus intake is adequate to meet growth and/or maintenance requirements. The ratio of calcium to phosphorus cited in Table 2.2 is nearly 1:1 on average.

The calcium requirements of growing animals are often met by kikuyu's calcium content of 3.5 g/kg DM (Table 2.2). However some tropical species (including kikuyu) contain oxalic acid which combines with many elements (including calcium) to form oxalates (Marais, 1998). Calcium oxalate has a low solubility and the calcium in this complex is poorly available to the grazing animal (Marais, 1998). Therefore, supplementation of calcium on kikuyu pastures is necessary.

2.5 Factors affecting the intake and digestibility of kikuyu

2.5.1 Methods to determine kikuyu intake and digestibility estimates

Early digestibility investigations date from the 1860's (Schneider & Flatt, 1975). The digestibility of a feed is termed apparent digestibility as there are materials of non-dietary origin (body cells, microbial entities and digestive juices) that are found in the faeces. Apparent digestibility is defined as the proportional difference between the quantities consumed and excreted in the faeces (Minson, 1990) as shown in equation [2.1]. Conventional digestibility trials are carried out in metabolic crates where feed intake and faeces are collected separately as described by Briggs and Gallup (1949).

$$Apparent\ digestibility\ (\%) = \frac{dry\ matter\ consumed\ -\ faecal\ dry\ matter}{dry\ matter\ consumed} \times 100 \qquad \textbf{[2.1]}$$

Feed intake can either be measured directly or indirectly (by faeces collection or the use of markers). The most common method of measuring feed intake directly is by the use of electronic feed gates. Electronic feed gates (Calan gates) were designed to measure individual feed intake of a group of penned animals, as described by Broadbent *et al.*, (1970).

Intake can be calculated if equation [2.1] is transposed and "intake" is made the subject of the formula (to derive equation [2.2]) along with known faecal output and digestibility measures.

$$Intake = \frac{faecal\ output}{1\ -\ digestibility} \qquad \textbf{[2.2]}$$

In 1934 Garrigus (cited by Minson, 1990) used equation [2.2] to calculate the intake of grazing steers. Faeces were collected in canvas bags and apparent digestibility coefficients of the forage was determined by feeding cut forage to cattle in stalls. As pointed out by Minson (1990) the collection of total faeces was labourious and animals usually selected a diet higher in digestibility than would have been achieved by grazing animals.

Equation [2.2] has further been used in connection with (indigestible) markers to determine digestibility and ultimately intake (alkane method). There are two different kinds of markers, namely external markers which are materials that are added to the diet or administered orally or intra-ruminally to the animal, and internal markers which are indigestible materials occurring naturally in feeds (Merchen, 1993). If equation [2.2] is used to estimate intake (and digestibility is calculated by using an external marker), faeces output can be calculated by equation [2.3] (Minson, 1990).

$$Faecal\ output = \frac{Q}{C} \quad [2.3]$$

where

Q = quantity of marker fed per day

C = concentration of marker in a representative sample of faeces

Common external markers are chromium and rare earth metals. Chromium sesquioxide (Cr_2O_3) has been the most popular external marker administered to animals (Kotb & Luckey, 1972) and is conventionally analysed by the method outlined by Costigan and Ellis (1987). Chromium can be administered in various forms namely, gelatine capsules containing 1 or 10 g Cr_2O_3 (chromic sesquioxide) in an oil base (Raymond & Minson, 1955), paper impregnated with chromium (Langlands *et al.*, 1963), chromium mordanted fibre (Udén *et al.* 1980); and a controlled release device which is retained in the rumen and releases Cr_2O_3 at a regular rate for a few weeks (Laby *et al.*, 1984; Furnival *et al.*, 1990a and 1990b; Parker *et al.*, 1990; Buntix *et al.*, 1992; Luginbuhl *et al.*, 1994). Chromium is more suitable as a digestibility marker than a passage marker because digestibility measurements depend on the even distribution and passage of the marker down the digestive tract and chromium may move independently of the liquid or particulate phases (Van Soest, 1982).

Several of the rare earth elements (lanthanum, samarium, cerium, ytterbium and dysprosium) have been used as markers (Merchen, 1993). However, these are unsuitable as there have been reports of the elements becoming soluble in the acid conditions of the abomasum or have been retained by rumen bacteria (Merchen, 1993).

Commonly used internal markers are lignin, silica, acid insoluble ash and alkanes. Due to lignin being indigestible it has been used as a marker, but is considered unsuitable as there have been reports of lignin disappearance during digestion (Merchen, 1993). Most of the disappearance occurs in the rumen (Fahey & Jung, 1983). The use of indigestible neutral detergent fibre as an internal marker has limited use as reported recoveries were between 83 and 111 % (Lippke *et al.*, 1986). Silica has been used as an indigestible marker, but consistent over recovery of silica in faeces, most likely due to ingested soil containing silica was a problem (Merchen, 1993). Acid insoluble ash is insoluble when boiled with hydrochloric acid and has been used as an internal marker. Van Keulen and Young (1977) reported faecal recoveries of nearly 100 % (differences were not statistically different). A further advantage of acid insoluble ash is that diurnal variation was not observed (Van Keulen & Young, 1977), but can only be used if feedstuffs contain appreciable amounts of acid insoluble ash.

In the early 1930's Chibnall and co-workers reported the presence of alkanes in the cuticular wax of plants (Chibnall *et al.*, 1934). Later Mayes and colleagues (Mayes & Lamb, 1984; Mayes *et al.*, 1986a, 1986b, 1986c) were the first workers to study the possible use of alkanes as markers to estimate herbage intake. At present it is well established that the cuticular wax alkanes of pasture plants can be used, in combination with orally administered synthetic alkanes to estimate individual herbage intake of ruminants (Mayes *et al.*, 1986b; Dillon & Stakelum, 1989; Dove *et al.*, 1989a, 1989b; Dove & Mayes, 1991; Laredo *et al.*, 1991; Ohajuruka & Palmquist, 1991; Vulich *et al.*, 1991; Vulich *et al.*, 1995; Dove & Mayes, 1996).

The double alkane method of intake estimation is explained as follows: pasture plants contain mixtures of n-alkanes having chain lengths ranging from 21 to 35 carbon atoms, with the odd-numbered alkanes predominating. Animals are dosed with known quantities of an even-chain alkane and intake is estimated from the daily dose rate, the herbage and faecal concentrations of the dosed (even-chain) alkane and a natural (odd-chain) alkane adjacent in chain length. Equation [2.4] describing the previously mentioned variables is (Dove & Mayes, 1991):

$$Intake\ (\frac{kg\ DM}{d}) = \frac{\frac{Fi}{Fj} \times Dj}{Hi - (\frac{Fi}{Fj} \times Hj)} \qquad [2.4]$$

where

Dj = daily dose of the even-chain alkane

Fi = faecal concentrations of the odd-chain alkane

Hi = herbage concentrations of the odd-chain alkane

Fj = faecal concentrations of the even-chain alkane

Hj = herbage concentrations of the even-chain alkane

Digestibility is calculated using equation [2.5], based on the assumption that pentatriacontane (C_{35}) has a recovery rate of 95 % through the ruminant digestive tract (Dove & Mayes, 1991).

$$Apparent\ digestibility\ (\%) = [1 - (\frac{herbage\ C_{35}}{faeces\ C_{35}} \times 0.95)] \times 100 \qquad [2.5]$$

Although the faecal recoveries of alkanes are incomplete within the digestive tract of the ruminant, alkanes with similar carbon lengths have similar faecal recovery rates (Mayes *et al.*, 1986b; Dove & Mayes, 1991, 1996). This implies that errors arising to incomplete faecal recoveries are cancelled out (Mayes *et al.*, 1986a) (see equation [2.4]). Another advantage of the alkane method is that it accommodates for herbage digestibility differences between individual animals (Dove & Mayes, 1991, 1996). The reliability of the alkane method is summarised in Table 2.3.

Table 2.3: A comparison of known herbage intakes of sheep and cattle with those estimated from using the alkane method

Animals	Actual intake per day	Percentage discrepancy
[1] **10 week old lambs (*Lolium Perenne*)**	112-273 g DM	0.21 %
[2] **Mature dry beef cows**	4 kg DM	-1.7 %
[3] **Lactating dairy cows**	14.2 kg DM	-0.6 %
[4] **34 kg wether lambs**	778 g DM	2.6 %
[5] **27 kg wether lambs**	688 g DM	4.5 %

[1] Mayes *et al.* (1986a) [2] Mayes *et al.* (1986c) [3] Dillon & Stakelum (1989)
[4] Vulich *et al.* (1991) [5] Vulich & Hanrahan (1995)

In general, the error on estimating dry matter intake using the alkane method was less than 5 % (Table 2.3).

The most important advantage of using an internal marker combined with an external marker (such as the alkane method) is that the digestibility is calculated in the individual animal for each estimation of intake. One of the greatest disadvantages in measuring faecal production and indirectly intake is that external markers are often excreted unevenly in the faeces due to diurnal variations in feed intake (and faecal excretion) (Minson, 1990). Hence the development of the controlled marker release devices. Although diurnal variation can never be entirely removed (Minson, 1990), the alkane method of intake estimation is within 5 % of actual values (see Table 2.3).

2.5.2 Digesta retention time and faecal marker excretion patterns

Although the methods for determining herbage intake and digestibility have been discussed in Section 2.5.1, the relationship between these two concepts and retention time needs to be quantified. Besides the physiological state of the animal, the environment, management and roughage characteristics, there are many factors within the animal that determine and influence feed intake (see reviews by Balch and Campling, 1962; Ketelaars and Tolkamp, 1992). To quantify the relationship between forage intake, digestibility and retention time, only the fundamental principles will be considered.

Disappearance of forage from the rumen occurs by digestion and passage down the digestive tract (Poppi *et al.*, 1987). The rate of digestion is determined by the chemical and structural composition of the forage and the adequacy of nutrients for microbial growth (Poppi *et al.*, 1987). On the basis of size, the particles in the reticulo-rumen can be considered as being made up of two pools, one consisting of particles too large to leave the rumen, the other consisting of particles small enough to leave (Lechner-Doll *et al.*, 1991). The critical particle size for cattle is considered to be from 1 to 2 mm, although larger particles may pass through the rumen-omasal orifice (Lechner-Doll *et al.*, 1991). Faichney (1986) determined that the mean retention time of the larger particle-pool was 12 hours and that of the smaller particle pool was 18.4 hours (50 % longer) in sheep. The lower flow rate of small particles, rather than the faster breakdown rate of the large particles, limits the passage of particulate matter (Lechner-Doll *et al.*, 1991), water flow through the rumen being the mechanism by which small particles are transported to the lower digestive tract. Increasing the flow of small particles from the rumen markedly increases intake (Poppi *et al.*, 1987).

Retention time is the time that a defined fraction of digesta is retained in the gut or in a segment of it (Warner, 1981). The mean retention time is defined as the average time of retention of all the elements of digesta (Warner, 1981). The mean retention time in the whole digestive tract and the extent of digestion are mainly controlled by the reticulo-rumen (Warner, 1981; Hume & Sakaguchi, 1991).

Digestibility is the product of the retention time and the degradation characteristics of a foodstuff (Forbes, 1995). The longer a foodstuff stays in the rumen, the closer it will come to being digested to the maximum extent possible. However, factors such as the level of intake and rumen capacity cause variations in the residence time and therefore the digestibility (Forbes, 1995). In general terms intake of herbage increases with increasing digestibility (Stobbs, 1975).

The rate of passage of digesta is a measure of how long individual portions of digesta are retained in the gut, subject to the processes of mechanical mixing, digestion, microbial fermentation and absorption (Warner, 1981). Rate of passage is practically measured by fractional flow rates. Fractional flow rate is the fraction of digesta (of the gut or of a segment) that moves out of the organ in unit time (Warner, 1981). The mean retention time is equal to the reciprocal of the fractional flow rate, provided steady state conditions apply (Warner, 1981). Further, if steady state conditions apply, the relationship between mean retention time and flow rate is defined in equation [2.6]. Although there is diurnal variation in foraging, steady state conditions should apply since disappearance of digesta from the reticulo-rumen is a fairly continuous process but may vary (Balch & Campling, 1962).

$$Retention\ \ time\ \ (h)\ =\ \frac{rumen\ \ pool\ \ size}{volumetric\ \ flow\ \ rate} \qquad [2.6]$$

There is a positive relationship between the rate of digestion (hence digesta flow) of a forage and its intake by ruminants, although it is not a precise relationship (Forbes, 1986). Doubling intake only leads to a 20 to 40 % decrease in the particle retention time in the reticulo-rumen (Lechner-Doll *et al.*, 1991), bearing in mind that other factors such as gut volume may also play a role. Various studies concluded that an increased feed intake results in a faster rate of passage of liquid and particulate matter (Grovum & Williams, 1977; Warner, 1981). However, their conclusions were based on data measured under restricted feeding conditions. It is questionable whether the same trend would be applicable under *ad libitum* feeding conditions. Other sources maintain that the rate of disappearance from the reticulo-rumen determines the intake of roughage (Balch & Campling, 1962; Faichney, 1993); when digesta was removed from the reticulo-rumen intake was stimulated while insertion of food directly in the rumen depressed intake (Balch & Campling, 1962). Furthermore, roughage intake was depressed when balloons of water were placed in the rumen (Balch & Campling, 1962). Although the latter school of thought seems to be more biologically sound, regardless of whether increased intake is the cause or the consequence of a shorter retention time (Balch & Campling, 1962; Ketelaars &

Tolkamp, 1991), a positive relationship between these two variables exists.

A further fundamental principle is that as intake of herbage increases, its digestibility is likely to decrease (because as the flow of digesta through the tract increases, the time spent in the rumen decreases and exposure to the microbes decrease and therefore fewer nutrients are extracted) (Schneider & Flatt, 1975; Merchen, 1993).

Another factor that could affect roughage intake is gut volume. Although measured under restricted feeding conditions, rumen volume increased as feed intake and rate of passage increased (Grovum & Williams, 1977). Lechner-Doll *et al.*, (1990) measured the reticulo-rumen volume and digesta flow parameters, of indigenous cattle, during the green and dry (poor quality grass) season in thornbush savannah in Kenya. The mean retention time of small particles was significantly longer (by 27 %) in the dry season than in the green. The increase in the mean retention time of particles was accompanied by 39 % increase in the reticulo-rumen volume. Although intake was not measured, the longer mean retention time in the dry season was primarily the effect of the lower digestibility of the forage rather than a lower feed intake.

The original model of Waldo *et al.* (1972) (defined in equation [2.7] and equation [2.8]) has been the basis describing the interactions between intake, rate of passage and digestibility, and although it has been expanded upon, the original hypothesis has withstood the test of time (Poppi *et al.* 2000). Potential digestibility (PD) is defined as the fraction which disappears after a long incubation period, while the indigestible fraction is that part which is unavailable to the micro-organisms. Since both fractions are part of the same plant particle, the fractional passage rate k_p applies to both fractions. The denominator in equation [2.8] is the mean retention time.

$$Digestibility = PD \times \frac{k_d}{k_d + k_p} \qquad [2.7]$$

$$Intake\ (kg\ DM) = \frac{rumen\ pool\ size}{\frac{PD}{k_d + k_p} + \frac{ID}{k_p}} \qquad [2.8]$$

where

PD = potential digestibility

ID = indigestible fraction

k_d = fractional digestion rate

k_p = fractional passage rate

Smuts *et al.*, (1995) found a significant correlation between a shorter retention time of digesta and high wool production of Merino sheep, indicating that retention time may play a significant role in the productivity of farm animals and may be a criteria for selection in breeding policies.

Albeit that the effect of digesta flow on intake and digestibility has been described in theory (aforementioned discussion), for comparisons to be made between treatments, digesta flow needs to be quantified mathematically. Various models describing digesta flow have been proposed (Blaxter *et al.*,1956; Grovum & Williams, 1973; Dhanoa *et al.*, 1985). Most of these models have their flaws, for example Blaxter *et al.* (1956) only identified one of the two compartments, of their model, as the rumen and the other was not identified (Faichney, 1986). A characteristic of the Grovum and Williams (1973) model is that the rumen mean retention time is always longer than the mean retention time in the caecum and proximal colon, which was proved incorrect by Faichney and Boston (1983). The Grovum and Williams (1973) model is considered to be the most appropriate for describing faecal marker excretion patterns (I.V. Nsahlai, personal communication, 1997) and will be discussed in more detail.

The Grovum and Williams model (1973) describes the passage of a marker through the alimentary tract and is defined in equation [2.9].

$$y = A \exp^{-k_1 (t - TT)} - A \exp^{-k_2 (t - TT)} \qquad [2.9]$$

where

y and A = adjusted marker concentrations in faecal dry matter

k_1 and k_2 = rate constants

k_1 represents digesta flow from the rumen

k_2 represents digesta flow from the caecum and proximal colon

t = sample time (hours)

TT = first appearance of marker in faeces

A curve peeling technique is carried out as follows: k_1 and a_1 are calculated by performing a linear regression on the natural logged concentration values (values after and including the peak concentration) against time (hours). The gradient of the regression equation is k_1 while the y intercept is a_1. The predicted values calculated from the regression are transformed to e^x and the observed marker concentration is subtracted from the corresponding predicted value (residual value). A further linear regression analysis is performed on the natural log of the residual values from the initial concentration to the peak concentration to yield k_2 which is the gradient, and a_2 which is the y intercept.

Equation [2.10] and equation [2.11] are used in calculating coefficients in equation [2.9].

$$A = a_1 - (k_1 \times TT) \qquad [2.10]$$

where

a_1 = y intercept

$$TT\ (hours) = \frac{a_2 - a_1}{k_2 - k_1} \qquad [2.11]$$

where

TT = transit time = first appearance of marker in faeces (hours)

The substitution of coefficients k_1, k_2 and TT into equation [2.12] allows for the calculation of the mean retention time (hours) that the marker spends in the digestive tract.

$$MRT\ (hours) = \frac{1}{k_1} + \frac{1}{k_2} + TT \qquad [2.12]$$

where

MRT = mean retention time of marker (hours)

The rate of faeces produced per hour (F) can be calculated by equation [2.13] (Grovum & Williams, 1973):

$$F\ (g/hour) = \frac{k_1\ k_2\ D}{A\ (k_2 - k_1)} \qquad [2.13]$$

where

F = rate of faeces production (g/hour)

D = amount of chromium in marker (g)

2.5.3 Animal factors affecting feed intake

The most important animal factor affecting feed intake is maturity type. The concept of maturity types (early maturing animal versus late maturing animal) has been well reviewed in literature (Paterson, 1991). To summarise, the late maturing animal has a greater average daily gain, grows for a longer period, reaches a greater mature size and consumes more food but with the same efficiency of feed conversion as the early maturing animal.

The comparison of Frieslands with other breeds has been performed in various studies (Carroll *et al.*, 1964; Garrett, 1971; Crickenberger *et al.*, 1978; Fortin *et al.*, 1981; Thonney *et al.* 1981; Truscott *et al.*, 1983; Jones, 1985; Jones *et al.*,1985; Hicks *et al.*,1990). Differences in performance were found, but it was difficult to distinguish between the effects of breed and maturity type on intake and growth, and direct comparisons between studies are often tenuous. In addition, "breed comparisons made at a specified live weight or age as end points are inappropriate because tissue growth patterns (physiological stages) vary and can only be inferred" (Berg & Butterfield, 1968). Whether correct or not, various researchers have found that Friesland animals have a greater maintenance requirement than other breeds (Truscott *et al.*, 1983; Fox & Black, 1984; Jones *et al.*,1985; Hicks *et al.*,1990). Truscott *et al.* (1983), Jones *et al.*(1985) and Hicks *et al.*(1990)

speculated that the higher proportion of body organs and visceral fat in Friesland steers could increase maintenance requirements compared with beef steers.

Ferrell and Jenkin (1984) state that higher maintenance requirements are not unique to the Friesland breed, but is applicable to cow types that have a higher milk production potential which have higher maintenance requirements (and hence intake) than cows with a lower milk production potential. Blaxter and Waiman (1966) recorded similar findings between dairy and beef breeds. NRC (1996) is in agreement and state that dairy and dual purpose *Bos taurus* cattle require about 20 % more energy for maintenance than beef breeds, with crosses being intermediate. NRC (1996) further suggest that there is a positive relationship between maintenance requirement and genetic potential (for example growth or milk production), i.e. a high producing dairy cow has an increased maintenance requirement over lower producing cows. As productivity increases so intake and rate of passage increase at the expense of digestibility (T.J. Dugmore, personal communication, 2000).

A further animal factor that affects intake is that the maintenance requirement of bulls is 15 % higher than that of steers or heifers of the same genotype (NRC, 1996).

2.5.4 Plant attributes affecting kikuyu intake

Plants have evolved with herbivores over time and have protective mechanisms that ensure their continued existence and survival (Van Soest, 1982). Nature has struck a balance between containing anti-predatory factors and defoliation as grasses have to be palatable to be defoliated by a herbivore otherwise a long-term buildup of stem material and dead organic matter will have a negative effect on survivability. Marais (1998) discussed the anti-predatory attributes of kikuyu comprehensively and a summary is as follows:

* **Lack of readily available energy**. Kikuyu contains small amounts of starch and fructan, which is the main form of non-structural carbohydrate in temperate grasses. Kikuyu only contains 30 to 50 % of the content of non-structural carbohydrates of Italian ryegrass cultivars.
* **Low digestibility of structural components**. As the content of hemi-cellulose:cellulose ratio increases so digestibility decreases. Hemi-cellulose is regarded as less digestible than cellulose. Kikuyu has a high ratio of hemi-cellulose:cellulose relative to other grass species.
* **Contains oxalic acid**. Although rumen microbes adapt and are able to metabolise oxalic acid to harmless products, the problem is that the oxalic acid binds with calcium and renders the calcium unavailable to the ruminant. Hence the need for calcium supplementation.
* **Low sodium content**. Kikuyu is a natrophobe.
* **High nitrate content**. Kikuyu responds readily to nitrogen fertilization which causes an increase in the nitrate content of kikuyu. During the breakdown of nitrate to ammonia, nitrite is a toxic intermediate derivative. Although few deaths occur due to nitrate poisoning, subclinical levels may have an impact on animal production.

Despite these anti-predatory attributes of kikuyu, kikuyu has a significant role to play in animal production, although plant breeders should be selecting against these anti-predatory factors.

2.5.5 The relationship between grazing behaviour and forage intake

Cattle spend a large proportion of a day grazing, which varies between 7 and 12 hours depending on the quality of the pasture (Ternouth, 1983). The most important pasture factor would be the height of the sward, as sward height decreases so intake decreases linearly (Hodgson, 1990). Forage intake is determined by bite size, biting rate and grazing time (Ternouth, 1983; Erlinger *et al.*, 1990; Hodgson, 1990). Grazing bites vary between 12 000 and 36 000 a day (Ternouth, 1983). Under conditions where leaf material is difficult to harvest, fatigue limits the time that can be spent grazing to 12 hours in 24 hours and grazing bites rarely exceed 36 000 per day (Stobbs, 1975). Once animal differences have been removed, the coefficient of variation for grazing time is usually 5 to 10 %, 10 to 15 % for biting rate and 20 to 50 % for measurements of bite size (Ternouth, 1983). Ruminating time is related to the quantity eaten and the fibrous nature of the feed and varies between 4 and 8 hours a day (Ternouth, 1983). Most grazing behaviour studies have been undertaken by visual observation, recording activity every few minutes (Erlinger *et al.*, 1990; Inwood *et al.*,1992; Khadem *et al.*, 1993; Morris *et al.*, 1993; Ferrer Cazcarra & Petit, 1995; Rook & Huckle, 1996) or vibracorders can be used (Ternouth, 1983).

Chapter 3

Growth of Hereford and Friesland bulls on kikuyu

3.1 Introduction

Growth parameters (mass, height and condition score) were measured throughout the trial period (November 1996 to April 1997) to determine if there was a significant difference between Hereford and Friesland bulls while on kikuyu pasture. The trial was conducted at Cedara Agricultural Research Station, which is situated at 1076 m above sea level in the Moist Natal Mistbelt, bioresource group 5 (Camp, 1997).

