UNIVERSITY OF GLASGOW

THE EFFECTS OF FORAGE SUPPLEMENTATION ON GRAZING DAIRY COWS

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All flesh is grass (Isaiah 40:6)

ABSTRACT

This thesis first presents a review of the literature on intake from grazed herbage. It reviews animal factors and how theoretical ruminant intake concepts could be used in the grazing situation. The effects of sward conditions on herbage intake and various supplementation strategies and supplementation practices are evaluated. After which the various possible measurement techniques for estimating herbage intake are discussed. A number of experiments are presented, all carried out at the Scottish Agricultural College, Crichton Royal Farm. In the first experiment the n-alkane technique for estimating herbage intake and diet selection in dairy cows offered perennial ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) herbage was evaluated. Pairs of animals were offered, 8, 10, 12 or 14 kg dry matter (DM) day^{-1} of herbage alone or with 2 kg DM day^{-1} of barley. Individual intakes and the white clover proportion of the diet were estimated during a 12 day period using the n-alkane technique. Three, least squares optimisation methods were compared in calculating the white clover proportion in the diet; then total DM intake was calculated. The different least squares optimisation methods gave similar predictions of the white clover content of the forage consumed. No significant ($P < 0.05$) effects of sampling routine, concentrate (barley) fed or interactions between the two were detected with respect to the difference between calculated and actual intake, the difference as a proportion of the total intake, and estimated white clover content of the diet. The difference between the calculated and actual intake ranged from 139 to 366 g DM day^{-1} depending on sampling routine. The results suggest that accurate herbage intake estimates can be achieved in dairy cows grazing perennial ryegrass/white clover swards. In a second experiment, the potential use of n-alkanes was evaluated for estimating supplementary grass silage intake. Dairy cows grazed a perennial ryegrass sward and were offered a supplement consisting of perennial ryegrass silage. The silage was marked with hexatriacontane (C_{36}). The mean silage intake estimated by weighing was 6.8 kg DM per day. The mean estimated silage intakes were 6.9, 8.7 and 8.3 kg DM per day respectively using odd-chain n-alkanes in the C_{27} - C_{35} range of naturally occurring alkanes, the odd-chain n-alkanes in the C_{27} - C_{35} range with C_{36} and C_{36} by itself to calculate forage supplement intake. The results indicate that the n-alkane technique can be used to estimate silage supplement intake of grazing dairy cows using naturally occurring n-alkane patterns but not when using artificial (even-chain) n-alkanes.

After establishing that the n-alkane technique can be used for intake estimation, a number of forage supplementation experiments were carried out. In the first supplementation experiment, two forage supplementation systems were examined over a 15 week period, using a continuous design. One system (A) consisted of introducing the supplement when sward surface height (SSH) decreased to 7 cm and, continuing supplementation until a maximum of 11 cm was reached. Supplementation was then discontinued until SSH decreased to the minimum (7cm). In the second system (B) supplementation was initiated when SSH fell to the pre-determined minimum (7 cm) and then continued until the end of the grazing season. Mean herbage heights during the experiment were 8.6 and 9.6 cm for A and B respectively. The proportion of the sward rejected was 0.05 for A and 0.22 for B. Individual animal performance and milk component yield per ha were not affected by supplementation system. Milk yields were 10,342 kg ha^{-1} and 10,446 kg ha^{-1} for A and B respectively over the 15 week period but system A used a total of 1,533 kg DM of silage while system B used 3,832 kg DM of silage. This resulted in a calculated utilised ME from grazed herbage (GJ ha^{-1}) of 45.4 for A and 29.4 for B. The experiment indicates that buffer feeding systems which take herbage height into account can improve sward utilisation relative to those who do not take account of sward height and, can result in large savings of silage supplements.

Thereafter two experiments are described investigating the effect of ME-content and degradability of the forage supplement on animal performance and total dry matter intake. In these two experiments two groups of grazing lactating dairy cows were offered straw/sugar beet pulp mixtures of different straw and sugar beet pulp content. The low straw mixture (LS) contained 310, 592, 65, 9 and 24 g kg^{-1} DM of barley straw, sugar beet pulp, cane molasses, urea and minerals respectively. The high straw mixture (HS) contained 540, 359, 65, 12 and 24 g kg^{-1} DM of barley straw, sugar beet pulp, cane molasses, urea and minerals respectively. This resulted in ME and DM degradability values of 10.4 and 8.4 MJ kg^{-1} DM and 48 and 42% for mixture LS and HS, respectively. The degradability of the straw mixtures was determined using fistulated sheep. In experiment 1, the mixtures were offered for one hour after each milking while in experiment 2 the amount of LS available was restricted to the intake of the HS mixture. The animals grazed a perennial ryegrass sward with SSH's of 7.5 and 6.9 cm respectively for experiment 1 and 2. In experiment 1, forage supplement intakes

were 5.3 and 2.3 kg DM day^{-1} while herbage intakes were 11.5 and 14.5 kg DM day^{-1} resulting in total forage intakes of 16.8 kg DM day^{-1} for treatments LS and HS respectively. No significant differences in terms of animal performance were detected. In experiment 2, forage supplement intake was 2.8 kg DM day^{-1} for both treatments while herbage intakes were 13.0 and 13.2 kg DM day^{-1} resulting in total intakes of 15.8 and 16.0 for treatment LS and HS, respectively. No significant differences in terms of animal performance were detected. It was concluded that under conditions when herbage was readily available, higher amounts of high energy/ high degradability forage supplement were consumed than of low energy, low degradability forage supplement. It is suggested that if buffer feeds of low energy or DM degradability are used, buffer feeding with these feeds could reduce total energy intake although the intake of such buffer feeds are probably limited due to short term fill effects.

The final experiment investigated the effect of forage supplement dry matter content and stage of lactation on dairy cow performance and herbage intake response. Four groups of dairy cows of which half were in early lactation and half in late lactation grazed perennial ryegrass swards and were either not supplemented (C), were offered a supplement at 30 % DM (C30), 55% DM (C55) or at 80% DM (C80). DM content of the supplement and stage of lactation did not significantly affect forage supplement intake. Herbage intake was however significantly affected by supplement DM content and stage of lactation. Herbage intakes were 14.2, 8.0, 10.3 and 9.0 kg DM day^{-1} for forage supplement treatment C, C30, C55 and C80 respectively, and 11.4 and 9.3 kg DM day^{-1} for early and late lactation respectively. This resulted in significant differences in terms of total dry matter intake as affected by stage of lactation being 15.1 and 12.9 kg DM day^{-1} for early and late lactation respectively. The different types of supplements did not significantly affect animal performance. The yield of fat and protein corrected milk (FPCM) was significantly ($P<0.01$) affected by stage of lactation. Forage supplementation resulted in a negative milk production response in late lactation cows and in a positive milk production response in early lactation. However, this response was not significantly different. The increase in FPCM with supplementation was significantly ($P<0.05$) different between early (+3.3 kg FPCM day^{-1}) and late lactation cows (-0.5 kg FPCM day^{-1}). The results of this experiment suggest that early and late lactation animals will consume similar amounts of forage supplement when offered, but will respond differently with a positive response in early lactation and negative response in late lactation animals.

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GLOSSARY OF TERMS

ADF	Acid detergent fibre
CF	Crude fibre
cm	centimetre
CP	Crude protein
CRD	Controlled release device
Cr_2O_3	Chromic oxide
CV	Coefficient of variation
D	Day
DE	Digestible energy
Df	Degrees of freedom
DM	Dry matter
DMD	Dry matter digestibility
EE	Ether extract
FADF	Faecal acid detergent fibre
FN	Faecal nitrogen
FV	Fill value
g	Gram
G	Graminee
GJ	Giga Joule
H	Hour
Ha.	Hectare
kg	Kilogram
L	Leguminous
ME	Metabolisable energy
MJ	Mega Joule
NCGD	Neutral cellulase gaminase digestibility
NIRS	Near infrared reflectance spectroscopy
NDF	Neutral detergent fibre
OMD	Organic matter digestibility
OMI	Organic matter intake
PI	Pasture intake
R	Substitution rate
RSE	Residual standard error
SE	Standard error
SSH	Sward surface height
VFA	Volatile fatty acid
W	Live weight
%	Percentage
$W^{0.75}$	Metabolic weight
UK	United Kingdom
OM	Organic matter

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1. INTRODUCTION

Pastoral agriculture occupies around 20% of the land surface of the globe, and is directly or indirectly responsible for meeting the economic and material needs of a substantial proportion of its human population. Within the UK, grassland occupies 67.8% of the agricultural land area (McInerney, 1995) and therefore gives grass a special place in the farming economy (Table 1).

Table 1. Utilisation of UK agricultural land, 1994

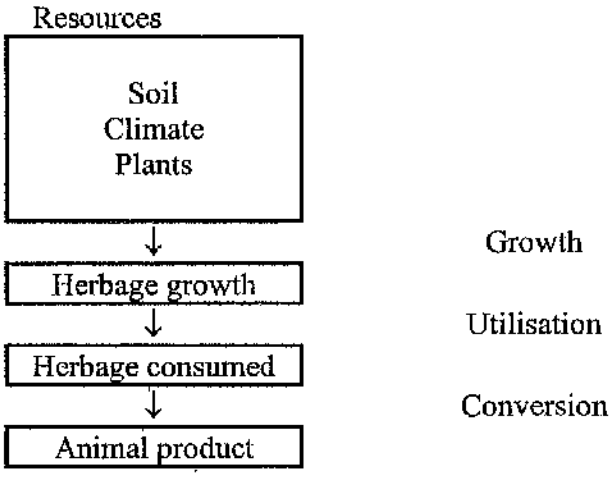
	Area (1000 ha)	% of total
Grass < 5 years	1436	6.8
Grass > 5 years	5322	28.8
Rough grazing	4551	24.6
Common land	1224	6.6
Total grass	12533	67.8
Cereals	3042	16.5
Other arable	1471	8.0
Other land	1436	7.8
Total agricultural area	18482	100

Source: McInerney 1995

Farming is a land and climate based economic activity. It depends on how well these resources are managed which determines how successful this economic activity is. The dairy industry in terms of milk output is responsible for 21% of total agricultural output and 47% of the agricultural output of the grass based livestock industry (MAFF, 1994). Grazed grass is potentially the cheapest feed resource in dairy production systems (Brown *et al.*, 1995), however, its effectiveness within dairy production systems depends on how well this resource is managed. This is dependent on the skills of the production system manager, the resources available to him, the economic climate he is producing within and, more recently, concerns expressed by the general public with regards to pollution, animal welfare and the relationship between consumption of cattle products and human health.

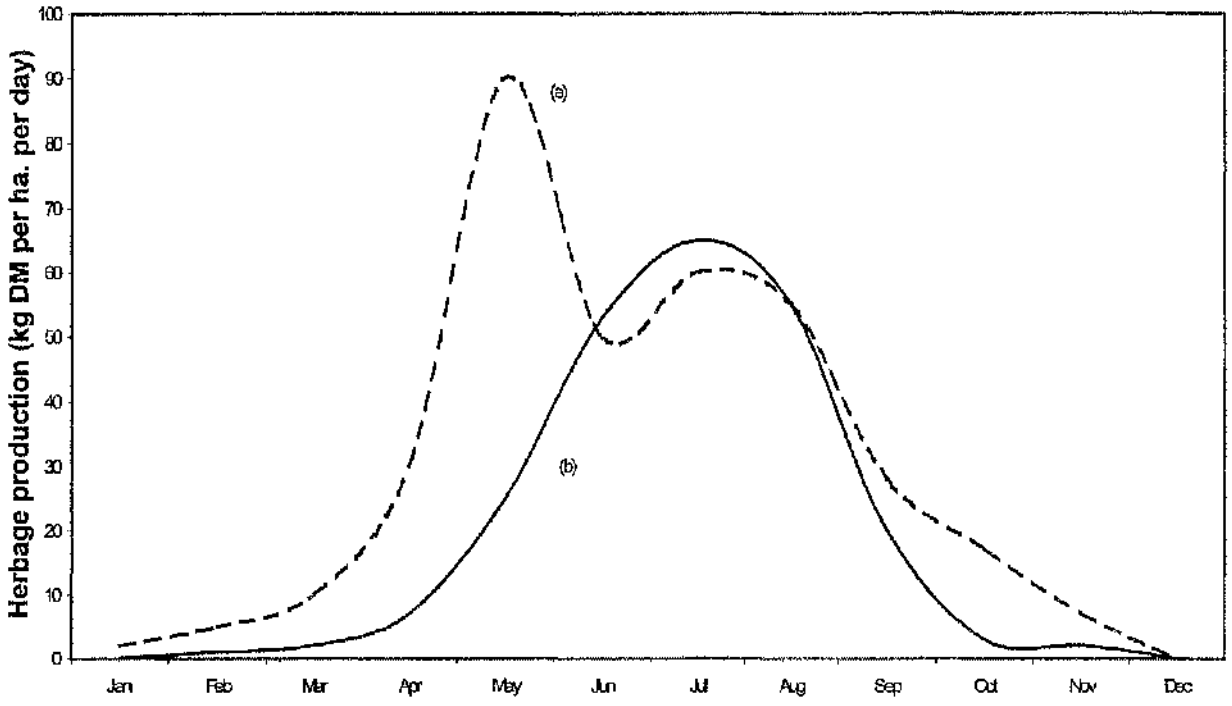
The fundamental process in grazing systems is the harnessing of the sun's energy and the supply of plant nutrients from the soil for the production of plant tissue. The plants are consumed by animals and then converted into usable animal products (Figure 1).

Figure 1. A simple grazing system



Each of these stages has its own efficiency (output expressed as proportion of input) which can be influenced by management, and together these efficiencies determine the production achieved. The grazing system described above is a very basic form in which only grazed herbage is involved and output is basically dependent on herbage growth patterns. In dairy production systems the main output is milk and this means that the physiological process involved is lactation. In the UK, and most temperate grasslands in the world, herbage growth is seasonal (as shown in Figure 2) due to variations in climate.

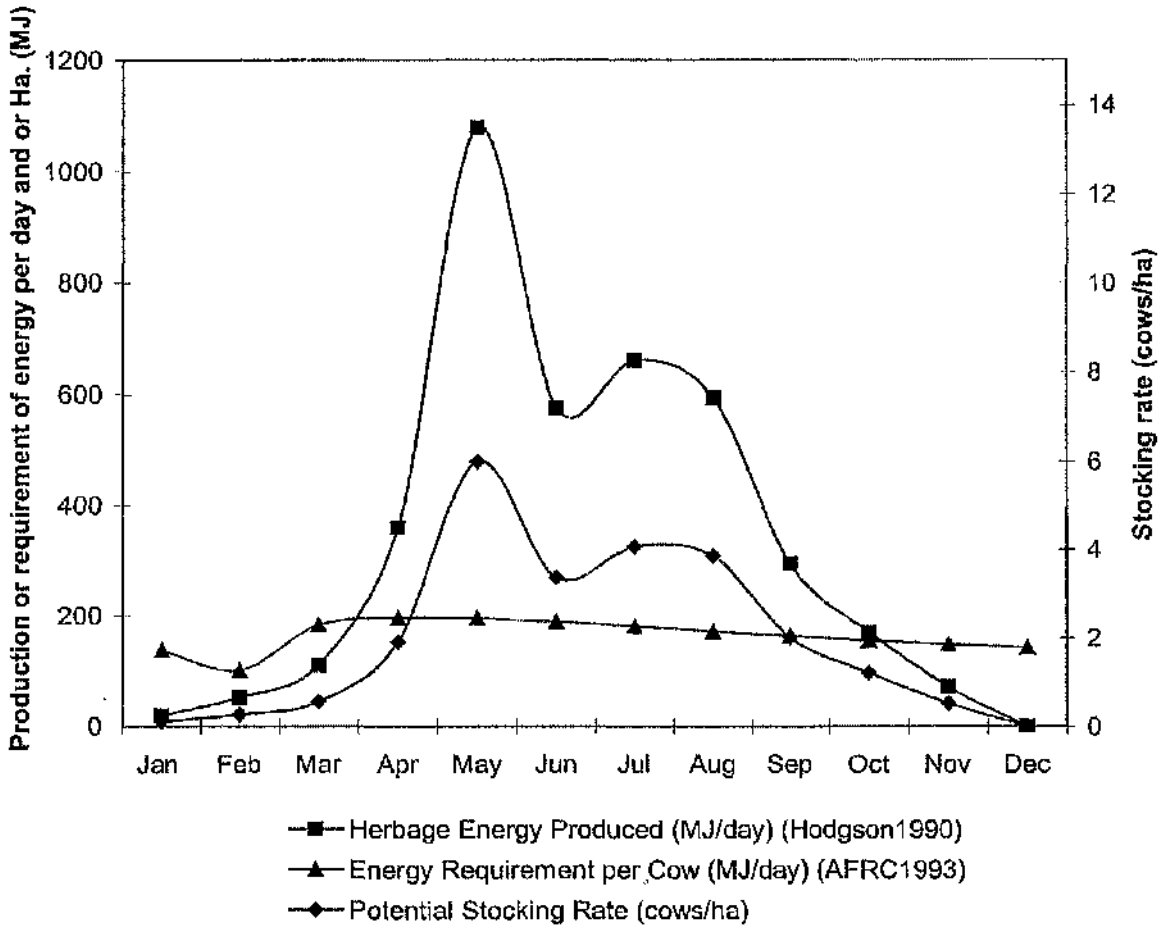
Figure 2. Seasonal patterns of herbage production in grass swards in different environments



Curve a relates to a perennial ryegrass sward in the Thames Valley in Southern England, curve b relates to a similar sward at an altitude of 350 m on the Cheviot Hills, UK (Hodgson, 1990)

In order to achieve high efficiencies (utilisation of herbage produced) the requirements of the animals need to match production of the herbage. This is often difficult to achieve in dairy production systems as illustrated in Figure 3.

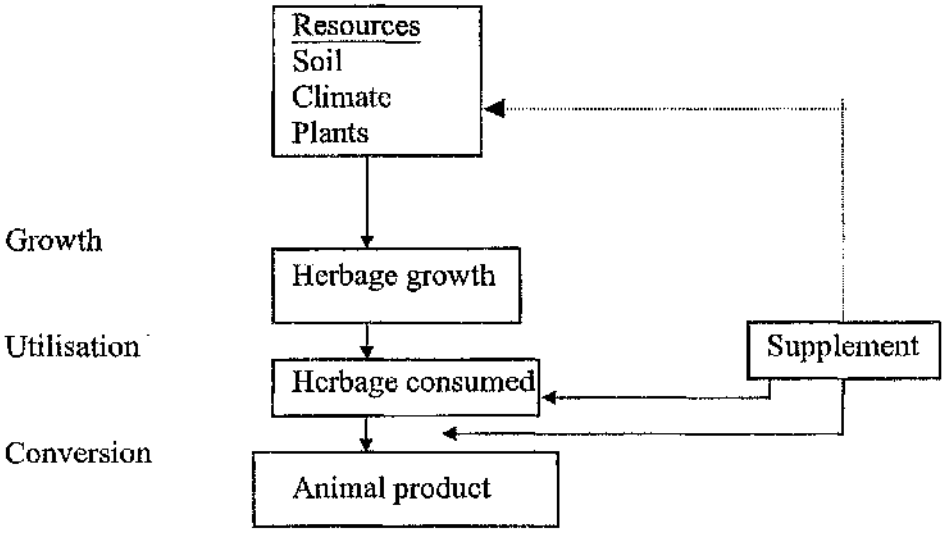
Figure 3. Seasonal herbage production and energy requirement of March calving dairy cows producing 6500 l per lactation and potential stocking rate



Since milk and its processed products are perishable, creating a continuous requirement for fresh product, continuous production will have to take place. This means that the requirement for grazed herbage does not always match that of herbage production. In addition, since lactation is involved, dairy cows can only tolerate a limited period of herbage intake below requirements. Therefore additional food needs to be made available to the lactating animal to sustain lactation. Some smoothing of the more extreme seasonal variation in herbage production can be achieved by the use of plant species or varieties with complementary growth patterns e.g. legumes have a slower spring growth and more sustained summer production than grasses (Figure 2). However, the scope for varying the seasonal pattern of herbage production is limited. This has led to the introduction of additional feed resources;

supplements. Supplementation with either conserved herbage or feeds originating from non-grassland based agricultural production systems are frequently used in dairy production systems to overcome temporary shortfalls of herbage or, under certain economic circumstances, are used to replace grazed herbage. The introduction of supplements has a number of influences on the grazing system as illustrated in Figure 4.

Figure 4. A simple grazing system with supplementation



Supplementation has potentially major influences on the utilisation process and the conversion process and a more indirect influence on the herbage growth process. In this thesis the various components of the grazing system will be discussed. The discussion will limit itself to dairy production systems using dairy cows, based in the temperate grasslands of the world (between latitudes 30° and 60°). It will concentrate on the herbage intake and conversion process and not on herbage growth process although the latter two are not always independent of each other. In Chapter 2 the literature will be reviewed with regards to intake from herbage, supplementation of grazing dairy cows, management of the grazed herbage resource and techniques to measure herbage intake. In Chapter 3 an experiment is described investigating the potential use of alkane markers for measuring herbage intake by dairy cows offered a perennial ryegrass/ white clover mixture. In Chapter 4 an experiment is described investigating the potential use of alkanes to estimate supplementary grass silage intake in grazing dairy cows. In Chapter 5 an experiment is reported describing the effects of two supplementary forage strategies on dairy cow performance and the effect on the sward. In Chapter 6 the effects of supplementing grazing dairy cows with straw-based mixtures of

differing composition are described. In Chapter 7 an experiment is described reporting on the effects of offering supplementary forage of differing DM contents to early and late lactation dairy cows. In Chapter 8 general aspects of the use of the alkane technique are discussed and the results of the supplementation trials are evaluated and general conclusions are drawn.

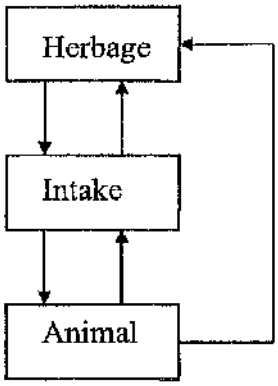
2. INTAKE OF GRAZED HERBAGE; LITERATURE REVIEW

2.1. INTRODUCTION

In the first presidential address to the British Grassland Society, Stapledon (1946) stated that "grassland agronomists must admit that they have neglected the grazing animal, to cater for whom is the "raison d'etre' of all their endeavours." This situation has improved slightly and limited progress has been made. This lack of progress is partly due to the cost of experiments with grazing animals and partly due to the difficulty in measuring herbage intake with grazing animals (see Leaver, 1985; for a review). The estimation of herbage intake from pre and post-grazing sward measurements can be successful as shown by Meijs (1981). However, this type of measurement estimates intakes of groups of animals, and if replication has to be achieved, very large numbers of animals are required. In order to reduce the requirement for large numbers of animals, individual intake measurement techniques were developed. The techniques are based on faecal indicators, initially based upon the faecal N technique (CAB, 1961) and then the use of indigestible markers, particularly chromic oxide (Le Du and Penning, 1982) and more recently alkanes (Mayes *et al.*, 1986[ab]).

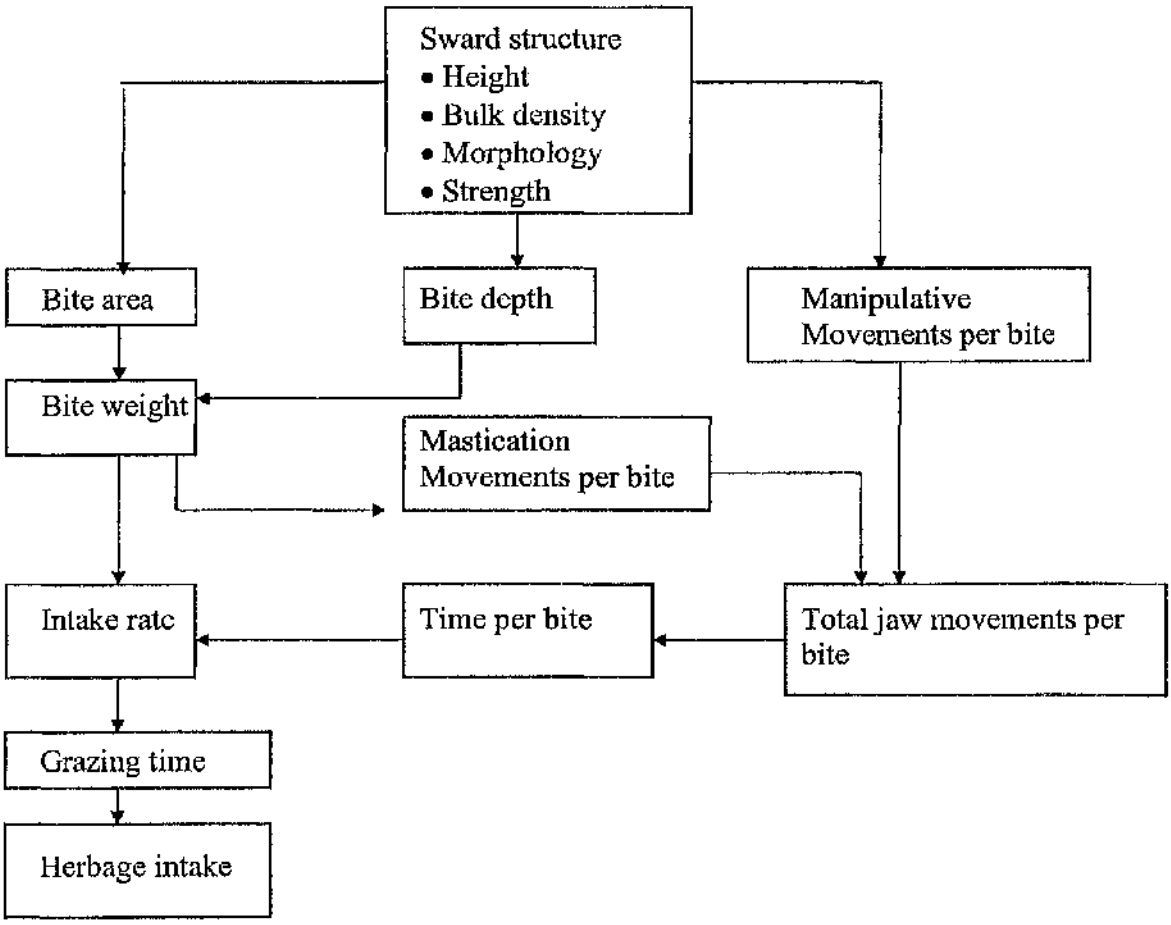
In order to understand the process of herbage intake, a number of interactions need to be understood as shown in Figure 5. In simple terms, herbage intake is the removal of herbage by the grazing animal. This process is influenced by a great number of factors that are dependent on the herbage characteristics of the herbage on offer and the animal characteristics of the animal removing the herbage. In addition, the grazing animal by grazing, affects the herbage on offer.

Figure 5. Interactions between herbage, intake and the grazing animal



Sward measurements have been an established part of agricultural research for over 150 years (Beddows, 1953) and there has been a particularly lively awareness of the importance of quantitative sward measurements since the Welsh Plant Breeding Station was established in 1919. The measurement of animal characteristics initially concentrated mainly on production parameters since these were, and still are, the economic driving force. This was also in part due to the difficulty in measuring other characteristics. Since intake now can be more accurately estimated, together with description of production potential of the animal, the importance of behavioural limits to herbage intake in grazing was realised. Allden *et al.* (1970) first defined herbage intake in terms of components of ingestive behaviour (Figure 6). This simple concept provided the basis for a further understanding of the grazing process. This was aided further by the development of equipment for the recording and processing of data describing grazing behaviour initially by Stobbs (1970) and more recently by Penning (1983) for sheep and Rutter *et al.* (1997) for cattle.

Figure 6. Components of ingestive behaviour that mediate between sward structure and short term intake rate



Current marker techniques are only able to measure intake over a relative long term span (e.g. 1 week), whilst the behaviour measurement devices can be used to measure ingestive behaviour over very short time periods. Penning and Hooper (1985) evaluated the use of short-term weight changes to estimate short-term herbage intake. This technique, in combination with measurement of animal behaviour, facilitated the measurement of short-term herbage intake (e.g. 24 hours). The technique is based on the measurement of intake over a short period (e.g. 2 hours) which in combination with 24-hour behaviour data, could be used to calculate daily intake. However, Gibb *et al.* (1998) showed that intake rates change during the day and therefore the measurement of short-term weight changes in combination with 24 hour recording of animal behaviour would result in over or under estimations of herbage intake over a 24 hour period. This does not mean that measurement of the components of the ingestive process as shown in Figure 6. are not useful in trying to

explain responses, in terms of total herbage intake (measured using markers or other techniques), to different sward structures.

Supplementation of the grazing animal is normally undertaken to improve animal performance over and above that which can be produced from herbage alone, or to maintain animal performance during periods of a temporary herbage shortage. Supplementation therefore affects mainly the animal, in terms of animal performance, but also affects the grazing behaviour of that animal. In this chapter animal factors determining herbage intake will be reviewed and then sward factors determining herbage intake will be reviewed. Finally the effect of supplementation of grazing animals with both concentrates and forages will be reviewed. Implications for grassland management will be evaluated and techniques to measure herbage intake will be reviewed.

2.2. ANIMAL FACTORS

The factors affecting herbage intake which are independent of the sward can be divided into two categories.

1. Type of animal
2. Status of the animal

These factors determine the "motivation" of the animal to harvest herbage and the herbage intake that can potentially be achieved.

2.2.1. Animal type

The type of animal used in dairy production systems determines in part the potential for herbage intake. Foldager and Haarbo (1994) showed that maximum feed intake capacity was related to the breed of the animal. It was reported that for stall-fed animals the maximum feed intake capacity of Danish red or, black and white dairy cows was 20% higher than that of Danish Jersey cows on an per animal basis but intake capacity on a per kg live weight basis was similar. Genetic selection for milk yield has and will in the future also change the type of animal used in dairy production systems. Veerkamp *et al.* (1994) observed differences in DM intake of cows of high genetic merit compared to cows of medium genetic merit. Patterson *et al.* (1996) showed that genetic merit affected potential dry matter intake, but only at higher levels of concentrate input. This seems to indicate that when the food is limiting in terms of bulk, these differences will not be expressed. Selection for milk yield (or yield of milk components) tends to result in larger (heavier) animals which are more efficient in

converting food energy and protein into milk (Veerkamp *et al.*, 1994). However, they also showed that cows of higher genetic merit were leaner compared to cows of medium genetic merit. This poses an interesting problem for the future within dairy production systems. As discussed before, herbage supply is variable and does not always coincide with the requirement from a lactational perspective. If animals used in future dairy production systems have a reduced ability to store lipids and as a result have fewer reserves to overcome periods of herbage shortage; this could have major implications with respect to how these animals have to be managed. Supplementation of these animals during periods of temporary shortage could be essential to maintain lactational and reproductive functions. Selection for characteristics specifically for animals that perform in grazed herbage based dairy production systems has not been carried out extensively. However, this has been attempted indirectly by Visscher and Goddard (1995) who analysed profit (profit being defined as (net income)/(food requirement) and food requirement being size of the agricultural holding). Their analysis showed that even within grazed pasture based systems the larger Holstein/Friesian cow was more profitable than the smaller Jersey cow, even if life-time production was taken into account.