3.2 Materials and methods

3.2.1 Experimental design

The experimental unit was a yearling bull and the two treatments were the different breeds, Friesland and Hereford. Replication was limited to eight animals per treatment due to practical and financial constraints. Eight Hereford and five Friesland bulls were obtained from Cedara. Four Friesland steers (bulls were not available) were bought from a commercial herd, an extra steer was purchased to make allowance for disease. All the bulls had previously been on kikuyu pasture but were fed silage and hay during the winter months.

The experimental design was that eight bulls per breed would graze the same kikuyu pasture for a period of six months while growth parameters were measured. Some animals were removed from the pasture during the trial period but were still fed kikuyu *ad libitum*, for the feed intake investigation (26 November to 23 December 1996) and the digestibility investigation (17 February to 28 February 1997).

3.2.2 Experimental measures

Weight, height and condition score measurements were taken throughout the trial period. Animals were weighed every Thursday at the same time (8h30) to minimize the effects of gut fill on animal weight. The animals were not weighed during the feed intake and the digestibility investigations.

The height of the animals was measured four times during the season. Measurements were taken with an apparatus consisting of a sliding horizontal bar fitted to a calibrated vertical bar. The horizontal bar was rested on the animal's withers and the height was read off the vertical bar. The variability of height measurements was increased by the unevenness of the animal handling facility floor and the movement of the animal.

Condition score assessments were carried out five times during the trial according to Mulvaney's dairy scale (Mulvaney, 1977). The condition score assessments were performed by two or more people because of the subjective nature of the assessment.

3.2.3 Animal health

All necessary inoculations for common diseases in KwaZulu-Natal had been done prior to the trial. Dipping for external parasites was carried out four times during the season (21 December 1996, 11 February 1997, 13 March 1997 and 21 April 1997). Animals were dosed for internal parasites four times during the trial (25 October 1996, 12 November 1996, 30 January 1997 and 20 March 1997). The first three doses were done with Valbazen (Albendazole 7.5 %m/v) and the fourth with Levisol (Leavamisole Hydrochloride 2.5 %m/v).

Three steers (numbers FS1, FS2, FS4) contracted Red Water (*Babesia bigemena*) and were treated with Veriben and Engemycin on the 22 December 1996. Steer FS4 died on the 10 January 1997 from stress after having fallen into a hole.

During the months of January and February 1997 the steers (FS1, FS2 and FS3) showed low weight gains and looked unthrifty. The veterinarian examined them (1 March 1997) and diagnosed pulmonary disorders; blood tests indicated that the steers also had Gallsickness and were treated accordingly.

3.2.4 Pasture management

A calcium lick was made available to the animals on the pasture for reasons discussed in Section 2.4.3.

A pasture rotation system was used to provide sufficient high quality kikuyu so as not to restrict dry matter intake. Five camps of 0.5 ha each were used to give a stocking rate of 6.4 animals/ha; this was, however, subject to change so as to fit in with the grazing management of Cedara. Based on visual observation of the pasture, when the sward appeared on average to be below 10 cm, the animals were moved to a new camp. Animals usually spent about 7 days in each camp.

Pastures were fertilized with 250 kg nitrogen/ha/season. This was given as five 50 kg top-dressings during the kikuyu's growing season. The first dressing was given as ammonium sulphur nitrate (ASN) to maintain the kikuyu pasture's sulphur requirements while the remaining top-dressings were given in the form of limestone ammonium nitrate (LAN). Potassium and phosphate were applied according to requirement as determined by soil analyses (as recommended in Section 2.2.3).

All the pastures were dry-land and relied on rainfall for moisture. Rainfall and evaporation data for the trial period are shown in Figure 3.1.

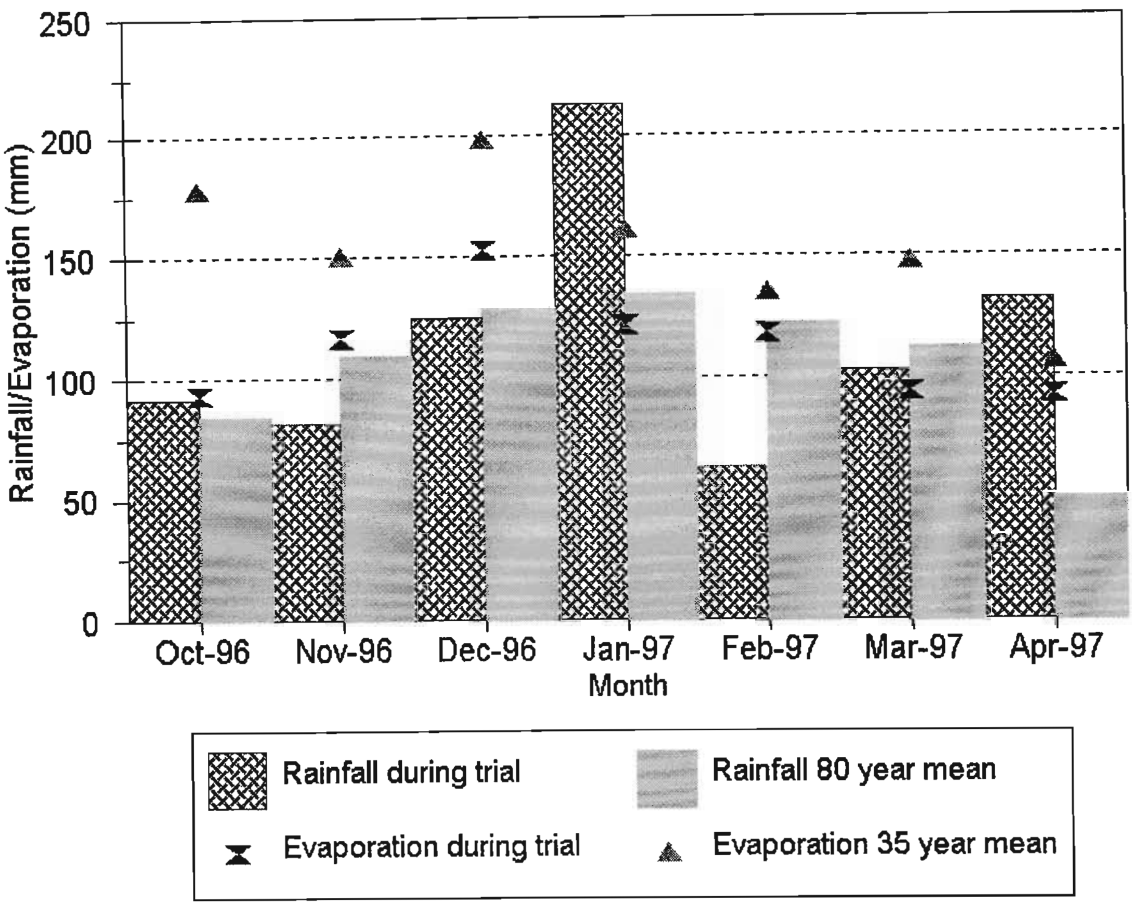

Figure 3.1: A comparison of monthly rainfall (mm) and evaporation (mm) during the trial period with the long-term running averages (Institute for Soil, Climate and Water, 1997).

The trial period (October 1996 to April 1997) was a moist season with a total rainfall of 809 mm as compared with the 80 year average of 744 mm. The distribution of rainfall, as shown in Figure 3.1, indicates that the rainfall during the months of January, February and April 1997 were significantly different to the monthly 80 year mean rainfall. January and April were wet months with an additional rainfall of 85 and 80 mm, respectively, being recorded. The additional rainfall that fell during the month of April was more than double the 80 year mean. February 1997 was a dry month in that the rainfall recorded was only half that of the 80 year mean rainfall.

The evaporation during the trial, as shown in Figure 3.1, was considerably lower than the 35 year mean (790 vs 1078 mm, respectively). The higher total rainfall and the lower total evaporation implies that more moisture, relative to the long term running average, was available for plant growth during the season. The increased rainfall could have had a negative influence on plant growth, since more nutrients were potentially leached from the soil, or the rainfall possibly contributed to a decrease in sunshine hours.

Temperature data for the trial period is shown in Figure 3.2.

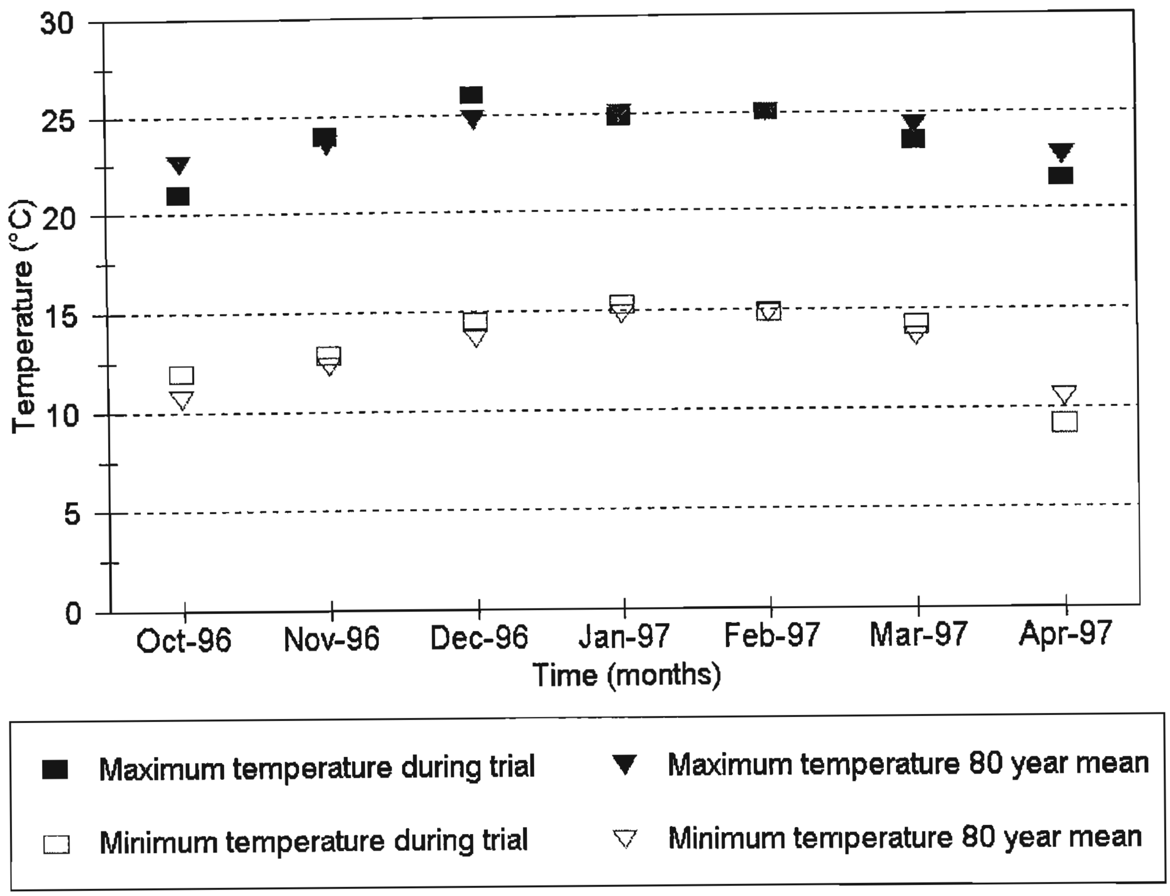

Figure 3.2: A comparison of monthly maximum and minimum temperatures (°C) during the trial period with the long-term running averages (Institute for Soil, Climate and Water, 1997).

The monthly maximum and minimum temperatures recorded during the trial period, as shown in Figure 3.2, were similar to the 80 year average values. Temperature-wise, the trial period was thus an average season.

3.2.5 Statistical methods

The Genstat 5 (Release 3.1) statistical program (Lawes Agricultural Trust, Rothamsted Experimental Station) was used for statistical analyses. Statistical differences between treatment means were determined from analysis of variance tables with the use of the Students t-test at the 5 % level. Regression analyses (linear and quadratic), where possible, were also performed.

3.3 Results and discussion

Growth parameters (weight, height and condition score) were analysed to determine if there was a significant difference between Hereford and Friesland bulls while on kikuyu pasture.

The data used to derive the treatment means is contained in **Appendix A.**

3.3.1 Age of trial animals

The exact birth dates of the Friesland bulls were unknown, however, they were all born between the middle of August and the middle of October 1995. The mean ages of the Hereford bulls and Friesland steers are presented in Table 3.1.

Table 3.1: Mean age (days) of Hereford bulls (HB), Friesland bulls (FB) and steers (FS) at the start of the trial (23 October 1996)

Measurement	HB (n = 8)	FB (n = 5)	FS (n = 3)
Initial age (days)	394	404	276
Range (days)	374 to 435	374 to 435	267 to 302

The data presented in Table 3.1 indicates that there is a large age difference (more than 115 days) between the Friesland steers and the Hereford and Friesland bulls. An analysis of variance performed on the Hereford bull and Friesland steer age data indicated that the difference in ages (394 versus 276 days) was highly significant ($P < 0.01$).

3.3.2 Weight gain

Weekly weights of the breeds during the trial period are shown in Figure 3.3.

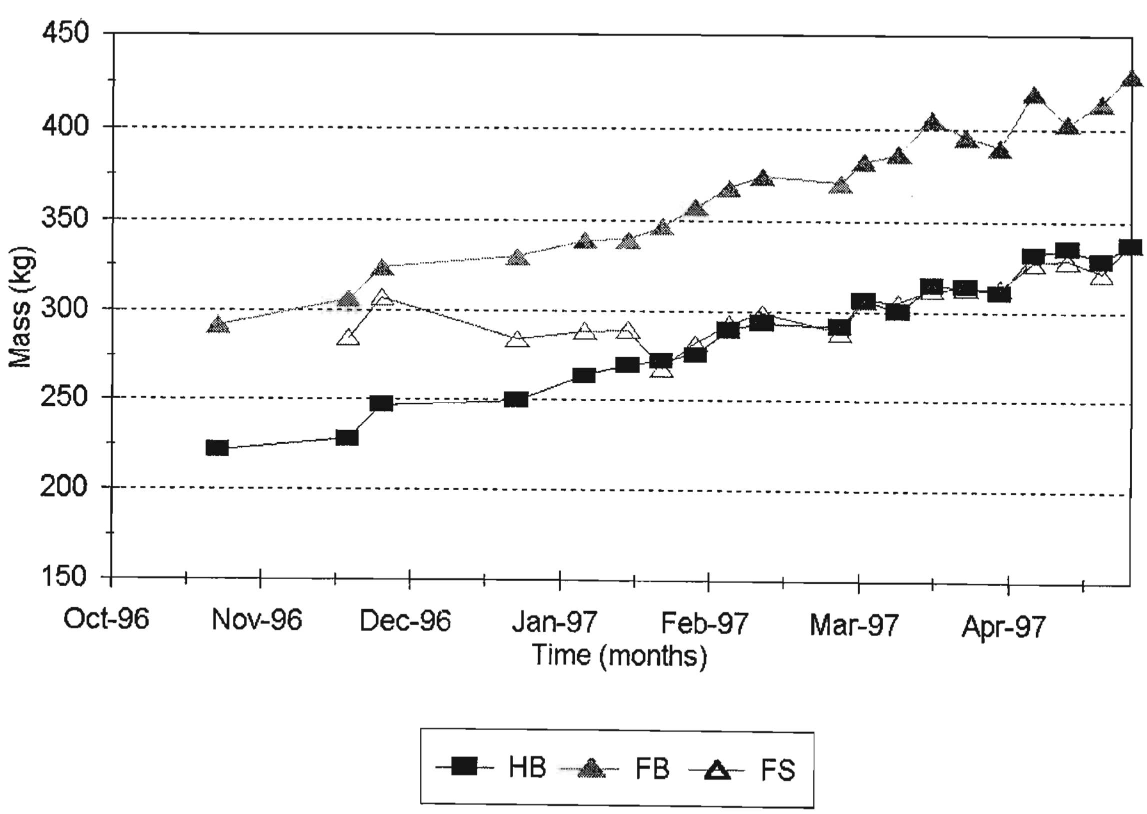

Figure 3.3: Average weight (kg) of Hereford bulls (HB), Friesland bulls (FB) and steers (FS) during the trial.

The Friesland steers were on average 60 kg heavier than the Hereford bulls at the start of the trial. The steers lost about 20 kg in weight during a period of two months from the middle of November to the middle of January due to the illness discussed in Section 3.2.3 and had a similar final average weight to the Hereford bulls at the end of the trial. The growth rate of the steers was affected by their vulnerability to disease. The steers were bought from a commercial herd in the Bisley Valley area and thus had no resistance to the strains of disease organisms at the trial site.

The Friesland steer data was excluded in the growth analysis investigation because of the significant age difference (118 days) and since growth was stunted by the various sicknesses (see Section 3.2.3) the steers contracted.

A summary of the weight performance of the Hereford and Friesland bulls during the trial is presented in Table 3.2.

Table 3.2: Weight performance of Hereford (HB) and Friesland (FB) bulls during the trial

Measurement	HB (n = 8)	FB (n = 5)	CV %
Initial weight (kg) (±SE)	221 [a] (±15)	292 [b] (±16)	16
Final weight (kg) (±SE)	338 [a] (±16)	429 [b] (±24)	13
Weight gain (kg) (±SE)	116 (±9)	137 (±9)	18
Average daily gain (kg/d) (±SE)	0.61 (±0.05)	0.73 (±0.05)	18
Initial metabolic weight (kg $W^{0.75}$) (±SE)	57.2 [a] (±2.9)	70.6 [b] (±2.9)	12
Final metabolic weight (kg $W^{0.75}$) (±SE)	78.6 [a] (±2.8)	94.2 [b] (±3.9)	10
Metabolic weight gain (kg $W^{0.75}$) (±SE)	1.48 (±0.1)	1.45 (±0.05)	16
ADG/metabolic weight (g/kg $W^{0.75}$/d) (±SE)	7.8 (±0.54)	7.7 (±0.25)	16

[a,b] Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

The results of the analysis of variance is summarised in Table 3.2 and confirms the trend in Figure 3.3. The Friesland bulls were found to be significantly heavier than the Hereford bulls, both at the start of the trial (by 71 kg) and at the end of the trial (by 91 kg). Even though the Friesland bulls had significantly different initial and final weights to the Hereford bulls, the weight gained during the trial was not significantly different (0.73 kg/day for the Friesland bulls and 0.61 kg/day for the Hereford bulls).

A linear regression model was found to fit the data the best (quadratic regression was inappropriate) and is illustrated in Figure 3.4, but only accounted for 60 % of the variance affecting weight gain. The equation describing weight gain over time (see Figure 3.4) for the Frieslands was:

$$y = 0.6562(\pm 0.0495)x + 293.86(\pm 7.06) \quad [3.1]$$

and that for the Herefords was:

$$y = 0.6562(\pm 0.0495)x + 214.37(\pm 5.41) \quad [3.2]$$

where y is weight (kg) and x is time (days).

The slope coefficients of equation [3.1] and [3.2] describing weight gain were the same (0.656) indicating that there was no significant difference in rate of weight gain over time between the breeds even though the y intercepts were different (due to different initial weights, with the Friesland bulls being 71 kg heavier).

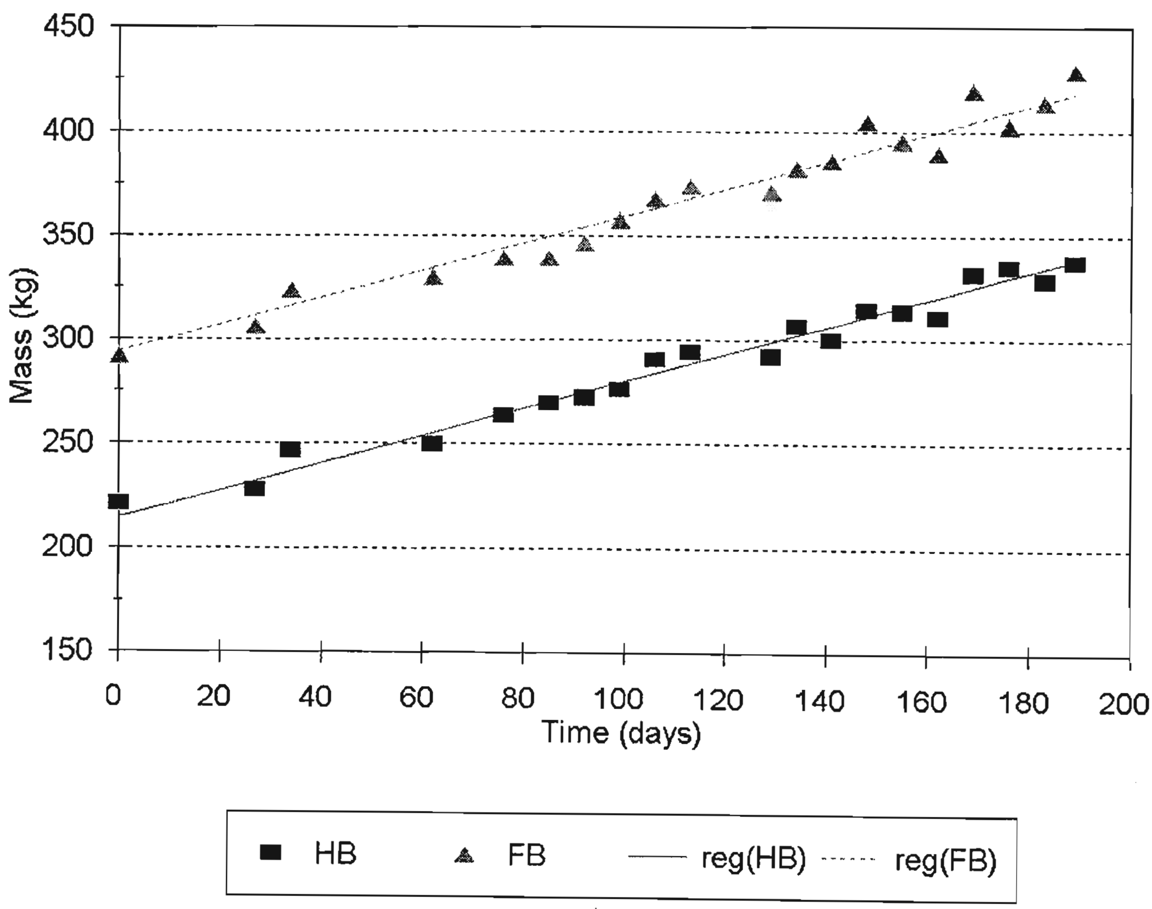

Figure 3.4: Linear regression model (equation [3.1] and [3.2]) of weight (kg) for Hereford (HB) and Friesland (FB) bulls over time ($r^2 = 0.6$).

3.3.3 Height gain

Average heights of the breeds during the trial period are shown in Figure 3.5.

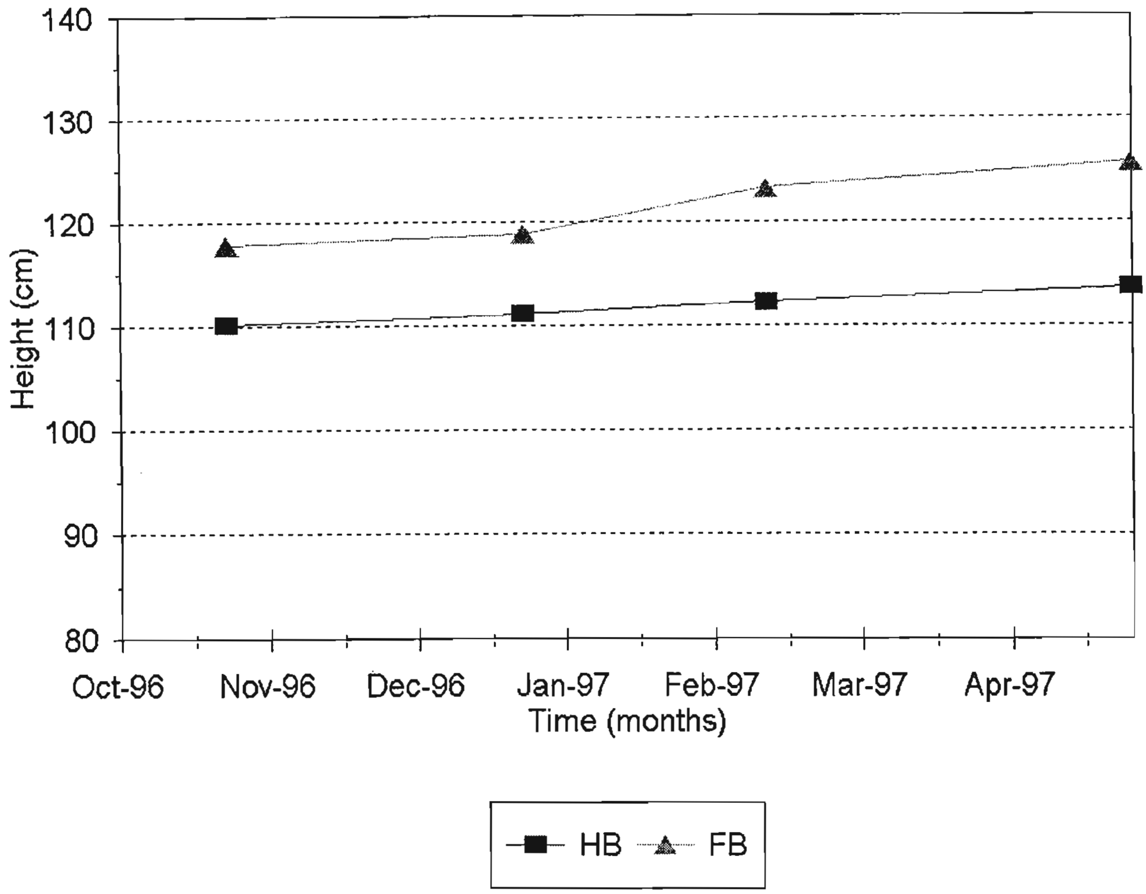

Figure 3.5: Average height (cm) of Hereford (HB) and Friesland (FB) bulls during the trial.

From the analysis of variance (results summarised in Table 3.3) the height of the Hereford bulls was significantly lower than the Friesland's for the initial and final measures (see also Figure 3.5). However, the height gain during the season (3.5 cm for the Hereford bulls and 7.8 cm for the Friesland bulls) was not significantly different for the two breeds ($P > 0.05$).

A summary of the Hereford and Friesland height performance during the trial is presented in Table 3.3.

Table 3.3: Height of Hereford (HB) and Friesland (FB) bulls during the trial

Measurement	HB (n = 8)	FB (n = 5)	CV %
Initial height (cm) (±SE)	110.1^{a} (±2.4)	117.8^{b} (±1.3)	5
Final height (cm) (±SE)	113.6^{a} (±1.6)	125.6^{b} (±1.3)	3
Height gain (cm) (±SE)	3.5 (±1.7)	7.8 (±0.8)	77

^{a,b} Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

As mentioned in Section 3.2.2 the variability of this measurement was high and is reflected in the coefficient of variation which was 77 % for height gain during the trial. A linear regression model was fitted to the data and only accounted for 54 % (Figure 3.6) of the variance affecting growth in height. The equation describing height gain for the Friesland bulls was:

$$y = 0.02866(\pm 0.00920)x + 118.74(\pm 1.33) \quad [3.3]$$

and that for the Herefords was:

$$y = 0.02866(\pm 0.00920)x + 109.17(\pm 1.31) \quad [3.4]$$

where y was height (cm) and the x was time (days). The regression model is presented graphically in Figure 3.6.

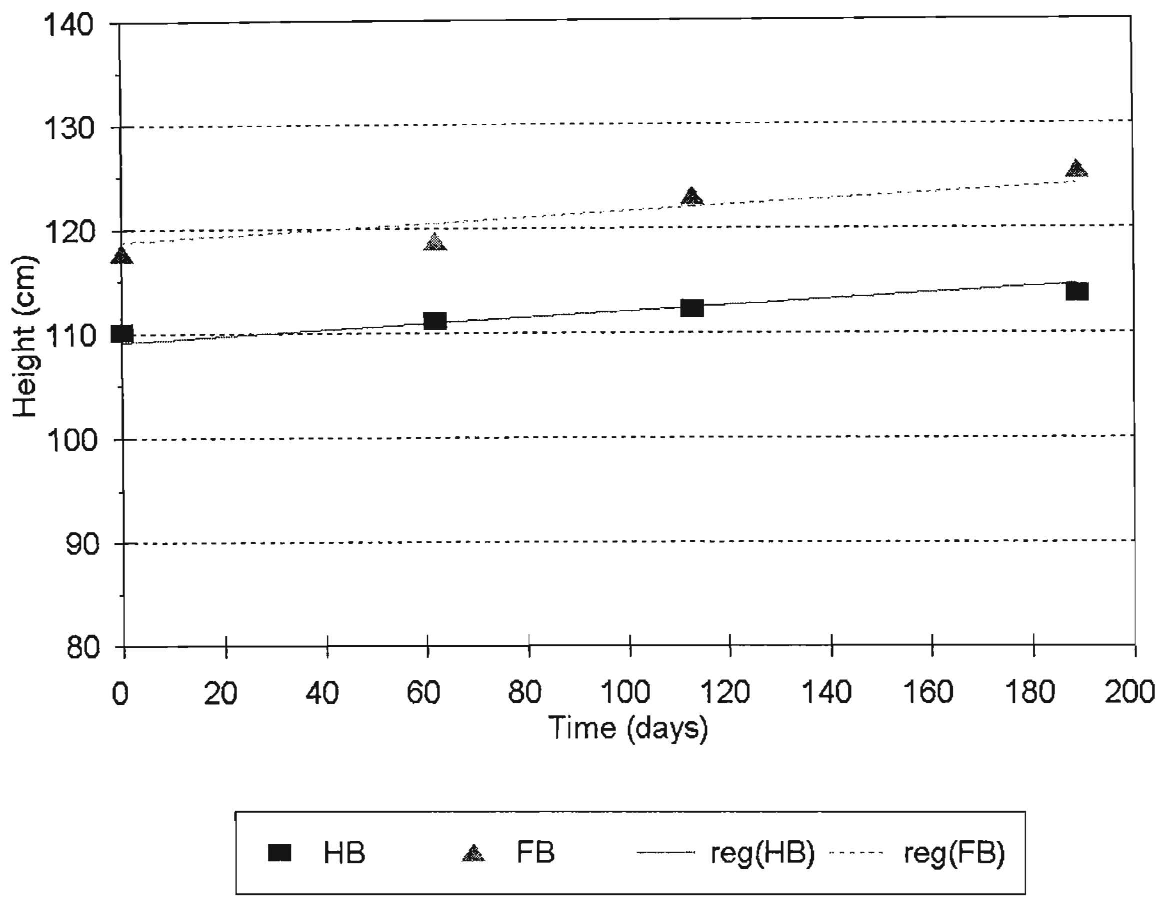

Figure 3.6: Linear regression model (equation [3.3] and [3.4]) of height (cm) for Hereford (HB) and Friesland (FB) bulls over time ($r^2 = 0.54$).

The slope coefficients of equation [3.3] and [3.4] describing Friesland and Hereford height gain were the same (0.02866) while the y intercepts were different (118.74 for the Friesland and 109.17 for the Hereford bulls) indicating that although the Frieslands were taller than the Herefords at the start of the trial the average gain in height during the trial was not significantly different.

3.3.4 Condition score gain

Average condition scores of the breeds during the trial period are shown in Figure 3.7.

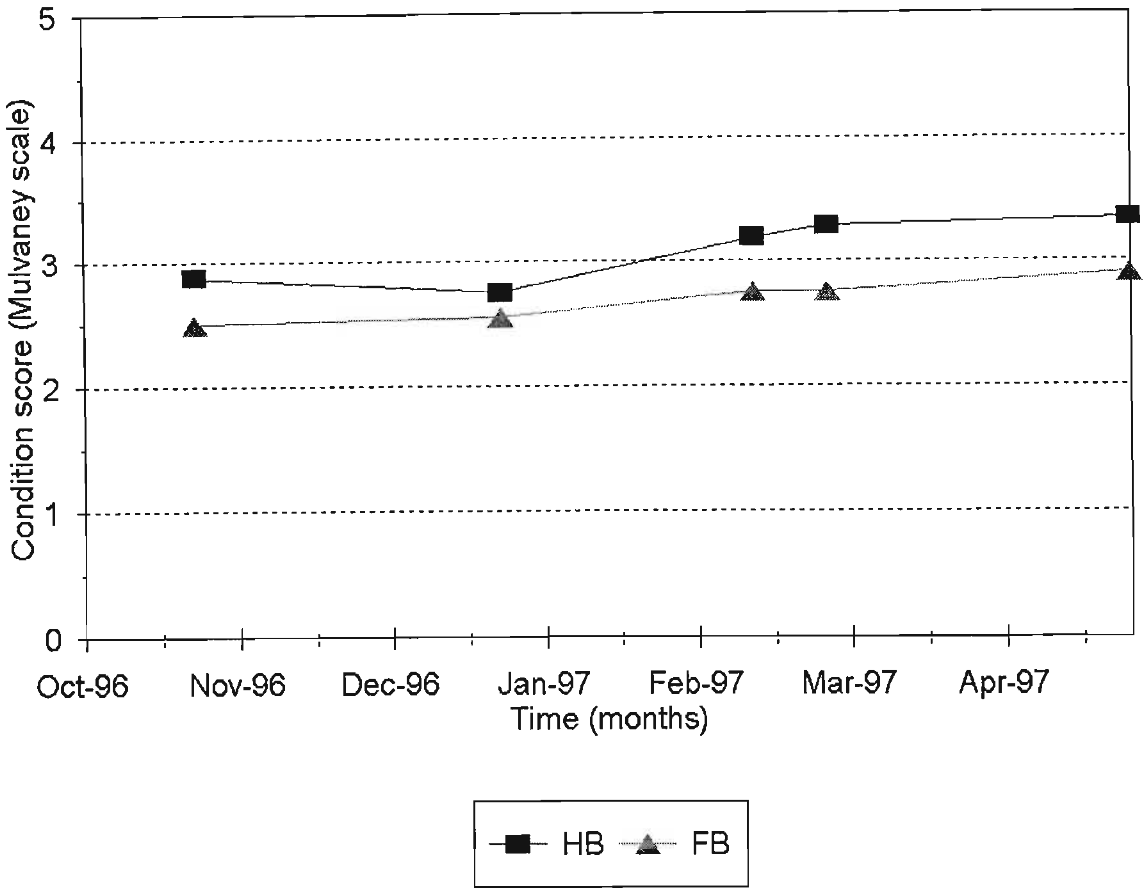

Figure 3.7: Average condition score (Mulvaney scale) of Hereford (HB) and Friesland (FB) bulls during the trial.

A summary of the Hereford and Friesland bull condition score performance during the trial is presented in Table 3.4.

Table 3.4: Condition score measures (Mulvaney scale) of Hereford (HB) and Friesland (FB) bulls during the trial

Measurement	HB (n = 8)	FB (n = 5)	CV %
Initial condition score (±SE)	2.9 ^{a} (±0.08)	2.5 ^{b} (±0)	7
Final condition score (±SE)	3.3 ^{a} (±0.07)	2.9 ^{b} (±0.15)	8
Condition score gain (±SE)	0.5 (±0.09)	0.4 (±0.15)	64

^{a,b} Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

The same trend was present as that of the weight and height measures, i.e. the breeds start (2.9 for Hereford and 2.5 for Friesland bulls) and end at different condition scores (3.4 for Hereford and 2.9 for Friesland bulls) but have similar condition gains during the season (0.5 for the Hereford bulls and 0.4 for the Friesland bulls, $P > 0.05$).

3.4 Summary

The growth of Hereford bulls, Friesland steers and Friesland bulls was compared by recording weight, height and condition score for a period of 190 days while the animals were on kikuyu pasture. The Friesland steer growth data was excluded from the growth analysis due to disease. The trial period was a fairly moist season with a total rainfall of 809 mm.

The Friesland bulls were, in total, 71 kg heavier ($P < 0.05$) at the start of the trial and 91 kg heavier ($P < 0.05$) at the end of the trial than the Hereford bulls. However the average weight gain during the trial period was not significantly different for the Hereford and Friesland bulls. The average weight gain of all the animals was 0.66 kg per day.

The combined height of the Friesland bulls was 8 cm greater ($P < 0.05$) at the start of the trial and 12 cm greater ($P < 0.05$) at the end of the trial than the Hereford bulls. However the average height gain during the trial period was not significantly different for the Hereford and Friesland bulls. The average height gain of all the animals was 6 cm.

The Friesland bulls were 0.4 of a condition score less ($P < 0.05$) at the start of the trial and 0.5 of a condition score less ($P < 0.05$) at the end of the trial than the Hereford bulls. However the average condition score gain during the trial period was the same for both Hereford and Friesland bulls (average 0.5).

The results of the growth investigation indicates that there was no significant difference between the growth rate of Hereford and Friesland bulls while on kikuyu pasture.

Chapter 4

Estimation of kikuyu intake of Hereford and Friesland bulls

4.1 Introduction

Kikuyu intake was measured for a period of 10 days to determine if there was a significant difference between Hereford and Friesland bulls. A further objective was to compare kikuyu intake estimated by the alkane method to electronic-controlled feed gates (both methods described in Section 2.5.1). The investigation was performed at Cedara's Calan gate (electronic-controlled feed gate) pens from 14 to 23 December 1996. The adaption period extended from 27 November to 13 December 1996.

4.2 Materials and methods

4.2.1 Experimental design

Since there were only 11 functional Calan gates to measure kikuyu intake, six animals were excluded from the Calan gate investigation and remained on the pasture. Five of the eight Hereford bulls, four of the five Friesland bulls and two of the four Friesland steers were chosen randomly and were allocated randomly to the pens.

The experimental design was that five Hereford bulls and five Friesland animals (four bulls and one steer; an extra steer was also included) were penned on concrete in the Calan gate facility to measure dry matter intake for a period of 10 days. Each animal had access to a particular feed trough that contained cut kikuyu grass and a mineral supplement. Intake was also estimated using the alkane method for all animals (including the three Hereford bulls, one Friesland bull and two Friesland steers remaining on the pasture).

4.2.2 Experimental measures

All the animals were weighed before the adaptation period (26 November 1996) and at the end of the trial (24 December 1996). The Calan gate facility was about three km from the scale where the animals were usually weighed, as a result the animals were not weighed on a weekly basis during the intake investigation (27 November to 23 December 1996).

Kikuyu grass was cut daily from one of the pastures allocated for the trial. Each animal was allocated a particular bag containing grass for that day. After the bags were weighed at 10h30, grass was put into each animal's feed trough (only half filled) at regular intervals. At 8h00 the following day the remaining grass in the feed trough was removed and placed in the correct bag. All bags were weighed again and the quantity of grass removed from each bag was equal to the kikuyu intake of that particular animal for that day.

Originally the grass was fed long (unchopped) to the animals in the Calan gate facility. However, most of the grass was wasted on the floor. For example, an animal would open its gate, take a mouthful of grass, reverse (the gate would close) and while the animal was masticating the grass most of it would drop out of the animal's mouth and be wasted. To alleviate this problem the grass was chopped before it was fed to the animals. This also prevented selection between leaf and stem parts.

Kikuyu grass samples were collected daily from the pasture where the animals were grazing and where the grass was cut for the Calan gate facility. All grass samples were oven dried (60 °C) until a constant weight was attained and then milled using a 0.5 mm screen. The grass samples were analysed for the concentration of the alkanes, calcium, phosphorous, ash, neutral detergent fibre and acid detergent fibre content.

The animals were orally administered 1 g of dotriacontane (C_{32}) daily at 6h00. Faecal samples were collected from the rectum of each animal daily at 6h00 and 18h00. All faecal samples were oven dried (60 °C) until a constant weight was attained and then milled (0.5 mm screen).

Maximum and minimum environmental temperatures (°C) were recorded daily. The thermometer was placed at the centre of the facility about one m beneath the corrugated iron roof.

4.2.3 Experimental techniques

The alkanes were analysed according to Mayes method as described in Section 2.5.1 (Mayes *et al.*, 1986b) that was adapted by Marais and co-workers (Marais *et al.*, 1996). The Mayes method was modified so that the marker was administered to the animal in the form of a suspension instead of a compressed pellet. The samples containing the alkanes were heated in glass-stoppered tubes in a water bath instead of in screw cap bottles (with PTFE-lined screw caps) in a dry block heater as in Mayes method. Marais' method also omitted the saponification procedure with the 1.5 M ethanolic potassium hydroxide solution. The remainder of the procedure was the same as in Mayes method.

Based on Fushai's (1997) recommendation and Marais (personal communication, 1996) the dose rate was increased to 1 g of C_{32} per animal per day (previously was 0.5 g). To coat dotriacontane (C_{32}) onto a solid support, 10 g of C_{32} (an even-chained alkane) was dissolved in petroleum ether (60-80 °C boiling point) in a rotary evaporator flask. Fine milled (0.5 mm) kikuyu was added (100 g) and the solvent was slowly evaporated at 60 °C under pressure on a rotary evaporator. The dried, coated material was sieved to remove lumps. To administer the coated material to the animal in a practical and consistent manner, it was suspended in a 0.4 % solution of xanthan gum (Keltrol GM, Merck and Company, Rathway, NJ) and administered in a dosing gun (2 x 80 ml) once a day. The dosing gun could deliver accurate amounts of suspension (coefficient of variation was 0.8 %).

Once herbage and faeces samples had been collected, dried in an oven (at 60 °C) and milled (using a 0.5 mm screen) the alkanes were extracted according to the following procedure (Marais *et al.*, 1996 and personal communication with Marais, 1997):

(i) An alkane internal standard was made up by dissolving 0.2 g of hexatriacontane (C_{36}) in 300 g of undecane.

(ii) 0.6 g of the internal standard mixture (containing 0.04 mg C_{36}) was added to a 50 ml glass-stoppered test tube, to which 1 g faeces or 1.5 g grass was added.

(iii) About 40 ml of petroleum ether (80-100 °C boiling point) was added and the tube was heated in a water bath at 70 °C for 2 hours with occasional shaking.

(iv) Once the material had settled, the supernatant petroleum ether was decanted into a 50 ml beaker and evaporated.

(v) The dried extract was dissolved in 2 ml petroleum ether (60-80 °C boiling point) and applied to the top of a column (disposable polypropylene column, Supelco, Bellefonte P.A., U.S.A., containing silica gel (Kieselgel 60, 70-230 mesh, Merck, Darmstadt, West Germany) with a bed volume of 5 ml.

(vi) The alkanes were eluted with about 25 ml of petroleum ether (60-80 °C boiling point).

(vii) The petroleum ether solution containing the alkanes was evaporated.

(viii) Extracted alkanes were dissolved in hexane (0.7 ml) and a 1 µl of this solution was applied to a gas chromatogram column (megabore, 25 m, 100 % methyl polysiloxane, 32 microns, carrier gas was nitrogen. The temperature program was as follows: 220 °C for 3 minutes, rising at a rate of 30 °C/min to 240 °C, holding for 2 minutes, thereafter, rising at a rate of 35 °C/min to reach a final temperature of 298 °C which was held for 5 minutes. The initial injector temperature was 300 °C and the initial detector temperature was 320 °C).

Coated grass samples were extracted using the same procedure as outlined above, except that 0.5 g of sample and 0.05 g of hexatriacontane (C_{36}) were initially added to the 50 ml glass-stoppered tube and instead of all the supernatant petroleum ether as in step (iv), an aliquot of 0.3 ml was applied immediately to the silica column.

4.2.4 Statistical methods

The Genstat 5 (Release 3.1) statistical program was used for statistical analyses. Statistical differences between treatment means were determined from analysis of variance tables with the use of the Students t-test at the 5 % level or by least significant differences. Regression analysis, where possible, was also performed.

Intake results are presented in kg of grass consumed per day (kg DM/d) and in grams of grass consumed per kg live weight raised to the power of 0.75 (defined as metabolic weight) (g DM/kg $W^{0.75}$/d). Both forms of intake results are presented to allow for comparison with other scientific papers. The advantage of converting an intake estimate to g DM/kg $W^{0.75}$/d is that intake differences due to live weight differences are removed yielding an unbiased estimate.

4.3 Results and discussion

Kikuyu intake estimates were calculated using equation [2.4] and the data was analysed to determine if there was a significant difference between Hereford and Friesland bulls. Friesland steer data was not included in the investigation (due to the reasons discussed in Section 3.2.3 and Section 3.3.2). Although intake was measured for 10 days, the intake estimates of the last seven days (17 to 23 December) could only be analysed since FB4's Calan gate was faulty on the 15 and 16 December. Likewise, only four days (17 to 20 December) of data could be used for the comparison between pasture and Calan gate animals since intakes dropped in FS2 and FS3 on the 21 December which were treated for Red Water (*Babesia bigemena*) on the 22 December. However, four days was too short a period for any meaningful conclusions to be drawn, therefore the Friesland comparison was discarded. A comparison of seven days of intake data of the Hereford bulls in the Calan gates and the Hereford bulls on the pasture was performed.

Apparent dry matter digestibility estimates can be calculated by substituting the alkane concentrations in equation [2.5]. Dry matter digestibility estimates were analysed to determine if there was a difference between Hereford and Friesland bulls.

The data used to derive the treatment means is contained in **Appendix B.**

4.3.1 Initial weight

Although the trial animals were weighed before and after the intake investigation, the period of 28 days was too short to make any meaningful conclusions. The initial weight for the Friesland bulls was significantly different to the Hereford bulls (315 kg versus 235 kg, CV % = 12.5 %).

4.3.2 Kikuyu composition

Average composition of the kikuyu grass samples taken daily during the investigation are presented in Table 4.1.

Table 4.1: Average composition (g/kg DM) of kikuyu samples during the intake investigation

Measurement	Calan gate grass	Pasture grass	CV %
Crude protein (g/kg DM) (±SE)	87.6 ^{a} (±4.6)	220.7 ^{b} (±7.9)	9
NDF (g/kg DM) (±SE)	709.3 ^{b} (±13.6)	586.1 ^{a} (±7.5)	4
ADF (g/kg DM) (±SE)	390.7 ^{b} (±8.8)	256.4 ^{a} (±6.4)	3
Ash (g/kg DM) (±SE)	84.9 (±4.3)	92.9 (±1.2)	12
Calcium (g/kg DM) (±SE)	4.1 (±0.2)	3.8 (±0.1)	10
Phosphorous (g/kg DM) (±SE)	2.2 ^{a} (±0.1)	3.8 ^{b} (±0.2)	12

^{a,b} Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

It is evident from the data presented in Table 4.1 that there was a significant difference in the chemical composition of the grass fed to the animals in the Calan gates (crude protein was133 g/kg DM lower, NDF was 123 g/kg DM higher and ADF was 134 g/kg DM higher) compared with the animals grazing kikuyu pasture. The crude protein, NDF and ADF values of the Calan gate herbage indicate that it was either very mature kikuyu (high stem fraction) or nitrogen fertilization may have been lacking. The greater fibre content of the Calan gate grass could have been compounded by the height at which the Calan gate grass was cut. The Calan gate herbage was cut at ground level with a mower that did not have adjustment heights while the pasture herbage samples were taken as representative of what the animals were grazing, which was mostly leaf material. A further factor that could contribute to the higher fibre content of the Calan gate herbage in comparison with the pasture herbage is that the pasture herbage was from a well established (> 15 years) kikuyu paddock with a high nutrient status whereas the Calan gate herbage was cut from a less frequently (approximately seven year old pasture) established paddock (most likely with a lower nutrient status).