These findings can be explained by the fact that maintenance nutrient requirements are related to $W^{0.75}$, while rumen volume and gut capacity are isometric with W implying that large animals are capable of eating larger amounts of food relative to their maintenance requirements (Demment and Van Soest, 1985). In addition, W not only affects the animal's gut capacity but also incisor breadth. Illius and Gordon (1987) devised a general relationship between incisor breadth and bodyweight from data on 32 grazing ruminant species. Incisor breadth, in mm was 8.6 $W^{0.36}$. These measurements correspond with measurements carried out by Burlison *et al.* (1991) and Penning *et al.* (1991) in sheep. Illius and Gordon (1985) showed that incisor breadth explained part of the variation found in bite weight in cattle under a range of grazing systems with larger animals having a larger bite weight. Hodgson and Wilkinson (1967) derived a linear relationship for OMI and W for a range of ages and types of grazing dairy cattle. Animal type should therefore be considered when evaluating herbage intake as it determines the potential maximum feed intake capacity and potentially affects the efficiency of harvesting herbage. Secondly, animal type determines in part the animals potential for milk production and its "motivation" to consume herbage. The latter will be further discussed in the next paragraph.

2.2.2. Status of the animal

Galloum and Le Magnen (1987) have reviewed the history of studies of control of food intake. Two main concepts are generally accepted as determining food intake in ruminants. The first concept is that intake is restricted because the diet is highly fibrous, bulky, and digested slowly and, therefore its disappearance from the rumen sets a limit on the rate at which more food can be eaten (Physical fill). Balch and Campling (1962) demonstrated this concept experimentally. The positive relationship between the rate and extent of digestion of a forage, its level of voluntary intake, which is so important in the utilisation of forages, was established and used as evidence for a physical limit to intake.

The second concept is that energy requirement regulates food intake as long as physical fill does not limit food intake. However, this concept has potential pitfalls since it assumes that the energy requirements are known. For example, Friesian dairy cows offered a feed low in roughage *ad libitum* and not remated were seen to increase in weight at the rate of about 1 kg per day and to show no sign of slowing down after 70 weeks, when they weighed 700 kg (Monteiro, 1972). This example suggests that the requirement of the animals was dependent on the food on offer., It is however accepted that ruminants can control their food intake to meet their nutrient requirements under quite a wide range of circumstances and there is evidence of sensitivity to the chemical and osmotic properties of the digesta which allow a "metabolic" control of intake (Forbes, 1995). For example, Faverdin (1990) observed that 3 or 6 mol of mixed VFA infused into the rumen during 3 h of feeding depressed DM intake by 1.5 kg in lactating dairy cows and by 0.8 kg in dry cows. These depressions in intake were established during the second and third hour of infusion and were not recovered during the rest of the day.

In order to understand intake, it is important to quantify if physical or metabolic factors control intake. If physical factors are involved, the diet plays an important role, if metabolic factors play a role, it is important to understand the metabolic requirement of the animal. Within both these concepts it is assumed that the animal is healthy and free from parasites, deficiencies and the foods do not have toxic properties. In this review it will be assumed that this is the case when further discussing the two previously mentioned concepts which control intake.

2.3. THEORETICAL INTAKE CONCEPTS IN THE GRAZING SITUATION

2.3.1. The concept of physical fill in the grazing situation

The concept of physical fill in ruminants is mainly related to distension of the reticulo-rumen wall. Epithelial receptors in this wall respond to increased distension and these are connected to the central nervous system (Leek, 1986) which controls intake. Ulyat *et al.* (1967) showed that ruminants keep the volume of liquid in the rumen constant despite different voluntary intakes of dried hay. The volume of the rumen of ruminants varies isometrically with W. Demment and Van Soest (1985) have demonstrated the relationship. They showed that maximum physical fill can in principle be calculated from live weight. It is still not clear how, for example, a quantity of feed DM can be translated to the volume it will occupy in the rumen. However, it has been shown that the rumen volume occupied by feed is not necessary related to, for example, the dry matter in the rumen, but more the type (density) of the material (Egan, 1972). The application of this knowledge has led to the development of "Fill systems" for dairy cow rationing purposes. Hyppölä and Hasunen (1970) proposed a very simple fill-unit system assuming that maximum intake is restricted by the bulkiness of the food. Cows are ascribed a capacity in relation to their weight and each feed is allocated a fill value (FV), assuming cows would continue eating until the total fill eaten equals the capacity given.

2.3.2. Fill systems

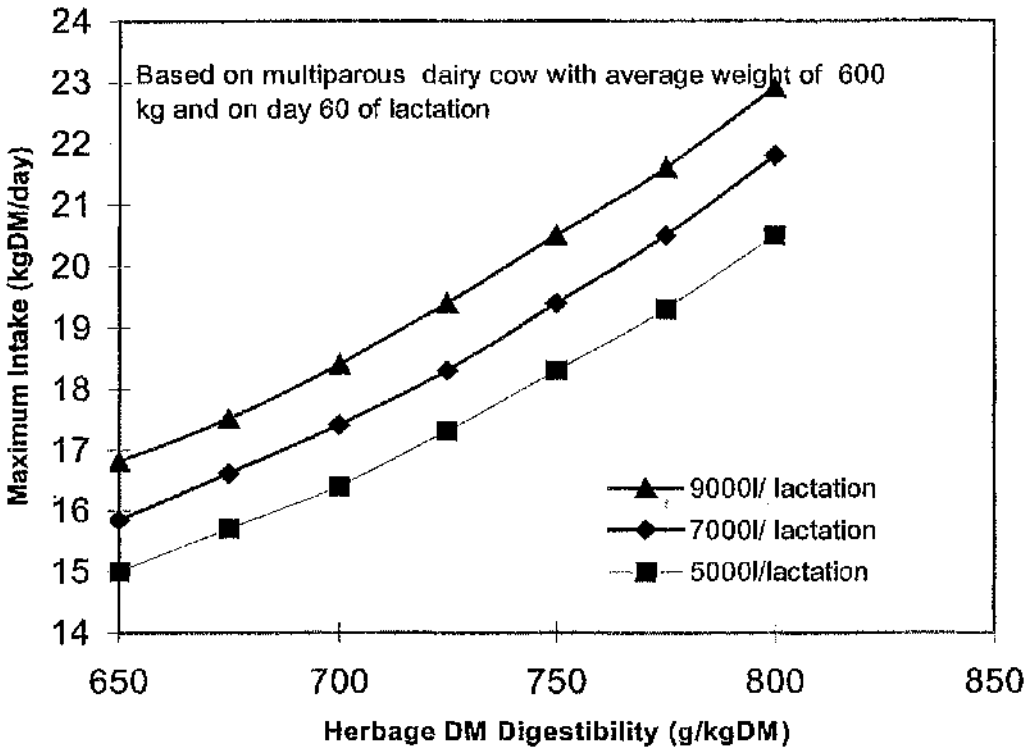
This approach was further adapted in Denmark (Kristensen and Kirstensen, 1986) and in France (Jarrige, 1986; Coulon *et al.* 1989). The Danish system introduced additional animal factors to describe intake capacity, like stage of lactation, potential milk yield or housing system (Kristensen and Kristensen, 1986). FV for concentrates are assumed to be constant and equations were developed in which FV for forages may be calculated according to digestible energy (DE) and crude fibre (CF) content. In France the INRA fill unit system (Jarrige, 1978) is based on a vast amount of data on the in-digestibility of roughage's measured in feeding experiments. The system was recently revised (Dulpy *et al.* 1987). In this system FV for roughages are tabulated while the FV for concentrates depends on both roughage and animal characteristics. In the United States and United Kingdom the prediction of maximum dry matter intake is described by models which take both physical fill and

metabolic factors into account since they introduce factors such as actual milk yield (e.g. Mertens 1987, Lewis 1981, NRC 1987).

However, assuming these metabolic factors to be constant, the American system (NRC, 1982) and UK systems (AFRC, 1993) in principle determine potential DM intake by live weight of the animal, digestibility of the diet, DM of the forage and level of concentrates fed. None of the models described above have really been developed for the grazing situation. All models expect a knowledge of the quality of the herbage consumed and this can vary greatly due to season (Gustavsson, 1993) and selection by the animal within the sward (Dumont *et al.*, 1995). This means that the French system is especially difficult to apply in the grazing situation since it depends on book values. The AFRC (1993) and NRC (1987) systems mix metabolic factors with physical factors when predicting maximum forage intake. Using metabolic factors for predicting potential forage intake often results in energy balance calculation because actual milk yield is used. As a result, one does not really predict forage intake potential but forage requirement.

One system, the Danish fill system. which is relatively independent from metabolic factors, predicts potential forage intake, and potentially could be easily used when herbage digestibility is known. Besides animal characteristics it only requires digestibility of the forage (or feed) to predict potential intake. In Figure 7 the potential herbage intake purely based on "fill" is shown for a dairy cow consuming herbage, for a range of digestibility's and 3 genetic potentials are shown as predicted by this system. In Table 2 some maximum DM intakes, measured in cows with a very high herbage allowance, from the literature are shown. When comparing these with the values predicted by the Danish fill system it shows that these are in reasonable agreement and, do not seem to be related to actual level of milk production.

Figure 7. Relationship between herbage dry matter digestibility and potential intake using the Danish fill factor system for cow with genetic potential of 9000, 7000 and 5000 l per lactation

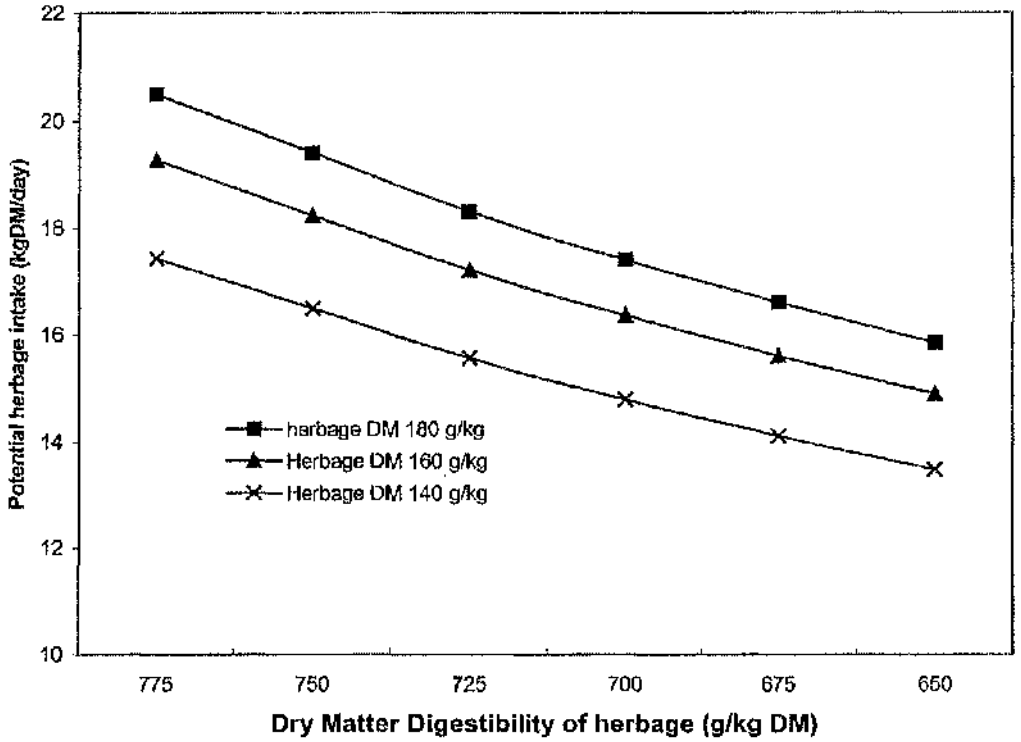


As shown in Figure 7 the potential maximum herbage intake depends on the animal itself which in principle determines the size of the rumen and secondly the "quality" of the material which enters this system. Since the latter determines the speed with which the material leaves the rumen. In order for feed particles to leave the rumen they need to be reduced in size. Two processes reduce the size of the particles in the rumen; rumination and digestion. Poppi *et al.* (1980) showed that for sheep the particles, which leave the rumen, must be able to pass a sieve with 1-2 mm apertures.

Table 2. Herbage DM intakes reported for grazing dairy cows receiving low levels of concentrate supplement (<2 kg day^{-1})				
Source	Herbage allowance (kg DM cow^{-1})	DM Digestibility of herbage on offer (g kg^{-1} DM)	Milk yield (l day^{-1})	Herbage intake (kg DM day^{-1})
Holden *et al.*(1994)	52.2	777	16.7	15.6
Arriaga-Jordon & Holmes (1986)	-	843	30.2	20.1
Rook *et al.* (1994)	25	-	21.5	16.8
Kibon and Holmes (1987)	34	859	27.8	17.3
Hodgson and Jamieson (1981)	27.8	800	17.9	17.4
Jennings and Holmes (1984)	-	842	26.1	15.4

Andrews and Ørskov (1970) showed that the particle size for passage out of the rumen depends on the animal type and age (size) of the animal, while Welch (1982) showed that not only the animal itself was important but that type of diet also had an influence. Rumination can account for 85% of particle size reduction (Kennedy, 1985). Rumination is mainly stimulated through extension and tactile stimulation of the recticulo-rumen-epithelium (Ruckenbush, 1988). Total time ruminating has rarely been shown to exceed 10 hours per day (Welch *et al.*, 1970). The implications of the above for grazing animals is difficult to assess. Most of the experiments referred to above were carried out with dry or low quality diets. Tactile stimulation of the recticulo-rumen- epithelium is possibly not as high when animals consume fresh herbage compared to, for example, a straw-based diet. However, extension of the recticulo-rumen-epthelium could be great, since fresh herbage contains large amounts of intra-cellular water and therefore, the rumen volume occupied per unit DM consumed can be large. Vérité and Journet (1970) reported that the critical DM content of grazed herbage was 180 g kg^{-1} with an estimated depression of 0.34 kg DM intake per 10 g kg^{-1} fall in herbage DM. The effect of herbage DM content on intake is illustrated in Figure 8.

Figure 8. The effect of herbage DM content on potential herbage intake for a 600 kg dairy cow with a milk yield potential of 7500 l per lactation



Thomas *et al.* (1961) showed that if water was added to the rumen per fistula, no detrimental effect on forage intake could be detected. This suggests that it is not the DM content of the diet, but intra cellular water which could be an important component of rumen fill in grazing animals. Ulyatt and Wagham (1993) even suggested that this is one of the main limitations of high levels of dairy production from pasture. In order to release this intra-cellular water, and therefore reduce rumen fill, rumination is extremely important.

2.3.3. Rumination

Welch (1982) showed that average rumination rate is about 0.02 g cell wall minute^{-1} kg^{-1} body weight. In a follow up study (Dong Ho Bae *et al.*, 1983) it was shown that body size was the most important variable affecting rumination efficiency. Efficiency of chewing increased with increased live weight. If particle reduction is an important factor determining rate of passage this could have important implications. Larger animals not only have a larger rumen but also greater capacities to reduce particle size and thereby potentially increase rate of passage. This could explain that, even in the grazing situation, cows of high genetic merit (which are larger and heavier) could consume more herbage (Grainger *et al.*, 1985). For a given animal, rumination is therefore an important factor in reducing rumen fill and allowing further intake. Rook *et al.* 1994 (Table 3) suggests that total rumination time for dairy cows grazing a temperate grass/clover sward is possibly a limiting factor for intake.

Table 3. Effect of total DM intake and forage digestibility on rumination activity in dairy cows grazing a grass clover sward

Season	Intake (kg DM day^{-1})	OMD (g kg^{-1}OM)	Total Rumination time (hours day^{-1})	Rumination per kg DM intake (min kg^{-1} DM)	Rumination chewing rate (chews min^{-1})	Chews per bolus
Spring	13.9	580	4.2	18	50.9	66.2
Spring	15.3	618	5.7	22	62.4	68.5
Spring	16.8	602	5.2	19	44.3	49.2
Summer	13.5	665	5.5	24	61.0	72.8
Summer	14.1	652	6.1	26	70.7	116.0

Source: Rook *et al.* 1994

Rumination time did not seem to be related to total herbage intake or the quality of the forage on offer. The same was the case for rumination activity. Total rumination times reported by Rook *et al.* (1994) are well below the maximum of 10 hours reported by Welch *et al.* (1970). Phillips and Leaver (1985[ab]) and Roberts (1989) report maximum rumination times for non-supplemented animals of 6.8, 7.5 and 8.0 hours day^{-1}. This study (Rook *et al.*, 1994) does not seem to support the theory that rumination is a limiting factor for herbage intake in grazing dairy cows.

2.3.4. Fermentation

The second important process, which in combination with rumination reduces particle size and allows dry matter to leave the rumen, is fermentation. The reticulo-rumen serves as a large reservoir in which the digesta are maintained at a near constant temperature, in aerobic conditions, at a pH between 5.5 and 7.0. Within this environment microorganisms (bacteria and protozoa) grow and multiply, degrading protein and structural and non-structural carbohydrates to supply the energy required for the synthesis of the microbial biomass. The waste products of the microbial metabolism are VFA's, that are absorbed from the rumen and form a major energy source for the animal. Ammonia is absorbed and converted into urea and methane and carbon dioxide is largely eliminated from the rumen by eructation. As a result of the fermentation process the bonds between the herbage fibres are dissolved and, as a result particle breakdown is enhanced.

The potential for breakdown of forage particles is often described as degradability of the forage. In order to maximise degradability it is important to provide the rumen microbial population with the optimum mixture of nutrients to maximise their activity. Rumen microorganisms use carbohydrates as their main energy source. In fresh herbage soluble sugars, fructosans and cell wall polysaccharides are the main carbohydrates. The second important nutrient for the microbial population is nitrogen. In fresh forages 70 to 90% of the N is present as true protein (Tamminga, 1986) mainly in soluble enzymes in chloroplasts and cytoplasm and insoluble protein (mainly chlorophyll) in the chloroplast membrane (Mangan, 1982). Sugars and fructosans and soluble N components are supposed to be instantly available for the rumen biota and therefore, assumed to possess an infinite rate of degradation. Cell wall components and insoluble N components are however degraded at much slower and variable rates. In order to optimise nutrient availability to the grazing ruminant not only is there a need for provision of the right balance between energy and nitrogen but there also needs to be a balance between readily available carbohydrates (e.g. soluble sugars) and readily available nitrogen. The basis for choosing a more dynamic approach to feeding the microbes in the rumen was the development of the nylon bag technique for evaluating ruminal feeds by Ørskov and Mehrez (1977) and Ørskov and McDonald (1979). This allowed both the protein fraction and the energy fraction of the diet to be split into a readily available fraction (water-soluble nitrogen or carbohydrate) and a potentially degradable fraction. This was first integrated into a rationing system in the UK (ARC, 1984) for protein, while the

division into different fractions of the energy substrate is still ignored in most rationing systems (Vérité and Peyaud, 1989; Hvelplund and Madsen, 1990; CVB 1991). Most energy and protein evaluation systems propose the use of a proportion of the digestible energy as a determinant for energy available to the rumen microbes (e.g. ARC, 1980; ARC, 1984; propose 0.65 of total DOM). The UK system recently (AFRC 1993) moved forward to a fermentable energy system that at least acknowledges that certain substrates like fat will never yield energy for the rumen microbes. For the grazing dairy cow the degradability of fresh herbage depends therefore on the nutrients it contains which then allow the rumen microbes to break down the fibre particles in combination with the rumination process.

As a result of this process particles are able to leave the rumen but in addition energy is made available to the animals in the form of VFA and protein in the form of microbes which leave the rumen to be digested in the intestines.

The chemical composition of grass depends on a wide range of genetic and environmental factors (Gill *et al.* 1989) such as grass species and variety, rate of fertilisation, solar radiation, rainfall and maturity at time of grazing. These factors not only influence the chemical composition but also the rate and extent of rumen degradation. Peyraud *et al.* (1997) investigated the effect of level of nitrogen fertiliser applied to the sward. They showed that fertiliser application could have a large effect on the nitrogen content of the herbage. The CP content of the herbages was 150 vs. 106 g kg^{-1} DM for fertilised and non-fertilised swards respectively. The OM of the non-fertilised sward was slightly less digestible but the site of digestion was unaffected. Organic matter truly digested in the rumen for both swards was 0.94 of digestible organic matter intake. This shows the importance of the rumen for digestion of fresh herbage.

Van Vuuren *et al.* (1990) investigated the nutrient supply to the microbes of cows consuming a range of herbages differing in their maturity. They concluded that when cows are consuming fresh grass it is very unlikely that the nutrient supply to the microbes is insufficient, for a range of maturities. However, they pointed out that, especially in fertilised swards, CP might be oversupplied. This CP is highly degradable and could cause high concentration of ammonia N in the rumen and in addition a large proportion of this CP is used as an energy supply to the rumen microbes which yield less ATP per kg fermented OM than cell wall carbohydrates (Demeyer and Tamminga, 1987).

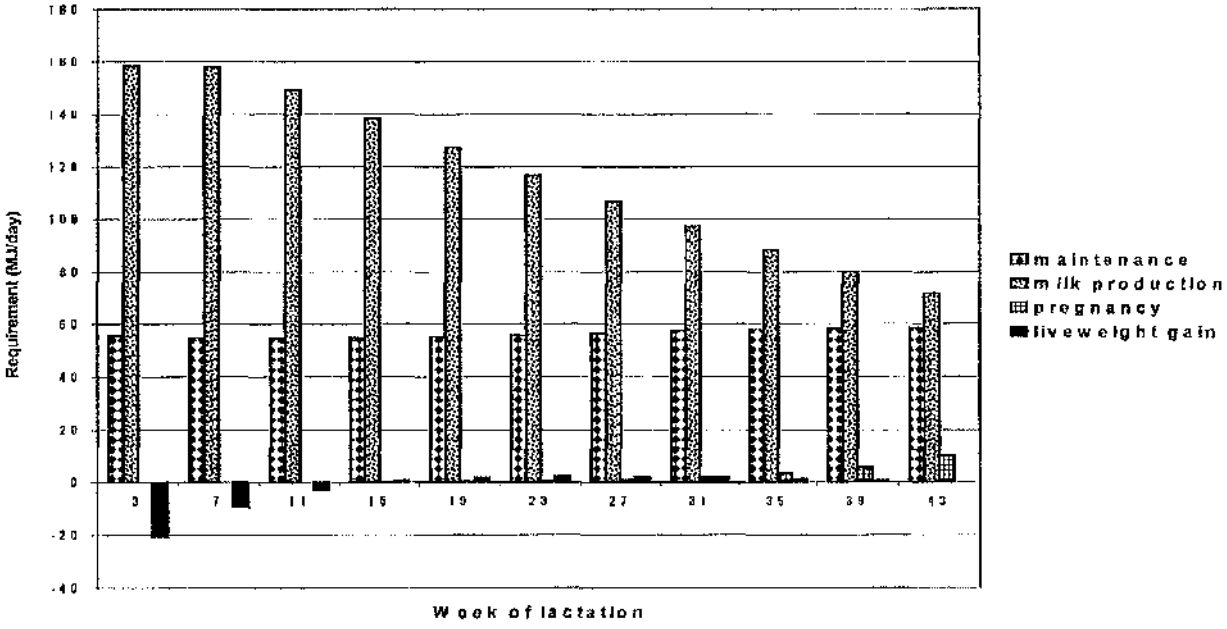
Therefore it seems that for the grazing dairy cow the breakdown of particles is the main

limiting factor for reducing rumen fill and that fresh herbage (if not containing high amounts of protein) provides an excellent substrate for rumen microbes to enhance this process. It is therefore the potential for degradation of the forage consumed that will determine the potential outflow rate and thereby potential intake potential of the herbage.

2.3.5 Energy requirement of the animal

It is generally accepted that nutrient requirements represent one of the most important driving forces of eating as long as " physical fill"does not limit food intake. As discussed before, the concept of "energy requirement" has potential pit falls since no singular requirement may exist as demonstrated by Monteiro (1972).

Figure 9. Metabolisable energy requirements of dairy cow producing 7500 kg milk per lactation at 4.2% fat and 3.4% protein and average live weight of 600 kg



However, what an energy requirement system does allow is the calculation of the energy requirement for a potential level of production. This is especially important for economic evaluation of certain feeding strategies. A potential production response can be calculated to an additional amount of energy supplied.

In most countries a net energy (metabolisable or digestible) energy system is used, (NRC, 1989; Coulon *et al.*, 1989; SCA, 1990; AFRC, 1993). To calculate the requirement for energy (which in the UK is described by AFRC, 1993), the net requirement is calculated which is than multiplied by an efficiency factor (k) for the varying requirements, e.g.: maintenance or milk production, to calculate a total metabolisable energy requirement. The advantage of this approach is that the energy content of the feed can also be expressed in metabolisable energy which is usually derived from an estimate of *in vivo* or *in vitro* digestibility (McDonald *et al.*, 1995). The use of the AFRC (1993) method requires the calculation of the net energy requirements for maintenance, activity, milk production and live weight change which are then divided by their appropriate efficiency factor to obtain a metabolic requirement.

In Figure 9, the metabolisable energy requirements are presented for a cow producing 7500 kg of milk according to a Wood's curve, (Wood, 1967) at 4.2% fat and 3.4% protein, also according to a Wood's curve (Wood, 1976) and a live weight change model according to Korver *et al.* (1985) assuming pregnancy at 90 days after parturition. As can be seen in Figure 9, the main requirement for energy is for milk production. In early lactation this is as high as 3 times maintenance. Live weight change is important during early lactation when large amounts of the animal's fat reserves are used as an additional source of energy. However, as shown by both Veerkamp *et al.* (1995) and Patterson *et al.* (1995), with current genetic progress less energy will be available from these reserves because the high genetic animal of today puts less reserves down during late lactation, resulting in less being available during early lactation.

Since a part of the energy consumed can be used for lipid deposition, less energy will be available for milk production. As shown by Broster and Broster (1984) and Thomas (1987), it is difficult to predict how much of the energy available to the animal will be used for milk production and how much will be deposited as body lipids. It is therefore difficult to predict actual milk production responses to additional quantities of energy. However, in the future with leaner cows, this could be less of a problem as the high genetic cow deposits relatively little into body lipids. The latter also means that less will be available as a reserve and therefore, adequate nutrition, especially in early lactation, will be essential in future production systems because, as can be seen in Figure 9., as much as 20 MJ day^{-1} is available from lipid loss in early lactation.

In the AFRC (1993) system milk energy content is calculated using the formulas of Tyrell and Reid (1965) and, for live weight change, the values published by Gibb *et al.* (1992). The maintenance component consists of a fasting metabolism component and an activity allowance. (AFRC, 1993). The activity allowance assumes 500 m walking, 14 hours standing and 9 position changes, which totals to 0.0095 MJ d^{-1} kg W^{-1}. For grazing animals this activity allowance might have to be increased depending on distances walked by the grazing animal.

Various authors have investigated the net energy cost of walking. Taylor (1970), used a mixture of animals ranging from a mouse to a horse to develop the equation:

Ew = 0.418 x 10 (167 W 0.126)

In which Ew is net energy expended to move one kg W m. $^{-1}$. Ribiero *et al.* (1977) defined the cost of walking at 2 J kg^{-1} W m^{-1} moved, while the cost of moving vertically was 26 J kg^{-1} W m^{-1} moved. These values were confirmed by Lawrence and Stibbards (1990). Lawrence *et al.* (1989) also discovered that the maintenance requirement increased after extensive walking. The additional energy cost of walking proposed by ARC (1980) of 2.6J kg^{-1} W m^{-1} for horizontal movement and 28 J kg^{-1} W m^{-1} for vertical movement seems to be very sensible. However, no suggestions are presented by AFRC (1993) in how to apply these units in the grazing situation. Only SCA (1990) and NRC (1996), for beef cattle, give some guidance in how much additional energy might be used by grazing animals. Mathewman *et al.* (1989) investigated the effect of sustained exercise in lactating animals. These animals walked 10.6 km day^{-1} and climbed 480 m day^{-1}. In response, milk yield dropped during the first 3 days but recovered completely after 5 days of daily exercise indicating that walking does not necessarily result in reduced production if the animals are able to compensate by using their fat reserves, as was the case here, or by consuming additional food. The amount of walking during grazing will very much depend on the state of the sward and the amount of selectivity the animal wishes to express while grazing. Assuming an extreme situation in which the animals have to walk 1 km to the paddock which is on a hillside, grazing for 8 hours day^{-1}, moving at a speed of 1 m min. $^{-1}$, walking up hill for half of the time at 1/2m min. $^{-1}$ half of the grazing time, this would require for a 600 kg cow milked twice daily;

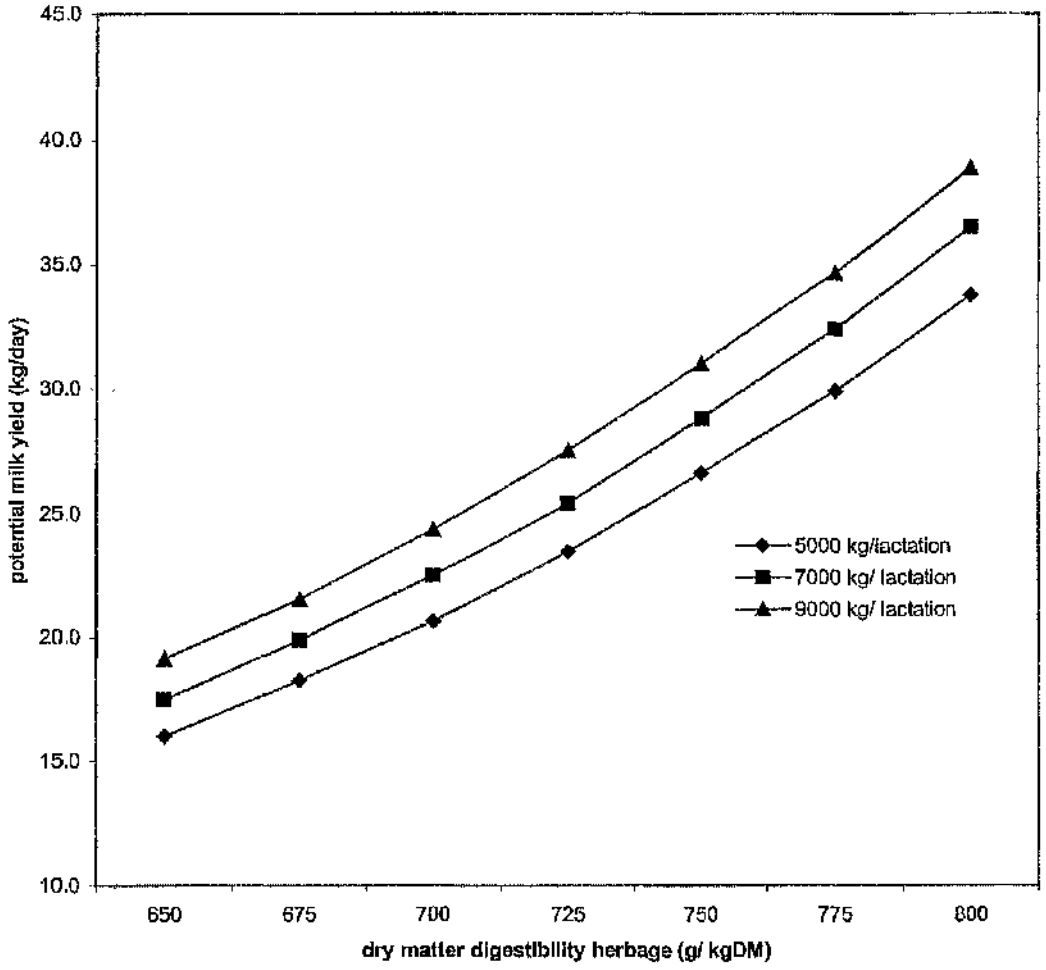
((4 x 1000) + 480) * 2.6 J) + (240 * 26 J) * 600 = 10.7 MJ day^{-1} in terms of Netto energy

Assuming an efficiency of 0.65 would result in an requirement of metabolisable energy of 16.5 MJ day^{-1}

For a cow with a daily requirement of, e.g., 180 MJ per day, this would mean an increased energy requirement of 16.5 MJ day^{-1} representing an increase in energy requirements of 10% or a decrease in milk production of approximately 3 kg day^{-1}. So, grazing could have a substantial impact on the energy requirement of animals and therefore, some guidelines should be developed as to how to use the activity energy requirements in grazing animals.