The pasture grass contained a greater proportion of leaf and thus had a greater crude protein content while the Calan gate grass samples were composed of a greater proportion of mature stem material and thus contained more fibre. In theory, a crude protein value of 86 g/kg DM is not sufficient to support growth of the bulls (discussed in Section 2.3).

Although the kikuyu grass for the Calan gate investigation was cut from one of the pastures allocated for the trial and the paddock chosen was done so for convenience reasons, in retrospect this was a fault. Even though it may have caused practical problems, the Calan gate herbage should have been cut from the same paddock as where the pasture animals were grazing at that time.

4.3.3 Estimation of kikuyu intake

4.3.3.1 Method of intake estimation

A comparison of the average intake estimated by the Calan gate and alkane methods is presented in Table 4.2.

Table 4.2: Kikuyu intake (of Hereford (HB) and Friesland (FB) bulls combined) estimated by the Calan gate (CG) and alkane methods

Measurement	CG (n = 9)	Alkane mean (n = 9)	CV %
Intake (kg DM/d) (±SE)	6.28 (±0.24)	6.21 (± 0.15)	23
Intake (g DM/kg $W^{0.75}$/d) (±SE)	93.6 (±3.16)	92.9 (± 2.07)	22

^{a,b} Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

The results of the analysis of variance as summarised in Table 4.2 indicates that there was no significant difference in the methods of intake estimation when measured in kilograms or grams per metabolic weight per day. The average intake of all the animals was 6.23 kg DM/day or 93.2 g DM/kg $W^{0.75}$/day.

4.3.3.2 Time of alkane measurement

A comparison of the average intake estimated by the Calan gate method comparing faecal samples collected in the morning (6h00) and the afternoon (18h00) is presented in Table 4.3.

Table 4.3: Kikuyu intake (of Hereford (HB) and Friesland (FB) bulls combined) estimated by the Calan gate (CG) method and different sampling times of the alkane method

Measurement	CG	Alkane method		CV %
		AM	PM	
	(n = 9)	(n = 9)	(n = 9)	
Intake (kg DM/d) (±SE)	6.28^{b} (±0.24)	5.61^{a} (±0.17)	6.81^{c} (±0.22)	23
Intake (g DM/kg $W^{0.75}$/d) (±SE)	93.6^{b} (± 3.16)	83.7^{a} (±2.17)	102.2^{c} (± 3.12)	22

^{a,b,c} Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

Although the alkane intake estimation (when morning and afternoon readings were combined) did not differ significantly from the Calan gate method (as presented in Table 4.2) when time was analysed significant trends were found. The morning reading (5.61 kg DM; 83 g DM/kg $W^{0.75}$/d) significantly under-estimated intake by 0.67 kg DM while the afternoon reading (6.81 kg DM; 102.2 g DM/kg $W^{0.75}$/d) significantly over-estimated intake by 0.53 kg DM; and both morning and afternoon readings were significantly different to the Calan gate estimate.

Literature (Dove & Mayes, 1991, 1996) on the alkane method of intake estimation recommends that faecal sampling should be done once a day since the variability of the faecal C_{33}:C_{32} ratio is less than 5 % (Dove *et al.*, 1986b). In order to explain the significant differences in the morning and afternoon estimates of intake, an analysis of variance was performed on the faecal C_{33}:C_{32} ratios, and the morning and afternoon sampling times were found to be significantly different. The morning sampling time was 18 % lower than the afternoon value. These results are in agreement with the alkane intake estimates where the morning and afternoon samples were significantly different. Therefore, these data indicate that sampling should be done twice daily.

4.3.3.3 Kikuyu intake of Hereford and Friesland bulls

A comparison of the average intake (estimated using both the Calan gate and alkane methods) for each breed is presented in Table 4.4.

Table 4.4: Average kikuyu intake of Hereford (HB) and Friesland (FB) bulls estimated by the Calan gate (CG) and alkane methods

Measurement	HB (n = 5)	FB (n = 4)	CV %
Intake (kg DM/d) (±SE)	5.67^{a} (±0.16)	6.94^{b} (±0.18)	23
Intake (g DM/kg $W^{0.75}$/d) (±SE)	94.3 (±2.51)	91.8 (±2.34)	22

^{a,b} Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

The analysis of variance data summarised in Table 4.4 indicates that weight influenced intake i.e. the heavier Friesland bulls (by 80 kg) ate significantly more kikuyu than the Hereford bulls (5.67 kg DM/d for Friesland bulls and 6.94 kg DM/d for Hereford bulls; $P < 0.05$). However when intake was expressed in grams per metabolic weight the difference between the breeds was not statistically significant. Both breeds were eating the same amount of kikuyu in proportion to body weight. The similar relative intake of kikuyu explains the similar growth, as discussed in Chapter 3, of the two breeds. Average kikuyu intake for the bulls was 93.2 kg DM/kg $W^{0.75}$/d.

4.3.3.4 Kikuyu intake (alkane estimation) of Hereford bulls in the Calan gates and on the pasture

A comparison of the average intake of the Hereford bulls in the Calan gate facility and on the pasture is presented in Table 4.5.

Table 4.5: Average kikuyu intake of Hereford bulls (HB) in the Calan gate (CG) facility and on the pasture estimated* by the alkane method

Measurement	CG (HB) (n = 5)	Pasture (HB) (n = 3)	CV %
Intake (kg DM/d) (±SE)	5.65 (±0.23)	7.31 (±0.23)	16
Intake (g DM/kg $W^{0.75}$/d) (±SE)	94.3 (±4.42)	110.5 (±5.32)	19

[a,b] Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

* morning and afternoon values were combined since there were only three pasture animals, hence the lower coefficient of variation than in Table 4.2

The analysis of variance data summarised in Table 4.5 indicates that there is no significant difference ($P = 0.066$) between the Hereford bulls on the pasture and those in the Calan gate facility despite the differences in kikuyu chemical composition (see Table 4.1). However, it should be noted that the Calan gate kikuyu was milled and should have a positive effect on intake.

4.3.4 Estimation of dry matter digestibility by the alkane method

Dry matter digestibility estimates of the breeds are presented in Table 4.6.

Table 4.6: Average kikuyu dry matter digestibility estimates (g/kg DM) of Hereford (HB) and Friesland (FB) bulls in the Calan gate (CG) facility calculated by the alkane method			
Measurement	**HB (n = 5)**	**FB (n = 4)**	**CV %**
Dry matter digestibility estimate (g/kg DM) (±SE)	[1] 628.5 [a] (±6.6)	[2] 590.3 [b] (±10.2)	10

[a,b] Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

[1] equivalent to 8.7 MJ ME/kg DM (AAC, 1990)

[2] equivalent to 8.0 MJ ME/kg DM (AAC, 1990)

The data presented in Table 4.6 indicate that there is a significant difference, of 6 %, in the dry matter digestibility of the kikuyu between the two breeds in the Calan gate investigation. The Friesland bulls had a heavier body weight and could have consumed more grass at the expense of digestibility.

Dry matter digestibility estimates calculated using the alkane method for comparing Calan gate intake and pasture intake for Hereford bulls is presented in Table 4.7.

Table 4.7: Average kikuyu dry matter digestibility estimates (g/kg DM) of Hereford bulls (HB) in the Calan gate (CG) facility and on the pasture calculated by the alkane method			
Measurement	**CG (n = 5)**	**Pasture (n = 3)**	**CV %**
Dry matter digestibility estimate (g/kg DM) (±SE)	[1] 628.5 (±6.6)	[2] 680.6 (±17.9)	11

[a,b] Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

[1] equivalent to 8.7 MJ ME/kg DM (AAC, 1990)

[2] equivalent to 9.6 MJ ME/kg DM (AAC, 1990)

The data presented in Table 4.7 indicate that there was no significant difference ($P = 0.086$) in the estimated dry matter digestibility in Hereford bulls in the Calan gate facility and on pasture.

4.3.5 Maximum and minimum temperatures

The average minimum temperature during the intake investigation at the Calan gate facility was 15.3 °C while the maximum temperature was 30.1 °C. There was no relationship between temperature and kikuyu intake for the animals in the Calan gate facility.

4.4 Summary

The kikuyu intake of Hereford and Friesland bulls was compared over a period of seven days while animals were penned in a Calan gate facility. The alkane method was applied to the bulls to measure kikuyu intake.

The Friesland steer data was excluded due to disease.

The alkane method compared favourably with the Calan gate method for intake estimation with the average intake being 6.23 kg DM per day or 93.2 g DM/W $^{0.75}$/day (the coefficient of variation was 22 and 23 % respectively). Although the intake estimates generated by the alkane method did not differ significantly from the Calan gate method there was a significant difference between the faecal sample collecting times ($P < 0.05$). The morning value under-estimated actual intake by 11 % while the afternoon value over-estimated actual intake by 9 %. The Friesland bulls consumed 12 % more kikuyu ($P < 0.05$) than the Hereford bulls when expressed in kilograms per day, since they were 80 kg heavier than the Hereford bulls. However when intake was reported in terms of g DM/kg W $^{0.75}$/d the difference between the breeds was not statistically significant. The average intake for the bulls was 93.2 g DM/kg W $^{0.75}$/day.

Since the Friesland steers could not be included in the intake investigation there were insufficient animals to compare both breeds in the Calan gate facility and those on the pasture. A comparison was thus made between the Hereford bulls at both locations. There was no significant difference between the intake (average intake was 102 g DM/kg W $^{0.75}$/day) of the Hereford bulls in the Calan gate facility and those on the pasture although the chemical composition of the pasture was significantly different from the grass fed in the Calan gate facility. However, the dry matter digestibility did not differ significantly between the sites.

The alkane method was used to measure apparent dry matter digestibility estimates of Hereford and Friesland bulls while they were confined in the Calan gate facility. The dry matter digestibility estimates of the Friesland bulls was 6 % lower ($P < 0.05$) than the Hereford bulls. The Friesland bulls had a heavier body weight and could have consumed more grass at the expense of digestibility. Dry matter digestibility using alkanes was also compared between that of the Hereford bulls in the Calan gate facility and those on the pasture. There was no significant difference between the sites, with 655 g/kg DM (equivalent to 9.1 MJ ME/kg DM (AAC, 1990)) being the average dry matter digestibility.

Chapter 5

Kikuyu dry matter digestibility of Hereford and Friesland bulls

5.1 Introduction

Kikuyu dry matter digestibility estimates were measured for a period of five days while animals were confined to metabolic crates to determine if there was a significant difference between Hereford and Friesland bulls. The investigation was carried out at Cedara's metabolic crate facility from the 24 to 28 February 1997. The adaptation period extended from 17 to 23 February 1997.

5.2 Materials and methods

5.2.1 Experimental design

Six metabolic crates were available for this investigation. Instead of randomly allocating three bulls per breed, the selection criterion was based on live weight. At the time of selection the average Friesland bull weighed 374 kg while the average Hereford bull weighed 294 kg. To reduce the effect of live weight differences, the three lightest Friesland bulls (excluding steers, were FB1, FB2, FB3; average weight of 341 kg) and the three heaviest Herefords (HB1, HB4, HB5; average weight of 338 kg) were selected for this investigation. The experimental design was that while the three Hereford and three Friesland bulls were confined to metabolic crates, measures would be taken to estimate intake and dry matter digestibility of kikuyu.

5.2.2 Experimental measures

Kikuyu grass was cut and fed to the animals according to the procedure described in Section 4.2.2. However, the grass was not chopped. Feed wastage was minimized by filling the feed trough only half full with grass several times a day. A mineral lick was also supplied to the animals.

Kikuyu intake and weight of faeces produced were recorded daily for each animal. The composite grass sample and all faeces samples were oven dried (60 °C), milled (0.5 mm screen) and analysed for the following: crude protein, ash, calcium, phosphorous, neutral detergent fibre and acid detergent fibre content.

A thermometer was placed in the metabolic shed and the daily maximum temperature (°C) was recorded.

5.2.3 Statistical methods

The Genstat 5 (Release 3.1) statistical program (Lawes Agricultural Trust, Rothamsted Experimental Station) was used for statistical analyses. Statistical differences between treatment means were determined from analysis of variance tables with the use of the Students t-test at the 5 % level.

5.3 Results and Discussion

Dry matter digestibility estimates were analysed to determine if there was a significant difference between

Friesland and Hereford bulls.

The data used to derive the treatment means is contained in **Appendix C.**

5.3.1 Kikuyu composition

Average composition of the kikuyu grass samples taken daily during the dry matter digestibility investigation are presented in Table 5.1

Table 5.1: Average composition (g/kg DM) of kikuyu samples during the dry matter digestibility investigation

Measurement	Mean	CV %
Crude protein (g/kg DM) (±SE)	155.1 (±17.5)	21
NDF (g/kg DM) (±SE)	628.5 (±20.8)	7
ADF (g/kg DM) (±SE)	309.4 (±3.2)	4
Ash (g/kg DM) (±SE)	91.6 (±6.8)	13
Calcium (g/kg DM) (±SE)	2.66 (±0.06)	7
Phosphorous (g/kg DM) (±SE)	3.36 (±0.25)	14

From the chemical composition, the kikuyu for the dry matter digestibility investigation could be classified as kikuyu in average condition when compared with trends from literature (discussed in Section 2.4). Although the grass was cut from the same camp as that for the Calan gate investigation (took place in December 1996) the increased crude protein content (of 67 g/kg DM) could be due to most of the mature residual winter material had been removed and the camp would have been grazed more frequently since the dry matter digestibility investigation (which took place end of February 1997).

5.3.2 Dry matter digestibility estimates

Average intake, faecal and dry matter digestibility estimates of the breeds are presented in Table 5.2.

Table 5.2: Intake, faecal production and dry matter digestibility estimates of Hereford (HB) and Friesland (FB) bulls during the dry matter digestibility investigation			
Measurement	**HB (n = 3)**	**FB (n = 3)**	**CV %**
Intake (kg DM/d) (±SE)	7.3 [a] (±0.3)	8.3 [b] (±0.4)	18
Intake (g DM/kg W $^{0.75}$/d) (±SE)	93 [a] (±4.5)	105 [b] (±5.2)	18
Faecal production (kg DM/d) (±SE)	2.2 [#] (±0.1)	2.4 [#] (±0.1)	14
Faecal production (g DM/kg W $^{0.75}$/d) (±SE)	29 (±1.4)	31 (±1.3)	14
Faecal dry matter (%) (±SE)	10.0 [a] (±0.32)	13.4 [b] (±0.18)	3
Dry matter digestibility (g/kg DM) (±SE)	[1] 687 (±166)	[2] 704 (±145)	7

[a,b] Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

[#] $F_{Probability} = 0.070$

[1] equivalent to 9.7 MJ ME/kg DM (AAC, 1990)

[2] equivalent to 10.0 MJ ME/kg DM(AAC, 1990)

Similarly to the intake investigation discussed in Section 4.3.3.3 the intake of the Friesland bulls was significantly greater (on a kg DM/day basis) than the Hereford bulls. However, unlike Section 4.3.3.3 where intake was not significantly different when expressed in g DM/kg W $^{0.75}$/day, intake was significantly different between the Hereford and Friesland bulls when expressed in g DM/kg W $^{0.75}$/day as shown in Table 5.2. The lower dry matter intake of the Hereford bulls may be related to a body condition (as described in Section 3.3.4) since there is a negative relationship between dry matter intake and fat content (Forbes, 1986).

There was no significant difference in the faecal production between the Hereford and the Friesland bulls. An average amount of 2.3 kg DM of faecal material was produced per animal per day. However an interesting difference between the breeds is the significant difference in dry matter content of the faeces. The Friesland's produced significantly drier faeces.

There was no significant difference in the dry matter digestibility estimates as shown in Table 5.2 of the Friesland and Hereford bulls. The dry matter digestibility estimates (of the digestibility investigation) were higher than the digestibility estimates calculated by the alkane method (in the intake investigation, reported in Table 4.6), but may be due to variation in herbage quality over the season.

5.3.3 Nutrient digestibility and faeces composition

Average composition of faeces samples and nutrient digestibility taken during the dry matter digestibility investigation are presented in Table 5.3.

Table 5.3: Average composition (g/kg DM) of faeces samples and average nutrient digestibility (g/kg) for the Hereford (HB) and Friesland (FB) bulls during the dry matter digestibility investigation

Measurement	HB (n = 3)	FB (n = 3)	CV %
Crude protein (g/kg DM) (±SE)	133 [a] (±1.9)	142.7 [b] (±1.7)	4
NDF (g/kg DM) (±SE)	559.3 [a] (±4.7)	545.8 [b] (±8.2)	3
ADF (g/kg DM) (±SE)	316.7 (±5.0)	318 (±5.8)	4
Crude protein digestibility (g/kg) (±SE)	728 (±13.2)	723 (±13.4)	5
NDF digestibility (g/kg) (±SE)	718 (±19.3)	739 (±18.1)	9
ADF digestibility (g/kg) (±SE)	678 (±20.3)	694 (±18.1)	9

[a,b] Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

It may seem that the faeces crude protein content of the Friesland bulls is significantly higher (by 7 %) than the Hereford bulls thus implying that the Friesland bulls could have been less efficient at extracting protein from the grass, or may have produced more microbial nitrogen in the hind gut, than the Hereford bulls. However, the crude protein, ADF and NDF digestibility estimates were not significantly different between the breeds and further confirms that nutrients extracted from the grass is the same between the Hereford and Friesland bulls.

5.3.4 Maximum temperatures

The average maximum temperature recorded during the dry matter digestibility investigation at the metabolic crate facility was 26.5 °C. There was no relationship between temperature and kikuyu intake for the animals in the metabolic crate facility.

5.4 Summary

The kikuyu dry matter digestibility of the three Hereford and three Friesland bulls was compared over a period of five days while the animals were confined to metabolic crates. To reduce the effect of live weight differences, the three lightest Friesland bulls and the three heaviest Herefords were selected for this investigation. There was no significant difference between Hereford and Friesland bulls in the dry matter digestibility of kikuyu. The average dry matter digestibility estimate was 696 g/kg DM (equivalent to 9.8 MJ ME/kg DM (AAC, 1990)).

Significant differences in intake, when expressed in kg DM/d and when expressed in terms of metabolic weight (g DM/kg $W^{0.75}$/d) were present between the breeds. The Friesland bulls consumed (105 g DM/kg $W^{0.75}$/d) 11 % more kikuyu than the Hereford bulls (93 g DM/kg $W^{0.75}$/d).

There was no significant difference between Hereford and Friesland bulls in the amount of faeces produced (average faeces produced per animal per day was 2.3 kg DM) or nutrient digestibility estimates. The Friesland bulls produced more concentrated faeces (25 % drier) than the Hereford bulls.

Chapter 6

Faecal marker excretion patterns of Hereford and Friesland bulls

6.1 Introduction

Markers were orally administered to the Hereford and Friesland bulls and faecal samples were collected for a period of four days. Marker concentrations were plotted graphically over time to determine if there was a significant difference in the residence time of kikuyu in the digestive tract between the Hereford and Friesland bulls. The investigation was carried out at Cedara's metabolic crate facility (as described in Chapter 5) from the 21 to 25 February 1997.

6.2 Materials and methods

6.2.1 Experimental design

The experimental design is similar to that described in Section 5.2.1. However, this investigation was done prior to the digestibility study. While the six bulls were confined to the metabolic crates, 2 g of dotriacontane (alkane marker) and one capsule of chromium sesquioxide were orally administered. Faecal samples were collected every three hours for two days and then every 12 hours for a further two days. Two markers were administered to the animals to ensure the reliability of the excretion pattern estimates.

6.2.2 Experimental measures

Faecal samples were collected once the rectum had been cleared of most of the faeces. This procedure was followed so that the sample would be representative of the faeces having passed most recently through the digestive tract.

Faecal samples were oven dried (60 °C) and milled using a 0.5 mm screen. All faecal samples were analysed for dotriacontane according to the alkane method described in Section 4.2.3 and for chromium as described in Section 6.2.3. Faecal marker patterns were modeled using both the Grovum and Williams model (1973) and a Genstat-defined curvilinear model.

6.2.3 Experimental techniques

The alkane method was used as described in Section 4.2.3. Chromium was analysed according to the method by Costigan and Ellis (1987). After faecal samples were dried and milled, 0.2 g of faeces was ashed in heat resistant tubes at 600 °C overnight. After samples were weighed, anti-bumping granules and 0.6 ml of the digestion mix (sulphuric and phosphoric acid) were added. The samples were placed in a heating block for 90 minutes at 140 °C. Once the samples had cooled to below 100 °C, 0.3 ml of potassium bromate (4.5 %) was added to the samples. The tubes containing the samples were placed in the heating block and were heated to 220 °C over 90 minutes. The tubes were then removed from the block and when cooled 9.72 ml of distilled water was added. Samples were shaken and centrifuged. Chromium concentrations were read with the aid of an atomic absorption spectrometer.

6.2.4 Statistical methods

The Genstat 5 (Release 3.1) statistical program (Lawes Agricultural Trust, Rothamsted Experimental Station) was used for statistical analyses. Statistical differences between treatment means were determined from analysis of variance tables with the use of the Students t-test at the 5 % level. Genstat-defined curvilinear curves were used in the analysis of data, where appropriate.

6.3 Results and Discussion

Faecal marker excretion patterns were analysed to determine if there was a significant difference between Hereford and Friesland bulls.

Originally the statistical models were fitted to the alkane and chromium data combined. However, since there was doubt whether the chromium marker passed through the digestive tract with the particulate or liquid phase (discussed in Section 2.5.1) it was decided to analyse for the markers separately.

The data used to derive the treatment means is contained in **Appendix D.**

6.3.1 Faecal marker patterns explained by Grovum and Williams (1973) model

The Grovum and Williams (1973) model is described in Section 2.5.1. Coefficients (k_1, k_2, a_1, a_2, A, TT, MRT, and F), of the model described in equation [2.9], equation [2.10], equation [2.11], equation [2.12] and equation [2.13], were calculated. Average coefficients are presented in Table 6.1 and Table 6.2 for the alkane and chromium markers, respectively.

Table 6.1: Average coefficients derived by the Grovum and Williams (1973) model of Hereford (HB) and Friesland (FB) bulls for the alkane marker

Coefficient	HB (n = 3)	FB (n = 3)	CV %
k_1 (±SE)	0.036 (±0.0012)	0.033 (±0.0013)	7
k_2 (±SE)	0.202 (±0.0259)	0.183 (±0.0285)	25
a_1 (±SE)	7.3 (±0.09)	7.1 (±0.03)	2
a_2 (±SE)	8.8 (±0.19)	8.7 (±0.31)	5
TT (±SE)	9.4 (±0.26)	10.6 (±0.34)	5
A (±SE)	1002 (±94)	878 (±22)	13
MRT (±SE)	42.3 (±1.2)	47.0 (±2.3)	7
F (±SE)	89.7 (±5.9)	92.4 (±5.1)	10

[a,b] Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

Digesta flow from the rumen (represented by k_1) is not significantly different between the two breeds as represented in Table 6.1. Likewise, the digesta flow from the caecum and proximal colon (represented by k_2) is not significantly different between the Hereford and Friesland bulls. The first appearance of the marker in the faeces (TT) (average is 10 hours), the mean retention time (MRT) (average is 44.6 hours) and the rate of faeces produced (average is 91 g DM/hour) were not significantly different between the Hereford and Friesland bulls.

The rate of faeces produced (F) compared favourably with the results obtained in the metabolic crate investigation: 2.15 kg DM from the Grovum and Williams model versus 2.2 kg DM measured in the metabolic crate investigation for the Hereford bulls. Likewise, the Grovum and Williams model calculated 2.22 kg DM versus 2.4 kg DM of faecal matter measured in the metabolic crate investigation for the Friesland bulls.

The alkane concentration data and the Grovum and Williams model are plotted in Figure 6.1.

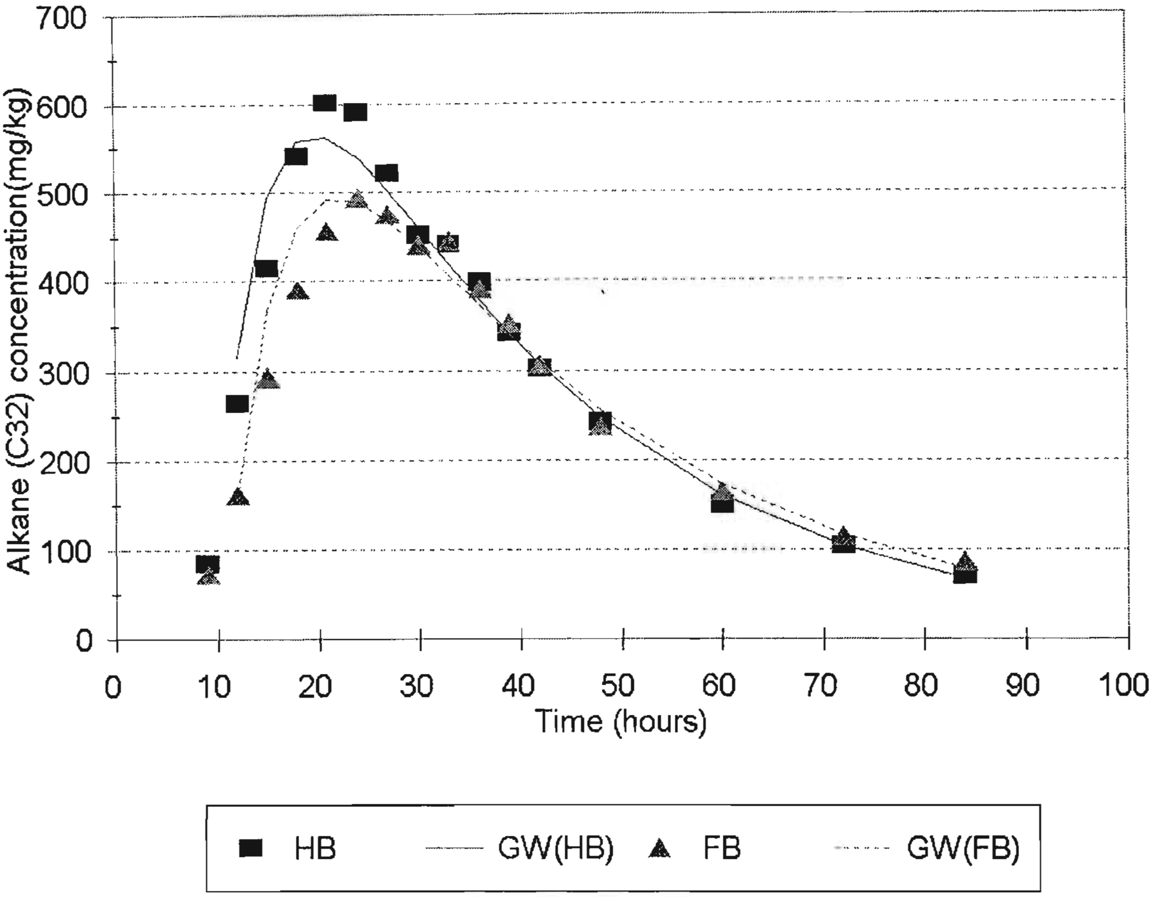

Figure 6.1: Grovum and Williams model describing digesta flow (equation [2.9] and coefficients from Table 6.1) of Hereford (HB) and Friesland (FB) bulls for the alkane marker (mg/kg DM) over time (hours).

Although the alkane marker peaked (shown in Figure 6.1) earlier and at a higher concentration for the Hereford bulls than for the Friesland bulls, the analysis of variance of the coefficients of Grovum and Williams model (Table 6.1) indicates that digesta flow and mean retention times were not significantly different between the breeds.

Table 6.2: Average coefficients derived by the Grovum and Williams (1973) model of Hereford (HB) and Friesland (FB) bulls for the chromium marker

Coefficient	HB (n = 3)	FB (n = 3)	CV %
k_1 (±SE)	0.049 (±0.0009)	0.047 (±0.0029)	8
k_2 (±SE)	0.204 (±0.0284)	0.166 (±0.0067)	19
a_1 (±SE)	9.2 (±0.14)	9.1 (±0.12)	3
a_2 (±SE)	10.7 (±0.28)	10.4 (±0.16)	3
TT (±SE)	10.0 (±0.66)	11.4 (±0.80)	12
A (±SE)	5878 (±709)	5101 (±612)	20
MRT (±SE)	35.3 (±0.29)	38.6 (±2.13)	7
F (±SE)	79 (±5.3)	84 (±20.0)	29

[a,b] Values bearing different superscripts in the same row are significantly different (P < 0.05)

Similar trends as with Table 6.1 are present in Table 6.2. No significant differences were present for any of the coefficients. The average mean retention time (37 hours) was lower than the average mean retention time of the alkane marker (44.6 hours). This indicates the chromium definitely passed through the bull's digestive tract at a faster rate and may have associated more closely with the liquid phase (as discussed in Section 2.5.1).

6.3.2 Faecal marker patterns explained by Genstat QDQ curve

The best fitting Genstat curve that fitted the curvilinear data was a QDQ curve, defined in equation [6.1].

$$y_i = A + \frac{B + Cx_i}{1 + Dx_i + Ex_i^2} \qquad [6.1]$$

The QDQ curve for the alkane faecal concentrations accounted for 91 % of the variance. The equation describing the Hereford rate of passage was:

$$y = -83.5(\pm 45.8) + \frac{-135.5(\pm 60.3) + 25.33(\pm 8.06)x}{1 - 0.073(\pm 0.0054)x + 0.0025(\pm 0.00027)x^2} \qquad [6.2]$$

and that for the Frieslands was:

$$y = -65.7(\pm 52.1) + \frac{-56.1(\pm 42.1) + 15.17(\pm 5.65)x}{1 - 0.061(\pm 0.0062)x + 0.0018(\pm 0.0002)x^2} \quad [6.3]$$

The accumulated analysis of variance indicates that there was a significant difference between all parameters of the curve i.e. completely separate curves fit the data as shown in Figure 6.2.

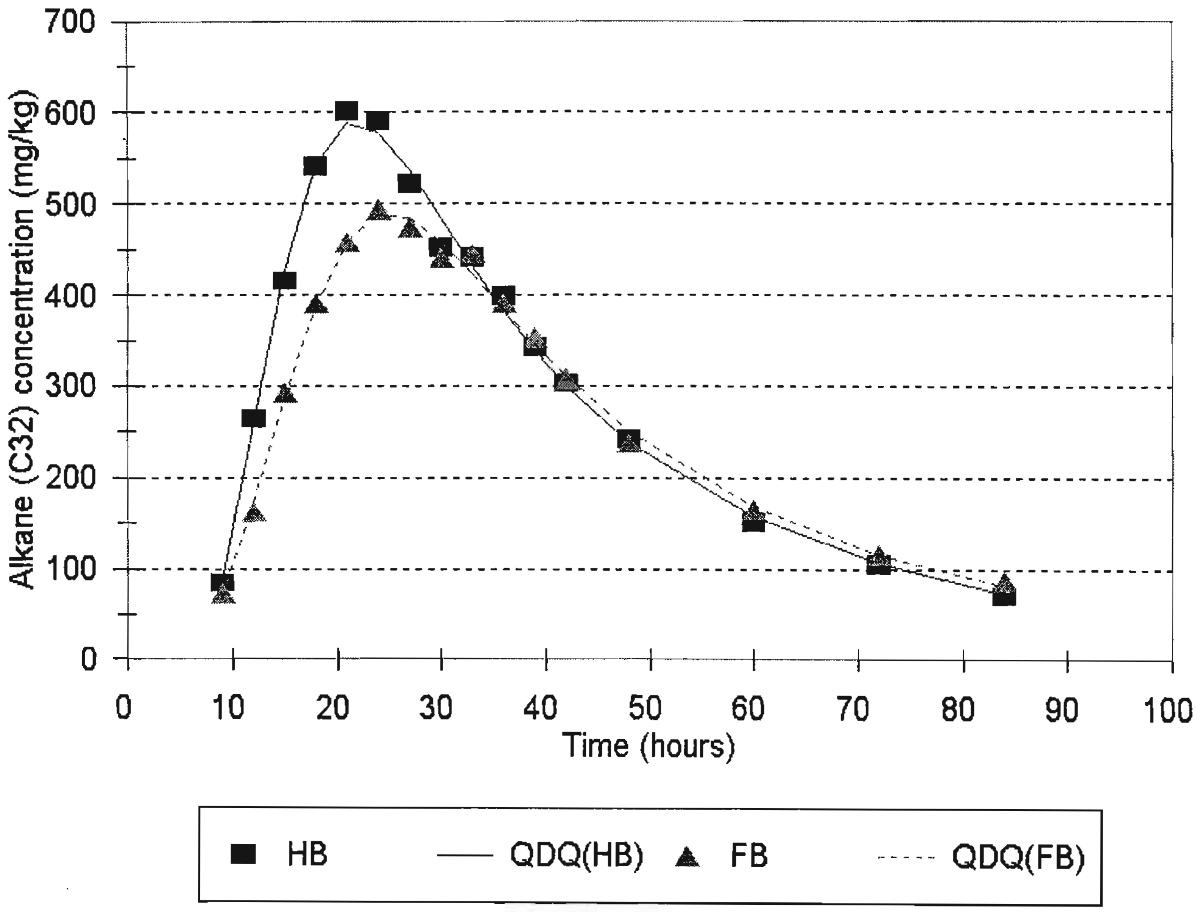

Figure 6.2: QDQ model describing digesta flow (equation [6.4] and [6.5]) of Hereford (HB) and Friesland (FB) bulls for the alkane marker (mg/kg DM) over time (hours) ($r^2 = 0.91$).

The QDQ curve for the chromium faecal concentrations accounted for 88 % of the variance. The equation describing the Hereford rate of passage was:

$$y = -594.6 + \frac{-252.9 + 91.43x}{1 - 0.07(\pm 0.0030)x + 0.0022(\pm 0.00015)x^2} \quad [6.4]$$

and that for the Frieslands was:

$$y = -393.8 + \frac{-673.8 + 90.62}{1 - 0.07(\pm 0.0030)x + 0.0022(\pm 0.00015)x^2} \quad [6.5]$$

From the accumulated analysis of variance only the linear parameters (A, B and C) were significantly different between the Hereford and Friesland breeds.

The inconsistent trend of the non-linear parameters (D and E) being significantly different in the alkane faecal concentration and not in the chromium concentrations, was most likely due to the chromium associating with the liquid phase in the digestive tract and not with the particulate phase as with the alkane marker. This result is in agreement with Van Soest (1982).

Average peak times from the QDQ curve for Hereford and Friesland bulls are presented in Table 6.3.

Table 6.3: Average peak times (hours) of Hereford (HB) and Friesland (FB) bulls calculated from the QDQ curve

Measurement	HB (n = 3)	FB (n = 3)	CV %
Peak time (alkane) (±SE)	21.9 (±0.68)	25.4 (±1.79)	10
Peak time (chromium) (±SE)	21.3 (±0.87)	25.2 (±1.77)	10

[a,b] Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

The analysis of variance data indicated that there was no significant difference in the peak time of digestion (as shown in Table 6.3). Although the alkane QDQ curve identified two different curves for the Hereford and Friesland bulls, the peak times of digestion was consistent with the mean retention time of the Grovum and William's model in that there were no significant differences between the Hereford and Friesland bulls.

Although the peak times (Table 6.3) and the mean retention times (Table 6.1 and Table 6.2) were not significantly different it was interesting to note that the Friesland bulls had a longer peak time and a longer mean retention time. This was surprising since intake was greater (Chapter 5) and it was expected that digesta flow should have been greater than the Hereford bulls. Initially it was speculated that the Friesland bulls had an inability to digest fibre comprehensively (Section 1.2). However this is not true since in Table 5.3 (Section 5.3.3) the Friesland bulls extracted more NDF and ADF fractions from the grass (although this trend is not significantly different). So far it has been assumed, which may be incorrect, that the gut volume would be constant between the Hereford and Friesland bulls. Bearing in mind equation [2.6] as intake increases either the volume size increases or the retention time (denominator) decreases but retention time was longer therefore volume must have increased. The Friesland bulls could have had a greater gut volume which would agree with the lower marker concentration (see Figure 6.1) and could explain why the peak time and mean retention time were delayed and why the NDF and ADF digestibility estimates (Section 5.3.3) were greater (although not significantly different) than in the Hereford bulls.

6.3.3 Faecal marker patterns explained by Genstat gompertz curve

The best fitting Genstat curve that fitted the accumulated marker concentration was a gompertz curve defined as:

$$y = A + Ce^{-e^{-B(x-D)}} \quad [6.6]$$

The gompertz curve fitted to the accumulated alkane concentrations accounted for 97 % of the variance. The equation for the Hereford bulls was:

$$y = 104.3 + 5489e^{-e^{-0.0986(\pm 0.0049) \times (x-22.6(\pm 0.55))}} \quad [6.7]$$

and that for the Frieslands bulls was:

$$y = -117.4 + 4945e^{-e^{-0.0986(\pm 0.0049) \times (x-22.6(\pm 0.55))}} \quad [6.8]$$

The analysis of variance indicates that only the linear variables (A and C) were significantly different between the breeds i.e. the Herefords had a higher alkane concentration. The same trend applied to the accumulated chromium concentrations as shown in Figure 6.3. The equation for the Hereford bulls was:

$$y = 653.5 + 24177e^{-e^{-0.103(\pm 0.0074) \times (x-22.3(\pm 0.80))}} \quad [6.9]$$

and that for the Frieslands was :

$$y = -1111 + 20882e^{-e^{-0.103(\pm 0.0074) \times (x-22.3(\pm 0.80))}} \quad [6.10]$$

The percentage variance accounted for was 93 % and only the linear variables were significantly different.

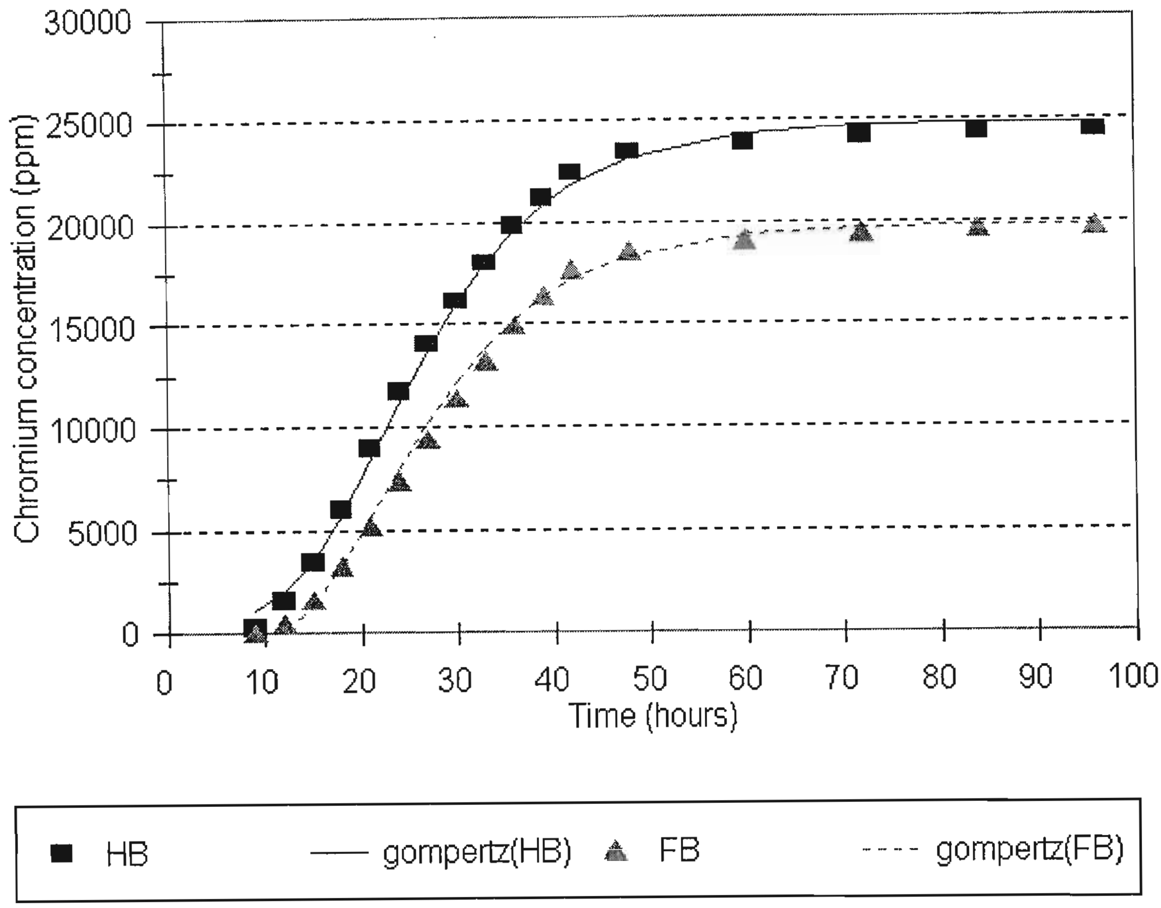

Figure 6.3: Gompertz model describing chromium marker concentration accumulation (ppm) (equation [6.7] and [6.8]) of Hereford (HB) and Friesland (FB) bulls over time (hours) (r^2 = 0.93).

That only the linear variables were significantly different implied that the total concentration of the marker over time was lower in the Friesland bulls. This supported the hypothesis that the Friesland bulls could have had a greater gut volume which the marker would be dispersed in. Gut volume would have to be measured to quantify the relationship of digesta flow comprehensively.

6.4 Summary

Markers were administered to three Hereford and three Friesland bulls while confined to the metabolic crates and faecal samples were collected every three hours for two days and then every 12 hours for a further two days.

The faecal marker patterns were analysed using the Grovum and Williams model, Genstat QDQ and gompertz curves. The Grovum and Williams model indicated that there were no significant differences in the digesta flow through the digestive tract for the Hereford and Friesland bulls for both the alkane and chromium marker.

The alkane QDQ curve analysis fitted two separate curves for the digesta flow (r^2 = 0.91) but peak time was not significantly different between the breeds (average was 23.7 hours). The chromium QDQ curve analysis revealed that only the linear parameters were significantly different between the breeds and that peak time was not significantly different between the breeds (average was 23.3 hours).

The gompertz curve analysis (alkane and chromium) only indicated that the linear parameters were significantly different i.e. the Herefords had a greater accumulation of marker concentration over time.

Chapter 7

Grazing behaviour of Hereford and Friesland bulls

7.1 Introduction

Animal activity (time spent grazing, ruminating and idling) was recorded over a 24 hour period to determine if there was a significant difference between the activity of Hereford and Friesland bulls while on kikuyu pasture. The investigation was performed at Cedara on the 7 and 23 April 1997.

7.2 Materials and methods

7.2.1 Experimental design

The experimental design was that while eight Hereford and five Friesland bulls were grazing the same kikuyu pasture their activity was recorded every three to five minutes for 24 hours. The observation of animal behaviour was done twice.

7.2.2 Experimental measures

Animal activity was classified into three categories: grazing, ruminating ("chewing the cud") or idling (which included drinking water, playing, resting or any other activity).

7.2.3 Climatic conditions

The climatic conditions for both behaviour observations is reported in Table 7.1.

Table 7.1: Climatic data for the behaviour study investigation (Institute for Soil, Climate and Water, 1997)

Factor	Study 1 7/4/97	Study 2 23/4/97
Sunrise (HH:MM)	6:17	6:26
Sunset (HH:MM)	17:45	17:28
Day length (HH:MM)	11:29	11:02
Maximum temperature (°C)	16.8	21.5
Minimum temperature (°C)	3.5	12.3
Average temperature (°C)	10.2	16.9
Rainfall (mm)	0.0	0.8
Evaporation (mm)	5.5	1.8

7.2.4 Statistical methods

The Genstat 5 (Release 3.1) statistical program (Lawes Agricultural Trust, Rothamsted Experimental Station) was used for statistical analyses. Statistical differences between treatment means were determined from analysis of variance tables with the use of the Students t-test at the 5 % level. Regression analysis, where possible, was also performed.

7.3 Results and discussion

Animal activity was analysed to determine if there was a significant difference between the activity of Hereford and Friesland bulls. Although the Friesland steers had caught up to the Hereford bulls in terms of growth (see Figure 3.3) the Friesland steer data was excluded from the behaviour investigation for consistency with Chapter 2 and Chapter 4.

The data used to derive the treatment means is contained in **Appendix E.**

7.3.1 Kikuyu composition

The chemical composition of the kikuyu pasture of the behaviour investigation is reported in Table 7.2.

Table 7.2: Composition (g/kg DM) of the kikuyu pasture during the behaviour study investigation

Measurement	Study 1 7/4/97	Study 2 23/4/97
Crude protein (g/kg DM)	176	236
Calcium (g/kg DM)	2.6	2.9
Neutral detergent fibre (g/kg DM)	629	554
Acid detergent fibre (g/kg DM)	295	255
Phosphorous (g/kg DM)	3.4	2.4
Ash (g/kg DM)	102	112

These kikuyu samples (as shown in Table 7.2) were comparable to the quality of the pasture grass from Chapter 4 which was to be expected since it was collected from a long established pasture with a good nutrient status. The difference in crude protein content (60 g/kg DM) between the first and second behaviour study could be due to weather conditions.

7.3.2 Activity analysis

The breed means for time spent grazing, ruminating and idling are reported in Table 7.3.

Table 7.3: Average animal activity (minutes) of Hereford (HB) and Friesland (FB) bulls per 24 hour period

Measurement	Study 1 7/4/97			Study 2 23/4/97		
	HB (n = 8)	FB (n = 5)	CV %	HB (n = 8)	FB (n = 5)	CV %
Grazing (min) (±SE)	455 (±15)	451 (±36)	13	452 (±16)	400 (±28)	12
Ruminating (min) (±SE)	545 (±15)	515 (±15)	9	449 (±12)	449 (±28)	11
Idling (min) (±SE)	440 (±21)	474 (±48)	18	539 (±16)	591 (±37)	11

[a,b] Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

The analysis of variance data summarised in Table 7.3 indicates that there was no significant difference between the behaviour of the Hereford bulls and Friesland bulls and steers. Upon further analysis, when an analysis of variance was carried out on pooled values of both behaviour studies, no significant differences were found.

The time spent grazing by both breeds was the same in both studies. The amount of time spent ruminating and idling changed from study 1 to study 2. The longer time the animals spent ruminating during study 1 was possibly due to the higher neutral detergent and acid detergent fibre content which causes greater chewing activity. The results of the animal activity investigation are in agreement with other studies (Inwood, *et al.*, 1992; Khadem, *et al.*, 1993; Morris, *et al.*, 1993).

Analysis of variance was done comparing the breed activity for 6 hour time intervals (07:00 to 13:00; 13:00 to 19:00; 19:00 to 01:00 and 01:00 to 07:00) to investigate whether activity varied throughout the day. However, the coefficients of variation for the information were too high to be of any statistical value.

Finding no significant difference between grazing (or other activities) for Hereford and Friesland bulls confirmed the result of Chapter 4 with there being no significant difference in the intake of Hereford and Friesland bulls while consuming kikuyu pasture.

Average grazing time (minutes per hour) of the breeds for each behavior study are shown in Figure 7.1. The graphs support the trend in Table 7.3, that there was no difference in the grazing frequency of the Hereford and Friesland bulls.