If "fill", as calculated using the Danish fill system, was the only factor controlling herbage intake then a potential energy intake can be calculated. Milk yields as shown in Figure 10, would be achievable for a cow weighing 600 Kg on day 60 of lactation. This model assumes that sward characteristics do not affect potential herbage intake and, from a sward with a digestibility of 80%, milk yields ranging from 33 – 38 Kg could potentially be achieved. However, these levels of production, from grazed grass only, are not often achieved in practice. This would suggest that 'fill factors' are not a constrained when grazing high quality swards.

Figure 10. **Potential milk yields of cows with different milk yield potential when grazing herbage of differing digestibility without supplementation assuming fill constraint only applies.**



2.4.1 *THE EFFECT OF SWARD CONDITIONS ON HERBAGE INTAKE*

In the UK not one common guideline/advisory model to predict herbage intake is currently in use as is the case, for example, for preserved forages (AFRC, 1993). Guidelines in terms of e.g. height are available (Thomas *et al.*, 1991) but these are aiming for two objectives at the same time; maximising herbage utilisation and fulfilling some of the cows requirements for herbage. These guidelines do not allow the grassland manager to make choices e.g. maximise herbage intake or increase herbage utilisation. In some countries e.g. New Zealand (Holmes, 1984; Bryant, 1981), the Netherlands (PR, 1997) specific guidelines have been developed based on herbage allowance (kg DM^{-1} cow^{-1}). However, these systems can only be used in rotational grazing systems while in the UK set stocking is the most common system. These guidelines also only apply to very specific situations as e.g. the very extensive system of New Zealand in which the primary objective is to maximise herbage utilisation and cows therefore are unable to maximise intake. The opposite can be encountered in the Netherlands where herbage utilisation is of lesser importance but high production per animal is the objective. As a consequence animals are supplemented with large amounts of concentrate and forage and the grazing system is an integral part of herbage conservation.

The objective for the future is to develop guidelines in terms of sward characteristics which enable the grassland manager to achieve levels of intake as required with the levels of utilisation as required. Genetic progress has resulted in cows that are less well able to cope with variations in herbage intake. In addition, the relative ratios between fixed cost and herbage production have changed dramatically (Gardner, 1996; Allen, 1998). In the future more emphasis should be directed to the development of guidelines which allow for high intakes of herbage and consequently less emphasis on herbage utilisation of the grazed sward.

2.4.1.The high intake sward

The first factor determining the potential intake of a sward is the digestibility or, maybe better defined as the rate at which the indigestible factor can leave the rumen. As shown by Minson (1987), 80 % of the organic material in the rumen is indigestible so, the speed at which this can leave the rumen is essential.

Factors affecting the digestibility of the sward depend on the leaf stem ratio of the material consumed, the age of the material consumed and the amount of dead material consumed. Variety and species differences will also affect the digestibility of the material consumed. However, the impact of the variation in digestibility, in for example, ryegrass swards is possibly limited. Peyraud *et al* (1996) reported that herbage intake increased by 0.2 to 0.25 kg OM d^{-1} per percentage unit increase in pepsin cellulase digestibility of the herbage.

The second factor of importance, which determines the potential intake from pasture, is the harvestability of the pasture. Harvestability is the effort/time required by the cow to harvest the herbage on offer. A large number of factors affect this so-called harvestability. The main factors are assumed to be (Minson, 1990):

1. Herbage availability and sward structure
2. Herbage variation
3. Pasture Management

These factors of course can not be seen as completely separate components because they overlap and influence each other. Herbage intake has often been studied during the last 15 years using a reductionist approach to the grazing process and herbage intake has been reduced to a simple formula in which

Herbage intake = Intake Rate* Time grazed

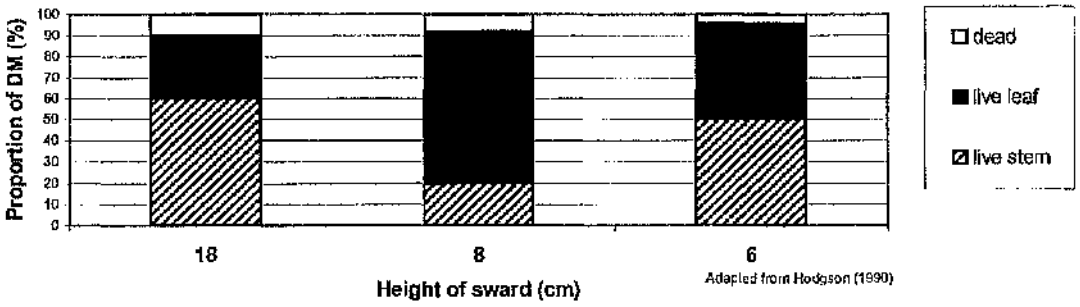
Most of the research has concentrated on the interactions between intake rate and sward characteristics. Intake rate was for this purpose further divided into bite volume x sward density x biting rate (Rook, 1997). The problem with this approach is that it is almost impossible to measure all these components accurately. While small errors in the measurement of any of the components, when multiplied up to an animal intake can result in a large error in terms of herbage intake estimation. More importantly is that Gibb *et al.* (1998), have shown that the animal continuously changes the various components (e.g. bite mass, bite rate) during a 24 hour period. It is interesting to note that various grazing models have been able to predict grazed herbage intake in field circumstances using an average daily bite size

(Herrero *et al.*, 1998; Brereton and McGilloway, 1998; Parson *et al.*, 1994). Only recently have experimental techniques been developed to measure these components of intake (Lacca, 1992; Cushnahan *et al.*, 1998) under experimental circumstances, certainly not reflecting the normal grazing situation.

This does not indicate that this information is not useful as it will certainly help to explain the limiting factors preventing high pasture intakes to be achieved. It is however questionable if this approach can be used to predict a daily intake.

Potential intake from a given sward depended on the characteristics of the sward such as height, density, leaf/stem ratio. Basically a sward consists of leaf, stem, dead material and in some occasions seed heads. The sward characteristics really describe how the different components are distributed within the sward and, as a consequence, this will determine which components can be easily harvested. As shown in Figure 11, swards height has a marked effect on the distribution of the different components.

Figure 11. The effect of grass height on the components of sward



Generally, the taller the sward the lower the density of tillers and the higher the proportion of stem and dead material.

A sward, with a low height, will contain more tillers and more leaf until a certain minimum is reached, after which the proportion of stem increases. The interesting aspect is that both tall and short swards could potentially have the same availability (kg DM $ha^{-1}cow^{-1}$). Hodgson (1982[a]) and Gross *et al.* (1993) showed that the main determinant of potential intake from a sward is bite size (mass per bite) and this is mainly determined by sward height and bulk density of the sward. If bite size is not sufficiently large then there is scope for increasing grazing time and biting rate.

Biting rate (or biting time) has been shown to be linearly related to the number of mouth movements per bite, which increases with increased bite size. Hodgson (1985) reported a bite rate range of 20-66 bites per minute in cattle. Petit and Bechet (1995) for lactating ewes and Leaver (1985) for dairy cows, showed that animals will increase their biting rate when bite size is low but that this is often not enough to prevent a depression in herbage intake. The second option is to increase grazing time. Rook *et a.* (1994) reported grazing times as high as 12 hours per day. Both Rook *et al.* (1994) and Pulido and Leaver (1995) showed that this increase in grazing time was not sufficient to overcome a decrease in herbage intake under circumstances of low herbage availability.

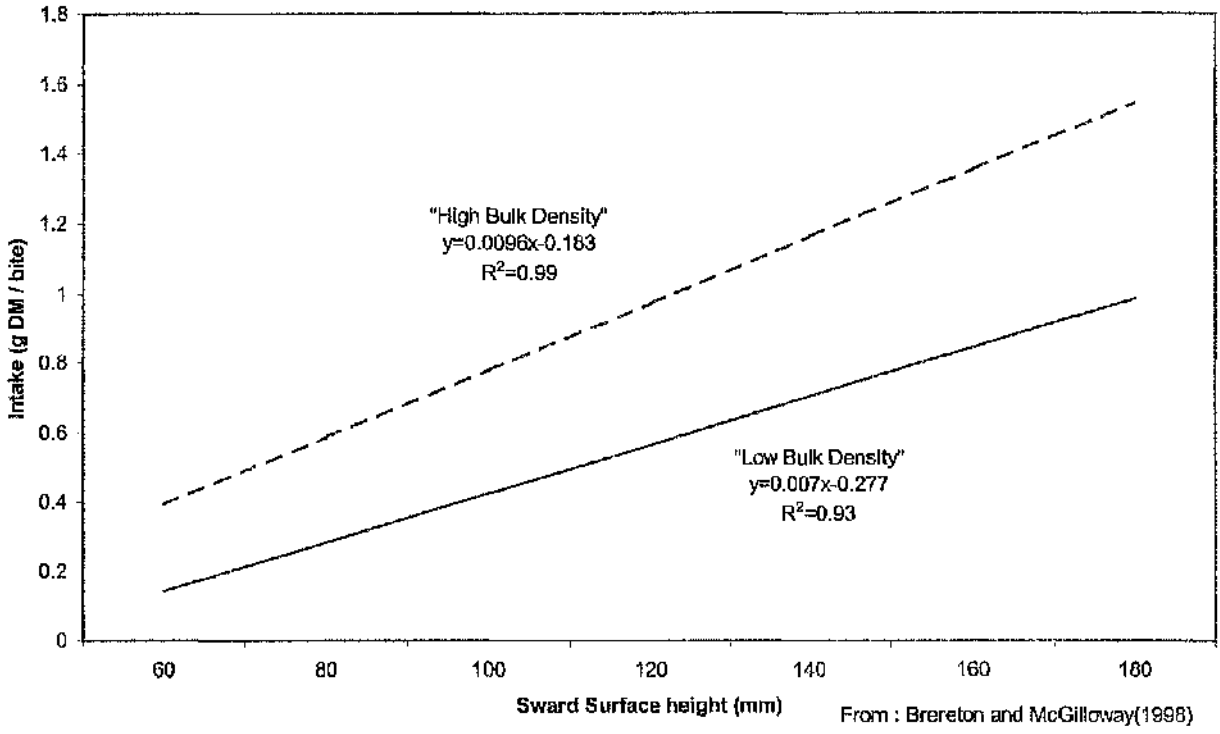
2.4.2. Effects of sward characteristics

The leaf /stem ratio is an important characteristic of the sward which may determine potential herbage intake both due to the effect on digestibility and rumen outflow rate and its effects on harvestability to the grazing animal. Generally leaf is more digestible but, as shown by Laredo and Minson (1973 and 1975) when animals are offered leaf and stem at similar digestibility, 59% more leaf will be eaten. This may possibly be due to increased outflow rate of leaf particles. Hodgson(1982[a]) suggests that bite depth will decrease in swards with a higher proportion of stem. Consequently, the bite size of the animal decreases resulting, potentially, in a reduced herbage intake. Fisher *et al.* (1995[ab]) demonstrated how leaf/ stem ratios could be manipulated in the practical grazing situation. Increases in milk yield of up to 3 kg day^{-1} were reported. Recent plant breeding efforts (Wilkins, 1995) have resulted in decreased proportions of flowering tillers in swards and, most recently, the discovery and application of the "stay green gene" (Wilkins, personal communications) offers exciting opportunities for the improvement of the leaf /stem ratio in grazed swards.

As shown by Greenhalgh and Reid (1969), different plant species will result in different intakes and consequently differences in production. Differences between species and within species will also result in differences in the presentation of the sward and consequently of the harvestability. To differentiate between the effects of harvestability and digestibility will be very difficult as these effects are associated and difficult to separate experimentally. However, if harvestability effects are important, it is important to use the appropriate animal type for testing. Penning *et al.* (1998) showed that differences between species in terms of harvestability were detected with sheep but not with dairy heifers. Ulyatt et al. (1986) suggested that the shear strength (the energy required to break the herbage up) could be an important selection criterion. Recent work at ARINI (McGilloway, personal communication) has shown that differences between grass varieties in terms of shear strength were mainly associated with stage of development of a specific herbage species and that breeding for these characteristics would therefore be impossible.

The density of the sward is another important factor that determines the potential intake from the sward. Although bite area decreases with increased sward density (Laca et al. 1992), bite size still increases. As shown in Figure 12 these differences can be substantial and the difference increases with increased sward surface height *. As can be seen in Figure 12, at a grass height of 14 cm the increase, due to an increased density, can be as high as 0.5 g DM per bite (Brereton and McGilloway (1998).

Figure 12. The effect of sward surface height (mm) on intake (g DM per Bite) at different bulk densities

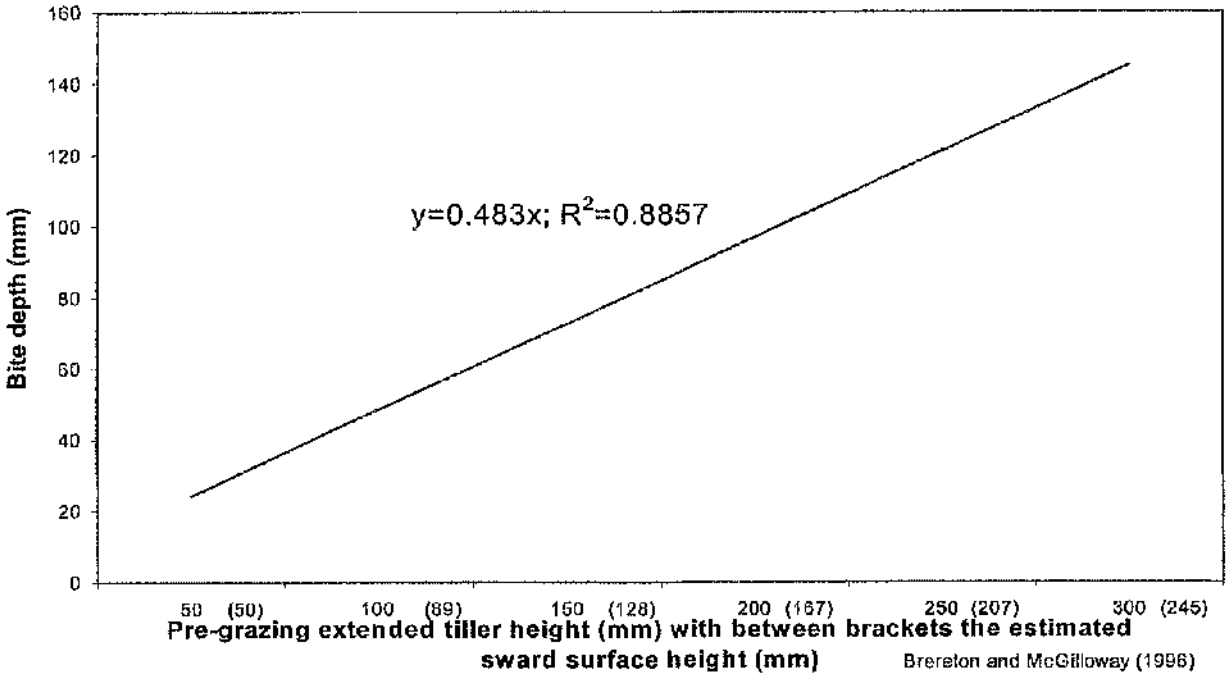


**In order to be able to compare between different literature references, where possible indicators are re-calculated to sward surface height on basis of formulas in appendix 2.*

Laca (1992) showed that bite depth is related to sward height. This was recently further investigated by Brereton and McGilloway (1998) measuring intake over short periods of time as shown in Figure 13. Increasing sward height results in increased bite depth and increased bite area and, as a consequence bite size is increased. As can be seen in Figure 12 bite size was greatest at the 140 to 180 mm sward surface heights. This is much higher than the 70-100 mm sward surface height, which Hodgson (1990) advised for dairy grazing.

The difference could be due to the genetic progress recently achieved. Peyraud *et al.* (1996) reported that with high genetic merit, high yielding dairy cows intake increases could be achieved at sward surface heights above 120 mm, while this was not the case for lower yielding animals.

Figure 13. The relationship between bite depth (mm) and extended tiller height (mm)



2.4.3. Describing herbage availability

As discussed in the previous paragraph, herbage intake can be affected by many factors and consequently, herbage availability is a difficult concept. In the majority of grassland management systems available, the unit mass is used. Most systems will use the unit kg DM per grazing animal. Some systems will use kg DM per unit area to predict intake as can be seen below. Sward height is often used as an indicator of kg DM per unit area in these models.

Table 4. Functions to estimate the effect of herbage availability on DM intake of grazing ruminants

Source	Function to estimate relative intake (RI)
Woodward (1995)	RI=(Imax*(DM/DM+x))/Imax
Doyle *et al.* (1989)	RI=[Imax*(1-exp(-DMH/Imax)$^{1.23}$)$^{1/1.23}$]/Imax
Loever *et al.* (1987)	RI= 2*FA/B-FA^2/B^2 (B=750)
Seman *et al.* (1991)	RI= 1-((1-0.1)/(HI-low)^2)*(HI-SH)^2 Where HI=20 and low =5

Imax = Potential Intake (kg DM Animal^{-1} day^{-1})
DM = Pasture dry matter (kg ha^{-1})
X = Michaelis constant for consumption (g (m^2)^2)
DMH = Available DM per animal (kg DM animal^{-1} day^{-1})
FA = Forage available per kg body weight (g DM kg^{-1} BW)
B = Threshold level of forage available (kg DM ha^{-1})
HI = Height above which additional increases in sward height do not affect intake (cm)
Low = Height below which herbage is unavailable for grazing (cm)
SH = Sward Surface Height

As long ago as 1966, Arnold and Dudzinki (1966) showed that when less than 1000-1500 kg DM ha^{-1} was available for grazing, herbage intake would be reduced.

Various authors (Greenhalgh *et al.*, 1966; Combellas and Hodgson, 1979; Peyraud *et al.*, 1996b) have demonstrated a curvilinear relationship between herbage allowance (kg DM ha $^{-1}$) for cows producing less than 23 litres day^{-1}. Peyraud *et al.* (1996^b) showed that although a high allowance is required to achieve maximum intake per cow, herbage intake does not seem to be overly restricted provided herbage allowance (cut above 5 cm) equals 18 kg day^{-1}. Herbage intake increased slowly (+0.04 kg DM day^{-1} per kg increase in allowance)

DM day^{-1} per kg DM decrease in herbage allowance between 18 and 12 kg DM $animal^{-1}$ day^{-1}). It seems that sufficient information is available to predict herbage intake for low producing cows but that more information is required to predict intake for high producing cows. For example, Peyraud *et al.* (1996[b]) reported a decrease in intake of high producing cows when less than 2500 kg DM ha^{-1} was available or grass height (using a plate reader) was less than 14 cm. They also showed that this decrease could be partly overcome by increasing the herbage allowance (Hoden *et al.*, 1991). However, trying to maintain swards of high quality at these heights will be very difficult as illustrated by the work of Fisher *et al.* (1995 [ab]).

Herbage availability changes as soon as the animal enters the paddock as it will selectively start removing herbage and thereby, change the availability and increase the variation in the sward. Newman *et al.* (1994[a]) showed that in sheep the "Noy-Meir principle" (Noy- Meir, 1975) applies. Sheep will select that which will maximise the benefits to the animal. Distel *et al.* (1995) reported that large ruminants when offered a choice will spend most of their grazing time in those areas in which they can maximise intake rate. Ungar *et al.* (1992) suggested that large ruminants will graze a sward down in layers always consuming the highest parts first.

A second factor in the development of localised variation in herbage availability, is the effect of rejection due to defecation and urination. Mean size of the actual area covered by a dung patch has shown to vary from 0.02 to 0.07 m^2 (Bastiman and Van Dijk, 1975). With animals depositing 4 to 13 times per day (Marsh and Campling, 1970) at a stocking rate of 3 cow ha^{-1} and a grazing season of 180 days this would mean assuming no overlaps, that only 2.7 to 4.9% of the grazing area is actually covered. A similar calculation can be carried out for urine. Urine patches are greater than faecal patches, at 0.2 to 0.7 m^2 at 4 to 12 urinations per day would result in a cover of 4.3 to 45% of the grazing area.

The actual area covered by fouling is not that important but the area rejected around the dung and urine patches can be large especially in cattle grazed swards. The areas around the dung patch have been estimated to be five times (Bastiman and van Dijk, 1975) to twelve times (Greenhalgh and Reid, 1969) the area of the dung/urine patch itself. As a consequence, the area affected by dung or urine can increase to 12.5 to 84 %. These factors have to be taken into account when calculating herbage allowances for dairy cattle. The difficulty is that the amount rejected depends very much on previous grazing pressure and local weather circumstances. The period effect of herbage rejection may vary from 2-18 months (Watkins and Clements, 1978).

A third factor affecting how much herbage is actually available to the animal is the grazing system used. The two most common and clearly defined systems are the rotational system and the continuous stocking system. In the rotational system, the animals are allowed access to a certain proportion of the grazing area for a certain time while in the continuous stocking system the animals have access to the total grazing area all the time. The system most common in the UK is a half way house between these two systems where very large paddocks are available to the animals in which they might graze for a relatively long period. Various authors have reported on the differences between rotational vs. continuous grazing systems. Castle and Watson (1975), Baker *et al.* (1982), Evans (1981) and Carlier and Andries (1981) found no differences in terms of animal performance while McMeekan and Walshe (1963) and Walshe (1971) reported improved performance in terms of milk yield per ha of up to 16 to 20% more milk per ha. Campbell (1966) could not detect differences in terms of herbage production but suggested that under rotational grazing, higher levels of production are possible. Evans (1981) and Leaver (1976) suggested that under rotational grazing it is easier to adjust to temporal changes in herbage production because they are more easily seen. The disadvantage of rotational grazing is the amount of fencing, roads and water supplies required, to create the various paddocks. This might be cost effective when these can be used throughout the year, but may not be if the grazing season only lasts 5-7 month as is common in Europe. The second potential disadvantage of the rotational system (especially if one-day paddocks are used) is that a high level of grassland management will be required. It is easy to over or under supply herbage to the grazing animals since the paddocks need to be continuously adapted in size in relation to grass growth.

This is, to a lesser extend, a problem in continuous grazing system since more herbage is available at any point in time but shortages can still occur. It seems therefore, that the rotational system is better suited to production environments where high levels of production per ha. are required. Continuous systems of grazing appear more suited to a production environment where high levels of production per individual animal are required although they do not offer the high herbage heights suggested required to maximise intake per bite (Figure 12). It is interesting to note that high production per animal herds in New Zealand have opted for the continuous grazing system (Simons, 1978).

A third system, which is really an adaptation of the rotational grazing system, is the leader follower system. In this system the high producing animals graze a paddock first and then the lower producing animals are used to graze the remaining herbage. Mayne *et al.* (1990), using

a leader follower system, did not find any improved yield of milk per ha. The improved milk yield of the high-producing animals was offset by the reduced milk yield of the low-producing animals. This system could be interesting for future use. As shown before the high intakes that can potentially be achieved can only be obtained with very high sward heights but these are very difficult to maintain through out the grazing season without reducing digestibility of the sward. This problem could potentially be overcome by using the later lactation cows as followers to graze the swards down to maintain quality. But what ever system of grazing is used it is the pasture manager, which makes the system work.

2.5. *SUPPLEMENTATION OF GRAZING DAIRY COWS*

2.5.1. *Introduction*

Supplementation is a strategy often used to alleviate seasonal deficits in grazed forage or to achieve production levels, which are thought not to be achievable with forage only. In certain cases supplementation is used to provide specific nutrients thought to be deficient in the overall diet of the grazing animal. This scenario will not be discussed. Increasing the stocking rate of temperate grassland has been shown to increase the amount of utilisable metabolisable energy (UME) ha^{-1}, which can be harvested (Gordon, 1973; Baker, 1980). However, this increased utilisation of harvested energy will be realised with a reduction in individual performance per cow (especially milk yield). If animal performance is decreased, the proportion of the feed used for maintenance of the cow is increased and consequently animal efficiency declines. The optimal stocking rate is therefore the optimal balance between fixed cost per unit-harvested energy and the decrease in animal efficiency. Most farmers will usually operate below this level, although mean annual income can be increased with increased stocking rates. The variation in annual income will also increase (Doyle and Lazenby, 1989). Stability of annual income is considered by many farmers to be more important than increasing mean annual income (Johnson and Bastiman, 1981). The provision of supplementary feed could potentially reduce the variation in annual income and may increase income levels, depending on the type and cost and effectiveness of the feed (Newton and Brockington, 1975; Mayne, 1990).

Supplementary feeds can be divided into two feed types, although the differences are not always clear:

- concentrate supplements
- forage supplements (buffer feeds)

Both will enable the variation in nutrient intake due to seasonal deficits to be counteracted, but the responses to, and uses of these two different feed types can be very different. Concentrates are those supplements which contain high levels of energy (ME> 12.0 MJ kg^{-1} DM), generally contain low levels of fibre, are of high DM content (DM> 800 g kg^{-1}DM) and are often composed of cereals or agricultural by-products like sugar beet pulp or soya meal.

Due to their high energy density and high DM content, they tend to contribute less (per kg DM consumed) to the physical limit (fill) of the grazed herbage diet. In contrast forage supplements are based on forages which have been preserved. Their energy concentration is generally below 12 MJ kg^{-1} DM, they are high in fibre and often low in DM content. Greenhalgh (1975) defined a forage supplement as a purchased or home grown feed, available *ad libitum*, that is eaten when the nutrient intake from the basal forage (grazed herbage) is restricted, but not in preference to the grazed herbage. Due to the high fibre content and low DM content of the diet, forage supplements will tend to add to the physical limit (fill) of an all grass diet. The main consequence of this difference between concentrates and forage supplements is that in conditions in which sward conditions (herbage availability) are not preventing the animal from achieving its potential of grazed herbage intake, forage supplementation can result in substitution rates as high as 1.02 (Phillips, 1988). In contrast, concentrate supplementation, adding less to the "physical fill" limit, under similar grazing conditions can result in lower substitution rates (Meijs and Hoekstra, 1984).

2.5.2. Responses to supplementation

Supplementation under the appropriate conditions seldom completely substitutes for grazed herbage and consequently milk yield will increase. When supplementing with concentrates Leaver (1985), in a review of the literature, reported an average response in milk yield of 0.32 kg milk kg^{-1} increase in concentrates fed. Journet and Demarquilly (1979) reported a mean response of 0.4 kg milk per kg additional concentrate fed in a review of 10 studies with cows producing more than 25 kg day^{-1}. These low yield response are in marked contrast to responses obtained with grass-silage based diets. Thomas (1987), in a review of the literature, derived a value of 0.79 kg milk per kg additional concentrate offered in addition to grass silage. Both Leaver (1985) in the grazing situation and Thomas (1987) in the winter feeding situation report large variations around these average values.

When supplementing with forage supplements, Phillips (1988), in a review of the literature, reported an average response of 0.13 kg milk per kg DM of forage supplement consumed in addition to grazed herbage. However, this response was -0.75 kg milk per kg DM of forage supplement consumed when herbage availability was not restricting herbage intake and, the response was 3.5 kg milk per kg DM forage supplement consumed when herbage availability was restricting potential herbage intake. The latter seems to indicate that the response to forage supplementation is directly related to herbage availability. Meijs and Hoekstra (1984)

and Grainger and Mathews (1989) showed that the same relationship exists for concentrate supplementation with a decreased response to concentrate feeding with increased herbage availability.

Generally reported responses to supplementation, especially when supplementation is evaluated in economic terms, concentrate on the milk production responses only. However, supplementation can result in an overall increase in the nutrient supply to the animal and therefore can also result in improvements in body condition or growth in size in e.g. dairy heifers. With current genetic progress which has resulted in animals with reduced body reserves (Veerkamp *et al.*, 1995), insufficient recovery of body reserves during lactation can result in fertility problems and reduced production in subsequent lactations. Very few grazing experiments report the effects of supplementation on live weight gain, body condition score or fertility as a response to supplementation. This is understandable since long term responses take long periods to establish and measure. During this period, the sward grazed by the animal will have undergone changes and, as a result, it then becomes difficult to differentiate between differences due to changes in the sward and the effect of supplementation or potential interactions between the two. In addition, these long-term responses have a large between animal variation and therefore, large numbers of animals are required to establish significant differences.

Many factors influence responses to supplementation and these responses change over time. Broster (1972) reported that the response to supplementation in terms of milk production was curvilinear, with 60-70% of the effect present after seven days and the full effect recorded after 12 to 14 days. However, when investigating the response to supplementation of heifers in early lactation, Broster *et al.* (1975), again reported a rapid build up in the milk yield response over the first two weeks but further increases in milk yield response in the next six to eight weeks of feeding. On the basis of experiments by Blaxter (1956) and Broster *et al.* (1975), Broster and Broster (1984) suggested a lag phase should be considered of at least 14-21 days for changes in the micro-flora to have taken place and the time required for the supplement to be digested and absorbed.

A number of different responses to supplementation can be established. The "immediate response", which is the increase in milk production recorded soon after the introduction of the supplement. This result reflects changes in the total quantity of nutrients absorbed and the way these are partitioned between milk production and live weight gain. As the period of supplementation increases, the response may change. Broster and Broster (1984) have defined this as the "cumulative response". The cumulative response is commonly calculated as an average response over a given period of time. This cumulative response is often different to the immediate response, especially in grazing experiments since changes may take place in the sward but also the animal will change over time. The third type of response is called the "residual response" or "carry over effect". This describes any additional production response that occurs after the supplementary feeding ceases. These responses are most often associated with increases in body condition, which allow a greater proportion of energy intake to be partitioned towards milk production, as discussed by Holmes and Wilson (1984).

Since it is almost impossible or prohibitive from a cost point of view to define/measure all these responses, the best solution would be to accurately define changes in nutrient intake during supplementation experiments. If this actually can be defined, responses could then be predicted on basis of experimentation under more controlled conditions e.g. indoor feeding studies.

2.5.3. Feeding concentrates to grazing dairy cows

Concentrate supplementation for grazing dairy cows is the most common form of providing additional nutrients to the animal. Concentrates are mostly based on industrial by-products, in a dried form, or cereals and therefore can be easily stored with low storage losses. They can be fed during milking and if individual cow allocation systems are in place can be dispensed in differential amounts to specific individual animals. Since the energy density of concentrates is generally high, they can increase the energy density of the diet, while reducing the "fill" of the rumen for a given quantity of nutrients consumed. It can be shown that, depending on the herbage quality only limited amounts of milk can be produced from herbage only, as shown previously in Figure 10.

Additional energy needs to be supplied to achieve higher milk yields. Provided there is no change in body weight, milk output response will essentially be linearly related to the energy input, although the level of feeding can induce curvi-linear responses. The additional energy input achieved by concentrate supplementation will depend on the rate of substitution of grazed herbage with the supplement and their relative nutrient contents. The relationship between substitution rate and herbage availability will be discussed in the next paragraph., Substitution rate is, however, also dependent on the energy requirement of the animal. When animals can fulfil their energy requirement from grazed herbage alone and are offered concentrates, one would expect herbage intake to decrease with an equivalent quantity of nutrients. The author is not aware of any studies which reported substitution rates of 1 or higher when supplementing with concentrates. This suggests that "energy requirement" is a difficult concept to quantify. In general, an increase in energy supply will result in an increase in milk output, together with either, an increase in body weight gain or a reduction in weight loss (Broster *et al.*, 1977). Broster *et al.* (1981 and 1985) in large scale experiments involving the addition of concentrates to a fixed diet, showed that the response in milk output was directly proportional to cow potential or current yield. The relationships were observed to apply equally to cows of different potential and, to the individual cow between different stages of lactation.