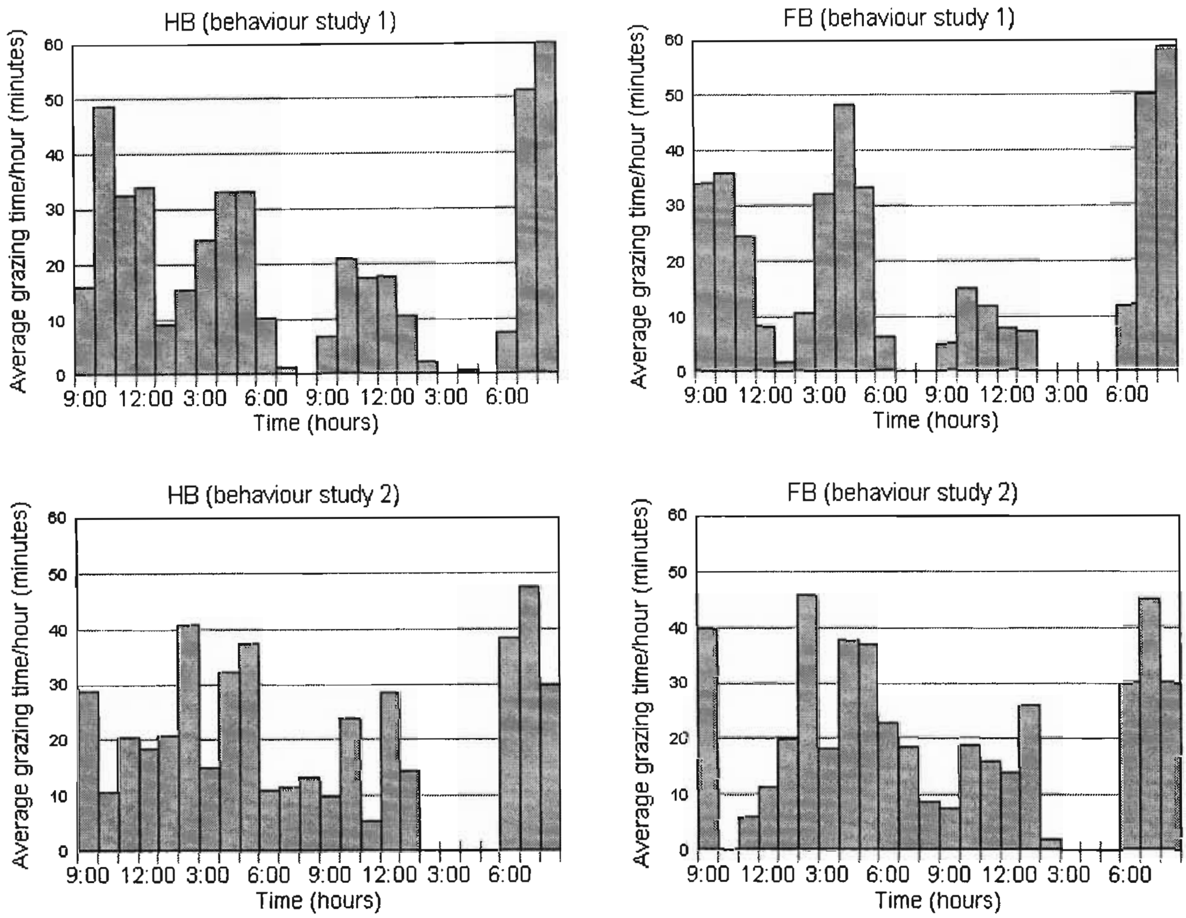

Figure 7.1: Average grazing time (minutes) per hour of Hereford (HB) and Friesland (FB) bulls for both the behaviour studies.

7.4 Summary

Animal activity (time spent grazing, ruminating and idling) was measured over two 24 hour periods. No significant difference was found between the time the Hereford and Friesland bulls performed each activity. Changes in non-grazing activity between the studies was possibly related to weather. The average bull spent 30 % of the day grazing, 34 % of the day ruminating and 36 % of the day was spent idling, for both studies combined.

Chapter 8

Internal organ masses of Hereford and Friesland bulls

8.1 Introduction

The bulls were slaughtered at Cato Ridge abattoir on the 15 May 1997. The internal organs were weighed to determine if there was a significant difference between the organs of the Hereford and Friesland bulls.

8.2 Materials and methods

8.2.1 Experimental design

The experimental design was that once the five Hereford and five Friesland bulls had been slaughtered the internal organs would be weighed. The five heaviest Hereford bulls were chosen (HB1, HB2, HB4, HB5 and HB8; average mass 365 kg) to compare with the five Friesland bulls (average mass 420 kg).

8.2.2 Experimental measures

The internal organs weighed were the heart, liver, lungs plus trachea and spleen.

8.2.3 Statistical methods

The Genstat 5 (Release 3.1) statistical program (Lawes Agricultural Trust, Rothamsted Experimental Station) was used for statistical analyses. Statistical differences between treatment means were determined from analysis of variance tables with the use of the Students t-test at the 5 % level.

8.3 Results and discussion

It was intended that the digestive tracts (including the rumen) would be weighed with and without gut contents to determine if there was a significant difference between Hereford and Friesland bulls. However, the abattoir's policy of not allowing non-employees in certain parts of the abattoir, and the rapid movement of the digestive tracts down the chute (identification tags of organs were removed) made this investigation impossible.

Internal organ data were analysed to determine if there was a significant difference between the organ size of Hereford and Friesland bulls. Internal organ mass was also expressed in terms of the ratio organ mass/kg metabolic weight (before slaughter metabolic weight) to remove the bias due to the larger Friesland animals.

The data used to derive the treatment means is contained in **Appendix F.**

Average mass of the internal organs of the bulls are shown in Table 8.1.

Table 8.1: Carcass and internal organ weights (kg) and ratio's of Hereford (HB) and Friesland (FB) bulls

Measurement	HB (n = 5)	FB (n = 5)	CV %
Live weight (kg) (±SE)	356 # (±18)	420 # (±21)	11
Metabolic weight (kg $W^{0.75}$) (±SE)	81.9 # (±3.1)	92.7 # (±3.5)	9
Warm carcass mass (kg) (±SE)	171 [a] (±9)	209 [b] (±14)	14
Heart mass (kg) (±SE)	1.37 ● (±0.10)	1.65 ● (±0.08)	13
Liver mass (includes bile) (kg) (±SE)	5.31 [a] (±0.38)	6.47 [b] (±0.25)	12
Lung (& trachea) mass (kg) (±SE)	5.62 (±0.44)	5.97 (±0.24)	14
Spleen (kg) (±SE)	1.24 (±0.12)	1.68 (±0.18)	24
Heart/metabolic mass (g/kg $W^{0.75}$) (±SE)	16.7 (±0.66)	17.8 (±0.51)	8
Liver/metabolic mass (g/kg $W^{0.75}$) (±SE)	64.5 (±2.7)	70.0 (±2.5)	9
Lung/metabolic mass (g/kg $W^{0.75}$) (±SE)	68.2 (±2.9)	64.2 (±2.4)	9
Spleen/metabolic mass (g/kg $W^{0.75}$) (±SE)	15.1 (±0.99)	16.6 (±2.3)	18

[a,b] Values bearing different superscripts in the same row are significantly different ($P < 0.05$)

● $F_{Probability} = 0.055$

$F_{Probability} = 0.051$

The analysis of variance summarised in Table 8.1 indicates that the Friesland bulls had significantly heavier carcasses than the Hereford bulls. This was to be expected and confirms the results of Section 3.3.2 where the Friesland bulls were significantly heavier at the start and end of the growth period although the average daily gain was not significantly different from the Hereford bulls. Likewise, there was no significant difference (except for the liver) in the organ masses or the ratio's of organ mass/warm mass between the Hereford and Friesland bulls. The weight of the Friesland bulls' heart, liver, lungs and spleen were all slightly greater, even though the difference was not statistically significant, than that of the Hereford bulls presumable because the Frieslands were larger animals.

8.4 Summary

The internal organs (heart, liver, lungs plus trachea and spleen) of the Hereford and Friesland bulls were weighed when animals were slaughtered. The larger Friesland animals had heavier warm carcass masses, however, there was no significant difference (except for the liver) in the internal organ masses. There was no significant difference between Hereford and Friesland bulls once organ mass was divided by the metabolic mass.

Chapter 9

Conclusions and recommendations

9.1 Conclusions

Although all the objectives discussed in Section 1.4 were achieved, there were some unexpected results.

Growth parameters (detailed in Chapter 3) of Hereford and Friesland bulls was not significantly different. The Friesland bulls were, in total, 71 kg heavier ($P < 0.05$) at the start of the trial and 91 kg heavier ($P < 0.05$) at the end of the trial, than the Hereford bulls. However the average weight gain during the trial period was not significantly different for the two breeds. The average weight gain of all the animals was 0.66 kg per day. The Friesland bulls gained 0.73 kg per day while the Hereford bulls gained 0.61 kg per day.

Although it is not appropriate to compare the performance of bulls with heifers or even animals of the same sex between different years, because of management and season effects, the data of Horne (1996) and Fushai (1997) will be considered briefly. The average daily gain of the Friesland bulls of the current investigation was 0.7 kg when fed kikuyu *ad libitum*, and compares favourably with the growth rate of the Friesland heifers (ADG of 0.5 kg/d) of Fushai's investigation, but not with the growth rate of the Friesland heifers (ADG was zero) of Horne's investigation (Horne, 1996). The Hereford heifers of Horne's investigation had a growth rate of 0.8 kg per day while in Fushai's investigation the growth rate varied between 0.7 and 1.2 kg per day. The average daily gain of the Hereford bulls in the current investigation was 0.6 kg per day in contrast, however is not significantly different, to the heifers performance.

Provided nutrition is not limiting, bulls should have a higher growth rate than heifers of the same genotype (see Table 2.1). However if nutrition becomes the limiting factor, the effects should be more noticeable in the bulls because of their greater nutrient requirement over that of the heifers. The same principle applies to late maturing breeds, i.e. the effects of limiting nutrition should have a greater impact in late maturing breeds than in early maturing breeds.

The poor performance of the Friesland heifers on kikuyu pasture could be due to an interaction of factors. The greater energy requirements (20 %) of dairy and dual purpose breeds over beef breeds (NRC, 1996; in Section 2.5.3) could contribute to the poor performance of the Friesland heifers relative to Hereford heifers. Although, the Friesland heifers in Horne's (1996) investigation had a positive response to energy supplementation (ADG increased by 0.6 kg/d), the Friesland heifers in Fushai's (1997) investigation did not (ADG stayed the same). The greater nutrient requirements of a late maturing breed over an early maturing breed could contribute to the poor performance of the Friesland heifers, relative to the Hereford heifers. However, if these factors were responsible for the poor performance of the Friesland heifers on kikuyu, the Friesland bulls should have been similarly affected with a lower growth rate because of their greater nutrient requirements, relative to that of the heifers. The results in the current study do not substantiate this hypothesis. Although there is no apparent biological reason, the work of Horne (1996) and Fushai (1997), relative to this study, point to a gender factor (possibly associated with milk producing ability; as discussed in Section 2.5.3), where Friesland heifers have limited performance on kikuyu pasture.

The alkane method compared favourably with the Calan gate method for intake estimation (presented in Chapter 4) with the average intake being 6.23 kg DM per day or 93.2 g DM/kg $W^{0.75}$/day (coefficient of variation was 22 and 23 %, respectively). Although the intake estimates generated by the alkane method did not differ significantly from the Calan gate method there was a significant difference between the faecal sample collecting times ($P < 0.05$). The morning value under-estimated actual intake by 11 % while the afternoon value over-estimated actual intake by 9 %. When intake was expressed on a quantitative basis (kg DM) the Friesland bulls consumed 12 % more kikuyu ($P < 0.05$) than the Hereford bulls since they were 80 kg heavier than the Hereford bulls. However, when intake was reported in terms of g DM/kg $W^{0.75}$/day the difference between the breeds was not statistically significant. The average intake for the bulls in the Calan gate facility was 93.2 g DM/kg $W^{0.75}$/day. When the intake of Hereford bulls in the Calan gate facility was compared to the Hereford bulls on the pasture, no significant difference was found in intake, even though the pasture herbage was potentially of a higher quality (average intake was 102 g DM/kg $W^{0.75}$/day). These breed differences are in contrast to the work of Horne (1996) and Fushai (1997).

The significant differences found in the time analysis (6h00 versus 18h00 collection) of the alkane intake estimation (Chapter 4) and the faecal C_{33}:C_{32} ratio indicate how important the sample collection times are relative to the dotriacontane (C_{32}) administration. Based on the findings in Chapter 4, a recommendation of faecal sampling of 12 hours apart and pooling the sample is made, (while animals consume kikuyu). Further investigation may be required to determine if the problem is limited to kikuyu or the alkane technique.

The alkane method was used to measure apparent dry matter digestibility estimates (presented in Chapter 4) of Hereford and Friesland bulls while they were confined in the Calan gate facility. The dry matter digestibility estimates of the Friesland bulls was 6 % lower ($P < 0.05$) than the Hereford bulls but the Friesland bulls had a heavier body weight and could have consumed more grass at the expense of digestibility. Dry matter digestibility using alkanes was also compared between that of the Hereford bulls in the Calan gate facility and those on the pasture. There was no significant difference between the sites, with 655 g/kg DM being the average dry matter digestibility.

It is of interest to note that the alkane determined intake and digestibility estimates (presented in Chapter 4) of the Hereford bulls in the Calan gate facility and the Hereford bulls on the pasture were not significantly different, although the chemical composition of the kikuyu was significantly different for the CP, ADF and NDF fractions. These results support the findings of Dugmore and Du Toit (1988) where no significant association was found between chemical composition and the digestible organic matter content of kikuyu herbage. Van Soest and Robertson (1980) further support these findings: "the use of fibre to predict digestibility is not based on any solid theoretical basis, other than statistical association". The dry matter digestibility estimates of the Calan gate and pasture Hereford bulls were not significantly different and hence neither was their intake, even though the chemical fractions (CP, ADF and NDF) of the grass were.

There was no significant difference between Hereford and Friesland bulls in the dry matter digestibility of kikuyu (presented in Chapter 5). The average dry matter digestibility estimate was 696 g/kg DM. However there were significant differences in intake, when expressed in kg DM/day and in terms of metabolic weight (g DM/kg W $^{0.75}$/d), between the breeds. The Friesland bulls consumed (105 g DM/kg W $^{0.75}$/d) 11 % more kikuyu than the Hereford bulls (93 g DM/kg W $^{0.75}$/d). There was no significant difference between Hereford and Friesland bulls in the amount of faeces produced (average faeces produced per animal per day was 2.3 kg DM) or nutrient digestibility estimates, although the Friesland bulls produced more concentrated faeces (25 % drier) than the Hereford bulls in the dry matter digestibility investigation.

The voluntary intakes (kg DM) of the bulls recorded in the Calan gate and metabolic crate investigations were on average one kg higher than the values reported by NRC (1988), indicating that intake was comparable to expected intake.

The faecal marker patterns (presented in Chapter 6) were analysed using the Grovum and Williams (1973) model, Genstat QDQ and gompertz curves. The Grovum and Williams model indicated that there was no significant difference in the digesta flow through the digestive tract for the Hereford and Friesland bulls for both the alkane and chromium markers. The alkane QDQ curve analysis fitted two separate curves for the digesta flow ($r^2 = 0.91$) but the peak time was not significantly different between the breeds (average was 23.7 hours). The chromium QDQ curve analysis revealed that only the linear parameters were significantly different between the breeds and that peak time was not significantly different between the breeds (average was 23.3 hours). The gompertz curve analysis for both the alkane and chromium markers only indicated that the linear parameters were significantly different, i.e. the Herefords had a greater accumulation of marker concentration over time. It could be speculated that the Friesland bulls had a greater gut volume in which the marker would be dispersed.

Other than the separate curves fitted by the QDQ curve analysis, there is no indication from the analyses in Chapter 6 that suggest that the Friesland bulls had a faster rate of passage (related to the significant higher dry matter intake measured in the metabolic crates) than the Hereford bulls. This indicates that the Friesland bulls may have had a larger rumen (see equation 2.8) to accommodate a higher intake but similar digestibility estimates to the Hereford bulls. The significantly lower linear parameters of the gompertz model for the Friesland bulls support the hypothesis of the Friesland bulls having a greater rumen volume. A greater rumen capacity could be expected since the Friesland bulls are a late maturing breed. A moot question is whether the Friesland bulls could have a greater rumen capacity relative to their size (live weight/frame size) than the Hereford bulls.

Animal activity (presented in Chapter 7) (time spent grazing, ruminating and idling) was measured over two 24 hour periods. No significant difference was found between the time the Hereford and Friesland bulls performed each activity. Changes in non-grazing activity between the studies was possibly related to weather. The average bull spent 30 % of the day grazing, 34 % of the day ruminating and 36 % of the day was spent idling, for both studies combined.

The internal organs (heart, liver, lungs plus trachea and spleen) of the Hereford and Friesland bulls were weighed when animals were slaughtered (presented in Chapter 8). The larger Friesland animals had heavier warm carcass weights, however, there was no significant difference (except for the liver) in the internal organ weights. There was no significant difference between Hereford and Friesland bulls once organ mass was divided by the metabolic mass.

9.2 Recommendations

If the alkane technique (Dove & Mayes, 1991;1996) is used estimate kikuyu intake, daily faecal samples should be taken 12 hours apart and pooled.

The alkane marker (dotriacontane) proved to be a suitable marker in the determination of faecal marker excretion patterns.

Further work in the flow of digesta and measurement of gut volume needs to be explored in the Friesland breed.

Potential feed intake problems of Friesland heifers should be investigated using heifers and not bulls. However, it may be necessary to determine if the differences in growth between bulls and heifers on kikuyu pasture, are sex-linked.

Given the variability of the Friesland heifer growth rates on kikuyu in Horne (1996) and Fushai's (1997) research, the effects of the environment and rearing program can be investigated with the use of embryo transfer. Friesland embryo's could be implanted in Hereford recipient cows and the intake and growth rate investigation on kikuyu pasture be repeated.

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Appendix A

Growth parameters

The data of the growth parameters (weight, height and condition score) discussed in Chapter 3 is reported in this appendix.

Table A.1: Age (days) of Hereford bulls and Friesland steers at the start of the trial (23/10/96)

Animal number	Age (days)
HB1	435
HB2	419
HB3	409
HB4	374
HB5	384
HB6	378
HB7	381
HB8	374
FS1	267
FS2	263
FS3	302
FS4	271

Table A.2: Weekly weight (kg) values of trial animals

	1996				1997															
	23/10	19/11	26/11	24/12	7/1	16/1	23/1	30/1	6/2	13/2	1/3	6/3	13/3	20/3	27/3	3/4	10/4	17/4	24/4	30/4
days	0	27	34	62	76	85	92	99	106	113	129	134	141	148	155	162	169	176	183	189
HB1	242	254	273	275	298	308	310	310	330	328	336	338	336	360	358	360	374	380	380	380
HB2	226	235	260	269	287	283	288	292	304	308	306	324	314	324	322	322	350	344	335	340
HB3	187	205	216	218	225	231	242	248	259	264	261	285	273	286	291	287	308	316	310	335
HB4	250	247	265	263	272	282	285	294	306	312	302	314	306	324	322	316	346	348	345	355
HB5	304	289	316	316	332	342	350	336	366	374	368	380	378	398	384	378	396	416	400	405
HB6	187	194	209	203	208	213	215	220	234	239	227	241	236	249	249	251	267	258	260	260
HB7	180	196	213	217	226	234	236	242	252	260	262	280	275	283	294	285	306	306	295	315
HB8	195	203	222	236	261	264	251	266	273	269	274	293	283	294	290	289	308	314	305	310
FB1	286	304	316	328	330	334	342	348	356	364	364	382	366	390	380	378	408	388	405	425
FB2	260	269	286	291	300	295	312	312	324	332	324	342	340	354	350	344	368	362	365	375
FB3	256	270	291	295	298	276	287	306	318	326	326	324	340	358	348	340	368	346	360	380
FB4	336	344	368	372	366	384	382	404	406	416	408	418	428	452	442	440	466	454	465	475
FB5	322	344	358	364	402	408	410	418	438	434	434	446	458	470	458	448	488	464	475	490
FS1	#	326	354	330	338	328	296	308	316	334	322	342	336	348	346	346	352	354	335	355
FS2	#	279	302	269	284	266	240	255	272	286	285	302	302	296	298	299	316	316	315	330
FS3	#	257	282	270	264	276	267	285	292	278	260	275	278	294	296	295	314	316	315	330
FS4	#	279	290	270	271	*														

no weight values were recorded for the Friesland steers as they were only purchased on the 23/10/96
* FS4 died on the 10/1/97

Table A.3: Height (cm) measurements of trial animals

	23/10/96	24/12/96	13/2/97	30/4/97
days	**0**	**62**	**113**	**189**
HB1	116	112	118	119
HB2	106	109	115	118
HB3	111	111	111	112
HB4	120	118	118	118
HB5	116	115	117	115
HB6	104	104	105	108
HB7	100	112	106	109
HB8	108	108	108	110
FB1	117	117	120	123
FB2	120	122	122	128
FB3	113	116	119	123
FB4	119	117	125	125
FB5	120	122	130	129
FS1	126	129	129	128
FS2	119	118	118	120
FS3	116	116	120	121
FS4	124	124	*	

* FS4 died on the 10/1/97

Table A.4: Condition score assessments (Mulvaney scale) of trial animals

	23/10/96	24/12/96	13/2/97	28/2/97	30/4/97
days	**0**	**62**	**113**	**129**	**189**
HB1	3.00	2.75	3.25	3.50	3.25
HB2	3.00	3.00	3.25	3.50	3.25
HB3	3.00	2.50	3.25	3.50	3.50
HB4	2.50	2.50	3.25	3.25	3.00
HB5	2.50	3.00	2.75	3.00	3.50
HB6	3.00	2.50	3.25	3.00	3.50
HB7	3.00	3.00	3.25	3.25	3.50
HB8	3.00	2.75	3.25	3.25	3.25
FB1	2.50	2.25	2.50	2.50	2.50
FB2	2.50	2.50	2.50	2.50	2.75
FB3	2.50	2.50	2.75	2.75	2.75
FB4	2.50	3.00	3.00	3.00	3.25
FB5	2.50	2.50	3.00	3.00	3.25
FS1	2.50	2.00	1.50	1.50	1.50
FS2	2.50	2.00	1.25	1.75	2.00
FS3	2.00	1.50	2.00	1.50	2.00
FS4	2.00	1.00	*		

* FS4 died on the 10/1/97

Appendix B

Intake measures

The data of the intake estimates discussed in Chapter 4 is reported in this appendix.