When evaluating responses to concentrates at grass Leaver *et al.* (1968) and Journet and Demarquilly (1979) reported responses of 0.33 and 0.40 kg milk (kg concentrate)$^{-1}$ respectively. These responses are much lower than those reported by Leaver (1988), Broster and Thomas (1981) and Coulon and Rémond (1991) for cows fed a winter ration. This can partly be explained by the fact that if good quality herbage is available the relative difference in energy density of the DM is smaller and, as a consequence the relative increase in density per unit supplement fed is small.

As shown by Veerkamp *et al.* (1995) and Patterson *et al.* (1995), selection for milk yield has resulted in leaner cows. Within a grazing system, where herbage availability may be variable, these animals are more susceptible to a negative energy balance and, because of their limited reserves, this will have direct effects on milk yield. Most studies evaluating responses to concentrates at grass do not report changes in condition score or live weight gain.

This is due to the difficulty of measuring long term responses in grazing experiments when the grazed herbage is changing in quality during the experiment. Therefore, the effect of herbage cannot be differentiated from the long term response to supplementation. Most concentrate supplementation experiments carried out with grazing dairy cows have been carried out with animals at relatively low levels of production. This is mainly due to a large number of experiments carried out within extensive dairy production systems in which the main cost is land and therefore herbage utilisation is of importance. However, in production systems in Northern Europe in which housing is required and welfare standards have to be upheld, the main costs are associated with animal units (housing of one cow) and therefore production per animal unit is more important. Higher levels of production will have to be achieved to reduce the overhead costs per unit of milk produced. In Table 5 a number of grazing studies are presented in which average production levels are above 25 kg d^{-1}. The average response to concentrate feeding is 0.74 kg^{-1} and this is very similar to the values reported by Leaver (1988), Broster and Thomas (1981) and Coulon and Rémond (1991) for cows fed a winter ration.

Table 5 Milk yield responses to concentrate feeding in experiments in which grazing dairy cows produce more than 25 kg d^{-1}

	Milk yield ($kg\ day^{-1}$)	Concentrate fed ($kg\ DM\ d^{-1}$)	Milk yield response ($kg\ kg^{-1}$)
Dillon *et al.* (1997)	25.9	2.7	0.54
Jennings and Holmes (1984)	26.4	4.5	0.69
Rook *et al.* (1994)	26.1	3.4	1.15
Kibon and Holmes (1987)	28.4	4.0	0.57
Mean	26.7	3.7	0.74

2.5.3.1. Herbage availability, concentrate supplementation and substitution rate

In his review of the literature, Leaver (1985) concluded that variation in responses to concentrate supplementation at grass was mainly due to variations in herbage availability. Castle *et al.* (1960), Castle and Watson (1978), Gleeson (1981), Rook *et al.* (1994) and O'Brien *et al.* (1996) have shown that milk yield responses greater than 0.8 kg milk per kg additional concentrate can be obtained while Arriaga-Jordon and Holmes (1986[b]), Roger (1985), Granger and Mathews (1989) and Mayne and Steen (1990) have shown that milk yield responses lower than 0.25 kg milk per kg additional concentrate are also possible.

The primary reason for explaining these differences, is the difference in substitution effect obtained on herbage intake, with the net effect being a large difference in additional nutrient intake. The extent of substitution is influenced by a number of factors including herbage availability, seasonal changes in herbage quality, nature of the supplement and the yield potential of the dairy cow. However, most studies investigating the differential response to concentrate supplementation have examined only the interaction between herbage supply and response to supplementation by altering herbage availability through adjustments in herbage allowance (Meijs and Hoekstra, 1984; Granger and Mathews, 1989; Rogers, 1985), herbage height (Rook *et al.*, 1994; Mayne and Steen, 1990) or adjustments in stocking rate (Castle *et al.*, 1960; Hoden *et al.* 1991).

Grainger and Mathews (1989) when evaluating the effect of one level of concentrate supplementation devised a highly significant linear relationship between pasture intake without supplementation (PI) and substitution rate (R):

$$R = -0.0445 + 0.315\ PI$$

PI equals pasture intake (kg DM cow^{-1} day^{-1} (100 kg w)$^{-1}$). This equation suggest that at a given level of supplementation, substitution rate is only dependent on the size of the cow and the intake potential of the sward on offer e.g. substitution rate would be zero for a 400 kg cow when offered a sward with an intake potential of 5.6 kg DM day^{-1} and for a 600 kg cow with a sward with an intake potential of 8.4 kg DM day^{-1}. This suggests that aspects of "physical fill" play an important role in explaining substitution responses. However, Grainger and Mathews (1989) tested only one level of concentrate supplementation (Table 6) and the production level of the animals on these experiments were 24 kg milk d^{-1} at the highest herbage allowance.

Meijs and Hoekstra (1984) examined the effect of level of concentrate supplementation on herbage intake with dairy cows offered differing herbage allowances. The best fitting model to their data was described by the equation:

$$HI = -0.61 - 0.981A + 0.479C - 0.039A*C - 0.014A^2$$

Where HI is herbage intake (kg DM day^{-1}), A is daily herbage allowance (kg DM day^{-1} $animal^{-1}$) and C is concentrate intake (kg DM day^{-1}). This relationship clearly illustrates that substitution rate depends on herbage availability as indicated by Grainger and Mathews (1989) but, in addition shows that the level of concentrate supplementation also effects substitution rate.

The increase in relative substitution rate per additional kg of concentrate supplement will be greater at higher herbage allowances. As a consequence, when evaluating responses to concentrate it is important not only to compare herbage availability but also concentrate level fed. In Table 6 a number of studies are presented in which the response to concentrate supplementation, in terms of substitution rate and milk yield response, at different level of herbage availability are shown. Most studies illustrate the negative relationship between herbage allowance and substitution rate.

High responses in terms of milk yield can be achieved at low levels of herbage availability but, even at high levels of herbage availability, milk yield responses of at least 0.21 kg milk per kg DM of concentrate fed can be expected. Only one study (Meijs and Hoesktra, 1984) evaluated the effect of different levels of concentrate supplementation demonstrating the interaction between concentrate level and herbage availability. With current genetic improvements and the resulting increase in the intake capacity of the dairy cow, it can be expected that dairy cows can sustain milk yields of approximately 25 kg d^{-1} from herbage alone. As shown in Table 6 only two studies report production levels of > 25 kg d^{-1} and in both cases reported very low substitution rates and high responses to supplementation. All other studies report production levels < 25 kg d^{-1}. With current genetic progress in terms of increased milk yield potential at 1.4% per year (a 8000 kg cow could be yielding 9120 kg in the year 2000) (Hill *et al.*, 1995), but without the increase in intake potential (Patterson *et al.*, 1995) to support the increase in nutrient demand required, there is a real need to investigate the response of high genetic index cows to concentrate supplementation. Responses of these animals could be very different to those responses reported in the literature. Much lower substitution rates and much higher milk production responses can be expected.

Table 6. The effect of additional concentrates fed and herbage availability on herbage substitution and milk yield response

Reference	Additional Concentrate fed (kg DM d^{-1})	herbage height (cm)	Allowance (kg DM cow^{-1})	Substitution rate (kg DM Kg^{-1}DM)	milk yield response (Kg $day^{-1}kg^{-1}$ conc.	level of milk production (kg d^{-1})
Stakelum (1986[b]) [1]	3.8	-	20.0	0.31	0.28	18.2
	3.8	-	13.3	0.33	0.28	17.8
Stakelum (1986[a])[1]	3.3	-	21.4	0.30	0.21	9.0
	3.3	-	14.3	0.26	0.61	7.0
Granger and Mathews (1989) [1]	3.2	-	31.4	0.69	0.28	24
	3.2	-	16.2	0.25	0.69	23
	3.2	-	7.6	-0.10	0.89	18.5
Meijs and Hoekstra (1984)[2]						
1981 experiment	2.5		16.2	0.0	-	22.2
	2.5		24.6	0.3	-	
	4.0		17.3	0.1	-	
	4.0		24.7	0.5	-	
1982 experiment	3.3		16.4	-0.1	-	
	3.3		24.3	0.6	-	
	5.8		16.2	0.2	-	
	5.8		24.0	0.5	-	
Mayne and Steen (1990)[3]	1.7	11.0			0.40	
	1.7	9.6			0.35	
	1.7	7.0			0.30	
	1.7	5.9			1.20	
Kibon and Holmes (1987)[4]	4.0	5.0 (7.5)		0.0	0.57	27.2
	4.0	6.5 (9.8)		0.34	0.58	29.6
Rook *et al* (1994)[5]	3.4	4.0		0.50	1.15	20.8
	3.4	6.0		0.44	0.85	24.6
	3.4	8.0		0.09	0.90	26.1

[1] Stakelum (1986ab) and Granger and Mathews (1989) estimated mass to calculate allowance from ground level
[2] Meijs and Hoekstra (1984) only reported an average milk yield of all animals on the experiments and estimated mass from a height of 3 cm.
[3] Mayne and Steen (1990) reported only a residual sward height (HFRO, 1986) within a paddock grazing system.
[4] Kibon and Holmes (1987) employed a plate reader (Holmes, 1974) to measure herbage height(values between brackets are estimated SSH)
[5] Rook *et al.* (1994) measured herbage heights using a plate reader (Holmes, 1974) but reported herbage heights for a HFRO (1986) sward stick based on an internal calibration set.

2.5.3.2. Effects of energy source of the concentrate supplement

Grazed herbage in the temperate climate regions of the world provides a relatively complete substrate for fermentation in the rumen for most of the season. The only problem experienced is the decline in overall digestibility throughout the season and its associated consequences for potential intake as limited by "fill factors". Concentrate supplementation will allow the digestibility of the overall diet to be increased. However, as a consequence, highly digestible components will be consumed; mainly starch, water soluble carbohydrates and highly digestible fibre. This could disturb the nutrient balance of available nutrients in the rumen compared to an all herbage diet, especially if cereals are used. The inclusion of large amounts of starch in the ruminant diet has been associated with reductions in rumen pH and reduced cellulololytic activity (Mertens and Loften, 1980; Ørskov, 1976) resulting in decreased forage intake and utilisation (Mansbridge *et al.*, 1994; Agnew *et al.*, 1996, Arriaga-Jordan and Holmes, 1986[8]) and, in more extreme cases in "off feed" problems (De Visser and De Groot, 1981; Sutton *et al.*, 1987). These problems can be reduced in the winter feeding situation, by increasing the frequency of feeding concentrates (Sutton *et al.*, 1986; Agnew *et al.*, 1996), the use of complete diets (Phipps *et al.*, 1984), chemical treatment of the cereal (Mayne and Doherty, 1996; Mansbridge *et al.*, 1994) or adapting the processing method. Ørskov *et al* (1976) showed that the degree of processing of grains will affect forage intake in beef cattle. In the grazing situation where cows are normally supplemented with concentrates during milking, twice a day, the options of feeding complete diets or feeding concentrates more frequently are not practical in the grazing situation and, as a consequence, only chemical treatment or changes in the processing method of the cereal are an option.

Table 7. The effect of concentrate energy source on response of grazing dairy cows

Reference	Concentrate type	Concentrate level (kg DM day^{-1})	Herbage Intake (kg DM day^{-1})	Substitution (kg DM kg^{-1} DM)	Milk yield (kg day^{-1})	Fat (g kg^{-1})	Protein (g kg^{-1})
Kibon and Holmes (1987)	S	4	14.4	0.52	29.7	38.3	-
	F	4	15.2	0.17	29.4	37.9	-
Meijs (1986)	S	5.7	11.5	0.45	25.6	39.6	34.0
	F	5.7	12.6	0.21	26.9	41.0	33.7
Garnsworthy (1990)	S	3.4	-	-	21.2	37.1	33.0
	F	3.4	-	-	20.7	42.6	32.0

S = high starch concentrate
F = high fibre concentrate

Few studies have compared the effect of concentrate composition in terms of comparing different energy sources at grass. As shown in Table 7, herbage intakes tend to be higher with fibre-based concentrates and consequently, this results in reduced substitution rates. The difference in energy source does not seem to affect milk production level but high starch concentrates tend to reduce milk fat content. While there exists a tendency for high fibre concentrates to depress protein content, although this could also be a result of the increased fat content of fibrous concentrates used by both Meijs (1986) and Garnsworthy (1990). It seems therefore, that concentrate energy source has very little effect on the animal production response, although this has not been tested at very high levels of concentrate supplementation. Sutton *et al.* (1987) suggests that concentrate energy source only becomes important with winter diets when more than 10 kg DM day^{-1} is fed.

The only period when grazed herbage might not supply a balanced substrate for rumen fermentation is in early spring at turnout. The change from a winter ration onto a basal forage of lush spring herbage and the consequent sudden change in diet composition, particularly the drop in fibre content, frequently results in a depression in the fat content (Whitemore, 1980; Waite *et al.*, 1959). This depression is possibly related to a reduced level of fermentation and consequently reduced level of VFA production resulting in a reduced milk fat concentration. The milk fat content depression can be easily overcome by supplying forage supplements (e.g. Phillips and Leaver, 1985[b]; Huber *et al.*, 1964). However, this can result in an overall decrease in the energy concentration of the ration thus decreasing potential performance. Murphy (1985) showed that a dried molassed beet pulp supplement could overcome this problem and resulted in increased milk yield (1.4 kg d^{-1}) and fat concentration (1.7 g kg^{-1}) resulting in a 12% increase in fat yield and a small increase in milk protein yield. Garnsworthy (1990) compared the effect of a starch (cereal)-based concentrate with a fibre-based concentrate. As shown in Table 8 this resulted in a significant increase in fat content and milk fat production but a decrease in milk yield and milk protein content, although the latter were not significant. This experiment also demonstrated that the effect of milk fat depression is only a temporary problem since milk fat production was similar for the two supplementation treatments at week 5 after turnout.

Table 8. Performance of grazing dairy cows offered either a cereal (S) - or fibre (F) - based compound		
	S	F
Milk yield (kg day^{-1})	21.2	20.7
Milk fat (g kg^{-1})	37.1	42.6
Milk protein (g kg^{-1})	33.0	32.0
		(Garnsworthy 1990)

A second strategy to attempt to overcome milk fat depression is to supply lipid. However feeding lipids to dairy cows can result in a further depression in the fat content of milk due to their effect on fibre digestion (Palmquist, 1984). The development of protected lipid supplements for ruminants (Cook *et al.*, 1972) has potentially provided a more practical means of decreasing the severity of milk fat depression. Smith *et al.* (1977) and Jenkins and Palmquist (1984) have shown that these protected forms of lipids have less effect on rumen fermentation than free fatty acids. Fisher (1979) supplemented dairy cows with grain mixtures containing 0, 5 or 10% protected lipid. Protected lipid was not effective in countering the milk fat depression caused by the onset of the grazing season. The inclusion of the protected lipid in the diet at the rate of 5 and 10% in the grain mixtures, resulted only in a recovery of 10 and 27% of the lipid fed, compared to the cows fed the control ration. Garnsworthy (1990) in a subsequent study presented in Table 8, observed that the effects of fibre and protected fat inclusion on milk fat content were additive (Table 9), although milk protein tended to be depressed when fat was included with high fibre concentrates.

Table 9. The effect of high fibre concentrates and protected fat inclusion on performance of grazing dairy cows following turnout				
	Supplement type			
	Starch	Starch + fat	Fibre	Fibre + Fat
Milk yield (kg day^{-1})	21.3	22.5	22.9	22.3
Fat (g kg^{-1})	39.9	44.5	42.7	47.1
Protein (g kg^{-1})	34.4	34.2	34.8	33.0
Garnworthy (1990)				

The results of this experiment should be interpreted with caution, as there was no non-supplemented control treatment. It is possible that the inclusion of fibre and/or fat in the concentrate merely rectified the depression in fat content, which could be attributed to supplementation with barley. However, a study by King *et al.* (1990), including long chain fatty acids in the supplements offered to grazing dairy cows, overcame the negative effect of starch supplementation on milk fat content, resulting in a similar fat content with non-supplemented animals and those receiving the fatty acid supplement. The study was, however, not carried out on lush spring herbage with a low fibre content. In addition the recovery of

long chain fatty acids was only 17.8% in milk fat, with 18.6 % being excreted in the faeces and 63.6% being deposited in tissue. It seems therefore that the only approach to improving rumen fermentation and hence milk fat content is the use of high fibre supplements. The use of fats in various forms allows milk fat content to be improved, although, with very low efficiency since most of the fat supplemented is deposited in body tissue.

2.5.4. Forage supplementation of the grazing dairy cow

The use of conserved forages and supplements to grazing dairy cows has been reviewed previously (Leaver, 1985; Phillips, 1988; Mayne, 1990). The current review will update these reviews and only use studies in which cows are actually grazing and are not stall fed fresh herbage (e.g. Spörndly and Bursted, 1992; Bryant and Donnelly, 1974). In addition, a clear distinction will be made between two systems of forage supplementation; one system called "buffer feeding" in which animals have access to forage supplements once or twice a day after milking and, a second system called "partial storage feeding" in which animals have access to forage supplements during the night and access to grazed herbage during the day. This has important implications since as shown by Phillips (1985[b]), when buffer feeding, cows can have access to grass for 20.5 h d^{-1} while cows which are partially storage fed only have access to herbage for approximately 7.5 h d^{-1}.

Roberts (1989) evaluated the effect of either buffer feeding or partial storage feeding with a straw concentrate mixture (ME 10.3 MJ kg^{-1} DM) throughout the grazing season as shown in Table 10. Although there were no large differences in animal production response, the intake from the forage supplement was doubled with partial storage feeding compared to buffer feeding.

Table 10. A comparison of no forage supplementation (G) with buffer feeding (B) and partial storage feeding (P)			
Treatment	G	B	P
DM intake (kg DM day^{-1})			
Herbage	11.5	8.8	4.7
Forage supplement	-	4.2	8.8
Concentrate	1.7	1.7	1.7
Total	13.2	14.8	14.7
Total ME intake (MJ day^{-1})	158	171	163
Animal performance			
Milk yield (kg day^{-1})	21.0	21.2	21.3
Fat (g day^{-1})	761	788	788
Protein (g day^{-1})	721	729	700
LWG (kg day^{-1})	0.23	0.37	0.05
			Roberts (1989)

Interestingly, as far as the author is aware, no studies have been reported in which animals have a real choice in which the supplement is available in the grazing paddock. Stockdale *et al.* (1981) offered hay in the grazing paddock but restricted availability of hay and herbage to achieve specific hay and grazing herbage intakes.

When supplying supplementary forages, the objective, in contrast to concentrate supplementation is not necessarily to increase the energy density of the diet, but to allow the grazing dairy cow access to a feed which can be readily consumed. Phillips and Leaver (1985[b]) reported an intake rate of grazed herbage of 23.7 g DM min^{-1} and silage supplement intakes of 63 g DM min^{-1}. Another reason for forage supplementation might be to overcome seasonal deficits in available herbage and thereby achieve more persistent lactation curves (Pinares and Holmes, 1996) or attempting to improve reproductive performance of grazing dairy cows (McDougall *et al.*, 1994). The most often suggested reason for forage supplementation is to improve grazed herbage efficiency per unit area. Grazing at higher stocking rates will improve efficiency of utilisation of the herbage produced. However, grazing at high stocking densities will reduce performance of individual animals. This can be partly overcome by forage supplementation as has been shown in Table 11.

Table 11. Utilised metabolisable energy (UME) and estimated stocking rates for grazing and silage areas used for buffer feed production			
Stocking rate when grazing (cows ha^{-1})	8	10	12
UME on grazing area (GJ ha^{-1})	69	76	67
Grazing area (ha cow^{-1})	0.125	0.100	0.083
Silage area (ha cow^{-1})	0.115	0.124	0.132
Total area (ha cow^{-1})	0.240	0.224	0.215
Overall stocking rate (cows ha^{-1})	4.17	4.46	4.65
Roberts and Leaver (1986) UME - Utilised metabolisable energy			

Increasing the stocking rate can increase the utilisation and output of utilised metabolisable energy (UME). However, if due to the high stocking rates, animal performance is reduced to such a level that the proportion of feed used for maintenance of the cow increases substantially, overall efficiency will decline as shown in Table 11. This can partly be overcome by forage supplementation. The UME of the grazed area was 76 GJ ha^{-1} at a grazed stocking rate of 10 cows ha^{-1}. When the stocking rate was increased to 12 cows ha^{-1} overall efficiency declined. Under current economic conditions in which investment levels per cow are high (housing with high welfare standards, hygiene etc), high levels per cow need to be achieved, as this would result in the highest profit levels per cow. This questions if high UME values are directly related to profit. It is possible that UME values will indicate that forage utilisation is high but the profit margin for the farm unit is still low. If no high UME is required concentrate supplementation offers an interesting alternative. Although this would result in an importation of nutrients into the production system, which with current environmental regulations, could be a less acceptable side effect. To fully evaluate which indicators of the production system should be maximised or minimised in order to maximise profit would require the development of a complete systems model. This is not part of this study.

With the current trend towards higher levels of production per animal, high levels of forage intake need to be achieved when grazing. As a consequence, swards need to be offered with high intake characteristics (Wade, 1989; Hodgson, 1990). However, these characteristics are not the characteristics of swards with a high level of utilisation. This has been illustrated by Reeve *et al.* (1986) who offered spring calving cows either an *ad libitum* herbage allowance or a restricted allowance. Overall stocking rate on the restricted allowance was 33% higher but with a 10% reduction in milk yield per cow, although a 21% increase in yield per ha.

Forage supplementation potentially could allow a balance to be found between high levels of forage utilisation and high levels of individual cow performance.

The interpretation of the results of forage supplementation should be carried out with extreme caution. The problem that existed when carrying out these experiments was that there were no accurate methods available to measure both the grazed herbage and forage supplement intake. In addition, in only one partial storage feeding study (Aston *et al.*, 1990) are individual forage supplement intakes reported while in all other non-replicated group averages are reported. Furthermore, in many studies herbage intake was calculated on the basis of the ME balance method in which the ME requirement for the animal was calculated on basis of performance data from which the ME intake from the supplements was then deducted. Herbage DM intake was then calculated by dividing the remaining ME requirement with the ME value of the herbage on offer (Leaver, 1982). These results should be treated with caution as this method assumes that all animals consume a similar amount of forage supplement.

2.5.4.1. Buffer feeding

In Table 12 the effect of buffer feeding for different parts of the season is evaluated. A range of potential feeds was evaluated although all were of low quality especially when compared with the herbage on offer for grazing. Consuming the forage supplement would therefore result in a reduction in the energy density of the diet. In all experiments, except Roberts (1989), the animals had only access to the supplement for one period (mostly approximately 1 hour) per day. Phillips (1988) concluded from this that potential intakes achieved by buffer feeding are low. The experiment by Roberts (1989) seems to suggest that higher intakes for the forage supplement can be achieved by increasing the access period to twice daily (Table 10). However, in this experiment a straw/concentrate mix was used while Phillips and Leaver (1985[ab]) used hay and grass silage. With a mixture of straw and brewers grains (Leaver and Campling, 1993) or silage (Phillips and Leaver, 1985[b]) higher intakes can be achieved later in the season, while hay intake does not seem to increase later in the season.

Apart from the experiment by Phillips and Leaver (1985[a]), forage supplement intake increases during the season in all experiments (Table 12). Unfortunately, herbage height and herbage quality decreases also. It is therefore unclear if the increases in forage supplement intake are due to a decrease in herbage height or a decrease in herbage quality. In addition, these

experiments were carried out under continuous grazing conditions and as shown by Ernst *et al.* (1980) swards will develop a mosaic of severely and laxly grazed areas in both rotational and continuously grazed pastures. As shown by Korte (1981) and Holmes *et al.* (1983) these laxly grazed swards contained more stem and dead material and have a lower digestibility. As can be seen in Table12, in all experiments herbage height decreased during the season and in addition, taking into account the change within the sward, it can be expected that the characteristics of the sward, both in terms of total amount available and intake characteristics, are restricting potential intake from grazed herbage. It is therefore not surprising that increased forage supplement intakes were achieved, particularly, if forage supplement intake is dependent on herbage availability, which these studies seem to suggest.

A second factor affecting supplement intakes are the intake characteristics of the supplement. It could be that the short-term intake potential of the supplement is dependent on short term "fill effects." Various characteristics have been suggested to affect rate of intake and meal size. Wilman *et al.* (1996) showed that rate of intake was related to the physical structure of the plant.

Table12. Effect of buffer feeding on DM intake compared to no buffer feeding

Season and Source	Supplement		Herbage		DM Intake				
	Type	ME content (MJ kg^{-1} DM)	Sward Height [2] (cm)	ME content (MJ kg^{-1} DM)	Total (kg DM d^{-1})	Forage supplement (kg DM d^{-1})	Concentrate supplement (kg DM d^{-1})	DM intake response (kg DM d^{-1})	Substitution Rate (kg DM per kg DM)
Spring									
Phillips and Leaver (1985[a])	Hay[3]	9.2	7.6 (11.4)	12.2	16.6	1.5	2.2	+1.0	0.33
Phillips and Leaver (1985[a])	Hay[4]	9.2	7.5 (11.2)	12.1	17.2	1.3	2.2	+1.0	0.23
Phillips and Leaver (1985[b])	Silage	10.5	7.2 (10.8)	12.2	13.8	1.7	1.7	-0.3	1.18
Leaver and Campling (1993)	Straw + bg	10.0	6.1 (9.2)	12.0	16.1	1.9	0.9	+1.4	0.26
Roberts (1989)	Straw mix[1]	10.3	5.0 (7.5)	12.4	16.0	3.0	2.0	+0.2	0.93
Mid summer									
Phillips and Leaver (1985[a])	Hay[3]	9.2	6.0 (9.0)	11.2	15.3	1.7	2.8	+6.3	0.82
Phillips and Leaver (1985[a])	Hay[4]	9.2	6.2 (9.3)	11.2	15.7	1.5	2.8	+0.7	0.29
Roberts (1989)	Straw mix	10.3	<8.0 (12)	11.5	14.8	4.1	2.0	+2.1	0.49
Leaver and Campling (1993)	straw +bg	10.0	4.9 (7.4)	11.2	13.0	3.0	0.9	+1.2	0.60
Late summer/Autumn									
Phillips and Leaver (1985[a])	Hay[3]	9.2	5.5 (8.3)	10.3	13.9	1.8	3.5	+1.3	0.28
Phillips and Leaver (1985[a])	Hay[4]	9.2	5.8 (8.7)	10.2	15.3	1.6	3.5	+1.8	-0.13
Phillips and Leaver (1985[b])	Silage	10.9	6.1 (9.2)	11.2	13.8	4.1	1.7	+1.2	0.70
Roberts (1989)	Straw mix[1]	10.3	<8.0 (12)	10.6	13.9	5.6	2.0	+2.2	0.50
Leaver and Campling (1993)	straw+bg	10.0	4.8 (6.8)	10.7	12.2	3.9	0.9	+1.8	0.54

Key

bg = brewers grains

[1] - In all studies cows had access to the forage supplement once daily while in Roberts (1989) access was twice daily

[2] - Sward height measurement using plate meter and between brackets recalculated sward surface height

[3] – Stocking rate 4.9 cows ha^{-1}

[4] – Stocking rate 4.3 cows ha^{-1}

Table 13. Effect of buffer feeding on animal performance compared to no buffer feeding

Season and source	Supplement	Grazing time (hours day^{-1})	Increase in ME intake (MJ d^{-1})	Level of production (kg d^{-1})	Milk yield (kg d^{-1})	Fat content (g kg^{-1})	Protein content (g kg^{-1})	LWG
Spring								
Phillips and Leaver (1985[a])	Hay[1]	8.1	-7	25.6	+1.0	+1.4	+0.5	+
Phillips and Leaver (1985[a])	Hay[2]	8.3	+10	25.6	+1.0	+1.2	+0.1	+
Phillips and Leaver (1985[b])	Silage	7.4	-8	19.6	-0.3	+1.3	+0.2	-
Roberts (1989)	Straw mix[3]	6.0	-4	26.8	-1.3	+0.6	-0.3	-
Leaver and Campling (1993)	straw + bg	-	+12	31.0	+0.9	+0.6	+0.5	+
Mid summer								
Phillips and Leaver (1985[a])	Hay[1]	9.0	+1	21.1	+1.9	+0.5	+0.1	+
Phillips and Leaver (1985[a])	Hay[2]	9.5	+6	20.5	+0.6	+0.1	0.0	+
Roberts (1989)	Straw mix[3]	8.2	+2	21.4	+2.1	+1.4	+0.1	+
Leaver and Campling (1993)	straw + bg	-	+11	25.5	+1.2	+0.1	+0.7	+
Late summer/Autumn								
Phillips and Leaver (1985[a])	Hay[1]	8.5	+11	15.5	+1.1	+0.5	-0.1	+
Phillips and Leaver (1985[a])	Hay[2]	7.9	+20	15.5	+0.6	+0.1	0.0	+
Phillips and Leaver (1985[b])	Silage	7.6	+15	14.3	+0.6	+0.1	0	+
Roberts (1989)	Straw mix[3]	6.2	+22	15.5	+2.2	+0.4	-0.3	+
Leaver and Campling (1993)	straw + bg	-	+16	23.3	+2.7	-1.3	-0.9	

Key
bg = brewers grains
[1] - stocking rate 4.9 cows ha^{-1}
[2] - stocking rate 4.3 cows ha^{-1}
[3] - In all studies cows had access to the forage supplement once daily while in Roberts (1989) access was twice daily

From the forage supplement intakes reported (Table 12) it is difficult to explain the differences in forage supplement intake as this could also be related to herbage height and sward conditions which could have been very different in the studies. Santini *et al.* (1983) showed that forage particle length was important. Thomas *et al.* (1961) showed that water content could be important, while Woodford and Murphy (1988) suggested NDF content of the forage consumed.

As a result of forage supplementation total DM intake was increased by supplementation in almost all experiments (Table 12). However, overall estimated forage DM intake was relatively low and decreased over the season. The substitution rates (Table 12) are very variable, ranging from 1.18 to -0.13 and seem to be independent of season. By eating the supplement the animals in all cases decreased the energy density of the diet however, in all cases except for spring when the herbage quality was above 12 MJ kg^{-1} DM, increased their ME intake (Table 13). Especially in late summer/autumn, relatively large increases in energy intakes were achieved. Production levels (Table 13) were decreasing in all experiments throughout the season. Average levels of production were relatively low and below 25 kg d^{-1} except for Leaver and Campling (1993). These animals might not really have required forage supplementation if sufficient herbage was available. Except for the spring period, milk yield responses were achieved, although in addition fat content was increased and protein contents of the milk was decreased (Table 13). Buffer feeding seems to consistently improve animal performance from mid summer to autumn (Table 13) However, the comparison suggests that this was achieved in situations where herbage availability levels were restricting herbage intake. In addition, the buffer feeds used in all experiments contained less energy per kg DM than the herbage on offer and, as a result, consumption of the supplement would result in a decrease in energy density of the diet. To compensate the animals would have to eat more to achieve a similar energy density when compared to herbage only. The actual intakes of the supplements could be modified by access time and physical characteristics of the feeds. However, conclusions on the latter two cannot be drawn on basis of the currently available literature. Overall the results from the various experiments seem to suggest that the highest DM intake responses, accompanied by the lowest substitution rates, are obtained at low herbage heights and in late summer/autumn. Milk yield level of the animal does not seem to affect the response to buffer feeding, although in few studies milk production was above 27 l.

The studies suggest that buffer feeding is only effective when herbage heights are low and in late season when herbage quality decreases.

2.5.4.2. Partial storage feeding

In Table 15. the effect of partial storage feeding on DM intake compared to no forage supplement is evaluated. A range of feeds was evaluated in spring while only straw mixes and grass silage were evaluated in mid summer and late summer/autumn. Again, as was the case with buffer feeding, only low energy density feeds were used compared to the herbage on offer. Consuming the forage supplement would therefore result in a decrease in the energy density of the diet. Access to the supplement was in all cases overnight and, as a consequence, potential time available for grazing was restricted. This can have restricted intake from grazing. Approximately 80% of grazing occurs during daylight hours but the proportion of night time grazing increases as day length decreases (e.g. Rook *et al.*, 1994[b]). Grazing time required per day depends on various factors e.g. energy requirement (Ferrer *et al.*, 1995) or sward surface height (Pulido and Leaver, 1995) and can be as high as 12 h per day when sward state is limiting intake rate (Rook *et al.*, 1994 [b]; Hodgson, 1985). The upper limit to grazing time is set by the need to undertake other activities such as ruminating. When partial storage feeding, the period the animals are at grass ranges between 8-10 hours and, during this time the animal requires time for rumination and other activities. It is therefore very likely that potential herbage intake was restricted purely due to the fact that the animals had no access to the herbage for grazing.

As shown in Table 15 partial storage feeding results in high intakes of the forage supplement compared to buffer feeding. Phillips and Leaver (1985[b]) achieved silage intakes as high as 10.4 kg DM d^{-1}. The evaluation of the results in Table 15 seems to indicate that the quality of the forage supplement has a large bearing on the intake achieved from the forage supplement as shown by both Aston *et al.* (1990) and Roberts (1990) who showed that increasing the energy density of the supplement increased the intake of the supplement. It could be suggested that in the partial storage feeding situation more long term effects of "fill" are involved which are mainly determined by the speed at which the material can be reduced in size and digested by rumen fermentation and, as a result, leave the rumen as shown by the Madsen *et al.* (1994) and Stensig *et al.* (1974).

The forage supplement consumed forms a large part of the total forage intake as shown in Table 15. This possibly may reflect the ease with which the forage supplement can be consumed. The physical form of the material affects the speed with which the material can be consumed (Roberts and Kelly, 1990; Roberts, 1990) but more interestingly, the amount of forage supplement consumed affects the rate of herbage intake during the day as illustrated by data from Roberts (1990) in Table 14.

Table 14. The effect of intake of supplement

	L	H	G
Forage supplement (MJ kg^{-1} DM)	8.6	10.7	-
Forage supplement intake (kg DM d^{-1})	5.0	10.0	-
Intake rate supplement (g DM min^{-1})	28.5	48.9	-
Intake rate herbage (g DM min^{-1})	16.6	7.9	16.0

(Roberts, 1990)

L - low quality forage supplement
H - high quality forage supplement
G - no forage supplement

The production levels of the animals (Table 14) were only 13.5, 16.0 and 16.5 kg d^{-1} for treatments L, H and G respectively for animals consuming up to 10 kg of a supplement with a ME of 10.7 and as a consequence a large proportion of their energy requirements was fulfilled. This seemed to result in a decrease in grazing intensity. That hunger drive can affect grazing intensity has been shown in sheep (Newman *et al.*, 1994 [b]). The animals on treatment L consuming very low quality forage supplement, reduced their potential energy intake resulting in a depression in milk production. The herbage bite rate was very similar to the animals of the grazing only treatment.

The effect of forage supplementation using storage feeding resulted in a mixed DM intake response in spring (Table 15). Especially when herbage availability was high, a reduction in total DM intake was observed. While using straw mixtures, an increase in total DM intake could be observed, although, in most of these experiments herbage availability was low. In mid summer and late summer/autumn in almost all cases a positive response in herbage intake was reported (Table 15). Substitution rates when partial storage feeding seems to be consistently high compared to buffer feeding where the substitution rates are much more variable.

Table 15. Effect of partial storage feeding on DM intake compared to no forage supplements

Season and Source	Supplement		Herbage		DM Intake				
	Type	ME content (MJ kg^{-1} DM)	Sward height (cm)[1]	ME content (MJ kg^{-1} DM)	Total (kg DM d^{-1})	Forage supplement (kg DM d^{-1})	Concentrate (kg DM d^{-1})	DM intake response (kg DM d^{-1})	Substitution rate
Spring									
Phillips and Leaver (1985[b])	silage	10.5	9.3 (13.9)	12.2	14.7	5.8	1.7	+0.6	0.90
Roberts (1989)	1) Straw mix	10.3	<8.0 (12.0)	12.4	13.2	7.7	1.8	+1.1	0.86
Aston *et al* .(1980)	silage 1	9.9	8.4 (12.5)	12.1	13.8	4.3	0	-1.3	1.35
	silage 2	10.3	7.7 (11.5)	12.1	13.7	6.1	0	-1.5	1.25
	silage 3	10.1	6.0 (9)	12.1	14.3	6.5	0	-0.6	1.09
	silage + bg	10.4	6.0 (9)	12.0	15.8	8.5	0	+1.5	0.82
Roberts (1990)	straw mix 1	8.2	4.7 (7.1)	12.2	13.0	5.0	1.8	+0.8	0.84
	straw mix 2	10.4	4.7 (7.1)	11.9	16.0	10.0	1.7	+1.7	0.83
Roberts and Kelly (1990)	straw mix	10.1	5.1 (7.7)	12.1	15.6	9.2	1.8	+1.7	0.81
	silage	9.5	5.1 (7.7)	12.1	14.3	4.2	1.8	+0.4	0.90
Mid summer									
Roberts (1989)	straw mix	10.3	<8.0(12)	11.5	13.8	8.3	1.8	+1.1	0.87
Roberts and Kelly (1990)	straw mix	10.1	5.1 (7.7)	10.8	14.9	9.0	1.8	+1.8	0.80
	silage	10.6	5.1 (7.7)	10.8	13.5	6.0	1.8	+0.4	0.93
Late summer/Autumn									
Phillips and Leaver (1985[b])	silage	10.9	6.7	11.2	15.6	10.4	2.6	+3.0	0.96
Roberts (1989)	straw mix	10.3	<8.0	10.6	13.4	8.4	1.8	+0.8	0.90
Roberts and Kelly (1990)	straw mix	10.1	5.1	11.9	14.5	9.1	1.8	+0.9	0.90
	silage	10.6	5.1	11.9	13.1	5.1	1.8	-0.5	1.10

Key
bg-brewers grains
[1] - sward height measured with rising plate meter and between brackets the calculated sward surface height

Table 16. The effect of partial storage feeding on animal performance compared to no partial storage feeding

Season and source	Supplement	Grazing Time (hours day^{-1})	Increase in ME intake (MJ d^{-1})	Level of production (kg d^{-1})	Milk yield (kg d^{-1})	Fat content (g kg^{-1})	Protein content (g kg^{-1})	LWG
Spring								
Phillips and Leaver (1985[b])	silage	4.4	0	18.9	-1.0	+2.5	-0.3	+
Roberts (1989)	straw mix	4.6	-3.0	25.5	-2.6	+3.3	-1.2	-
Aston *et al.* (1990)	silage 1	-	-25.5	15.7	-2.1	+3.8	-2.5	-
	silage 2	-	-24.5	16.1	-1.5	+2.5	-2.6	-
	silage 3	-	-15.9	15.1	-2.8	+4.8	-0.8	-
	silage + bg	-	+8.0	18.9	+0.2	+3.0	-0.5	+
Roberts (1990)	straw mix 1	5.8	+13.0	13.5	-0.5	+0.4	-0.8	+
	straw mix 2	4.4	+16.0	16.0	-3.0	-0.9	-0.8	+
Roberts and Kelly (1990)	straw mix	5.0	+2.0	22.3	-0.8	+1.4	-2.0	+
	silage	5.7	-6.0	20.0	-3.1	+2.3	-2.7	+
Mid summer								
Roberts (1989)	straw mix	5.5	+3.0	21.5	-0.3	+0.4	-0.9	-
Roberts and Kelly (1990)	straw mix	5.8	+11.0	19.1	-0.1	+0.1	-1.9	-
	silage	5.2	+3.0	17.6	-1.6	+0.7	-2.5	-
Late summer/Autumn								
Phillips and Leaver (1985[a])	silage	3.8	+29.0	15.6	+0.4	+2.8	-0.8	+
Roberts (1989)	straw mix	3.9	+15.0	16.8	+3.5	-1.6	-2.7	-
Roberts and Kelly (1990)	straw mix	5.6	-13.0	15.9	+1.0	-2.2	-3.2	-
	silage	6.2	+29.0	15.6	+0.4	+2.8	-0.8	-

bg - brewers grains

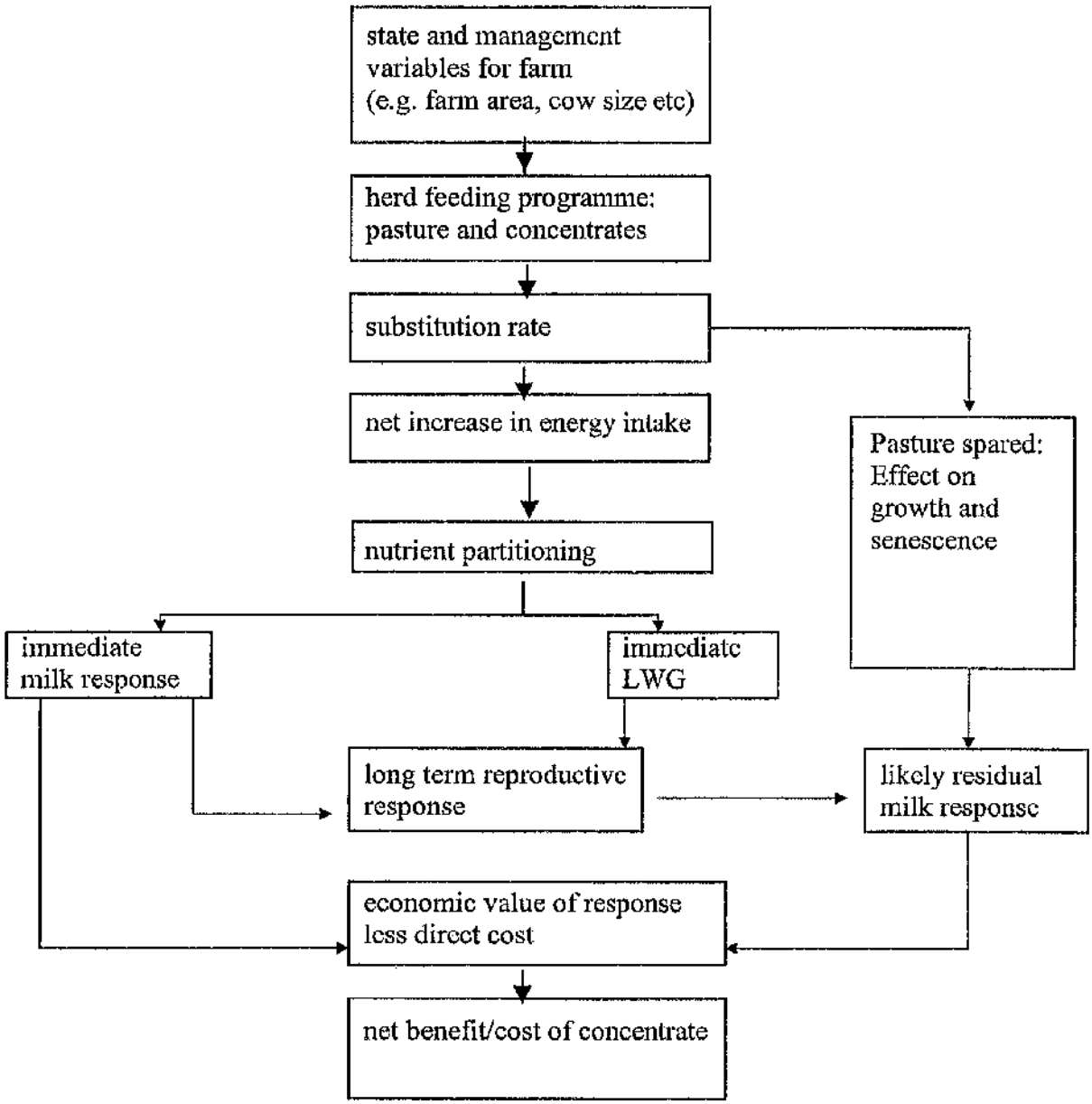
As shown in Table 16 the effect of partial storage feeding on energy intake seemed to be very variable, with a tendency for a negative effect on energy intake, especially if grass silages were used (Aston *et al.*, 1990) and a tendency for a positive energy intake response in mid summer and late summer autumn (Table 16). Actual grazing times per day were low and do not seem to indicate that there exists a relationship between grazing time and the response to partial storage feeding. Levels of production in most trials were low. Only Roberts (1989) reported a milk yield above 25 kg d^{-1}. The effect on milk yield, by partial storage feeding, was negative up to mid summer with some very low responses in late summer/autumn. Partial storage feeding tended to result in an increase in milk fat content and reduced milk protein consistently, while frequently resulting in a decrease in live weight gain. It seems that when partial storage feeding, with feeds which were lower in energy concentration compared to the herbage on offer, the energy concentration of the diet of the animals decreased to such an extent that they were not able to make up for this with additional DM intake. However, production levels were low and therefore the drive to consume food must have been low. It is surprising that partial storage feeding resulted in a reduction in live weight gain in a high number of cases.

The potential benefits of partial storage feeding seem to be a reduced need for grazing during the season. This can only be achieved if the cost of the feed used as supplement is lower than that of grazed grass and, the supplement needs to be of similar nutritional quality to grazed herbage. Otherwise partial storage feeding will result in decreased production.

2.5.5. Supplementation Strategies

The decision to supplement grazing dairy cows is normally driven by the economic conditions the production system has to perform within. Knowledge of a whole range of economic and physical variables is required to evaluate if a certain supplementation strategy is cost effective and can be modelled as illustrated by the decision support system developed by (Neaves *et al.*, 1996).

Figure 14. Components of a decision support model for the feeding of concentrates to lactating cows grazing pastures (Neaves *et al.*, 1996)



The decision support system described in Figure 14 indicates the knowledge required for a great number of variables. This decision support model (Neaves *et al.,* 1996) was developed for dairy farm consultants in New Zealand and Australia and illustrates the danger of transferring these types of decision making aids to different production environments. The model assumes that grazed herbage is cheaper than the supplement and therefore, concentrates on the potential net increase in energy intake that can be achieved by supplementation. The latter is certainly not always the case especially if housing of animals is required, which as a result, would increase fixed cost to the farming operation and as a consequence, since fixed costs are related to number of animals housed, it could be economically beneficial to increase individual animal performance. The decision to supplement is therefore very much dependent on the local situation and depended on the situation on the individual farm. Decisions on supplementation strategies should never be made on a simple production response benefit versus cost basis but, whole production system characteristics should be evaluated as illustrated by Conway and Killen (1987). However, there are a number of basic physical objectives that can be achieved with supplementation of grazing dairy cows as listed below:

- Increase the stocking rate
- Overcome the variability in forage supply
- Improve total nutrient intake

In production environments in which the availability of land is limited or the cost of land is very high relative to the cost of imported supplements, stocking rates can be increased by supplementation, although in the long term this could have negative environmental effects since it could result in an increased concentration of nutrients on a limited land area as illustrated by Van Dijk and Hoogervorst (1982). A second reason for increasing stocking rate is to increase the efficiency of grazing (defined as herbage energy consumed per unit area/herbage energy grown per unit area). Roberts and Leaver (1986) suggest that a system of storage feeding of dairy cows (no grazing - 100% supplementation) can increase UME efficiency by 15%. Increased DM utilisation levels of 25-30% on conserved forage compared with grazed areas, when high levels of nitrogen have been applied, have been reported by Richards (1977).

Grant *et al.* (1982) reports grazing efficiencies ranging from 0.8 to 0.5 for swards that were maintained at 1,250 kg DM ha-1 and 2,500 kg DM ha^{-1}. As shown by Parson *et al.* (1982) these differences are mainly due to the fact that high gross photosynthesis may be achieved by stocking at lower stocking rates but this is inevitably associated with high rates of loss of matter to death. The "efficiency of harvest", the proportion of gross photosynthesis harvested as animal intake is therefore low. Maximum animal intake per ha is achieved in a sward maintained by hard grazing at a leaf area index that is substantially below the optimum for photosynthesis. Trying to maximise animal intake per ha. has an obvious consequence for intake of individual animals. If maximum animal intake per ha is to be achieved, low herbage allowances per animal are required. A number of studies have demonstrated a curvilinear relationship between herbage allowance and individual intake for dairy cows producing less than 15 kg milk d^{-1} (Greenhalgh *et al.*, 1966; Combellas and Hodgson, 1979; King and Stockdale, 1980; Mayne *et al.*, 1987) or more than 20 kg milk d^{-1} (Peyraud *et al.*, 1996[a]). This conflict between production per cow and per unit area is at the centre of many stocking rate decisions. For example Reeve *et al.* (1986) offered spring calving cows either a '*ad lib*' herbage allowance or a restricted allowance. Overall stocking rate on the restricted allowance was 33% higher. This resulted in a 10% reduction in milk yield per cow but a 21% increase in yield per ha. Supplementation might be an option in order to achieve both high stocking rates and high levels of individual performance.

A second reason why high stocking rates may be required is to maintain sward quality. Increasing herbage allowance in spring to achieve higher intakes has been shown to result in a deterioration in sward quality in mid to late season both in rotational grazing systems (Hoden *et al.*, 1991; Mayne *et al.*, 1987) and in continuous grazed pasture (Baker and Leaver 1986; Fisher *et al.*, 1995 [ab]). This has implications for potential intake later in the season. Peyraud (1996) showed that intake decreased by 0.20 - 0.25 kg OM per unit decrease in digestibility.

Concentrate supplementation has been shown to compensate for the decrease in herbage intake and equal levels of animal performance can be achieved at levels of production below 25 kg d^{-1} (Meijs, 1986; Mayne and Steen, 1990; Stakelum, 1986;

Reeve *et al.*, 1986; Granger and Mathews, 1989; Holmes and Curran 1967; Holmes *et al.*, 1966) and, as discussed in paragraph 2.5.3.1 low levels of substitution can be achieved at low levels of herbage availability. Since concentrates are generally higher in energy content than grass, either no or small increases in total DM intake have to be achieved to maintain total energy intake. As far as the author is aware no buffer feeding or partial storage feeding comparisons have been carried out with a grass only control evaluating the interaction between stocking rate/herbage allowance and forage supplementation. Roberts and Leaver (1986) evaluated the interaction between three day time stocking rates on performance of dairy cows when partial storage fed grass silage overnight. When increasing the stocking rate from 8 to 10 cows ha^{-1}, the animals were able to compensate by consuming more silage while, when increasing the stocking rate to 12 cows ha^{-1} the animals were not able to compensate and a decrease in performance resulted. It is therefore difficult to assess if forage supplementation can overcome decreases in individual forage intake. Most forage supplementation experiments were carried out with forages of a lower energy density than the herbage on offer. Therefore the animals would have to increase their total DM intake to maintain energy intake. At low levels of performance this is possibly not a problem but at high levels of performance the physical fill factor will become limiting. In the case of buffer feeding when access to the forage supplement is limited, and as a result total intake from the forage supplement is limited, this could result in decreased total intakes. It seems therefore that forage supplementation can allow performance to be maintained at low herbage allowance but, this will depend on the level of performance of the animal and the level of herbage allowance.

Supplementation will allow the direct stocking rate of the grazed area to be increased, however in the case of home produced supplements, if the overall farm-stocking rate will be increased, depends on the efficiency with which these supplements can be produced and conserved. Supplementation will allow individual production per animal to be increased since food supply of the animal becomes independent of the seasonal growth pattern and, as a result, both milk output per animal and milk production per ha. will increase. In the case that supplements are obtained from outside the farm unit, stocking rates will be allowed to increase. To evaluate the various interactions between supplementation, substitution rate, stocking rate, and effects on stocking rate and output per ha, a good production systems model would have to be developed and this will not form part of this study.

2.6. MEASURING HERBAGE INTAKE IN GRAZING RUMINANTS

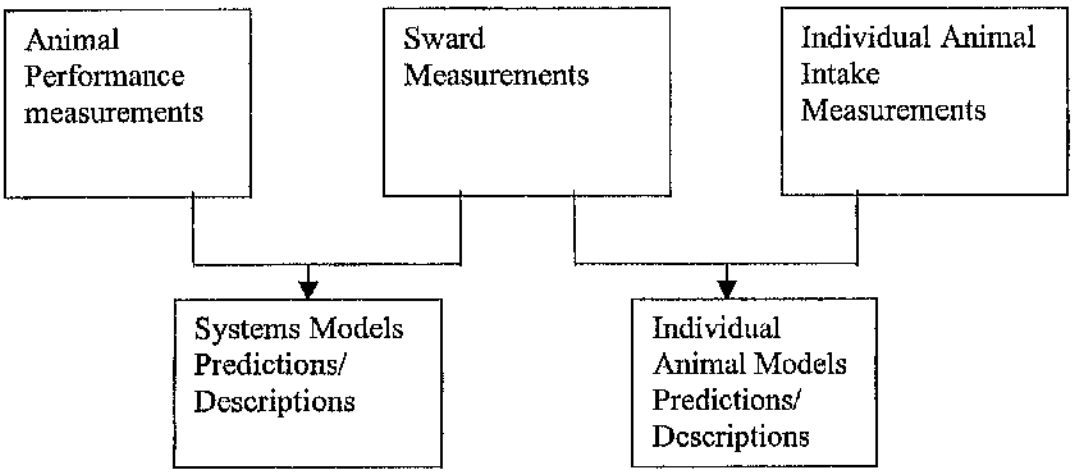
2.6.1. Introduction

A large range of techniques have been developed over the years to attempt to estimate herbage consumption in grazing animals. The techniques developed, range from sward-based techniques in which the intakes of groups of animals are estimated to marker techniques in which the intake of individual animals are estimated. The techniques used in various grazing experiments, are based on the resources available or the objectives of the experiment. For example, if the objective is to provide simple guidelines for farmers, different techniques should be used. When the objective is to explain animal responses to specific sward conditions or supplementation strategies. Since in all grazing experiments the objective is to explain the response of the animals when grazing a certain pasture, some form of sward measurement is always involved. Techniques to estimate herbage intake can be divided into three main groups:

1. Herbage intake-based techniques in which intake is based on the difference between herbage in the field before and after grazing.
2. Animal production based techniques in which the intake is based on the inversion of the animal requirement system.
3. Individual animal intake based on the diet digestibility and the estimation of faecal output or other methods to obtain individual intakes.

Which of the techniques are used depends on the resources available and the objective of the experiment as shown in Figure 15.

Figure 15. Relationship between measurement type and experimental objectives



Both types of predictions are of equal importance but the choice depends on the purpose of the experiment. When the objective is to provide systems information it is important to minimise the effort required to gather information within the year and replicate over years. While when the objective is to produce individual animal models, replication within the year is of greater importance.

2.6.2. Sward-Based Techniques

The principle of sward -based techniques is based on the difference that exists between the herbage mass estimated at the beginning of the grazing period and the end of the grazing period, often corrected in some form for the growth during the period. The calculated consumption per unit area is then converted to intake per animal. The problem of this technique is that it depends on accurate estimates of herbage mass and some estimate of herbage accumulation during the grazing period. Particularly the latter may cause problems (t' Mannetje, 1978). The use of this type of estimate of herbage intake is therefore mainly applicable in systems where the grazing periods are relatively short and grazing pressures are high (Meijs *et al.*, 1982). Moreover, sward methods can only provide intake data on an individual animal basis where the animals are kept in individual plots. However, to obtain a normal grazing behaviour pattern, animals need to graze in groups in order to express their herd behaviour (Penning *et al.*, 1993; Rook *et al.*, 1996).

In addition, to reduce labour requirements, intake studies are usually carried out with groups of animals and therefore no information is available relating to individual animal intake. An advantage of the sward-based techniques is that at the same time information is provided on the herbage allowance and the efficiency of grazing.

2.6.2.1. Methods of estimating herbage mass

Herbage mass can be estimated by destructive or non-destructive techniques or by a combination of the two. Although non-destructive techniques are not completely non-destructive since they are calibrated against a destructive estimate. The type of destructive or sward cutting technique used, depends on the situation under which the estimate of mass has to be made. The main principle question, which has to be answered when choosing a method to cut herbage, is to which height will the animal graze. Since the cutting height will have to be below the height of grazing. In Table 17 a classification of three cutting methods based on their suitability for estimating herbage mass under different circumstances is presented.

Table 17. Classification of three cutting techniques

	Approximate cutting height (cm)	Animal Type	Grazing pressure
Cutting at field-scale mower level	5	Cattle	low
Cutting at lawnmower level	3	Cattle Sheep	Moderate Low
Cutting close to ground level	0	Cattle Sheep	High High

Adapted from Meijs *et al.*, (1982)

Frame (1981) and Frame (1993) have extensively described types of equipment and sampling procedures. When choosing the appropriate technique for mass estimation one should also consider the potential effects of animals lying down and thereby compressing the sward and, the potential for faecal and soil contamination. The higher the sward can be cut, the lower the error of the mass estimate will be (Meijs, 1981).

The higher the cutting height the easier it will be to maintain the cutting height when cutting. The lower the cutting height the greater the chance for soil contamination and contamination

with dead material. Cutting at ground level should, theoretically make it possible to maintain an identical sampling height between the offered herbage and the refused herbage at the end of the grazing period. In practice however, the cutting height can vary by 0 to 2 cm according to sampling conditions and the experimenter (Hardy *et al.*, 1978; Meijs 1981). With grass swards in the temperate regions, the density at ground level is about 500 kg $OM^{-1}cm^{-1}$ ha^{-1} and as a consequence, a slight change in cutting height will lead to a greater change in estimated intake. Meijs (1981) therefore proposed a two stage cutting system; using a rotary lawnmower in the second pass. However, large amounts of dead material and soil can be sucked up. The most common devices for cutting at ground level are sheep shearing hand pieces. These possibly offers the highest level of accuracy, although if grazing has taken place under wet conditions it might be difficult to use due to the undulation of the sward surface. The problems encountered with this technique are the high level of soil contamination, the inclusion of root material and the inclusion of dead material in the samples obtained (Matches 1963). Meijs (1982) compared the different techniques as shown in Table 18.

Table 18. Comparison of cutting equipment			
Reference	Meijs (1981)		Walters and Evans (1979)
Cutting Equipment	Motorscythe	Motorscythe + Lawnmower	Sheep Shearing Head
Cutting height (cm)	4.5	3.3	± 0
Cutting width (m)	0.6	0.5	0.08
Cutting length (m)	12	12	25
Labour Requirement in the field per paddock* (man hours)	1.5	2.0	1.7
Avoiding Grass below cutting height	-	+	+
Achieving comparable stubble (pre and post)	-	+	+
Low soil contamination	+	±	-
Little damage to the sward	+	+	-
* Assuming 10 estimates per paddock (Meijs,1982) - = Negative aspect + = Positive aspect			

The number of samples and the area cut required will depend on the variation of the sward and the precision required. It is generally advised to cut long strips so the potential variation due to soil differences can be accounted for e.g. Meijs (1981) used 12 m strips while Walters and Evans (1979) used 25 m strips. It is important to realise that variation will increase during the grazing period and therefore, the number of strips will have to be increased.

A number of non-destructive techniques have been developed over the years and reviewed by Frame (1981 and 1993) and 't Mannetje (1978), these being based on eye estimates, height and density measurements and other non-vegetative attributes. Although the term non-destructive implies that the sward does not need to be cut, these techniques need continuous calibration to obtain regression equations to relate to non-destructive scores of sward mass. The use of eye estimates is a potentially very rapid method to estimate mass.

Pasture scores following training can be made at a rate of 1 every 30 seconds (Meijs, 1982). The problem with the technique lies in the fact that it depends on a trained observer who has to develop a correlation between a 'mental' score and the herbage mass. Haydock and Straw (1975) suggest that a minimum of two observers is required to minimise observer error. Observer errors seem to be mainly related to the lack of training, persistent over or

under estimation and fatigue. The use of eye estimations should therefore be used with extreme care and continuous re-calibration/training is required.

Height and density measurements are very popular ways of describing the herbage mass. Height is normally measured using a ruler type instrument (HFRO, 1986) and density is defined as the percentage groundcover and is estimated by point quadrat or a visual estimate (Bakhuis 1960). More recently, the weighted disk grass meter (e.g. Earle and Mcgowan, 1979) has gained great popularity, providing some kind of integrated measurement of height and density. The great advantage of the above-mentioned techniques of grass height and height/density measurements is that they are independent of observers and therefore can be used in many locations and, even on farm. Therefore, guidelines developed with these measures of herbage mass can be directly transferred to farm level. The measurements require, if used under experimental condition, regular calibration, since the measurement is sensitive to error due to differences in sward structure, lodging or trampled swards, botanical composition, season and grazing management as recently investigated by Dowdeswell (1998).

Herbage mass can also be estimated from a number of non-vegetative plant attributes (e.g. capacitance, radioisotope attenuation, and spectral analysis). Neal and Neal (1973) reviewed the use of capacitance but found that the main limitation was its continuous need for calibration since even the moisture contents of the herbage affected the readings obtained (Angelone *et al.*, 1980). Therefore it is unlikely that this approach will find regular use in the near future.

In situations when, due to the variations in the sward, large numbers of samples need to be taken a combination of two methods of herbage mass estimation can be used in order to reduce the labour requirement. This approach can be effective as shown by Bakhuis (1960) and Hameleers and Sword (1992).

2.6.2.2. Calculating herbage intake based on sward measurements

The main difficulty when calculating herbage intake is the correction that needs to be applied to the estimate of herbage accumulation. Herbage accumulation is normally estimated by excluding a certain area from grazing, calculated from the estimates of the herbage mass at the beginning and the end of the grazing period. However, the growth which takes place in a non grazed sward is different from that in a grazed sward due to the abnormal microclimate within the enclosure cage, resulting in an herbage accumulation which is not typical for the rest of the sward. The magnitude of this effect is directly related to the length of time the area was excluded from grazing (t' Mannetje, 1978). If the grazing period is short e.g. 1 day and relatively large amounts of the material are eaten per unit area, during the period, this effect can be ignored, but when grazing takes place over an extended period (more than one day) this effect can not be ignored. Generally herbage accumulation in the grazed area is reduced due to defoliation, treading and faecal contamination. Therefore accumulation in the grazed area is 'g' times the accumulation in the excluded area. Herbage consumption can then be calculated as

$C = M - Mf + g\,Ml$

C= Herbage consumed (kg^{-1} ha)
M= herbage mass at the start of the grazing period (kg^{-1} ha)
Mf= residual herbage at the end of the grazing period (kg^{-1} ha)
Ml= Undisturbed herbage accumulation in the enclosure during the grazing period (kg^{-1} ha)
g= correction factor for the undisturbed herbage accumulation

Linehan *et al.*, (1947) assumed that the rate of herbage accumulation and the rate of consumption of herbage were proportional to the quantity of herbage present at a given time during the grazing period and, derived from the following equation:

$C = (M - Mf) * ((\log(M+Ml) - \log Mf)/(\log M - \log Mf))$

Bosh (1956) simply assumed g=0.5 when residual herbage mass was 20-30 % of the herbage mass at the start of the grazing period (cutting at 4cm) and found no difference between the two equations. Meijs (1981) calculated a 'g' of 0.68 but at much higher levels of residual herbage and cutting to 3 cm. The formula of Linehan *et al.*, (1947) is based on the assumption that the rate of herbage accumulation and the rate of consumption of herbage at any time during the grazing period are each proportional to the quantity of herbage remaining uneaten at any one time. The potential importance of the correction factor depends on the length of the grazing period (a longer grazing period will increase the proportion of accumulation as a fraction of intake), the rate of herbage growth and the level of herbage mass at the start or finish of the grazing period. Lantinga (1985) evaluated the formula developed by Linehan *et al* (1947). He found that the Linehan formula worked well for short grazing periods (up to three days) but not so well for longer periods of grazing. Lantinga (1985) developed an improved formula for calculating herbage consumption that should function also in longer grazing rotations as shown below:

$$C = (M-Mf) + (1-(Mf/M))/(-\log_e(Mf/M))*Ml$$

The final errors in estimating herbage intake will then depend on the accuracy with which the various components can be estimated.