Table B.1: Composition (g/kg DM) of kikuyu fed to trial animals during the intake investigation

Date	DM (g/kg DM)	CP (g/kg DM)	Ash (g/kg DM)	NDF (g/kg DM)	ADF (g/kg DM)	CF (g/kg DM)	Ca (g/kg DM)	P (g/kg DM)
Calan Gate samples								
16/12	187	78.7	83.6	759.8	427.4	320.9	4.1	2.2
17/12	298	78.8	71.7	732.2	409.6	#	3.8	2.0
18/12	281	75.1	71.1	694.4	381.9	#	3.4	1.9
19/12	251	111.5	108.4	754.0	397.8	318.4	5.0	2.7
20/12	278	95.7	94.0	686.4	377.3	319.9	4.2	2.5
21/12	254	99.9	87.8	642.2	349.4	332.9	4.5	2.4
22/12	181	82.2	84.4	701.8	408.4	#	4.1	2.0
23/12	232	78.9	77.9	703.9	373.5	#	3.8	2.2
Pasture samples								
16/12	173	209.6	91.8	575.7	272.9	266.3	3.5	3.4
17/12	188	183.8	98.5	607.3	281.2	242.4	4.2	3.6
18/12	172	230.5	90.8	574.5	258.8	239.7	3.8	3.4
19/12	181	237.3	93.1	597.8	235.7	#	3.9	3.8
20/12	197	220.3	88.5	593.0	251.9	201.7	3.7	3.8
22/12	140	247.6	92.2	603.4	257.2	#	4.2	4.4
23/12	153	215.9	95.1	551.2	236.9	216.5	3.4	4.4

Crude fibre analyses were only performed on selected samples

Table B.2: Calan gate intake estimation (kg DM)

No.	HB1	HB3	HB4	HB6	HB7	FB1	FB2	FB3	FB4	FS3	FS4
14/12	5.39	5.06	4.68	3.22	4.57	6.94	1.72	3.09	7.20	4.43	3.49
15/12	6.3	5.73	3.03	3.96	4.39	5.76	6.27	5.72	3.63	4.69	5.74
16/12	7.19	8.00	4.45	4.07	5.96	7.51	4.69	7.35	0.88#	6.67	6.38
17/12	7.72	8.04	4.06	5.36	5.27	7.25	3.57	7.29	7.11	6.13	4.97
18/12	6.63	4.53	3.88	4.61	2.40	9.40	5.66	5.26	7.34	5.90	4.16
19/12	7.25	6.65	5.13	5.08	6.18	7.51	7.92	7.68	7.89	7.11	2.59
20/12	9.31	6.27	5.41	6.56	6.91	12.29	7.88	8.01	11.04	10.51	1.36$
21/12	8.01	7.67	5.79	5.67	2.73	10.25	4.76	5.04	6.14	2.62	0.55
22/12	6.87	3.43	3.14	2.58	5.61	7.10	4.34	5.56	5.32	5.75	2.23
23/12	5.89	4.52	6.45	5.02	5.72	7.24	5.97	6.74	7.71	5.28	3.68

faulty Calan gate

$ FS4 contacted Red Water

Table B.3: Alkane intake estimation (kg DM) of Calan gate animals

Day	Time	HB1	HB3	HB4	HB6	HB7	FB1	FB2	FB3	FB4	FS3	FS4
16/12	am	8.02	3.94	3.98	4.79	*	6.58	6.07	5.31	8.04	4.39	4.28
16/12	pm	6.30	5.91	4.08	5.28	6.41	8.19	7.09	6.76	6.97	5.38	4.63
17/12	am	*	3.22	*	3.74	4.11	6.18	5.16	5.05	6.63	4.07	3.65
17/12	pm	5.60	*	3.52	4.73	5.73	7.28	7.38	7.01	4.49	5.98	4.87
18/12	am	6.23	*	3.18	3.28	3.54	*	4.83	4.70	2.86	*	4.26
18/12	pm	5.50	4.61	3.41	4.48	5.20	6.41	6.74	5.65	3.02	6.16	4.41
19/12	am	4.02	5.00	4.33	5.55	6.66	8.26	6.53	6.75	4.75	6.27	4.98
19/12	pm	9.01	7.53	4.71	6.31	7.69	9.55	8.89	8.52	8.28	8.21	5.84
20/12	am	7.77	4.84	4.35	5.04	5.11	7.18	6.61	6.82	6.30	5.89	4.92
20/12	pm	8.45	7.05	4.83	6.49	6.78	8.28	9.38	7.99	9.62	8.68	4.44
21/12	am	6.87	5.06	4.55	5.05	*	6.45	6.93	6.91	8.18	6.28	4.45
21/12	pm	8.88	7.04	4.56	*	6.82	7.93	8.13	6.34	9.57	8.11	3.89
22/12	am	7.45	*	5.65	5.16	4.67	*	6.72	6.29	8.44	6.54	4.22
22/12	pm	8.83	6.81	6.39	7.91	4.84	8.12	6.32	7.10	8.58	5.45	2.96
23/12	am	7.62	5.16	4.50	4.69	4.03	7.35	6.29	6.07	7.14	4.25	3.06
23/12	pm	11.61	6.36	5.30	6.10	5.51	7.72	5.84	6.53	7.56	5.85	2.47
24/12	am	5.97	4.17	4.55	2.98	4.96	5.75	4.92	4.76	5.69	5.08	2.26

* denotes missing values

Table B.4: Alkane concentrations (mg/kg DM) of kikuyu fed to animals in Calan gates

Day	C32	C33	C35
16/12	14.0	246.6	262.8
17/12	13.7	252.0	220.0
18/12	13.5	276.9	273.2
19/12	15.7	213.7	202.3
20/12	12.4	215.8	208.3
21/12	14.1	215.0	224.7
22/12	10.7	201.2	210.6
23/12	9.3	204.3	213.7
24/12	9.3	204.3	213.7

Table B.5: Dotriacontane (C_{32}) faecal concentration (mg/kg DM) of Calan gate animals

Day	Time	HB1	HB3	HB4	HB6	HB7	FB1	FB2	FB3	FB4	FS3	FS4
16/12	am	324.9	586.0	711.5	533.8	*	212.5	395.7	444.6	317.0	547.1	584.3
16/12	pm	377.1	441.9	647.9	486.7	332.0	314.2	328.9	374.7	359.6	492.1	558.8
17/12	am	*	670.5	*	626.3	514.0	358.0	386.8	489.7	352.8	571.9	610.4
17/12	pm	364.5	*	704.9	477.4	390.4	343.7	325.4	406.5	494	432.1	592.7
18/12	am	320.8	*	686.3	556.9	460.1	*	387.6	398.3	603.2	*	498.6
18/12	pm	356.2	517.3	681.5	482.1	397.1	334.8	319.6	357.3	578.5	362.6	440.8
19/12	am	737.8	553.3	711.0	506.5	625.1	324.4	390.5	376.2	449.8	458.0	602.5
19/12	pm	301.1	396.9	657.4	479.9	357.6	325.8	373.5	363.3	388.0	408.6	533.2
20/12	am	349.8	552.8	645.3	539.3	443.6	363.0	404.9	306.7	349.7	469.4	580.7
20/12	pm	331.1	50.7	629.4	518.2	460.0	346.2	328.1	372.0	340.9	361.6	491.3
21/12	am	368.2	600.1	588.3	510.6	*	390.2	385.0	424.1	349.6	475.0	656.0
21/12	pm	329.4	469.4	590.2	*	385.3	296.1	304.8	363.3	343.9	371.3	596.8
22/12	am	391.2	*	561.1	524.9	523.8	*	403.2	425.3	410.6	420.8	650.7
22/12	pm	375.5	415.8	524.8	444.4	422.1	351.1	243.4	381.5	276.6	354.0	903.2
23/12	am	387.6	685.2	514.1	587.2	384.0	338.7	358.3	421.4	322.1	470.1	1223.4
23/12	pm	288.0	603.4	495.1	475.9	521.2	251.7	368.7	355.2	368.0	463.2	1350.8
24/12	am	424.9	639.0	555.7	581.3	481.7	328.9	271.8	475.7	419.4	499.7	1270.1

* denotes missing values

Table B.6: Tritriacontane (C_{33}) faecal concentration (mg/kg DM) of Calan gate animals

Day	Time	HB1	HB3	HB4	HB6	HB7	FB1	FB2	FB3	FB4	FS3	FS4
16/12	**am**	577.7	539.7	661.5	591.4	*	315.9	546.0	541.6	565.1	557.7	581.8
16/12	**pm**	538.5	595.2	616.6	590.6	481.3	569.1	523.2	570.8	563.4	607.0	599.3
17/12	**am**	*	521.1	*	562.1	503.5	514.1	470.0	583.4	540.3	555.8	534.5
17/12	**pm**	477.7	*	597.2	534.5	523.0	573.4	549.8	655.2	526.4	602.2	681.5
18/12	**am**	510.9	*	580.3	484.2	430.9	*	486.3	487.0	460.1	*	556.0
18/12	**pm**	504.5	621.4	614.8	564.2	533.9	546.9	546.3	519.1	465.4	570.8	507.7
19/12	**am**	595.5	547.9	615.3	552.3	798.5	506.8	494.4	490.5	424.4	558.7	594.8
19/12	**pm**	507.5	570.8	616.3	588.2	524.3	577.8	622.5	582.9	607.3	634.7	608.9
20/12	**am**	534.6	544.5	574.2	551.4	460.3	516.6	533.6	416.1	440.7	555.7	581.1
20/12	**pm**	546.5	700.6	618.5	671.5	620.7	561.0	594.8	583.3	632.1	611.2	446.4
21/12	**am**	496.1	608.9	540.4	518.0	*	497.8	522.5	573.9	551.3	589.1	590.5
21/12	**pm**	559.2	646.2	543.9	*	515.6	454.1	478.0	454.5	624.0	580.9	472.7
22/12	**am**	543.2	*	601.4	512.3	469.0	*	508.8	504.1	639.9	517.3	528.4
22/12	**pm**	610.0	530.9	631.9	652.5	390.6	527.7	290.0	506.5	437.3	366.6	521.6
23/12	**am**	563.7	689.5	453.8	539.3	304.9	476.2	435.1	494.6	441.7	392.5	743.2
23/12	**pm**	616.5	740.6	511.1	561.3	558.3	370.4	417.5	446.8	530.9	525.3	665.2
24/12	**am**	490.9	524.2	496.1	344.1	466.5	366.7	261.4	443.0	463.3	495.3	574.4

* denotes missing values

Table B.7: Pentatriacontane (C_{35}) faecal concentration (mg/kg DM) of Calan gate animals

Day	Time	HB1	HB3	HB4	HB6	HB7	FB1	FB2	FB3	FB4	FS3	FS4
16/12	**am**	585.6	578.4	687.6	594.2	*	328.1	584.8	565.8	585.5	563.3	610.8
16/12	**pm**	543.2	646.0	645.7	602.6	514.3	597.9	580.0	598.9	594.0	604.1	651.6
17/12	**am**	*	533.4	*	572.1	541.1	514.2	518.1	611.2	586.9	580.4	595.3
17/12	**pm**	504.7	*	650.6	555.5	557.2	595.4	587.7	699.4	559.1	632.3	753.6
18/12	**am**	538.8	*	637.4	514.6	471.7	*	517.5	526.1	503.7	*	618.6
18/12	**pm**	520.1	627.6	671.2	571.6	549.7	519.1	553.1	574.6	508.1	627.8	594.3
19/12	**am**	661.7	531.9	666.3	572.2	743.9	490.4	499.1	534.3	483.8	563.2	662.5
19/12	**pm**	508.3	566.2	672.6	610.0	539.8	549.4	615.9	612.4	627.2	642.7	656.7
20/12	**am**	552.4	543.2	621.2	541.9	493.3	500.1	539.2	498.0	490.6	581.8	633.1
20/12	**pm**	549.0	675.8	647.4	664.2	626.1	538.5	614.3	623.2	636.4	604.8	529.4
21/12	**am**	504.7	577.6	561.2	512.6	*	451.7	547.3	591.7	553.8	566.8	631.7
21/12	**pm**	554.6	633.1	572.4	*	534.6	441.2	518.4	519.9	624.7	584.5	502.8
22/12	**am**	552.7	*	620.0	514.2	503.5	*	542.6	572.1	646.1	536.9	576.3
22/12	**pm**	566.2	583.6	669.5	664.4	465.9	453.3	374	560.4	515.0	416.9	572.0
23/12	**am**	592.4	681.6	554.8	576.4	375.0	465.5	486.9	559.8	502.9	424.3	770.8
23/12	**pm**	649.1	760.6	600.3	578.2	578.1	395.5	459.2	510.1	539.1	534.6	719.1
24/12	**am**	523.6	545.6	545.5	415.2	475.3	397.3	299.2	517.5	455.2	527.6	602.5

* denotes missing values

Table B.8: Alkane intake estimation (kg DM) of pasture animals							
Day	Time	HB2	HB5	HB8	FB5	FS1	FS2
16/12	am	7.25	6.70	9.34	8.14	5.56	4.72
16/12	pm	*	8.02	4.58	10.49	5.37	4.48
17/12	am	6.97	6.19	7.86	7.52	5.04	4.11
17/12	pm	5.15	6.91	*	9.29	4.61	4.15
18/12	am	8.11	5.68	8.10	6.33	5.24	4.03
18/12	pm	6.15	6.24	4.73	9.36	3.55	3.64
19/12	am	9.08	*	10.79	8.42	3.52	3.80
19/12	pm	*	7.61	5.53	11.44	3.68	3.86
20/12	am	8.18	7.31	8.89	8.47	3.73	3.50
20/12	pm	5.53	6.53	4.47	6.84	3.77	3.71
21/12	am	8.51	7.49	11.24	9.69	3.63	2.93
21/12	pm	5.60	5.88	*	6.67	4.00	2.30
22/12	am	*	8.19	13.46	12.19	3.60	2.00
22/12	pm	3.64	5.26	5.55	6.45	3.46	1.93
23/12	am	8.94	8.15	13.82	10.89	3.75	1.94
23/12	pm	*	4.82	4.93	6.39	5.03	2.63
24/12	am	7.61	6.71	13.22	10.81	4.30	3.18

* denotes missing values

Table B.9: Alkane concentration (mg/kg DM) of kikuyu that animals grazed on pasture			
Day	C32	C33	C35
16/12	15.8	235.3	191.2
17/12	10.8	228.3	208.2
18/12	13.2	218.3	168.3
19/12	21.2	220.3	150.2
20/12	11.1	212.2	146.0
21/12	18.4	228.6	170.3
22/12	25.6	245.0	194.7
23/12	17.0	226.1	172.5
24/12	17.0	226.1	172.5

Table B.10: Dotriacontane (C_{32}) faecal concentration (mg/kg DM) of pasture animals							
Day	Time	HB2	HB5	HB8	FB5	FS1	FS2
16/12	am	529.9	528.5	363.8	482.9	639.6	749.3
16/12	pm	*	483.7	650.7	417.7	667.8	805.3
17/12	am	640.6	595.4	439.6	513.3	637.2	812.7
17/12	pm	827.4	534	*	424.7	738.6	848.8
18/12	am	538.5	635.9	464.8	615.6	678.9	875.9
18/12	pm	719.8	622.2	731.3	444.4	1046.4	922.5
19/12	am	479.2	*	359.7	469.2	1019.5	920.4
19/12	pm	*	535.4	505.1	397.9	972.0	1020.9
20/12	am	484.1	497.2	244.0	476.7	858.3	887.3
20/12	pm	667.6	569.5	541.6	564.8	938.2	941.4
21/12	am	452.5	434.1	211.9	359.4	826.5	968.1
21/12	pm	575.9	497.2	*	491.6	690.1	1158.0
22/12	am	*	402.7	196.2	336.7	841.8	1404.5
22/12	pm	581.1	532.3	625.0	505.5	906.9	1456.2
23/12	am	451.1	460.3	163.3	359.2	816.1	1440.5
23/12	pm	*	657.9	480.3	551.4	619.4	1134.7
24/12	am	463.5	406.3	144.0	352.1	733.2	1030.2

* denotes missing values

Table B.11: Tritriacontane (C_{33}) faecal concentration (mg/kg DM) of pasture animals							
Day	**Time**	**HB2**	**HB5**	**HB8**	**FB5**	**FS1**	**FS2**
16/12	**am**	811.8	753.1	697.3	820.3	770.1	775.4
16/12	**pm**	*	810.1	654.2	884.9	777.9	792.7
17/12	**am**	947.6	788.8	727.0	814.5	695.5	729.2
17/12	**pm**	920.9	783.8	*	818.1	740.9	770.2
18/12	**am**	861.6	734.2	742.9	785.0	726.8	731.8
18/12	**pm**	894.6	783.4	710.8	808.6	775.6	699.8
19/12	**am**	804.1	*	695.8	738.7	735.6	712.9
19/12	**pm**	*	772.4	550.5	806.8	730.1	802.0
20/12	**am**	770.2	713.4	419.1	783.2	651.9	635.2
20/12	**pm**	738.4	735.7	489.2	762.2	720.3	711.8
21/12	**am**	761.2	653.2	451.3	675.7	643.1	614.9
21/12	**pm**	669.0	603.6	*	667.4	583.1	583.9
22/12	**am**	*	667.9	481.0	766.1	679.9	655.7
22/12	**pm**	474.3	603.9	743.8	685.1	706.3	657.1
23/12	**am**	791.8	745.3	413.1	746.1	650.8	610.4
23/12	**pm**	*	663.2	494.3	718.1	649.0	646.3
24/12	**am**	706.3	553.3	351.3	726.8	664.3	702.9

* denotes missing values

Table B.12: Pentatriacontane (C_{35}) faecal concentration (mg/kg DM) of pasture animals

Day	Time	HB2	HB5	HB8	FB5	FS1	FS2
16/12	am	716.2	689.2	605.2	716.2	629.3	618.6
16/12	pm	*	769.2	573.8	795.3	641.7	647.2
17/12	am	888.3	752.7	618.8	719.5	592.6	618.6
17/12	pm	868.0	765.6	*	753.2	628.8	644.4
18/12	am	768.8	706.7	600.5	694.2	633.4	637.8
18/12	pm	791.9	739.7	569.6	735.6	631.0	618.6
19/12	am	717.8	*	551.6	667.1	588.4	617.5
19/12	pm	*	698.2	441.0	736.6	569.4	668.2
20/12	am	636.6	628.2	315.7	683.1	509.2	555.4
20/12	pm	612.5	596.9	351.9	611.8	528.2	610.8
21/12	am	609.8	516.2	321.6	535.0	461.7	522.5
21/12	pm	524.8	469.1	*	539.7	418.2	492.4
22/12	am		508.8	334.4	605.5	479.3	555
22/12	pm	323.2	455.2	571.6	542.4	523.5	557.7
23/12	am	640.9	595.6	306.7	595.9	510.2	505.0
23/12	pm	*	554.4	359.9	561.9	532.6	546.5
24/12	am	597.4	511.0	271.7	578.5	553.8	583.9

* denotes missing values

Table B.13: Dry matter digestibility estimates (g/kg DM) of Calan gate animals calculated by the alkane method

Day	Time	HB1	HB3	HB4	HB6	HB7	FB1	FB2	FB3	FB4
16/12	**pm**	540	613	613	586	514	582	570	583	580
17/12	**am**	*	532	*	564	539	514	518	591	575
17/12	**pm**	586	*	679	624	625	649	644	701	626
18/12	**am**	612	*	672	594	557	*	596	603	585
18/12	**pm**	501	586	613	546	528	500	531	548	489
19/12	**am**	608	512	610	546	651	471	480	514	464
19/12	**pm**	622	661	714	685	644	650	688	686	694
20/12	**am**	652	646	691	645	610	616	644	614	608
20/12	**pm**	640	707	694	702	684	633	678	682	689
21/12	**am**	608	657	647	614	*	562	638	666	643
21/12	**pm**	615	663	627	*	601	516	588	589	658
22/12	**am**	614	*	656	585	576	*	607	627	670
22/12	**pm**	647	657	701	699	571	559	465	643	611
23/12	**am**	662	706	639	653	466	570	589	643	602
23/12	**pm**	687	733	662	649	649	487	558	602	623
24/12	**am**	612	628	628	511	573	489	322	608	554

* denotes missing values

Table B.14: Dry matter digestibility estimates (g/kg DM) of pasture animals calculated by the alkane method

Day	Time	HB2	HB5	HB8	FB5
16/12	pm	*	764	683	772
17/12	am	777	737	680	725
17/12	pm	772	742	*	737
18/12	am	792	774	734	770
18/12	pm	798	784	719	783
19/12	am	801	*	741	786
19/12	pm	*	796	676	806
20/12	am	782	779	561	797
20/12	pm	774	768	606	773
21/12	am	735	687	497	698
21/12	pm	692	655	*	700
22/12	am	*	637	447	695
22/12	pm	428	594	676	659
23/12	am	744	725	466	725
23/12	pm	*	705	545	708
24/12	am	726	679	397	717

* denotes missing values

Table B.15: Daily minimum and maximum environmental temperatures (°C) in the Calan gate facility

Temperature	14/12	15/12	16/12	17/12	18/12	19/12	20/12	21/12	22/12	23/12
Minimum	13.5	12.0	17.5	20.0	14.5	13.5	14.5	16.0	15.5	15.5
Maximum	27.0	29.5	30.0	36.0	36.0	24.0	27.5	36.5	23.0	31.5

Appendix C

Digestibility measures

The data of the digestibility estimates discussed in Chapter 5 is reported in this appendix.

Table C.1: Composition (g/kg DM) of kikuyu fed to trial animals during the digestibility investigation

Date	DM (g/kg DM)	CP (g/kg DM)	NDF (g/kg DM)	ADF (g/kg DM)	CF (g/kg DM)	Ash (g/kg DM)	Ca (g/kg DM)	P (g/kg DM)
21/2	180	173.0	634.2	286.3	#	95.0	3.0	3.7
22/2	213	123.4	712.7	323.3	#	81.6	2.5	3.2
23/2	172	148.7	649.8	310.4	#	92.4	2.5	3.7
24/2	168	134.0	675.9	319.6	303.5	86.5	2.8	3.2
25/2	258	128.2	640.0	309.6	283.5	82.0	2.8	2.9
26/2	221	144.7	643.7	312.6	283.6	80.4	2.5	2.8
27/2	184	144.9	632.0	302.5	281.7	91.5	2.6	3.8
28/2	130	223.9	550.9	302.9	259.3	117.5	2.6	4.1

these values were not done since this is part of the adaption period

Table C.2: Kikuyu intake (kg DM) during the digestibility investigation

Date	HB1	HB4	HB5	FB1	FB2	FB3
24/2	8.2	7.7	8.8	7.8	9.1	8.5
25/2	7.5	7.3	7.3	9.1	10.4	10.2
26/2	7.3	5.8	5.5	6.7	7.0	8.1
27/2	8.6	8.9	9.2	10.0	8.8	9.7
28/2	6.1	5.2	5.8	6.5	6.0	6.2

Table C.3: Faeces production (kg DM) during the digestibility investigation

Date	HB1	HB4	HB5	FB1	FB2	FB3
24/2	2.5	2.0	1.8	2.4	2.0	1.9
25/2	2.2	1.8	1.9	2.3	2.4	2.4
26/2	2.3	2.5	2.1	2.4	2.5	2.0
27/2	3.1	2.6	2.5	2.9	3.1	3.2
28/2	2.5	1.9	1.7	2.1	2.2	2.1

Table C.4: Dry matter digestibility estimates (g/kg DM) during the digestibility investigation

Date	HB1	HB4	HB5	FB1	FB2	FB3
24/2	695	740	796	692	780	777
25/2	707	753	740	747	769	765
26/2	685	569	618	642	643	753
27/2	640	708	728	710	648	670
28/2	590	635	707	677	633	661

Table C.5: Faecal composition (g/kg DM) during the digestibility investigation								
Sample No.	Animal	DM (g/kg DM)	CP (g/kg DM)	NDF (g/kg DM)	ADF (g/kg DM)	Ash (g/kg DM)	Ca (g/kg DM)	P (g/kg DM)
24/2	HB1	94	128.4	534.6	297.5	128.3	6.1	7.2
24/2	HB4	99	138.2	530.0	311.7	93.4	6.1	5.6
24/2	HB5	120	138.5	556.8	328.4	91.9	6.2	7.2
24/2	FB1	134	147.7	521.7	305.9	96.0	8.3	7.6
24/2	FB2	121	140.7	534.7	305.6	108.2	5.6	6.2
24/2	FB3	135	138.8	505.3	297.6	133.9	5.2	7.3
25/2	HB1	84	132.4	533.8	306.6	106.2	7.1	8.4
25/2	HB4	99	136.1	550.4	310.1	99.9	6.4	6.3
25/2	HB5	104	134.8	550.3	315.6	98.2	6.7	8.3
25/2	FB1	141	141.5	531.4	314.5	97.4	8.3	8.2
25/2	FB2	136	147.5	539.6	314.3	84.4	5.9	6.4
25/2	FB3	138	141.2	470.1	286.5	168.8	5.6	6.9
26/2	HB1	78	126.9	581.6	341.5	114.9	7.3	8.3
26/2	HB4	96	133.1	575.8	345.4	101.3	7.3	7.6
26/2	HB5	114	126.3	586.6	341.2	97.1	7.7	8.3
26/2	FB1	130	132.2	586.0	349.8	95.4	8.3	7.7
26/2	FB2	140	149.2	582.4	336.6	87.1	6.5	6.4
26/2	FB3	114	149.5	565.4	330.6	102.1	8.0	9.3
27/2	HB1	85	125.2	563.3	321.1	108.7	6.8	7.8
27/2	HB4	96	121.7	574.6	326.6	98.3	6.7	7.2
27/2	HB5	111	125.1	571.3	268.4	96.4	8.4	8.5
27/2	FB1	136	129.9	555.0	326.1	98.7	8.2	9.9
27/2	FB2	135	138.0	577.2	331.2	82.8	5.9	7.3
27/2	FB3	134	149.7	562.6	311.2	96.6	7.4	11.9
28/2	HB1	100	141.3	571.4	314.6	98.6	7.1	8.8
28/2	HB4	98	139.3	567.3	313.8	98.9	7.0	8.0
28/2	HB5	118	148.2	542.3	307.2	95.6	8.2	10.0
28/2	FB1	136	139.5	559.6	324.9	102.6	7.2	9.8
28/2	FB2	138	145.2	569.1	321.2	82.7	5.8	6.8
28/2	FB3	135	150.0	526.8	306.5	97.4	7.4	10.1

Table C.6: Crude protein digestibility estimates (g/kg) during the digestibility investigation

Date	HB1	HB4	HB5	FB1	FB2	FB3
24/2	707.9	732.1	788.6	660.8	769.2	768.5
25/2	697.1	738.2	726.3	721.0	734.5	740.8
26/2	723.7	603.5	666.7	672.7	631.8	744.9
27/2	688.5	754.6	765.4	740.0	664.5	659.2
28/2	741.4	772.7	806.0	798.7	762.2	773.1

Table C.7: NDF digestibility estimates (g/kg) during the digestibility investigation

Date	HB1	HB4	HB5	FB1	FB2	FB3
24/2	758.9	796.3	831.5	762.5	826.1	832.9
25/2	755.3	787.9	776.2	790.1	805.4	827.2
26/2	715.3	614.4	652.1	673.9	676.9	783.1
27/2	678.7	734.4	754.4	745.3	678.3	706.3
28/2	574.9	623.7	711.5	671.8	621.2	676.1

Table C.8: ADF digestibility estimates (g/kg) during the digestibility investigation

Date	HB1	HB4	HB5	FB1	FB2	FB3
24/2	716.2	746.7	789.8	705.5	789.8	791.9
25/2	709.5	753.0	734.7	743.3	765.7	782.3
26/2	655.8	523.7	583.2	599.2	615.4	738.9
27/2	617.4	684.6	758.9	687.4	614.3	660.6
28/2	574.3	621.5	702.7	653.5	611.2	657.3

Table C.9: Maximum environmental temperatures (°C) during the digestibility investigation

	24/2	25/2	26/2	27/2	28/2
Maximum temperature	31	24	33	24	21

Appendix D

Faecal marker concentrations

Faecal marker excretion concentrations discussed in Chapter 6 are reported in this appendix.