2.6.2.3. Estimating diet selection using herbage-based techniques

The samples obtained in estimating herbage mass often do not represent the actual herbage consumed by the animal due to selection by the animal. In order to assess the quality of the herbage actually consumed, attempts are made to simulate grazing by, for example, cutting at the grazing height or by hand plucking. In simple monocultures this can be done with reasonable accuracy although Langlands (1974) found that hand plucking overestimated digestibility and N content in high quality swards and underestimated these components in low quality pastures when compared with samples obtained from oesophageal fistulated animals. However, the ability of fistulated animals to harvest representable samples in terms of diet selection can also be questioned (Sidahmed *et al.*, 1977; Gonzales and Lambourne, 1966; Newman *et al.*, 1994). A second option is to estimate herbage selected from the sward by difference. Samples cut before and after grazing are analysed for their nutritional

characteristics and, by difference the herbage quality can be estimated using the formula below:

X= ((Y-Yf)/(M-Mf))*100

In which Y= kg ha of nutrients before grazing, Yf kg ha of nutrients after grazing, M = kg ha of DM before grazing and Mf= kg ha of DM after grazing. Walters and Evans (1979) showed that this technique could potentially yield digestibility estimates similar to those obtained by individual animal techniques. Both the above approaches work reasonably well in simple swards. Problems will arise when animals graze complicated swards with a mixture of species as shown by Kalmbacher and Washiko (1977).

2.6.3.Animal-Based Techniques

In grassland experiments often pastures are considered the experimental unit. However, in some cases animals may serve as the experimental unit. The measurement of individual animal intake is especially important if the response of the individual animals to specific sward conditions needs to be described or evaluated. Animal to animal variation is usually the greatest source of variation in grazing experiments (Peterson and Lucas, 1960). Mott and Lucas (1953) suggested that pasture variation for production per animal has a coefficient of variation (CV) of ± 5% whereas the corresponding animal to animal variation in terms of production response, may have a CV of 10 to 30%. The accurate measurement of herbage intake may therefore reduce the cost of grazing trails if only the knowledge of herbage intake is required. The performance of the grazing animal ultimately reflects the balance between its nutrient requirement and the nutrients it is able to consume. The understanding of the 'demand' side of the balance has increased greatly (AFRC, 1993; NRC, 1987; SCA, 1990) and detailed rations can be formulated. However, the understanding of the supply side of the balance is still severely limited. The accurate measurement of nutrient intake would allow the development of the understanding of the supply side of this balance.

A range of techniques have been developed to estimate herbage intake (without depending on animal performance e.g. milk yield).

1) Measurements of digestibility and faecal output
2) Live weight change, bite size and behaviour methods
3) Measurements of intake based on animal performance
4) Direct measurement of intake based on sampling of faeces and herbage using alkanes

2.6.3.1. Measurement of digestibility and faecal output

2.6.3.1.1. Measurement of diet digestibility

The measurement of diet digestibility is crucial for the accurate estimation of herbage intake and especially if highly digestible material is available. The first problem one encounters is the difficulty of obtaining a representative sample of herbage consumed. In simple swards the sample may be collected by hand, the experimenter observing the grazing behaviour of the animal and attempting to collect similar material to the grazing animal. Gibb and Treacher (1976) have shown that this method can give satisfactory results. More recently, the tissue flux technique has been developed by Grant *et al.* (1985) and Clark (1985). This technique is based on the marking of selected tillers of the plant and, after a period of time these tillers are checked again to find out which part of the plant has been removed. Similar material can than be cut to obtain a sample.

The second option is the use of animals with oesophageal fistulas (Torrel, 1954). The argument for the use of fistulated animals is that they overcome the subjectivity of the hand cutting technique. The problem with fistulated animals is that they should be adapted to graze in a similar manner as the rest of the herd. Sampling should also be carried out throughout the period of grazing since the composition of the ingested material evolves with the degree of defoliation of the plot. When ample forage is available samples can be collected in a few minutes. This is more difficult when feed is scarce. A common practice used is to fast the animals for a period of time before the sampling. Sidahmed *et al.* (1977) and Newman *et al.* (1994) showed that fasted sheep tended to be less selective as the length of the fast increased. In addition, samples collected using oesophageal fistulated animals become contaminated with saliva. Saliva is completely digestible and contains enzymes and

can therefore affect the chemical composition of the extrusa sample (Le Du and Penning, 1982).

Once having obtained a sample, digestibility can than be measured in confined animals. However, this is seldom done since collecting large amounts of representative material is often impossible. Therefore digestibility is often estimated in the laboratory based on an index of digestibility. The *in vitro* digestibility procedure of Tilley and Terry (1963) is the most widely used method. It involves digestion of the sample by microorganisms of rumen liquor followed by pepsin digestion. The technique has given good results under a variety of circumstances. A disadvantage of the technique is its use of rumen liquor. The digestibility depends on the rumen fluid from the donor animals and this, in turn, depends on the diet of the donor animal. The rumen fistulated animals should therefore be fed the same diet as that being tested.

More recently, enzymatic methods have been proposed which are based on a hydrolysis with a preparation of pepsin cellulase (Jones and Hayward, 1975; Aufrere and Demarquille, 1989). These techniques do not require the use of fistulated animals for the supply of rumen fluid but do, however, require that separate regression equations are developed for the different forage species at the local level. Stakelum *et al.* (1988) showed that enzyme-based techniques are equally good as *in vitro* techniques for estimating herbage digestibility.

A second method for estimating digestibility is based on the marker ratio technique. The technique is based on the knowledge of the concentration of a substance in the feed, in the faeces of the animal and the indigestibility of that substance (Kotb and Luckey, 1972). Digestibility of the feed can then be calculated using the relative concentration of the marker in the feed and faeces DM (Schneider and Flatt, 1975) using the following equation:

DMD = (concentration in feed DM)/ (concentration in faeces DM)

In which DMD is dry matter digestibility. The main plant components that have been suggested are lignin, indigestible acid detergent fibre, silica and plant wax n-alkanes.

Lignin was first used as a digestible marker by Forbes and Garrigus (1948) but there are reports that lignin is not completely indigestible (Van Soest, 1982; Fahey and Jung, 1983). Chromagens are plant pigments, mostly from chlorophyll origin. Irvin *et al.* (1953) reported an almost complete recovery of chromagen but Corbett (1960) has detected more chromagen in faeces than consumed by the animal.

The difficulty with using chromagen as an indigestible marker, is its difficulty of extraction in a stable chemical condition. As a consequence, the use of chromagen as an internal marker is limited until better analytical techniques are developed. Acid detergent fibre is the indigestible component of the plant cell wall and consists mainly of lignin and indigestible acid detergent fibre. Penning and Johnson (1983) concluded that indigestible acid detergent fibre could be a suitable marker and could be more accurate than the *in vitro* technique. However, Morgan and Stakelum (1987) showed that the proportion of indigestible acid detergent fibre recovered in the faeces was low and therefore a poor predictor of digestibility. Silica is another potential internal marker for digestibility. The main problem when using silica as an internal marker is the risk of contamination of the herbage with soil (McManus *et al.*, 1967). In addition, Wilson and Winter (1983) reported very high recoveries (127%) and large variation in recovery between animals as was reported by Morgan and Stakelum (1987).

A more recent development is the evaluation of the potential of the plant cuticular wax components as indigestible markers. This development is mainly due to the sophistication of the gas-liquid chromatographic techniques that allowed the accurate detection of low concentrations of alkanes in plant and faecal material. Mayes and Lamb (1984) suggested that the plant cuticular alkanes could be used as an internal marker to estimate digestibility. However their data and following investigations (Mayes *et al.*, 1986[ab]) indicate that the faecal recovery is incomplete. Dove and Mayes (1996) suggest that the recovery is independent from the digestibility of the diet and the between animal variation is small. Dove *et al.* (1990) suggested that digestibility can be more accurately estimated with alkane markers (assuming a standard recovery) than from *in vitro* based techniques.

A third method for estimating diet digestibility is the faecal nitrogen index technique. This method is based on the assumption that there is a close relationship between digestibility and faecal nitrogen concentration. Lancaster (1949) was the first to establish the link between digestibility of organic matter and the nitrogen content of faeces and the technique has proved successful both in temperate (Thomas and Campling, 1976; Barthiaux-Thill and

Oger, 1986) and in tropical swards (Boval *et al.*, 1996). The method is based on establishing a relationship (for animals in stalls) between forage digestibility, estimated from conventional indoors *in vivo* digestibility trials and the concentration of the indicator constituent in the faeces, and applying this regression to a grazing situation.

The regression equations reported are either linear or quadratic. The slopes of the equations are highly variable and it is therefore recommended to use a given equation for one particular plant species, geographical site or even for each cut (Greenhalgh and Corbett, 1960; Langlands, 1975) An investigation by Cameron and Peyraud, (1993) evaluating the effect of species and season, illustrates this problem as shown in Table 19.

Table 19. Prediction models for organic matter digestibility (OMD) of ingested herbage

Regression equation	R^2	Overall (RSE)	Species Effect (G/L) (RSE)	First cut (RSE)	Spring Re-growth (RSE)	Autumn Growth (RSE)
0.612+0.0427fN	0.72	0.020	0.008	NS	NS	NS
0.342+0.188fN-0.0187fN^2	0.83	0.016	0.011*	0.009	0.004	-0.013
0.78+0.0334fN-0.0038fADF	0.89	0.013	0.005	0.007	0.008	0.015

*= Significant at 5%

RSE= Residual Standard Error

G= Graminee; L = Leguminous

fN = Faecal Nitrogen

FADF = Faecal Acid Detergent Fibre

Source: Cameron and Peyraud 1993

The combined use of more than only nitrogen can improve the accuracy of the prediction. Chestnost (1985) obtained an improved level of accuracy in the prediction of the digestibility of a range of graminaceous species in cattle by using both nitrogen and soluble matter at 40 °c while Cameron and Peyraud (1993) decreased the RSE from 0.020 to 0.013 by introducing ADF content of the faeces.

As described above, all estimates of digestibility have their drawbacks and can only be used in specific situations.

When using the laboratory-based *in vitro* techniques to estimate diet digestibility the first problem that exists is to obtain a representative sample of the herbage consumed. But, more importantly, only one estimate of digestibility is obtained which is then used for all experimental units. This problem can be overcome by the use of the marker ratio technique or faecal nitrogen index technique. However no, suitable marker is currently available which is truly indigestible and/or can be recovered with sufficient accuracy to utilise the principle of the marker ratio technique. The faecal nitrogen technique shows promise but requires the continuous development of regression curves relating faecal nitrogen to diet digestibility while being able to account for individual animal variation in digestibility as well as the effects of change in herbage intake level on herbage digestibility. The problem with all these methods is that they are limited in their use when animals can select within the sward for different species of herbage or when they are supplemented due to the existence of interactions of feeds in terms of digestibility (Peyraud, 1996). Regression equations would have to be developed for the whole range of selection options or supplementation range.

A fourth method of measuring digestibility is the use of NIRS (Holechek *et al.*, 1982[ab]; Struth *et al.*, 1989). This method is very similar to the faecal nitrogen index technique. The assumption is that the faeces from grazing ruminants contain chemical bonds resulting from undigested residues and microbiological fermentation and host animal digestion end products, which can provide NIRS spectral information highly, correlated with digestibility of the diet. The limitation of the method is that again, a correlation has to be developed relating NIRS spectra with specific digestibility of a specific diet. However, Lyons and Struth (1992) showed that when a good calibration set is developed (over a range of herbage species and levels of intake and production), diet digestibility can be predicted with NIRS faecal analysis to a degree of precision equivalent to conventional laboratory diet analysis without the effects of physiological stage of the animals. The latter could be a potential advantage compared to the faecal nitrogen technique, which tends to be sensitive to this effect (Le Du and Penning, 1982).

2.6.3.1.2.Estimating Faecal output

Faecal output can be estimated by direct measurement or by the use of faecal markers. Total faecal output measured directly, can be carried out by harnessing animals (Cordova *et al.*

1978; Mitchell, 1977). The technique should be used with extreme care since collection can be incomplete (Milne, 1974) and the weight of the collection bag can hinder the movement of the animal.

In order to acclimatise the animal, the harness and dung bag should be fitted to the animal for several days before the collection period. Le Du and Penning (1982) recommend a collection period of at least 5 days and the technique is mainly suited to male animals (Pigden and Brisson, 1956) because of the difficulty of using urine separators in grazing female animals. Although, Le Du and Penning (1982) report on a method for female sheep in which a mesh bag is used to separate urine from pellets.

More generally, the measurement of faecal output is carried out by a technique involving the dilution of an indigestible marker. The requirements for a marker as a faecal output predictor, have been reviewed by Greenhalgh (1982) and Le Du and Penning (1982). The requirements are that they are non toxic, completely indigestible, quantitatively recoverable in the faeces, have no effect on digestion, should have no effect on the micro-organisms of the alimentary track and should be easy to determine accurately. Using a marker in this manner; faecal production can be calculated from the equation below.

Faecal output (g) =(weight of marker given (g day^{-1}) * RR)/(Mean concentration of marker in faeces (g g^{-1}))
RR= recovery of marker

Currently the most widely used marker is chromic oxide (Cr_2O_2). Edin (1918) first suggested chromic oxide while other types of markers have also been suggested. Mayes *et al.* (1995) suggested Titanium-oxide as a marker but as Titanium is usually present in the soil, and this may lead to systemic errors. Morgan *et al.* (1976) envisaged the use of Cr-EDTA, which is linked to the liquid phase of the digestive contents but Faichney (1975) reported that 5 –10 % can be excreted in the urine. Rare earth elements (e.g. Ytterbium) could be used when estimating faecal output because of their high faecal recovery (Peyraud, 1987). The use of these markers is common in controlled study of digestion in order to measure digesta flow (Siddons *et al.*, 1985; Ellis and Beaver, 1984). Hatfield *et al.* (1990) obtained reliable estimates of faecal output by feeding hay particles labelled with Ytterbium. The main problem with the use of labelled feeds is the awkwardness of its preparation and the accuracy of the delivered dose. However, the measurement of faecal output does not require the labelling to a specific fraction of the digestive contents so, rare earth oxides could

be used to estimate faecal output. To date no work has been carried out to investigate the use of rare earth oxides as a faecal output marker (Peyraud, 1996).

Still the most common marker used to estimate faecal output is chromic oxide. Kotb and Luckey (1972) have described its use in detail. The marker can be administered in four different ways: In a suspension in oil, mixed finely with a component of the diet, in gelatine capsules, impregnated on paper and more recently with a controlled intra ruminal release device. Administration in a suspension in oil has been found to result in highly irregular excretion (Chamberlain and Thomas, 1983). Corbett *et al.* (1969) reported that the flow of Cr_2O_2 through the duodenum was more regular when it was administered in impregnated paper compared to gelatine capsules. More recently, an intra ruminal controlled –release device (CRD), which delivers Cr_2O_2 at a constant rate is available (Furnival *et al.*, 1990, Parker *et al.*, 1990). The reduction in labour input arising from the use of the Cr_2O_2 –CRD allows the estimation of faecal output of much larger numbers of animals, but concern is still expressed about the consistency of the chromium release rate under varying dietary conditions (Buntinx *et al.*, 1994; Luginbuhl *et al.*, 1994) and further evaluation is required.

To reach equilibrium in the outflow of the marker in the faeces, a preliminary dosing period is required. The Cr_2O_2 concentration in the faeces normally reaches equilibrium 6-7 days after the initial dose and its recovery can be considered to be 100% (Chamberlain and Thomas, 1983). The time required to reach equilibrium depends on many factors but those of significant importance are the level of intake and the characteristics of the diet (Le Du and Penning, 1982). For example,. when using paper impregnated with Cr_2O_2, a longer preliminary dosing period is required than with gelatine capsules. The preliminary dosing period can be reduced to five days with highly digestible foods and 7-10 days may be required to reach equilibrium with poor quality foods (Pigden and Minson, 1969).

Pigden and Minson (1969) showed that the Cr_2O_2 concentration in the faeces follows a cyclical pattern throughout the day (diurnal variation). They suggested that taking two faecal grab samples during the day should overcome this problem of diurnal variation.. Other workers have chosen the timing of rectal grab samples on the basis of excretion kinetics trials carried out on animals in stalls (Zoby and Holmes, 1983). However, this approach does not protect against possible bias due to diurnal variation of Cr_2O_2 excretion because the

excretion patterns of grazing animals are not necessarily the same as those for stall-fed animals.

Wanyoike and Holmes (1981) and Melix and Peyraud (1987[ab]) compared cowpat sampling from the ground versus rectal grab sampling and showed that rectal grab sampling does not necessarily result in a serious bias (3-4%) but can increase the variability of an individual intake measurement by about 6%. Minson *et al.* (1960) and Peyraud *et al.* (1996) developed the field collection method using dyes or coloured particles to distinguish cowpats from individual animals and this method can be extremely useful in nutrition trials with low numbers of animals per treatment.
Since fluctuations of Cr_2O_2 concentration occur from day to day (Langlands *et al.*, 1963) a minimum sampling period of at least 5 days is recommended by Le Du and Penning (1982). There is no evidence of a systematic discrepancy in recovery rate between different cows or period of measurement (Melix *et al.*, 1987[a]) and therefore, the use of Cr_2O_2 does not require continuous calibration. However an additional degree of variability with respect to the direct measurement of faecal output will be introduced and is estimated to be 4-7% (Le Du and Penning, 1982; Melix *et al.*, 1987[ab])

2.6.3.1.3. Application of the digestibility and faecal output technique

The most common way of obtaining an estimate of digestibility is the use of a laboratory - based method. The difficulty of this method is obtaining a representative sample of the herbage consumed by the animals. The use of oesophageal fistulated animals does not resolve this problem. The second limitation of this approach is that it does not provide an individual estimate of digestibility and, as a consequence, calculated intakes are not really individual variables in an experimental design. In order to obtain individual estimates of digestibility the marker ratio technique was developed. However, no marker is currently available which offers satisfactory results in practice. An alternative is the faecal nitrogen technique. This technique is very sensitive to diet composition and therefore needs continuous calibration. In order to estimate faecal output most experience exists with the use of Cr_2O_2 and, when used appropriately, faecal output can be estimated with reasonable accuracy. The use of rare earth elements show promise as a faecal marker but its use has never been evaluated sufficiently.

Non of the currently available techniques using the digestibility and faecal output approach can really be applied in situations where animals can select between sward species or are supplemented. Therefore, the digestibility and faecal output technique should only be used in situations where this is not the case.

2.6.3.2 Live weight change, bite size and behaviour methods

With the developments in electronics and the availability of high capacity computers, two techniques to estimate intake have recently received much attention. Both techniques use as their basis knowledge of grazing time or even number of bites taken during the grazing period. One technique uses the change in live weight during a grazing period to estimate herbage intake while the second attempts to estimate the size of the average bite and multiplies this with number of bites taken.

2.4.3.2.1. Live weight change and behaviour methods

This technique is based on two measurements;

1) Live weight change during grazing periods (rate of intake)
2) Time spend grazing per day

The calculation of intake is then based on the simple model that assumes that herbage intake is the product of rate of intake and time spent grazing. Erizan (1932) was the first who suggested the use of weighing animals to estimate intake over short periods of time. Intake in this context is then described as:

$$\text{Intake (kg DM)} = (Wt_2 + F + U + I) - Wt_1 - L$$

Where Wt_1 and Wt_2 are live weights before and after a period of grazing, F and U are the weights of faeces and urine voided during the period of measurement, I is the insensible weight loss and L is the weight of water drunk.

Allden and Young (1959) and Allden (1962) used this technique first but their methodology lacked refinement. Intake was calculated using time at pasture; sheep where fasted for 4

hours prior to measurement of intake rate and I was not measured in the same sheep as those to measure intake rate. To use this method, animals are fitted with harnesses with dung bags and containers for urine collection. After grazing the animals are weighed again and faeces and urine production are estimated. Greenhalgh (1975) criticised the technique used by Allden and Young (1959) as they did not use the same animals to measure intake rate and insensible weight loss. More recently, Gibb *et al.* (1998) showed that insensible weight loss also varied substantially during the day and, that this was related to climatic conditions and should really be measured throughout the day. The development of modern electronic balances with high levels of precision has allowed far more accurate measurement of an animal's weight than previously possible. As a consequence, insensible weight loss can measured during a shorter period and therefore can be measured in the same animals as used to measure herbage intake rate. But as Gibb *et al.* (1998) suggested both intake rate and insensible weight loss need to be estimated at various times during the day as this will interfere with the expression of normal grazing behaviour.

In order to measure grazing time, initially vibra recorders were used (Alden, 1962; Stobbs, 1970). These have now been replaced by equipment developed by Penning (1983) which can accurately record jaw movements associated with grazing and ruminating. This equipment was further improved by Rutter *et al.* (1996) and allows far more accurate estimation of grazing time.

Penning and Hooper (1985) suggested that the combination of live weight change associated with intake and grazing time could be used to calculate absolute intake. However, recent work by Gibb *et al.* (1998) showed that intake rate changes during the day, independent of sward conditions, and the estimate of intake rate would therefore have to be carried out continuously which is practically impossible. The technique should be useful to evaluate short-term intake responses to different sward conditions to at least rank intake potential of certain swards as demonstrated by Cushnahan *et al.* (1999) and McGilloway *et al.* (1999). This approach is however unlikely to provide absolute daily intakes as suggested by Orr *et al.* (1998).

2.6.3.2.2. Bite size and Behaviour Methods

This technique is based on two measurements:

1) Number of bites taken during grazing
2) Estimation of the average bite size

The calculation of intake per day is then based on the model which assumes that herbage intake is the product of the number of bites taken and the size of each individual bite. Estimation of the numbers of bites taken during grazing in the past was carried out manually. Gibb (1996) defined 'bite' as 'the act of cutting with teeth'. As observed by Hodgson (1982) it is difficult to record biting accurately. Visual observation of jaw movements is difficult in grazing animals and may not result in an actual biting rate since some of the jaw movements are associated with the manipulation of the sward and some with the act of swallowing. The only way of accurately determining the number of bites taken by an animal is by listening and recording the number of times one hears the animal tearing off parts of the sward. This means that the observer needs to be relatively near to the animal. It is therefore almost impossible to estimate all bites taken as this would require continuous observation. As a result, rate of biting would be recorded over short periods during the day (Hodgson, 1982). Biting rate has been shown to vary during the day (Jamieson and Hodgson, 1979) and is related to sward conditions (Petit and Bechet, 1995; Laca *et al.* 1994) and hunger drive (Newman *et al.*, 1994) It is therefore of importance that the appropriate intervals and time points during the day are chosen to estimate biting rate. In addition, recording method can have an effect on the final result as illustrated by Jamieson and Hodgson (1979) from grazing calves. Estimates of biting rate derived from records of the time taken to make 20 uninterrupted bites were on average 16% greater than the estimates derived from records from the total number of bites taken during a 2 min. period. The shorter the period of counting the greater the end-point error of an estimate of biting will be. Hodgson (1982) suggests a minimum time interval of 30 seconds. Therefore, to obtain a reasonable accuracy of biting rate during a day various observations at various time points during the day will have to be carried out. One should especially be aware for changes in biting rate due to hunger drive (e.g. after milking) or changes in sward conditions as shown by Jamieson and

Hodgson (1979). Calves in a strip grazing system, when offered a lower allowance under similar sward conditions, had a higher initial biting rate when offered the new daily allowance but a lower biting rate later.

The pioneering efforts of Penning (1983) with the development of jaw –movement sensors and recording equipment has allowed the continuous measurement of bites. This can overcome the problems of short interval measurements. The potential problem lies in the fact that this equipment records jaw movements and not bites taken. However, the efforts from Rutter *et al.* (1996) using solid state recorders and the development of new software to analyse the signals obtained, suggest that number of grazing bites take during a 24 hour period can be obtained with reasonable accuracy.

The second measurement that needs to be obtained is the size of the bite; grams of OM or DM consumed per bite. This measurement is normally obtained by the use of oesophageal fistulated animals (Stobbs, 1973). Besides the difficulty in managing fistulated animals in such a way that they behave in a similar manor to non-fistulated animals, it is also questionable if the fistulated animals represent the actual group of grazing animals unless all experimental animals have fistulas. As shown in table 20 intake per bite has the highest CV in a number of ingestive behaviour variables measured in grazing cattle.

Table 20. Examples of the ranges of the within treatment variability, expressed as coefficients of variation (CV) of ingestive behaviour measured in cattle.

Variable	CV (%)
Grazing time	5-7
Biting rate	4-12
Total daily bites	6-12
Intake per bite	7-30
Rate of intake	7-18

Jamieson (1975)

Since the "between animal" variability is so great, large numbers of fistulated animals would have to be used to obtain an accurate estimate.

Reflecting on both, the difficulty of managing fistulated animals in the grazing situation and the large numbers of fistulated animals required, it seems that the measurement of intake per bite is the main difficulty. A small error in this estimate then multiplied by the number of bites taken could result in large errors in the estimate of total intake. It seems therefore that this approach is more appropriate when measuring short-term responses to sward conditions but, could result in large errors of estimated intake when used for this purpose.

2.6.3.3. Measurement of intake based on animal performance

The use of animal performance data to calculate herbage intake of grazing animals is possibly the simplest form of estimating herbage intake. Herbage intake is calculated using the energy requirement of the animal and the energy content of the herbage assumed to be consumed (Baker, 1982). Herbage intake is then calculated using the equation below.

$$HI = (E_{req} - E_{supp})/E_h$$

In which HI is herbage intake ($kgDMday^{-1}$), E_{req} is the energy requirement including production, growth/ live weight gain and pregnancy ($MJday^{-1}$), E_{supp} the energy supplied by the supplement ($MJ\ day^{-1}$) and E_h the energy content of the herbage on offer/ selected ($MJ\ kg^{-1}$ DM). The precision of the estimate is therefore entirely dependent on the adequacy of the energy standards, the ability to measure animal performance accurately, the assumption that a representative herbage sample can be collected and an accurate estimate of energy content can be obtained.

The difficulty of obtaining a representative sample of herbage consumed and, accurately estimating herbage digestibility and, from the latter predicting energy content, has been discussed before. Estimating individual animal performance of animals can be carried out with reasonable accuracy, although live weight change has to be measured over long periods. The difficulty is that the energy requirements for maintenance and production etc. are derived from stall fed animals. The maintenance requirements of grazing animals are higher than that for stall-fed animals (Logan and Pigdon, 1969). AFRC (1980) suggests an additional energy allowance of 10% for grazing animals while AFRC (1993) gives no guidance on this matter.

The technique does not really estimate herbage intake from individual animals, although animal performance and therefore energy requirements are individually estimated. Since no individual estimate of herbage quality is available, the estimate of herbage intake is not really from an individual animal. In practice however, the calculation is likely to give an indirect estimation of the relative removal from pasture by a grazing treatment compared to another grazing treatment and, as such, can be a useful indicator of the efficiency with which grassland is utilised.

2.6.3.4. Direct Measurement of intake based on sampling of faeces and herbage using n-alkanes

2.6.3.4.1. Introduction

Over half a century ago Chibnall *et al.* (1934) demonstrated the presence of n-alkanes in the cuticular wax of plants. The interest in the chemical composition of the cuticular wax intensified, as the analytical techniques (especially gas-liquid chromatography) became more sophisticated. Grace and Body (1981) showed that the cuticular wax of plants contain a wide range of long chain hydrocarbons. Hydrocarbons are organic compounds that only contain two elements, hydrogen and carbon. The composition of the n-alkane fraction in a range of temperate and tropical pasture species is shown in Table21.

Table 21. Concentrations of n-alkanes in the cuticular wax of a selection of temperate pasture species, tropical pasture species, rangeland species and temperate browse species[1]

mg/kg dry matter

Species	C_{21}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{30}	C_{31}	C_{32}	C_{33}	C_{35}	Ref. no
Monocotyledons														
Lolium perenne						19	5	73	9	137	9	116	18	1
						36	6	142	12	220	7	99	9	2
						26	7	163	14	261	8	110	7	3
				6		20		109		215		141		4
Lolium Multiflorum						105	8	260	11	250	4	43	0	2
				10		40		230	12	242		57	7	5
Lolium rigidum				30		83		196		298		47		4
Phalaris aquatica				31		41		50		35		4		4
Dactylis glomerata						20	2	38	2	58	2	21	0	2
Phleum pratence				32		24		15	0	17		14	7	5
Brachiaria decumbens						8	2	23	7	126	14	223	77	3
Digitaria decumbence						60	10	103	13	323	12	278	40	3
Eragostis eripoda				3		9	4	55	14	395	27	466	18	5
Aristida jerichoensis				10		14	8	48	17	365	11	122	7	5
Deschampsia cespitosa	0	4	3	17	6	43		384	17	657		95	4	6
Deschampsia flexuosa	0	8	5	32	17	107		373	16	411		49	5	6
Carex spp	5	5	2	13	5	36		192	25	157		5	0	6
Dicotyledons														
Trifolium repens						38	7	109	5	67	1	7	0	2
						19		75		66		5	0	5
Trifolium pratence						30	11	408	5	57	1	11	0	2
				15		34		376	3	42		8	2	5
				4		16		250		74		10		4
Trifolium subterraneum				4		15		118		26		5		4
Medicago sativa						36	9	202	12	324	7	21	0	2
				13		55		207		103	8			4
Leucaena leucocephala						10	5	37	4	29	3	18	2	3
Stylosantes scabra						T	T	58	11	241	21	198	1	3
Acacia aneura				226		119	9	126	17	1197	87	1646	11	5
Betula pubescens	22	590		801		70		144	3	53		4	2	6
Betula nana	4	159		143		278		263	15	320		26	2	6
Salix spp	1	9		38	15	162		74	3	63		19	2	6
Juniperus communis	21	4	2	5	2	9		23	3	73		477	55	6

References cited: 1, Mayes et al. (1986); 2, Mulossini et al. (1990); 3, Laredo et al. (1991); 4, Dove (1992); 5, Dove and Mayes (1991); 6, Mayes et al. (1994). 1 Spaces in table indicate that this alkane was not measured or reported; T indicates trace; From: Dove and Mayes, 1996

A number of interesting features occur;

1) Carbon–chain length of the main n-alkanes detected are usually in the range C_{25} (pentacosane) to C_{35} (pentatria contene)
2) The odd-numbered n-alkanes are present in greater amounts than the even numbered n-alkanes
3) While C_{29} (nona cosane), C_{31} (hentria contane) and C_{33} (tritria contane) are the dominant n-alkane in all species, there are marked differences in their levels and patterns

The first to study the possible role of n-alkanes as markers were Mayes and Lamb (1984). They suggested that n-alkanes could be used as an internal marker to estimate herbage intake. Now the technique is widespread and used to predict both herbage intake and diet selection.

2.6.3.4.2. Using n-alkanes to estimate herbage intake

As long ago as 1965, Oro *et al* (1965) observed large similarities between the n-alkane pattern of that extracted from cattle faeces and the pattern of n-alkane in the herbage consumed. Later Grace and Body (1981) reported that when white clover (Trifolium repens L) was fed to sheep significantly less ($p\pm 0.001$) C_{14}-C_{18} fatty acids ingested were excreted in the faeces. Interestingly, of the C_{19}-C_{32} fatty acids no significant difference between the amount ingested and excreted was reported. However, Mayes *et al.* (1986a) showed that the faecal recovery of n-alkanes was incomplete. Their major contribution was to argue that this incomplete recovery would not matter if the animals were dosed with synthetic, even chain n-alkanes as the external markers for the estimation of faecal output. Provided of course that the pair of natural (odd chain) and synthetic (even chain) n-alkanes have similar recoveries and, as long as no n-alkanes were synthesised within the animal. Mayes *et al.* (1988) established that negligible synthesis of n-alkanes occurs in the ruminant digestive tract, and although n-alkanes were predominantly associated with the particulate matter in digesta, incomplete recovery was due to absorption from the small intestine (Table 22)

Table 22. Recoveries of n-alkanes at the duodenum and terminal ileum and the faeces of sheep fed fresh perennial ryegrass (n=8)						
n-alkane	Duodenum		Terminal ileum		Faeces	
	Mean	SE	Mean	SE	Mean	SE
C_{27}	1.037	0.0387	0.626	0.0250	0.594	0.0174
C_{28}*	0.877	0.0424	0.759	0.0446	0.786	0.0210
C_{29}	0.997	0.0354	0.745	0.0224	0.697	0.0144
C_{31}	0.965	0.0340	0.815	0.0214	0.779	0.0095
C_{32}*	0.821	0.0433	0.819	0.0329	0.859	0.0101
C_{33}	0.988	0.0348	0.875	0.0209	0.839	0.0127
C_{35}	1.013	0.0352	0.977	0.0219	0.953	0.0090
C_{36}*	0.841	0.0415	0.876	0.0373	0.922	0.0115
* Dosed n-alkanes			Mayes *et al.* (1988)			

If the natural n-alkanes were to be used on their own as markers to estimate digestibility, corrections for their incomplete recovery would have to be made. As shown in Table 22, the variation in faecal recovery seems to be low. When evaluating the use of n-alkane markers as digestibility markers, Dove *et al.* (1990) showed that n-alkanes can provide more accurate estimates of digestibility than either the *in vitro* estimate or those estimated using lignin as a marker (Dove and Coombe, 1992).

When using the double (dosed even chain n-alkanes with natural odd chain) approach (Mayes *et al.*, 1986[a]), the recovery of the n-alkane becomes unimportant. The animal is dosed with a known quantity of a synthetic, even chain, n-alkane as an external marker for the estimation of faecal output. Intake is then estimated from the daily dose rate and the dietary and faecal concentrations of the dosed, even-chain n-alkane and the natural, odd chain, n-alkane adjacent in length. Since recoveries of the adjacent n-alkanes are similar, the errors associated with incomplete recovery cancel out in numerator and denominator. Herbage intake can than be calculated using the formula below:

$$I = ((Fi/Fj)*Dj)/(Hi-(Fi/Fj)*Hj)$$

In which I is herbage intake (kg DM day^{-1}), Hi and Fi are the herbage and faecal concentration of the odd-chain n-alkane, Hj and Fj are the equivalent concentrations of the even chain, dosed n-alkane and Dj is the daily dose of the even-chain n-alkane. As can

be seen from the equation, only the ratio of the natural and dosed n-alkane concentrations are required. If the concentrations of Fi and Fj are estimated with similar biases, these biases will cancel out. The influence of any difference in faecal recovery between n-alkanes within a pair is minor. For every percentage unit difference in recovery between two n-alkanes of a pair this will only result in error of 1.25% of estimated intake (Dove and Mayes, 1996). In contrast, Langlands (1975 and 1987) reported errors when intake was estimated for the Cr_2O_3/ in vitro procedure of 5% and 2.5% for diets of 80% and 50% digestibility respectively. Indoor validation studies of the technique have shown (Table 23) that the n-alkane technique for estimating intake can be more reliable.

Table 23. Comparison of known intakes of sheep and cattle with those estimated from dosed n-alkanes

Source	Animal	Known DM intake (kg DM day)	Discrepancy (known – estimated) (%)
Mayes *et al.* (1986[a])	Lambs	0.579	0
Mayes *et al.* (1988)	Lambs	0.273	-0.02
Dove *et al.* (1991)	Mature sheep	0.914	2.57
Mayes *et al.* (1986[b])	Beef cows	4.1	-1.70
Dillon (1993)	Dairy cows	14.2	-0.06

However, absolute validation of the method with grazing animals is virtually impossible to achieve as alternative methods to accurately measure intake with which to compare the technique may be no more reliable.

2.6.3.4.3. Factors affecting the accuracy of intake prediction with the n-alkane technique

The accuracy of the estimates of intake obtained using herbage and faecal n-alkane concentrations depends on a range of factors:

1) Accurate administration of dosed n-alkanes
2) Obtaining a representative sample of the faeces and herbage consumed
3) Accuracy of the analysis for the n-alkanes

The oral administration of synthetic, even chain, n-alkanes to animals has been evaluated with a variety of methods using both once or twice daily dosing in both sheep and cattle. It takes 5-6 days for faecal concentrations of the dosed n-alkane to reach equilibrium (Mayes *et al.* 1986a; Dove *et al.* 1989, Dove *et al.* 1991; Dillon, 1993) Mayes *et al.* (1986a) using paper pellets containing n-alkanes impregnated into shredded filter paper reported a CV of pellet n-alkane content of 2-5%. Dove *et al.* (1988) reported a CV of 1-2% when adding the required dose of n-alkane to powdered cellulose on a gelatine capsule. A third method, recently available, is the use of a controlled release device (CRD). This method was evaluated by Dove *et al.* (1991). Release rates of the n-alkane were shown to be constant and were within 1.5 to 4 % of the target daily dosing rate.

Within day variation, in the faecal concentration of the dosed n-alkanes has been reported not to exist using a twice daily dosing method with paper pellets (Dove and Mayes, 1991). However, Dove (1991) found a significant diurnal variation in faecal n-alkane content when using sheep dosed once daily, but when dosing twice daily no significant diurnal variation could be detected. In cattle significant diurnal variation in faecal n-alkane content has been reported with both once and twice daily dosing (Dillon and Stakelum, 1988 and 1990; Stakelum and Dillon, 1990). Dillon and Stakelum (1988) found that the variation in faecal ratios of the pairs of n-alkane natural and dosed was only significant with once daily dosing and not with twice daily dosing. The ratios of the faecal concentrations of alkane pairs seem to be less prone to diurnal variation and therefore, the effect on the calculated intake should be minimal. However, all their studies are based on stall-fed animals and further work is required with grazing animals to establish to what extent diurnal variation in the faecal ratios

of n alkanes could be a problem.

Obtaining a representative sample of the faecal material by sampling more than once daily should reduce the effect of diurnal variation on the faecal n-alkane concentration (Ferrer et al, 1994) and faeces should be collected over a period of four to five days (Mayes *et al.*, 1995). The main difficulty of this technique is to obtain an herbage sample that is representative of that consumed by the experimental animal, in terms of its n-alkane content. For sown pastures that are uniform, this should be relatively easy to achieve by hand plucking or by collection from animals with oesophageal fistula (Vulich *et al.*, 1991 and 1993). Under conditions in which the vegetation is very variable or complex in terms of different species, this might be difficult since alkane contents can vary considerably as a function of species, morphological components of plants and age of the growth (Laredo *et al.*, 1991).

The methodology of n-alkane analysis was initially described by Mayes *et al.* (1986a). The modifications since then have been the omission of the extraction step and the use of gas-liquid chromatography with capillary columns instead of packed columns. Although Mayes *et al.* (1995) reports that the analysis is straight forward and has high reproducibility, problems in consistency have been reported (Ferrer *et al*, 1994) in other centres.

2.6.3.4.4.The use of n-alkanes with supplementary feeds to estimate diet composition in the grazing animal

The greatest advantage of the use of n-alkanes is that the technique can potentially be used when animals are offered supplements or, when the opportunity exists for the animal to select from different forage sources e.g. grass or clover or, as could be the case with buffer feeding between a grass-silage and grazed herbage. When offering a concentrate supplement to grazing ruminants, the proportion of supplement and grazed herbage is different for each individual consequently, the potential interactions between the feeds, as shown by Vadiveloo and Holmes (1979) in beef cattle. They demonstrated that if low quality forages are supplemented with high quality forages or concentrates, interactions between feeds do exist. The result of this interaction could be a complete diet digestibility which is different. A marker system which depends on an external estimate of diet digestibility would be in-

appropriate as these systems do not account for the potential interactions, with respect to digestibility, between different feeds (Le Du and Penning, 1982; Peyraud, 1996). The n-alkane technique offers a solution since it is independent of digestibility. Dove and Mayes (1991) presented the following formula to be used for animals that are supplemented with a known amount of supplement:

$$I = ((Fi/Fj)*(Dj+Ic*Cj)-(Ic*Ci))/(Hi-(Fi/Fj)*Hj)$$

In which I is herbage intake (kgDM day^{-1}), Hi and Fi are the herbage and faecal concentration of the odd-chain n-alkane, Hj and Fj are the equivalent concentrations of the even chain n-alkane, dosed n-alkane and Dj is the daily dose of the even-chain n-alkane, Ic the intake of the concentrate supplement (kgDM day^{-1}) and Cj and Ci the concentrations of the even and odd chain n-alkane in the concentrate. Dillon and Stakelum (1990) evaluated the use of the n-alkane technique when supplementing dairy cows on a basal diet of grass silage with different concentrate types and levels of supplementation, and could not detect any effect of either concentrate type or level on the accuracy with which silage intake was predicted using n-alkanes.

The difference in n-alkane patterns and concentrations between species and also feeds can potentially be used to provide information on the composition of available and consumed herbage or forage supplement. The principle of using n-alkanes to estimate diet composition is the same for other chemical approaches; the composition of a representative sample of the mixture is determined on the basis of the concentrations of the chemical markers in the faeces and the concentrations of the chemical markers in the different diet components. The maximum number of components between which can be discriminated is theoretically limited to the number of markers. When using n-alkanes, 8-15 possible markers are available. Alkanes have now been used to determine diet composition from extrusa (Dove *et al.*, 1993) and from faecal samples (Armstrong *et al.* 1993; Dove *et al.*, 1993; Mayes *et al.*, 1994; Salt *et al.*, 1994). Initially it was suggested to use simultaneous equations to estimate botanical composition of herbage mixtures (Dove and Mayes, 1991; Dove, 1992). Subsequent work has shown that when there are more alkanes than plant species; several sets of simultaneous equations are possible and consequently, more than one solution can result (Dove and Moore, 1995; Newman *et al.*, 1995). To obtain a single estimate of diet

composition using all available n-alkanes, least-squares optimisation methods have been used in later studies (Armstrong *et al.*, 1993, Dove *et al.*, 1993, Dove and Moore, 1995; Mayes *et al.*, 1995; Salt *et al.*, 1994). Their procedures minimise the squared deviation between the observed n-alkane patterns in faeces and that indicated by the predicted diet composition. When faecal n-alkane concentrations are used to estimate diet composition, corrections for incomplete faecal recovery are necessary to prevent bias towards dietary components with a pre-dominance of long chain n-alkanes. Errors due to between animal variation in faecal recovery are likely to be small as the relative recoveries among n-alkanes are important.

In more complex environments such as rangeland forests, there may be more plant species available to the grazing animal than there are n-alkane markers. The solution then might be to combine a microscopic technique with the n-alkane technique (Salt *et al.*, 1994). The use of n-alkanes, in the case of animals having access to forage supplements has never been evaluated but should theoretically be possible as long as the n-alkane patterns of the two forages are sufficiently different. Most studies evaluating the n-alkane technique have been carried out with sheep, except for the studies of Dillon (1993), Stakelum and Dillon (1990) and Mayes *et al.* (1986). Especially the use of n-alkanes in diet composition studies needs further evaluation.

2.6.4. Which herbage intake measurement technique to use when?

As highlighted above, a large range of herbage intake measurement techniques are available to the experimenter. None of these techniques are perfect but, used in the appropriate situation could yield valid information. The choice of technique depends on the objectives of the experiment. To the base of any grazing experiment lies the description of the sward the animals are grazing. A description of this sward should always be undertaken. The intensity of measurement to obtain this description will depend on the objectives of the experiment. If responses to sward structure are to be measured an extensive description of the physical structure of the sward is required. However, if only management guidelines are to be evaluated a simple indication of mass can suffice. If animal responses are important, an additional measurement of herbage quality needs to be obtained. Herbage removal may be considered, particularly, if one is interested in grazing or herbage utilisation efficiency. If the objective of the experiment is to obtain individual animal intakes in order to define

animal responses, individual animal intake measurements are required. Which technique to use depends on the circumstances and treatments carried out within the experiment (Table 24).

Table 24. Type of intake measurement to be used with differing experimental objectives

Experimental objectives	Intake technique
Systems measurements	Sward based techniques - Herbage mass based intake - Animal performance based intake
Individual animal response measurements 1) Response to sward structure	Live weight change, bite size and grazing behaviour methods
2) Responses to grassland or animal management	a) Smaller experiments without supplementation- Cr_2O_3 in combination with the faecal index technique b) Larger production trials and if animals are supplemented- n-alkane techniques

In certain specific situations, a combination of techniques could be used. Extreme care should then be taken that the intensity of the measurements do not interfere with the normal expression of grazing intake in the experimental animals.

As shown, a great number of techniques to measure animal intake are available all with potential benefits and potential pitfalls. The recent development of the n-alkane technique offers great potential for evaluating supplementation strategies in simple swards, which in the past was difficult to evaluate. Measurement of individual intake is high in cost due to its high requirement for chemical analysis and labour. The value of the simple techniques such as intake calculation on the basis of animal performance or sward-based techniques should not be undervalued as long as one is aware that these techniques do not yield individual animal replication although sward replication could be carried out. If replication is carried out over years, highly valuable information will result, especially if information is required to develop management guidelines. The final choice of appropriate technique will depend on the skill of the experimenter and this will determine the value of the information gathered.

2.7. Discussion and conclusions, literature review

Grazed grass is potentially the cheapest feed resource in dairy production systems (Brown, 1995). However, grass growth patterns are seasonal and, to achieve high levels of

utilisation the requirements of the lactating animal needs to match production of grazed herbage alternatively supplementation strategies need to be developed to supply additional feed in periods of low grass growth. Supplementation will however, not only result in higher intakes for the lactating animal but will also affect the amount of grazed herbage consumed and the quality of the product (milk) produced as illustrated in fig.4.

A large number of factors are involved in defining what effect supplementation has on the interaction of the grazing animal with the grazed sward. The most important factors are:

1) Type of animal
2) The sward the animal is consuming
3) The supplementation strategy employed

Genetic selection for milk yield has resulted in larger animals that are more efficient in converting food energy and protein into milk (Veerkamp *et al.*, 1994). This can be explained by the fact that maintenance nutrient requirements are related to $W^{0.75}$, while rumen volume and gut capacity are isometric with W. As a consequence, the size of the animal sets an upper limit on the amount that potentially, can be consumed. Two generally accepted food intake concepts determine food intake:

1 The rate at which food disappears from the rumen sets a limit on food intake.
2 A system of metabolic control of food intake.

Very little information seems to exist on how to apply these concepts in the grazing situation as all food intake models that exist are developed for the indoor feeding situation. One of these models was used (Kristensen and Kristensen, 1986), to predict potential DM intake in the grazing situation for a range of herbage qualities. Intakes of grazed herbage from 16 Kg DM day^{-1} to 22Kg DM day^{-1} were predicted for a dairy cow with a weight of 600 kg, on day 60 of lactation and a genetic potential of 7000 l per lactation. These intakes could result in milk production levels ranging from 18 kg to 35 kg of milk per day without supplementation. However, very few grazing studies exist in which cows without supplementation achieve these levels of milk production.

This suggests that indoor food intake models do not apply in the grazing situation or, other factors that do not apply in the indoor situation limit food intake. Grazing animals consume live plants, which contain large amounts of intra-cellular water, and therefore rumen volume occupied per unit DM can be large. Verite and Journet, (1970) reported that the critical DM content of grazed herbage was 180g kg^{-1} with an estimated depression of 0.34 Kg DM intake per 10 g kg^{-1} decrease in herbage DM. Rook *et al.* (1994[a]), suggests that total rumination time for dairy cows is possibly a limiting factor for food intake but, this theory does not appear to be supported by other studies (Phillips and Leaver, 1985 [ab]; Roberts, 1989).

A more important factor affecting the potential intake of the sward is the sward itself. Two main factors determine the potential of sward; it's digestibility and it's ability to be harvested. A large number of factors affect the ability of herbage to be harvested. Two factors appear to be of significant importance:

1) Herbage quality and sward structure.
2) Herbage variation

Peyraud *et al.* (1986) reported a decrease in intake of high productive cows when less than 2500Kg DM ha^{-1} was available but, also showed that this decrease could be partly overcome as long as the herbage allowance did not fall below 18 kg DM $animal^{-1}$.

Sward structure has been shown to affect potential intake from the sward (Fisher *et al.*, 1995[ab]; Bereton and McGilloway, 1996). The two most important factors are density and height. The higher the density and the higher the height the higher the potential intake from the sward. However, achieving high-density swards at high herbage heights is difficult and, to maintain high digestibility of the harvested material was found to be even more difficult. Therefore, in order to maintain high digestible swards lower herbage heights/allowances are required which will result in that maximum intakes from grazed herbage will not be achieved. An option to obtain maximum total DM intakes and potential milk yield is to supplement the grazing animal with an additional food, a supplement.

Supplementary feeds can be divided into two feed types.

1) Concentrate supplements
2) Forage supplements

Responses to concentrates at grass reported in the literature, tend to be lower than those reported for cows fed indoors a winter ration. This can be explained in part by the situation that if good quality herbage is available, the relative difference in energy density per unit supplement is small. The most important explanation could be that most supplementation experiments where carried out with relative low productive animals (< 25 kg milk day^{-1}). When only evaluating experimental treatments in which cows produced more than 25 kg milk day^{-1} an average milk yield response of 0.74 kg milk per kg of concentrate fed was found, which is very similar to the responses reported in indoor feeding experiments. An important factor explaining the response to concentrate feedings was found to be substitution rate. In turn, the main factors affecting substitution rate were:

1) Animal size
2) Herbage allowance
3) Supplementation level

Concentrate composition apears to have little effect on substitution rate and response to concentrate supplementation. Only in the spring period, mainly at turnout, did concentrate composition affect the response to concentrate supplementation but, only in terms of milk composition.

The second form of supplementation is supplementation with forages. Two main systems of forage supplementation were identified.

1) Buffer feeding; Animals have access to the supplement once or twice a day after milking.
2) Partial storage feeding; Animals have access to the supplement during the night and access to the grazed forage during the day.

Forage supplementation experiments carried out in the past did not measure individual forage supplement intake or grazed herbage intake. The reported intakes were on the whole based on using the ME-balance method. This method assumes that all animals consume a similar amount of forage supplement. There exists a need to measure actual forage supplement and grazed herbage intake in order to begin to understanding the underlying mechanisms explaining responses to forage supplementation.

Experiments carried out using the buffer feeding strategy report a small increase in total DM intake as a response to buffer feeding. The highest DM intake responses accompanied by the lowest substitution rates, are found when the sward surface heights are low and/or in late summer autumn. Yield level of the cow does not seem to affect the response to buffer feeding although, in few studies milk production was above 27 l day^{-1}. These studies suggest that buffer feeding is only effective when herbage heights are low and, in late season when herbage quality is low without an interaction with the production level of the animal.

Partial storage feeding, in most cases, resulted in a small increase in total DM intake but this was accompanied by very high substitution rates, (>0.80) and in a reduced level of production of milk. The review of the literature on partial storage feeding indicates that the potential benefit of partial storage feeding appears to be a reduced need for grazing during the season, at the cost of reduced production and high levels of substitution.

The decision to supplement a grazing dairy cow is normally driven by the economic conditions of the production system. A great number of variables are involved in taking these decisions but the three physical objectives which can be achieved with supplementation in general are:

1. Increase the stocking rate
2. Overcome the variability of the forage supply
3. Improve total nutrient intake

Which supplementation strategy to follow is then dependant on the economic variables driving the production system.

A range of measurement techniques have been developed over the years in an attempt to measure herbage consumption in grazing animals. These techniques can be divided into three main groups:

1. Herbage intake-based techniques in which intake is based on the difference between herbage in the field before and after grazing.
2. Animal production based techniques in which the intake is based on the inversion of the animal requirement system.
3. Individual animal intake based on the diet digestibility and the estimation of faecal output or other methods to obtain individual intakes.

Which technique to use depends on the economic resources and the objectives of the experiment. In table 22 the type of intake measurement to be used for different experimental objectives is presented.
In the case of buffer feeding, the most appropriate technique is the n-alkane technique as this is the only technique in which intake can be measure if animals are supplemented. However, most studies evaluating the n-alkane technique have been carried out with sheep. No studies have been carried out evaluating the n-alkane technique while attempting to measure forage supplement intake.

In order to further improve the potential benefit of forage supplementation a different approach requires to be taken to understand the mechanisms that underlie the responses to forage supplementation. Most buffer feeding studies carried out in the past were of long duration ranging from a number of months to a complete grazing season. In these long-term studies very little information was presented in terms of sward characteristics. It can be expected that buffer feeding will result in a different sward structure in terms of density but, also in the variation of the herbage available (the effect of rejection due to defecation and urination). When employing long term studies (evaluation of strategies), the resulting data is often difficult to interpret since during the experimental period, the experimental animal changes (e.g. condition score, stage of lactation) and the sward changes (e.g. sward structure and quality). This presents problems as the data obtained reflects interactions between forage supplementation, changes in the experimental animal and changes in the sward. If true understanding is required of the underlying mechanisms explaining the expression of the

effect of buffer feeding, short term studies are required with individual animal forage supplement and grazed herbage intake. Only Aston *et al* (1990) has reported individual forage supplement intakes in a partial storage feeding experiment using Callan gates. Using this method in the buffer-feeding situation was found not to be effective. During a buffer feeding experiment carried out at Crichton Royal Farm, Callan gates were used. However a large proportion of the dairy cows did not attempt to open the gates to consume forage supplement (Roberts; personal communication). There are no reported measurements of grazed herbage from the forage supplementation studies. If short-term studies were to be carried out, techniques will have to be developed which will allow both herbage and forage supplementation intake to be measured. The n-alkane technique offers potential to measure both these components of total DM intake but, requires further evaluating in dairy cows.

In the various buffer feeding studies reported in the literature (Table 13 and 14), different forage supplements have been utilised. However, in none of these studies within the same experiment, different forage of varying quality have been evaluated. The quality of the forage supplement could have an effect on the response to buffer feeding. Roberts, (1990), demonstrated this in a partial storage feeding experiment while evaluation has never been carried out in the buffer feeding situation. The evaluation of the literature on concentrate supplementation suggests that the response to concentrate feeding is higher in high productive cows compared to low productive cows, (Table 5). The effect of level of production has, to date, not been evaluated in a buffer feeding experiment. For the reasons discussed above a number of studies are proposed:

1 Evaluation of the n-alkane techniques to measure both herbage and forage supplement intake in grazing dairy cows.
2 Evaluate the effect of buffer feeding strategy on sward characteristics.
3 The effects of forage supplement characteristics on response to buffer feeding.
4 The effect of level of production on the response to buffer feeding.

Where possible, these experiments will be carried out using short-term studies to prevent interactions between the treatment and changes in the experimental animal and the sward. Short term studies would allow responses to forage supplementation to be described with a specific animal and specific sward.

CHAPTER 3. THE USE OF N-ALKANES TO ESTIMATE HERBAGE INTAKE AND DIET COMPOSITION BY DAIRY COWS OFFERED A PERENNIAL RYEGRASS/WHITE CLOVER MIXTURE

3.1. INTRODUCTION

An understanding of the balance between the nutrient requirements of the grazing dairy cow and the nutrients it is able to consume requires a method for estimating herbage intake accurately. This is especially so if the dairy cow is grazing pastures containing more than one species when it has scope to select different species from the sward. The use of mixed swards of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens)*, as an alternative to pure perennial ryegrass swards has increased in dairy production systems (Bax and Thomas, 1992; Bax and Browne, 1994; Frankow-Lindberg *et al.*, 1995). It is essential to have an accurate estimate of both herbage intake and diet selection within perennial ryegrass/white clover swards, as their nutrient composition is different (e.g. Frame *et al.*, 1992).

The use of the n-alkane method as described by Mayes *et al.* (1986[a]) and Dove and Mayes (1991) offers the potential not only for accurately measuring forage intake but also for determining the proportion of grass and clover in the diet; however, this technique has been mainly evaluated with sheep. From validation experiments in which a range of two component dietary mixtures have been fed to sheep and goats (Dove and Mayes, 1996), and from comparisons of faecal recovery of n-alkanes in sheep (Dove and Mayes, 1991), there is no evidence that faecal recoveries for individual n-alkanes differ for different plant species. Limited available evidence suggests that the recovery of n-alkanes is different between sheep and cattle (Mayes *et al.*, 1986[b]; Dillon and Stakelum, 1988; Dillon 1993). However, these studies were carried out using monospecific diets of perennial ryegrass. When dealing with two component dietary mixtures, the proportion of each component of the diet will have to be predicted in order to predict total herbage intake accurately.

The principle of using n-alkanes to estimate diet composition is based on establishing the best match between the pattern of alkane concentrations in the components of the diet and the concentrations corrected for their recoveries in the faeces. Dove and Mayes (1991) presented a method of determining selection in grass/white clover swards using two simultaneous equations. Unique solutions are achieved when the numbers of equations (i.e. n-alkane

markers) are equal to the number of species in the mixture. However, in the case of a two-species sward (grass and white clover), several such sets of simultaneous equations are possible, as a range of different pairs of n-alkanes are available. The choice of the pair of n-alkanes could lead to errors as discussed by Newman *et al.* (1995).

More recently, to obtain a single estimate of diet composition using the concentration of more n-alkanes than there are plant species, a number of least squares optimisation methods has been used successfully. (Mayes *et al.*, 1994; Dove and Moore, 1995, Newman *et al.*, 1995). These procedures minimise the deviations between the observed n-alkane pattern in the faeces (corrected for their recovery) and that of the predicted diet compositions.

There is no published information on the use of n-alkanes to measure both intake and selection of large ruminants grazing grass/white clover mixtures. This study was designed to evaluate the accuracy of the n-alkane technique when estimating forage intake and the proportion of white clover eaten by dairy cows offered grass/white clover herbage.

3.2.MATERIALS AND METHODS

Over a 20-day period in June 1992, eight Holstein-Friesian cows with an average milk yield of 15 kg d^{-1} (s.e. = 1.8) and an average live weight of 616 kg (s.e. = 18.7) were allocated to four pairs on the basis of milk yield and live weight. Each pair was offered either 8, 10, 12 or 14 kg dry matter (DM) d^{-1} of grass/white clover herbage. One animal from each pair received in addition 2 kg DM d^{-1} of milled barley throughout the experiment. Fresh herbage was harvested daily, using a direct-cut forage harvester, from a perennial ryegrass (*L. perenne* cv. Merlinda and Morgana) /white clover (T. *repens* cv. Menna and Milkanova) sward cut to a stubble length of 2-4 cm. The cows were group-housed but fed individually through transponder- operated Calan Gates (Broadbent *et al.*, 1970). The appropriate amount of herbage DM was offered daily in four feeds at 9.00, 12.00, 16.00 and 19.00 h. If there were any refusals, these were weighed to estimate actual amount eaten. The material was chopped by a forage harvester to a length of approximately 2 cm, from which length it was assumed that dairy cows are unable to select for grass or clover; refusals were therefore not evaluated for their botanical composition. The concentrate, if appropriate, was fed at 12.00 h and it was all consumed.

The herbage intake and the ratio of ryegrass to white clover in individual cows were estimated using n-alkanes as faecal markers. Throughout the last 12 days of the experimental period, the animals were dosed twice daily after milking with pellets containing 561 mg dotriacontane (C_{32}) impregnated into shredded paper. During the last 5 days of the 12-day dosing, period faecal grab samples were taken from each animal after the morning (a.m.) and afternoon (p.m.) milking. These samples were bulked over the 5 days, to give one am and one p.m. sample for each animal. In addition, these samples were then sub-sampled to generate an "am + p.m." sample for each animal. A total of three samples were therefore generated for each animal. During the faecal-sampling period a sample of the barley, and the herbage, obtained with hand-held scissors prior to the harvesting with the direct-cut forage harvester were collected. Half of each herbage sample was then hand separated into perennial ryegrass and white clover fractions. One sample set was then freeze dried for n-alkane analysis while the second sample set was dried at 100° C for 24 hours to estimate the content of DM and the proportion of perennial ryegrass and clover in the DM of the forage offered. The barley sample was also split in two. One sample was then freeze dried for n-alkane analysis while the second sample was dried at 100° C for 24 hours to estimate the content of DM.

Freeze dried forage samples and faeces samples were analysed for n-alkanes as described by Mayes *et al.* (1986[a]). The samples were milled and treated directly with ethanolic potassium hydroxide solution (1 M) in sealed glass tubes for 16 h. at 90 °C. The n-alkanes were then extracted with n-heptane and purified through small silica-gel columns. The purified hydrocarbon extracts were then analysed on a PU4500 gas chromatograph (Philips Ltd, Cambridge) fitted with flame-ionisation detector. The column was a glass wide-bore capillary column (Supelco SPB1 30 m x 0.75 mm o.d., Supelco Ltd, Poolle). The process was operated isothermally at 265 °C with helium as the carrier gas. Tetratriacontane was used as the internal standard.

The perennial ryegrass/white clover ratio consumed was estimated from the concentrations of the odd chained n-alkanes, C_{27} - C_{35} by three different methods to enable a comparison of the three methods to be made.

The methods were:

1. An iterative routine (Microsoft Excel Solver) which minimises the sum of squares of the discrepancy between the observed n-alkane faecal levels (expressed as a proportion of total alkane content and corrected for their recoveries) and expected faecal n-alkane concentration calculated from the n-alkane content of the individual forage components (see Appendix I) and which has been described before by Mayes *et al.* (1994).

2. The method described by Newman *et al.* (1995). This method is known as "solving the normal equations of the least-squares problem" (Press *et al.*, 1988) and uses simple, linear mathematics. The technique was programmed into Genstat 5 (Lawes Agricultural Trust, 1990).

3. The method described by Dove and Moore (1995). The algorithm used here is known as "non-negative least squares" (NNLS; Lawson and Hanson, 1974). The programme called "Eatwhat" described by Dove and Moore (1995) was used.

Total intakes were then estimated (using the white clover proportion calculated with method 1) by calculating the C_{31} - and C_{32} - alkane concentration of the complete diet of each animal and using an adaptation of the formula (see Appendix I) of Dove and Mayes (1991). The recoveries of the different n-alkanes used were those reported by Dillon (1993) which were 0.753, 0.767, 0.826, 0.861, 0.838 and 0.882 for C_{27} -, C_{29} -, C_{31} -, C_{32} -, C_{33} - and C_{35} - alkane respectively. All calculations were carried out three times using the n-alkane concentration of the a.m., p.m. or a.m. + p.m. faecal samples respectively.