Table D.1: Dotriacontane (C_{32}) faecal concentrations (mg/kg DM)

Hours	HB1	HB4	HB5	FB1	FB2	FB3
3	63.0	115.3	76.0	54.4	43.9	123.3
12	239.5	303.4	250.0	97.5	166.4	222.0
15	379.7	461.8	404.4	203.0	291.2	386.0
18	504.0	606.7	515.1	310.4	423.2	439.7
21	513.4	751.7	539.9	410.3	479.2	483.6
24	529.0	679.0	565.7	412.1	577.0	493.6
27	480.7	505.7	578.8	445.1	471.1	508.5
30	414.7	440.4	500.7	459.1	409.8	453.7
33	343.2	492.0	488.5	490.7	405.0	440.5
36	298.6	466.0	432.5	430.5	340.3	402.1
39	277.4	360.8	388.4	397.3	314.2	346.0
42	259.0	329.4	320.4	363.6	234.9	323.0
48	207.9	241.4	279.6	272.7	196.1	245.6
60	125.6	150.9	174.8	200.3	138.5	154.7
72	87.6	102.5	123.8	135.2	94.0	115.5
84	63.2	66.2	82.7	107.9	73.2	80.6

Table D.2: Chromium faecal concentrations (ppm)						
Hours	**HB1**	**HB4**	**HB5**	**FB1**	**FB2**	**FB3**
9	117.7	535.9	165.5	2.9	33.0	42.9
12	1,088.9	1,509.8	1,243.2	159.4	466.6	739.8
15	1,982.1	2,003.5	1,665.4	745.0	999.6	1,658.4
18	2,322.4	2,692.9	2,662.4	1,354.5	1,472.3	2,011.7
21	2,517.0	3,647.3	2,704.9	1,865.6	1,712.7	2,424.7
24	2,455.6	3,078.9	2,719.1	1,954.5	2,031.5	2,449.8
27	2,314.5	1,878.0	2,840.3	2,133.1	1,456.7	2,541.1
30	1,777.2	1,859.4	2,549.3	2,144.0	1,351.5	2,360.7
33	1,383.1	2,001.7	2,307.1	2,209.1	1,282.5	2,159.6
36	1,375.5	2,132.4	1,865.0	2,034.2	1,008.9	2,049.6
39	1,165.6	1,377.0	1,625.4	1,779.7	1,004.4	1,560.3
42	1,063.6	1,433.0	1,331.1	1,580.8	613.3	1,584.7
48	759.2	969.1	1,139.6	1,167.8	503.3	1,094.8
60	355.1	477.9	613.5	761.8	248.6	630.4
72	186.7	209.2	308.8	445.0	122.5	387.9
84	172.6	175.7	152.2	224.4	95.7	199.9
96	76.8	91.9	102.3	154.2	*	60.8

* denotes missing values

Table D.3: Grovum and William (1973) model coefficients of Hereford and Friesland bulls

Coefficient	HB1	HB4	HB5	FB1	FB2	FB3
Alkane marker						
k_1	0.036	0.038	0.034	0.030	0.035	0.033
k_2	0.254	0.179	0.174	0.132	0.183	0.231
a_1	7.1	7.4	7.3	7.1	7.1	7.1
a_2	9.2	8.6	8.6	8.3	8.5	9.3
TT	9.8	8.9	9.6	11.0	9.9	10.8
A	823.1	1,141.8	1,041.0	911.8	836.9	884.5
MRT	41.7	40.6	44.5	51.6	44.2	45.1
F	101.3	85.5	82.3	86.4	102.4	88.3
Chromium marker						
k_1	0.048	0.049	0.051	0.044	0.053	0.045
k_2	0.258	0.162	0.191	0.154	0.177	0.167
a_1	8.9	9.2	9.4	9.2	8.8	9.2
a_2	11.0	10.2	10.9	10.6	10.1	10.5
TT	10.1	8.8	11.0	13.0	10.3	10.9
A	4,558.0	6,276.4	6,798.9	5,611.2	3,881.3	5,809.6
MRT	34.9	35.2	35.9	42.1	34.8	39.0
F	88.1	77.7	69.9	75.3	133.9	72.8

Table D.4: Peak times (hours) of Hereford and Friesland bulls calculated from faecal marker concentrations (QDQ curve analysis)

Peak time (hrs)	Chromium (ppm)	Dotriacontane (mg/kg DM)
HB1	20.14	21.13
HB4	20.84	21.25
HB5	23.02	23.24
FB1	28.61	28.93
FB2	22.67	23.32
FB3	24.32	23.83

Appendix E

Behaviour study measures

The data of animal activity (grazing, ruminating and idling) discussed in Chapter 7 is reported in this appendix.

Table E.1: Grazing time (minutes) of Hereford bulls (study 1)

Hour	HB1	HB2	HB3	HB4	HB5	HB6	HB7	HB8
09:00	46	5	13	24	60	19	10	53
10:00	18	4	19	0	0	24	10	9
11:00	30	34	41	18	0	10	25	4
12:00	0	42	0	0	0	44	0	60
13:00	10	10	13	17	14	28	43	29
14:00	39	41	33	32	56	51	28	46
15:00	0	11	23	12	38	0	29	7
16:00	48	22	25	18	29	23	51	42
17:00	35	25	42	58	39	45	26	28
18:00	7	0	19	15	24	0	8	13
19:00	0	15	13	5	15	11	9	23
20:00	0	7	0	9	60	29	0	0
21:00	14	0	3	12	1	0	47	0
22:00	52	0	34	52	0	53	0	0
23:00	0	2	0	6	2	17	0	15
00:00	44	56	0	51	60	0	16	0
01:00	39	0	0	6	24	0	45	0
02:00	0	0	0	0	0	0	0	0
03:00	0	0	0	0	0	0	0	0
04:00	0	0	0	0	0	0	0	0
05:00	0	0	0	0	0	0	0	0
06:00	46	46	39	46	21	15	46	46
07:00	43	48	56	43	54	60	36	40
08:00	0	24	41	41	25	29	60	16

Table E.2: Grazing time (minutes) of Friesland bulls and steers (study 1)

Hour	FB1	FB2	FB3	FB4	FB5	FS1	FS2	FS3
09:00	60	33	48	27	30	0	38	22
10:00	0	0	0	0	0	21	0	0
11:00	9	9	0	0	12	3	0	1
12:00	53	0	0	0	2	47	23	36
13:00	37	12	0	0	50	58	48	0
14:00	48	55	44	41	41	42	30	44
15:00	0	53	32	0	5	27	0	2
16:00	31	23	46	35	53	19	28	40
17:00	17	46	49	38	34	39	39	29
18:00	24	39	28	12	10	0	3	0
19:00	27	0	0	21	43	0	0	10
20:00	20	14	0	0	8	0	0	0
21:00	16	3	3	15	0	0	37	0
22:00	12	41	33	7	0	21	0	13
23:00	28	32	0	4	14	0	0	44
00:00	0	38	27	4	0	51	27	38
01:00	0	24	60	45	0	45	45	45
02:00	0	0	9	0	0	0	0	0
03:00	0	0	0	0	0	0	0	0
04:00	0	0	0	0	0	0	0	0
05:00	0	0	0	0	0	0	0	0
06:00	37	19	15	39	39	46	46	39
07:00	43	43	40	39	60	60	56	49
08:00	30	50	53	0	16	43	37	44

Table E.3: Ruminating time (minutes) of Hereford bulls (study 1)

Hour	HB1	HB2	HB3	HB4	HB5	HB6	HB7	HB8
09:00	0	22	42	14	0	0	26	0
10:00	39	5	22	20	25	14	8	26
11:00	7	0	0	16	31	30	0	36
12:00	55	10	46	49	24	16	38	0
13:00	19	33	19	43	35	27	0	25
14:00	0	15	0	11	0	0	32	9
15:00	0	49	0	33	0	56	0	33
16:00	8	12	0	17	15	15	0	7
17:00	0	0	6	2	8	0	0	24
18:00	2	28	6	39	5	19	32	28
19:00	60	35	47	40	38	49	25	34
20:00	10	41	52	42	0	16	29	38
21:00	46	9	21	17	44	29	13	32
22:00	0	13	26	0	33	0	42	32
23:00	57	39	39	43	58	43	39	28
00:00	9	0	16	9	0	60	35	44
01:00	21	54	21	15	36	42	0	36
02:00	51	39	51	51	34	51	42	18
03:00	57	60	36	32	39	21	31	29
04:00	23	19	4	41	37	23	23	33
05:00	52	58	31	60	48	54	60	32
06:00	0	0	0	7	25	17	9	0
07:00	0	0	0	0	0	0	0	0
08:00	39	14	0	4	3	0	0	10

Table E.4: Ruminating time (minutes) of Friesland bulls and steers (study 1)

Hour	FB1	FB2	FB3	FB4	FB5	FS1	FS2	FS3
09:00	0	0	0	0	4	60	0	14
10:00	35	30	38	55	40	26	36	20
11:00	24	5	21	30	31	50	23	33
12:00	0	60	26	2	22	0	23	11
13:00	14	18	28	26	0	0	3	54
14:00	0	0	0	0	0	14	30	3
15:00	36	7	7	0	29	33	46	9
16:00	6	27	9	0	0	5	9	13
17:00	0	0	0	0	0	0	0	0
18:00	0	1	0	0	1	0	36	34
19:00	31	45	47	17	17	44	37	29
20:00	39	46	49	34	52	29	32	60
21:00	26	47	0	37	41	0	23	25
22:00	37	8	27	26	60	0	40	47
23:00	24	28	39	38	10	48	43	0
00:00	22	22	11	43	38	9	33	13
01:00	54	15	0	0	60	0	0	15
02:00	39	35	5	21	39	51	42	39
03:00	39	31	36	35	39	16	31	39
04:00	45	60	41	60	41	19	29	38
05:00	28	18	27	35	44	27	32	50
06:00	21	41	34	14	14	14	7	0
07:00	0	0	0	0	0	0	0	0
08:00	8	4	0	0	0	11	14	10

Table E.5: Idling time (minutes) of Hereford bulls (study 1)

Hour	HB1	HB2	HB3	HB4	HB5	HB6	HB7	HB8
09:00	14	33	5	22	0	41	24	7
10:00	3	51	19	40	35	22	42	25
11:00	23	26	19	26	29	20	35	20
12:00	5	8	14	11	36	0	22	0
13:00	31	17	28	0	11	5	17	6
14:00	21	4	27	17	4	9	0	5
15:00	60	0	37	15	22	4	31	20
16:00	4	26	35	25	16	22	9	11
17:00	25	35	12	0	13	15	34	8
18:00	51	32	35	6	31	41	20	19
19:00	0	10	0	15	7	0	26	3
20:00	50	12	8	9	0	15	31	22
21:00	0	51	36	31	15	31	0	28
22:00	8	47	0	8	27	7	18	28
23:00	3	19	21	11	0	0	21	17
00:00	7	4	44	0	0	0	9	16
01:00	0	6	39	39	0	18	15	24
02:00	9	21	9	9	26	9	18	42
03:00	3	0	24	28	21	39	29	31
04:00	37	41	56	19	23	37	37	27
05:00	8	2	29	0	12	6	0	28
06:00	14	14	21	7	14	28	5	14
07:00	17	12	4	17	6	0	24	20
08:00	21	22	19	15	32	31	0	34

Table E.6: Idling time (minutes) of Friesland bulls and steers (study 1)

Hour	FB1	FB2	FB3	FB4	FB5	FS1	FS2	FS3
09:00	0	27	12	33	26	0	22	24
10:00	25	30	22	5	20	13	24	40
11:00	27	46	39	30	17	7	37	26
12:00	7	0	34	58	36	13	14	13
13:00	9	30	32	34	10	2	9	6
14:00	12	5	16	19	19	4	0	13
15:00	24	0	21	60	26	0	14	49
16:00	23	10	5	25	7	36	23	7
17:00	43	14	11	22	26	21	21	31
18:00	36	20	32	48	49	60	21	26
19:00	2	15	13	22	0	16	23	21
20:00	1	0	11	26	0	31	28	0
21:00	18	10	57	8	19	60	0	35
22:00	11	11	0	27	0	39	20	0
23:00	8	0	21	18	36	12	17	16
00:00	38	0	22	13	22	0	0	9
01:00	6	21	0	15	0	15	15	0
02:00	21	25	46	39	21	9	18	21
03:00	21	29	24	25	21	44	29	21
04:00	15	0	19	0	19	41	31	22
05:00	32	42	33	25	16	33	28	10
06:00	2	0	11	7	7	0	7	21
07:00	17	17	20	21	0	0	4	11
08:00	22	6	7	60	44	6	9	6

Table E.7: Grazing time (minutes) of Hereford bulls (study 2)

Hour	HB1	HB2	HB3	HB4	HB5	HB6	HB7	HB8
09:00	12	0	34	18	9	15	16	25
10:00	54	53	54	55	23	49	49	53
11:00	24	50	26	30	27	17	41	45
12:00	37	48	10	49	27	21	43	37
13:00	5	2	0	3	3	52	4	3
14:00	33	6	18	24	30	4	4	4
15:00	22	21	25	14	25	26	28	35
16:00	46	25	44	45	21	29	16	38
17:00	25	26	35	27	43	57	15	36
18:00	2	0	0	12	0	42	25	0
19:00	0	0	0	11	0	0	0	0
20:00	0	0	0	0	0	0	0	0
21:00	0	30	5	15	0	0	5	0
22:00	0	45	13	10	40	0	0	60
23:00	42	18	27	31	0	16	0	5
00:00	40	0	29	0	0	40	0	32
01:00	0	0	29	28	23	0	0	3
02:00	0	0	0	17	0	0	0	0
03:00	0	0	0	0	0	0	0	0
04:00	0	0	0	0	0	0	0	5
05:00	0	0	0	0	0	0	0	0
06:00	6	4	10	6	0	0	26	7
07:00	53	53	44	50	60	54	54	42
08:00	60	60	60	60	60	60	60	60

Table E.8: Grazing time (minutes) of Friesland bulls and steers (study 2)								
Hour	**FB1**	**FB2**	**FB3**	**FB4**	**FB5**	**FS1**	**FS2**	**FS4**
09:00	31	58	50	30	1	0	31	0
10:00	33	39	20	45	43	47	46	48
11:00	38	19	11	26	28	24	49	40
12:00	37	4	0	0	0	38	2	60
13:00	7	0	0	1	0	54	8	7
14:00	0	6	30	10	7	6	16	0
15:00	29	32	41	18	39	26	45	21
16:00	44	59	49	55	33	16	14	56
17:00	31	38	34	43	19	3	16	50
18:00	18	0	8	4	1	4	16	22
19:00	0	0	0	0	0	0	0	0
20:00	0	0	0	0	0	0	10	0
21:00	0	10	0	0	15	0	0	0
22:00	37	10	10	2	15	0	0	40
23:00	27	0	0	24	8	0	0	0
00:00	0	38	0	0	0	14	23	0
01:00	0	25	10	0	0	0	21	0
02:00	0	0	0	0	0	0	0	0
03:00	0	0	0	0	0	0	0	20
04:00	0	0	0	0	0	0	0	0
05:00	0	0	0	0	0	0	0	0
06:00	43	0	4	6	7	0	5	8
07:00	45	55	44	55	50	41	51	60
08:00	55	60	60	60	58	50	53	60

Table E.9: Ruminating time (minutes) of Hereford bulls (study 2)

Hour	HB1	HB2	HB3	HB4	HB5	HB6	HB7	HB8
09:00	35	30	0	25	33	45	44	20
10:00	0	0	0	0	0	0	0	0
11:00	9	0	23	0	6	22	0	10
12:00	8	0	23	0	21	22	0	23
13:00	46	36	35	56	45	6	37	45
14:00	5	0	33	1	14	8	24	24
15:00	0	7	7	20	5	11	0	3
16:00	0	0	0	0	23	17	8	16
17:00	20	0	20	8	3	0	22	10
18:00	35	47	33	28	60	16	0	49
19:00	45	11	27	35	28	16	28	24
20:00	41	53	51	15	43	34	30	28
21:00	35	0	5	31	25	40	15	10
22:00	35	15	30	13	10	45	50	0
23:00	9	31	16	0	16	0	0	55
00:00	1	53	13	38	17	20	35	0
01:00	40	24	31	0	11	27	13	35
02:00	29	22	8	43	34	35	43	27
03:00	20	30	25	16	6	35	15	10
04:00	25	15	35	25	40	40	35	10
05:00	35	45	5	30	15	15	30	35
06:00	0	5	30	0	32	26	9	0
07:00	0	0	0	0	0	6	3	13
08:00	0	0	0	0	0	0	0	0

Table E.10: Ruminating time (minutes) of Friesland bulls and steers (study 2)								
Hour	**FB1**	**FB2**	**FB3**	**FB4**	**FB5**	**FS1**	**FS2**	**FS4**
09:00	18	0	0	30	12	44	21	60
10:00	0	1	1	0	0	0	0	5
11:00	0	20	16	0	22	16	0	0
12:00	3	39	54	39	21	16	37	0
13:00	44	53	19	29	33	0	44	53
14:00	6	4	8	0	27	4	7	21
15:00	11	0	0	0	14	10	5	15
16:00	0	0	0	0	0	22	0	0
17:00	0	0	0	0	13	47	23	3
18:00	35	50	38	3	42	38	34	38
19:00	24	25	27	50	35	21	40	32
20:00	43	42	18	13	49	31	15	48
21:00	30	30	35	25	20	16	21	15
22:00	10	35	20	30	28	37	40	5
23:00	4	44	19	0	39	44	39	20
00:00	42	0	1	42	23	0	19	38
01:00	20	24	27	12	27	39	24	14
02:00	33	31	51	27	36	21	13	13
03:00	44	30	16	14	20	35	34	15
04:00	40	10	40	30	31	5	15	25
05:00	25	45	0	15	15	10	30	0
06:00	5	0	0	28	30	26	33	23
07:00	11	0	0	0	0	0	0	0
08:00	0	0	0	0	0	0	0	0

Table E.11: Idling time (minutes) of Hereford bulls (study 2)

Hour	HB1	HB2	HB3	HB4	HB5	HB6	HB7	HB8
09:00	13	30	26	17	18	0	0	15
10:00	6	7	6	5	37	11	11	7
11:00	27	10	11	30	27	21	19	5
12:00	15	12	27	11	12	17	17	0
13:00	9	22	25	1	12	2	19	12
14:00	22	54	9	35	16	48	32	32
15:00	38	32	28	26	30	23	32	22
16:00	14	35	16	15	16	14	36	6
17:00	15	34	5	25	14	3	23	14
18:00	23	13	27	20	0	2	35	11
19:00	15	49	33	14	32	44	32	36
20:00	19	7	9	45	17	26	30	32
21:00	25	30	50	14	35	20	40	50
22:00	25	0	17	37	10	15	10	0
23:00	9	11	17	29	44	44	60	0
00:00	19	7	18	22	43	0	25	28
01:00	20	36	0	32	26	33	47	22
02:00	31	38	52	0	26	25	17	33
03:00	40	30	35	44	54	25	45	50
04:00	35	45	25	35	20	20	25	45
05:00	25	15	55	30	45	45	30	25
06:00	54	51	20	54	28	34	25	53
07:00	7	7	16	10	0	0	3	5
08:00	0	0	0	0	0	0	0	0

Table E.12: Idling time (minutes) of Friesland bulls and steers (study 2)								
Hour	FB1	FB2	FB3	FB4	FB5	FS1	FS2	FS4
09:00	11	2	10	0	47	16	8	0
10:00	27	20	39	15	17	13	14	7
11:00	22	21	33	34	10	20	11	20
12:00	20	17	6	21	39	6	21	0
13:00	9	7	41	30	27	6	8	0
14:00	54	50	22	50	26	50	37	39
15:00	20	28	19	42	7	24	10	24
16:00	16	1	11	5	27	22	46	4
17:00	29	22	26	17	28	10	21	7
18:00	7	10	14	53	17	18	10	0
19:00	36	35	33	10	25	39	20	28
20:00	17	18	42	47	11	29	35	12
21:00	30	20	25	35	25	44	39	45
22:00	13	15	30	28	17	23	20	15
23:00	29	16	41	36	13	16	21	40
00:00	18	22	59	18	37	46	18	22
01:00	40	11	23	48	33	21	15	46
02:00	27	29	9	33	24	39	47	47
03:00	16	30	44	46	40	25	26	25
04:00	20	50	20	30	29	55	45	35
05:00	35	15	60	45	45	50	30	60
06:00	12	60	56	26	23	34	22	29
07:00	4	5	16	5	10	19	9	0
08:00	5	0	0	0	2	10	7	0

Appendix F

Internal organ measures

Internal organ mass data discussed in Chapter 8 is reported in this appendix.

Table F.1: Carcass and internal organ weights (kg) of Hereford and Friesland bulls

	HB1	HB2	HB4	HB5	HB8	FB1	FB2	FB3	FB4	FB5
Warm mass	181	170	161	198	145	194	188	179	238	245
Liveweight	390	350	340	400	300	405	375	380	460	480
Dressing percentage	46.4	48.6	47.4	49.5	48.3	47.9	50.1	47.1	51.7	51.0
Heart mass	1.64	1.29	1.17	1.56	1.21	1.59	1.58	1.45	1.93	1.72
Liver mass (including bile)	5.75	4.92	5.57	6.24	4.05	6.94	5.98	5.98	7.17	6.29
Lung (& trachea) mass	6.76	5.14	5.25	6.52	4.43	6.22	5.52	5.64	6.78	5.69
Spleen mass	1.61	1.11	1.04	1.46	0.99	1.42	2.18	1.60	2.00	1.22