Means of the n-alkanes concentrations in the herbages (n = 5) and barley (n = 5), the difference between the calculated and actual intake (hereafter referred to as discrepancy), the difference as a proportion of total intake (hereafter referred to as proportional discrepancy) and the calculated white clover content of the diet were calculated and expressed with standard errors (s.e.). These populations were found to be normally distributed and therefore analysed by Genstat 5 (Lawes Agricultural Trust, 1990) using ANOVA. The data was analysed as a split-plot design with cow as the main plot and sample - within - cow as the sub-plot, resulting in 6 residual d.f. for the comparison of concentrate level and 12 residual d.f. for the comparison of sampling regime and its interaction with concentrate level.

3.3. RESULTS

The concentrations of C_{29} - and especially C_{31} – alkane, were higher in perennial ryegrass than in white clover, while the concentration of C_{33} - alkane in white clover was very low compared with that in perennial ryegrass (Table 25).

Table 25. The means (n=5) and s.e. of n-alkane concentrations of herbages fed (mg kg^{-1} DM)

	C_{26}	C_{27}	C_{28}	C_{29}	C_{30}	C_{31}	C_{32}	C_{33}	C_{35}
Ryegrass	1.9	20.6	5.0	90.7	9.2	143.9	7.3	105.2	10.9
s.e.	0.22	1.13	0.22	2.92	0.38	6.25	0.85	4.45	0.65
White Clover	2.5	29.9	5.8	72.2	4.2	50.4	2.8	8.5	0.5
s.e.	0.29	2.26	0.73	5.43	0.47	8.22	1.22	4.04	0.50
Barley	1.7	12.5	2.0	13.7	1.8	8.3	0.9	1.4	0.4
s.e.	0.18	0.71	0.12	1.21	0.09	0.11	0.05	0.20	0.41

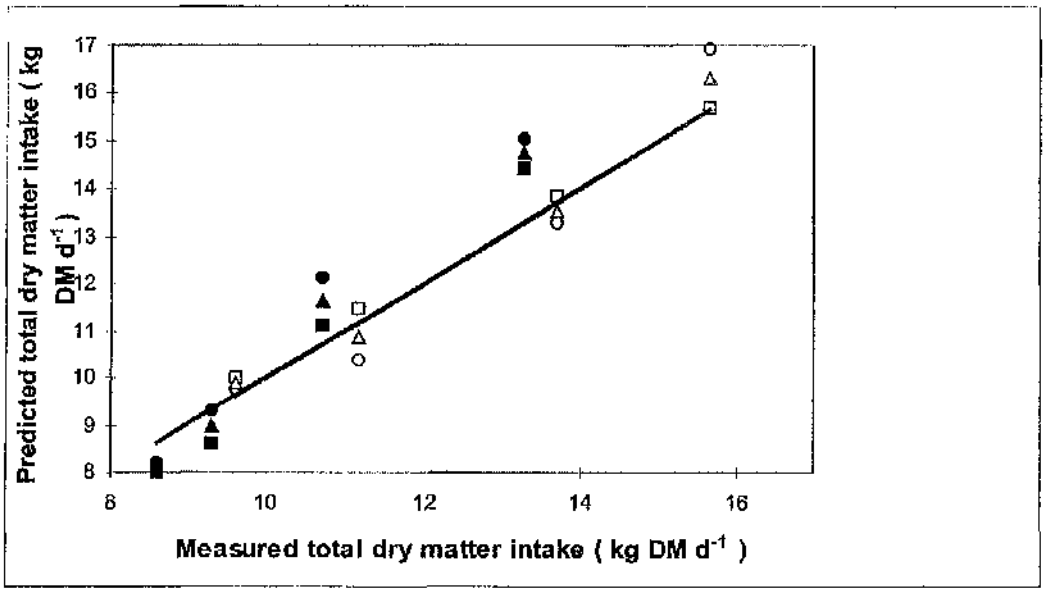
The n-alkane content of the barley was very low. In Table 26 are presented, the means of the predicted white clover contents of the diet using the different calculation methods. The resulting values are very similar to the actual white clover content of the herbage mixture offered which was 0.423 ± 0.008 (n = 5) in the DM estimated by botanical separation.

Table 26. The means (± s.e.) of the predicted white clover content of the diet for the different sampling routines using the different calculation methods

	am	p.m.	a.m. + p.m.
Method 1	0.413 ± 0.006	0.434 ± 0.008	0.425 ± 0.008
Method 2	0.414 ± 0.006	0.434 ± 0.008	0.425 ± 0.006
Method 3	0.417 ± 0.006	0.436 ± 0.008	0.427 ± 0.008

In Figure 16 the relationship between the actual total DM intake and the predicted total DM intake using the n-alkane technique is presented. Total DM intake tended to be slightly overestimated. There was not a consistent effect of sampling routine on under- or over-estimation of predicted intake.

Figure 16. **The relationship between the measured total dry matter (DM) intake and predicted total DM intake for each animal for each sampling routine. The solid line indicates the line of equality. The open symbols are those for cows receiving no concentrate. ○ am, □ pm, △am + pm, ● am + c, ■ pm + c, ▲am + pm + c.**



With respect to the discrepancy and the proportional discrepancy, no significant ($P < 0.05$) effects of sampling routine, concentrate feeding or interactions between sampling routine and concentrate feeding or significant interactions were detected. The standard error of the difference between means for the effect of sampling routine; concentrate feeding and their interaction was 0.186, 0.527 and 0.567 for the discrepancy; 0.013, 0.040 and 0.047 for the proportional discrepancy and 0.004, 0.014 and 0.015 for the calculated white clover content of the diet using method 1. The means for the effects of the different sampling routines on discrepancy and proportional discrepancy are presented in Table 27. The discrepancy was largest when using the PM sampling routine and smallest when using the AM sampling routine as was also the case for the proportional discrepancy.

Table 27. The means (± s.e.) for the different sampling routines of discrepancy and proportional discrepancy		
Sampling routine	Discrepancy †	Proportional discrepancy ††
am	0.139 ± 0.211	0.004 ± 0.020
pm	0.366 ± 0.344	0.020 ± 0.027
am + pm	0.249 ± 0.251	0.013 ± 0.021
† discrepancy is difference between calculated and actual intake †† proportional discrepancy is the difference as a proportion of total intake		

3.4. DISCUSSION

The *n*-alkane concentrations reported for the herbages are in the range shown by Dove and Mayes (1991) for both perennial ryegrass and white clover. They also show the typical differences between the two forage species, with no differences in n-alkane content for C_{26}, C_{27} and C_{28} but higher levels of n-alkane concentrations of C_{29}, C_{31} and C_{33} in perennial ryegrass than in white clover. Concentrations of C_{33} - alkane were very low in white clover. Absolute concentrations of n-alkanes are found to vary, e.g. Malossini *et al.* (1990) reported n- alkane concentrations approximately 75% lower than those of Mayes *et al.* (1986a). However, they reported similar patterns of the different n-alkanes for perennial ryegrass and white clover as reported by Dove and Mayes (1991) and as in this experiment. The barley supplement contained very low concentrations of *n*-alkane. It was for this reason that concentrate could be ignored in the calculation of the proportions of the diet components.

Although only one ratio of perennial ryegrass and white clover was fed, the ratio was estimated accurately with very little difference between the three least-squares procedures described in this paper. There seemed to be little difference in using this procedure (Mayes *et al.*, 1994) or procedures 2 and 3 presented by Newman *et al.* (1995) and Dove and Moore (1995), respectively, both in terms of actual proportions of the two forage components consumed and the variation with which the proportions were predicted for this data population. The range of white clover contents of perennial ryegrass/white clover swards that are grazed by dairy cows can be large. White clover proportions in the DM can be as low as 0.03 to as high as 0.60 as shown by Wilkins *et al.* (1994) and Frame *et al.* (1992).

Newman *et al.* (1995) suggested that owing to small and inevitable errors in the determination of n-alkane concentrations, their method (procedure 2) can occasionally produce nonsensical answers, such as negative proportions of a species known to be in the mixture, especially if the species represents only a very small proportion of the diet They overcame this problem by including a non - negativity constraint. Newman *et al.* (1995) also commented on the potential for unstable solutions with the possibility of small changes in measured alkane concentrations leading to large changes in the estimated diet composition. This will arise especially if two species have similar patterns of alkane concentrations. Dove and Moore (1995), (procedure 3) overcame this problem by using a different algorithm, known as "non - negative least squares" (NNLS; Lawson and Hanson 1974) to solve the equations. It was shown that with this algorithm proportions of diet components could be accurately predicted even if they are low. In addition, a major advantage of this algorithm is that it can be used when there are more than two dietary components. The here presented experiment is not an absolute validation of the ability of the n-alkane technique to predict different proportions of clover in the diet since only one proportion was evaluated but, this one proportion was accurately predicted.

The method for calculating DM intake when using n-alkanes as markers was first described by Mayes *et al.* (1986[a]). Although the faecal recovery of the alkanes is incomplete, this does not matter if the animals were dosed with synthetic, even - chain alkanes, provided that the pair of natural (odd-chain) and synthetic (even-chain) alkanes have similar faecal recoveries. Various experiments have investigated which of the n-alkane pairs would allow the most accurate prediction of herbage intake (e.g. Mayes *et al.*, 1986a; Dillon and Stakelum 1988; Vulich *et al.*, 1991), and often the C_{32}, $C_{33\ pair}$ is suggested. However, white clover contains only small amounts of C_{33} - alkane (Table 27) and the diet contained a high proportion of white clover. A small error in the estimation of C_{33} -alkane could therefore have a disproportionately large effect on the prediction of DM intake. White clover contains much higher concentrations of C_{31} - alkane. It was for this reason that the C_{31}, C_{32} pair was chosen in the calculation of total DM intake. As shown in Table 27, the total DM intake was accurately predicted. The mean difference between calculated and actual intake ranged from 139 g DM to 366 g DM per day, which resulted in a proportional discrepancy ranging from 0.004 to 0.020 depending on sampling routine. This is slightly lower than the proportional discrepancy reported by Dillon and Stakelum (1988) who reported values of 0.025. Various

sources of error could have caused this slight over-estimate. One possible explanation could be that the actual recovery of C_{31} was higher than C_{32}, as suggested by an over-estimate of intake. The diurnal variation, which has been shown to be a problem with other faecal markers (Minson, 1990), was probably minimised in this experiment by feeding the herbage allocation in four feeds between 8.00 and 18.00 h. In practice it can be expected that the grazing dairy cow will consume the majority of its herbage intake at regular intervals during daylight hours. As a result, diurnal variation in terms of the ratio between natural and dosed -alkanes can expect to be similar to that expected in the grazing animal. It would be impossible to simulate exactly the diurnal intake pattern of the dairy cow since this pattern will be very much affected by the management of the dairy cow e.g. milking time, change of paddock or grass height which would affect total grazing time. Absolute validation of the method with grazing animals is virtually impossible to achieve as alternative methods with which to compare may be no more reliable, or possibly inferior.

One aspect that was not addressed in this experiment, which could occur in the normal grazing situation, was the uncertainty of collecting a representative sample of the plant components actually consumed by the dairy cow. This should not be a problem in high quality swards generally grazed by dairy cows but further work is required to confirm that this is indeed the case.

CHAPTER 4. THE USE OF *N*-ALKANES TO ESTIMATE SUPPLEMENTARY GRASS SILAGE INTAKE IN GRAZING DAIRY COWS

4.1. INTRODUCTION

Supplementation of grazed herbage with other forages (buffer feeding) has been claimed to be an effective method of increasing dry matter (DM) intake in grazing dairy cows as reviewed by Phillips (1988). In all the experiments carried out using this system, forage supplement intakes for groups of animals were reported since no accurate method was available to measure individual intakes. However, accurate evaluation of this supplementation system would be greatly improved by a knowledge of individual animal intakes of the supplementary forage, which would help to explain interactions between animal characteristics, supplemental forage and grazed herbage intake.

When offering supplementary forages to grazing ruminants the opportunity exists for individuals to consume different proportions of the supplement and the grazed herbage and consequently, their total diet can be of very different composition. In addition, potential interactions between the feeds could result in different total diet digestibilities as a result of varying proportions of the diet components. It is therefore important when estimating forage intakes in these experiments that a marker system is used which does not depend on a knowledge of diet digestibility. The use of metal oxide based techniques is inappropriate since these depend on estimates of digestibility *in vitro* (Le Du and Penning 1982). Metal oxides based techniques use the concentration of the metal oxide in the faeces to estimate faecal output and then estimates of digestibility *in vitro* are used to calculate forage intake. A system of two different metal oxides, such as chromic oxide and titanium dioxide, one dosed in a known amount and the second incorporated into the forage supplement could, in principle, be used to estimate intakes from two different forages. However, such a system would be subject to errors caused by digestibility interactions between the two forages. The use of indigestible plant components to determine digestibility avoids these problems, but such markers have rarely been used because of difficulties in obtaining reliable analyses of plant and faecal material. However, hydrocarbons of plant cuticular wax (predominantly odd-chain n-alkanes) together with dosed even chain n-alkanes have recently been used successfully as markers for estimating intake (Mayes *et al.* 1986; Dove and Mayes 1991).

The use of n-alkanes to estimate intake of herbage as the sole feed by dairy cows (Dillon 1989; Stakelum and Dillon 1990) and herbage intake when supplemented with a known quantity of a concentrate supplement (Dillon and Stakelum 1990) has been adequately validated. An experiment was therefore carried out to investigate the potential of n-alkanes as markers to estimate herbage and supplementary grass silage intakes in dairy cows in a situation where grazed grass was available throughout the day and the grass silage supplement was available during two restricted periods during the day. The differentiation between the two forages is dependent on the n-alkane patterns being different. However, since both silage and grazed herbage in this experiment originated from the same perennial ryegrass sward, the n-alkane patterns were likely to be similar. Therefore an additional marker, hexatriacontane (C_{36}), was added to the silage to improve discrimination between silage and grazed herbage. Supplementary forages are frequently consumed as large meals. This could have implications for the diurnal pattern of excretion for the different n-alkanes. The experiment therefore examined the effect of two different faecal sampling routines (morning and evening) upon estimates of silage and herbage intakes.

4.2. MATERIALS AND METHODS

Eighteen spring calving Holstein/Friesian cows with a mean calving date of 23 February 1991 and producing on average 22.8 kg milk day^{-1} were paired on the basis of milk yield, live weight and parity. One animal of each pair was then allocated to one of two groups in order to provide two independent estimates of group silage intake. The animals grazed a 3.6 ha field of predominantly perennial ryegrass (*Lolium perenne* cv. Perma) which was divided into two equal paddocks of 1.8 ha, which were grazed continuously by each of the groups of cows. In addition each animal received 1.9 kg DM day^{-1} of a standard concentrate throughout the experimental period which had oven dry matter, metabolizable energy (ME) and crude protein (CP) concentrations of 870 g kg^{-1}, 12 MJ kg^{-1} DM and 200 g kg^{-1} DM respectively.

The cows were allowed access to the silage for approximately 1 hour and 15 minutes after each milking in a feed passage in separate groups. This together with specific paddocks for each group, allowed group supplement intake to be independently estimated for each group. The forage supplement was a grass silage with DM, ME and CP concentrations of 200 g

kg^{-1}, 11.6 MJ kg^{-1} DM and 167 g kg^{-1} DM that was produced from the sward that was subsequently grazed. Group silage intakes were measured daily over a 12-day period from 22 July to 2 August 1991. Individual silage intake and the ratio of silage to total forage intake (silage:total ratio) were estimated using n-alkanes. Animals were dosed twice daily (after milking) with paper pellets containing 627 mg dotriacontane (C_{32}) impregnated into shredded paper. The silage was additionally marked with hexatriacontane (C_{36}). The C_{36} was diluted in heptane (33 g of C_{36} per l heptane) which was then mixed with oven dry soya bean meal (90 ml of solution per kg soya bean meal) in a concrete mixer for 10 min. This was then left spread onto a plastic sheet until all heptane had evaporated. The marked soya was then heated to 95°C to glaze the soya particles with C_{36}. The resulting loading was 2.8 g C_{36} kg^{-1} soya bean meal. The soya bean meal with the C_{36} marker was mixed with the silage in a mixer wagon at a ratio of 1 kg soya bean meal to 125 kg fresh silage daily. During the last 5 days of the 12-day dosing period, faecal grab samples were taken from each animal after morning (AM) and afternoon (PM) milking. These samples were bulked to give one AM and one PM sample for each animal. During these 5 days, herbage samples were collected by hand plucking. Ten herbage samples were plucked from 2 paddocks (one per paddock per day for 5 days). Ten silage samples were collected (one per group per day for 5 days). All samples were frozen to -20°C and freeze dried at a later date.

The analysis of the freeze-dried forage samples and faeces samples for n-alkanes was carried out as described by Mayes *et al.* (1986[a]), with the modification that the milled samples were treated directly with ethanolic KOH solution, and a glass wide-bore capillary column (Supelco SPB1 30 m x 0.75 mm o.d.) was used for the gas chromatographic analysis as described in chapter 3. The silage intake and the silage:total forage ratio were calculated using three calculation methods. In method 1, the proportion of the silage:total forage ratio was estimated using the odd chained *n*-alkanes C_{27} - C_{35}. An iterative routine (Microsoft Excel Solver) minimised the sum of squares of the discrepancy between the observed n-alkane faecal concentrations (expressed as a proportion of total alkane content and corrected for their recoveries) and expected faecal n-alkane concentration (not corrected for their recovery) calculated from the n-alkane content of the two forage components. This method has been described before by Mayes *et al.* (1994) and is different from the method suggested by Dove and Mayes (1991) which only uses one n-alkane pair. Newman *et al* (1995) described a least-squares method using matrix mathematics. The method used here is similar

in that it uses all available information and not only one pair of n-alkanes. The method is different from Newman *et al.* (1995) in that the n-alkanes with the highest concentration will have potentially the largest influence on the predicted ratio of the two forage components. In method 2, the same calculations were carried out but the C_{36} concentration was added to the C_{27} - C_{35} range of odd chained n-alkanes. For both method 1 and method 2, total forage intakes were then estimated by calculating the C_{32} and C_{33} concentration in the diet of each animal using the previously calculated silage:total forage ratio and using the formula of Dove and Mayes (1991) which takes into account the concentrate consumption. In method 3, the dosed n-alkane C_{32} was used to estimate total faecal output, which was then used to calculate total faecal excretion of C_{36} from the measured faecal concentration. When corrected for its faecal recovery, this allowed calculation of buffer feed intake from the concentration of C_{36} in the forage buffer. Total forage intakes were calculated using the standard intake formula as described by Dove and Mayes (1991) using silage buffer intake and the concentrate as the supplement. These values were then used to calculate silage:total intake ratios. The recoveries of the different n-alkanes were assumed to be as reported by Stakelum and Dillon (1990).

Means of n-alkane concentrations in the forages using the 10 forage samples were calculated and presented with a standard error and the means of five daily measured group intakes from the silage buffer feed were calculated and expressed with a standard error. The differences between the means of the groups were examined using the statistical package Genstat 5 (Lawes Agricultural Trust, 1990) using ANOVA and the cows as block and sampling time (AM or PM) and group as treatment resulting in 16 residual degrees of freedom.

4.3. RESULTS

The concentrations of n-alkanes were higher in grass silage compared to the fresh herbage while the concentration of the n-alkanes in the concentrates was low (Table 28).

Table 28. Mean (n=10) n-alkane concentration (mg per kg DM) of hand plucked grass, offered silage and concentrate

n-alkane	C_{26}	C_{27}	C_{28}	C_{29}	C_{30}	C_{31}	C_{32}	C_{33}	C_{35}	C_{36}
Grass	2.65	24.77	5.59	73.90	8.14	116.8	6.63	88.28	12.46	-
SE	0.083	1.014	0.198	2.490	0.337	3.630	0.211	2.872	0.604	-
Silage	2.75	31.23	5.35	140.75	10.34	202.1	7.24	128.6	14.47	60.06
SE	0.050	0.686	0.103	1.996	0.104	2.114	0.078	1.191	0.114	4.051
Concentrate	0	3.69	0.63	7.25	0.59	8	0.52	1.52	0	0
SE	0	0.186	0.026	0.610	0.035	0.291	0.021	0.081	0	0

The mean group intake estimated by weighing was 7.1 kg DM per day (SEM = 0.67) for group 1 and 6.4 kg DM per day (SEM = 1.01) for group 2, resulting in an overall silage intake of 6.8 kg DM per day. For method 1 (C_{27}-C_{35}), both sampling methods gave accurate estimations (Table 29). Method 2 (C_{27} - C_{35} +C_{36}) and method 3 (C_{36}) resulted in an overestimate of silage intake for both faecal sampling routines except for the PM sampling routine in method 3 (C_{36}). When comparing sampling routines within method 2 and method 3, the estimate based on the AM faecal samples was significantly (P<0.001) higher.

Table 29. Comparison of the means (n=18) of the two sampling routines using the three different calculation methods to calculate silage intake and silage total forage ratio		
	Silage intake (kg DM per day)	Silage:total forage ratio
Method 1 (C_{27}-C_{35})†		
AM	6.7	0.44
PM	7.0	0.51
SEM*	0.22	0.026
P-value	0.34	0.08
Method 2 (C_{27}-C_{36})†		
AM	9.6	0.70
PM	7.8	0.57
SEM*	0.15	0.009
P-value	<0.001	<0.001
Method 3 (C_{36})†		
AM	9.2	0.70
PM	7.3	0.57
SEM*	0.15	0.009
P-value	<0.001	<0.001

† Measured intake based on group intake = 6.8 kg DM per day
* Residual degrees of freedom is 16
AM = calculation carried out using faecal samples collected after morning milking
PM = calculation carried out using faecal samples collected after evening milking
SEM = standard error of mean

In Table 30 the group differences using method 1 are presented in order to illustrate the potential of the technique. Group differences in terms of silage buffer intake were significant ($P < 0.05$). For group 1, silage intake was overestimated, while group 2 silage intake was underestimated by both sampling routines. No significant differences ($P < 0.05$) due to sampling routine and interactions between group and sampling routine were observed when using method 1.

Table 30. Comparison of the means (n=9) of the two groups of animals of the sampling routines to calculate silage intake and silage:total forage ratio using method 1 (C_{27}-C_{35})		
	Silage intake (kg DM per day)	Silage:total forage ratio
Group 1†		
AM	7.3	0.46
PM	7.8	0.55
Group 2††		
AM	6.0	0.43
PM	6.2	0.47
Group difference		
SEM*	0.35	0.027
P Value	<0.001	0.040
Sampling routine		
SEM*	0.43	0.033
P Value	0.773	0.131
Interaction		
SEM*	0.61	0.047
P Value	0.948	0.810

† actual intakes (from group intake) equivalent to 7.1 kg DM per day
†† actual intake (from group intake) equivalent to 6.4 kg DM per day
* Residual degrees of freedom is 16
AM = calculation carried out using faecal samples collected after morning milking
PM = calculation carried out using faecal samples collected after evening milking
SEM = standard error of mean

4.4. DISCUSSION

This study showed that the n-alkane technique can be used to estimate intakes of the silage supplements accurately in dairy cows grazing perennial ryegrass pasture using the naturally occurring odd chained n-alkanes in the two forages. Since the intakes of the buffer forage supplement occurred in two large meals during the day, there was considerable potential for diurnal variation in faecal n-alkane excretion. No significant differences between the two sampling routines could be detected when using the naturally occurring n-alkanes. However, the addition of C_{36} did result in differences between sampling routines, indicating that diurnal variation in n-alkane excretion might occur, especially if the n-alkane is added to the forage supplement. The results indicate that C_{36} can be added to a silage with reasonable accuracy as indicated by the s.e.m. value of the C_{36} concentration in the silage (Table 28) although the s.e.m. was larger in absolute terms by a factor of 2. Two possible reasons could explain the differences found in sampling technique when using C_{36}.

The first reason could be that the soya particles (to which the C_{36} was added), which are relatively small compared to the silage or herbage particles, leave the rumen relatively quickly as discussed by Sutherland (1988), which could result in a diurnal faecal excretion pattern of the n-alkane, in this case C_{36}. A second reason could be the tendency of plant and dosed alkanes to distribute differently between the particulate and liquid phases of digesta (Mayes *et al.* 1986[a]) which have different rates of passage. This could result in different diurnal excretion pattern of the n-alkanes of plant origin and artificial n-alkanes.

The data collected in this work do not allow a satisfactory explanation of the overestimation of silage intake when using method 2 or method 3. The significant differences due to sampling routine found do, however, indicate that diurnal variation in excretion patterns is important when n-alkanes are added to the supplement. The implication of the latter is that if n-alkanes are to be used to determine intake in forage supplementation studies, the forage supplement should contain naturally occurring n-alkanes at measurable concentrations and have a pattern of n-alkanes, which is different from that of the other forage.

CHAPTER 5. THE EFFECTS OF SUPPLEMENTARY FORAGE ON DAIRY COW PERFORMANCE AND THE GRAZED SWARD

5.1. INTRODUCTION

Supplementary feeding of forage (buffer feeding) is widely used to increase dry matter (DM) intake or extend lactation length (Pinares and Holmes, 1996) of grazing dairy cows but, the effect of supplementary forage on sward utilisation and morphology is less well understood. Various authors (Phillips and Leaver, 1985; Roberts and Leaver, 1986; Roberts, 1989, Leaver and Campling, 1993) reported the benefits to animal performance when a supplementary forage was offered while the potential interactions between supplementary forages, sward utilisation and sward morphology have been investigated to only a limited extent. Roberts and Leaver (1986) showed that supplementation with forages was most effective at high stocking rates when herbage height was below a certain 'minimum' and herbage availability was probably limiting herbage intake. Stockdale, King, Patterson and Ryan (1981) and King and Stockdale (1981) showed that the response to supplementary forage was not only dependent on herbage availability but also on stage of lactation of the animal. Cows in early lactation are more likely to respond to forage supplementation than those in late lactation. However, these experiments were not independent of season and consequently herbage quality, since the experiment with the cows in early lactation (Stockdale *et al.*, 1981) was carried out on spring swards and the experiment in late lactation (King and Stockdale, 1981) was carried out on autumn swards. Leaver (1985) suggested that in a continuous grazing system the critical herbage height ,using a plate reader, is between 6-8 cm. This translates to 9-12 cm using SSH by sward stick (appendix 2). Above this critical herbage height, supplementary forage resulted in a high substitution of forage supplement for grazed herbage. Herbage intake was derived from metabolizable energy (ME) balance calculations, (Phillips and Leaver, 1985). For supplementation with forages to be effective within dairy production systems, methods have to be developed which supplement during a shortage of grazed herbage but, do not result in high substitution rates.

All experiments carried out to date investigating forage supplementation of grazing dairy cows have considered only intakes of forage supplement and/or grazed herbage intakes for groups of animals as no accurate method was available to measure individual intakes of both herbage and the forage supplement. The development of the n-alkane technique (Mayes et al., 1986; Dove and Mayes, 1991; Dove and Mayes, 1996) for measuring herbage intake allows the measurement of individual herbage and forage supplement intake. The use of this technique for estimating intakes of forage supplement has been evaluated in Chapter 3 and 4. This experiment examined two systems of providing supplementary forage and their effects on animal performance, individual forage and herbage intakes and sward morphology. One system was to start supplementing when sward surface height (SSH) reached a defined minimum and cease when SSH reached a pre-determined maximum. In the second system supplementing began when SSH reached the defined minimum and then continued until the end of the grazing season. This second system was designed to test the ability of the cow to modify her intake of forage supplement in relation to grazing height and changing herbage quality during the season.

5.2. MATERIAL AND METHODS

5.2.1. Design

The experiment examined two different forage supplementation systems. System A consisted of introducing the supplement when SSH decreased to 7 cm and continuing supplementation until a maximum of 11 cm was achieved. Supplementation was then discontinued until SSH fell again to the pre-determined minimum (7 cm). System B initiated forage supplementation when SSH decreased to the pre-determined minimum (7 cm) but then continued supplementation until the end of the grazing season.

The experiment was of a continuous design and lasted 15 weeks from 19 June until 29 September 1991. The experiment commenced on 19 of June because no grazing area was available before this date at Crichton Royal Farm.

The animals grazed a silage aftermath which, in a normal farm situation, represents a large proportion of the grazing area. After the end of the experiment, the animals were monitored for an additional 4 weeks for potential short-term carryover effects and until the end of their lactation to estimate performance over the whole lactation.

Eighteen spring-calving Holstein/Friesian cows with a mid - calving date of 23 February (± 8.2 days), were paired at the start of the experiment on the basis of milk yield, live weight, parity and stage of lactation. The experiment was carried out in a 3.6 ha field of predominantly perennial ryegrass (*Lolium perenne* cv. Primo) originally sown in 1974. The sward received a spring application (3 April) of 110 kg N ha^{-1} in the form of urea and a silage cut was taken on 25 May, yielding 4.27 t DM ha^{-1}. The material harvested was precision chopped and formic acid (Add-Safe, BP Nutrition, Northwich, UK) was added. The material harvested was ensiled in an unroofed clamp silo and used as the forage supplement when required in the experiment. The aftermath received a total of 135 kg N ha^{-1} in 3 equal applications at 3-weekly intervals from 30 May onwards. The field was sub-divided into 2 equal paddocks of 1.8 ha. The two treatment groups of cows were each allocated to a paddock at random, which was then grazed continuously until the end of the experimental period. The initial stocking rate from 19 June was 9 cows per plot (5 cows ha^{-1}) but, to adjust for the reduction in herbage growth rate during the season this was reduced to 7 cows per plot (3.9 cows ha^{-1}) in week 8 until the end of the experiment. The animals were then housed as one group and fed grass silage *ad libitum* until the end of their lactation.

During the experiment the cows were milked at 07.00 h and 16.00 h. Milking time, including walking between the milking parlour and the grazing paddocks, lasted approximately 45 minutes each time. Throughout the experimental period the animals received 1.9 kg DM day^{-1} of a concentrate with DM, crude protein (CP) and metabolizable energy (ME) contents of 870 g kg^{-1}, 200 g kg^{-1} DM and 12.7 MJ kg^{-1} DM respectively. The separate groups of

cows were, according to protocol, allowed access in a feed passage to the forage supplement for approximately 75 minutes after each milking in separate treatment groups. The animals had access to drinking water but not to cubicles. The silage was offered fresh daily at 15% above the amount eaten the previous day on a DM basis.

5.2.2. Measurements

During the experiment and the period when short-term carryover effects were estimated milk yields were recorded daily, while on one day per week samples were taken from consecutive am and pm milkings for the analysis of fat, protein and lactose content (Biggs, 1979). Live-weights were recorded weekly, following afternoon milking and the animals were condition scored at the same time using the tail head system (Mulvany, 1977). During the pre- and post- experimental periods, milk yield was recorded daily from day of calving until drying off, while milk composition was analysed as described above, every 14 days.

Intakes by individual cows of grazed herbage and buffer fed silage were estimated using the n-alkane technique in weeks 5, 7, 11 and 15. Animals were dosed twice daily after milking with paper pellets containing dotriacontane (C_{32}) impregnated into shredded paper. During the last 5 days of the 11-day dosing period, faecal grab samples were taken from each animal after am and pm milking. The samples were bulked as a 5-day sample which was frozen at -20°C before analysis. During these 5 days daily herbage and, if applicable, silage samples were collected. Herbage samples were collected by hand plucking, to simulate grazing. Grazing animals were observed and samples were collected by hand plucking in that same area.

The individual samples were then frozen at -20°C to await analysis. When silage was fed, the amount fed and refused per group was measured daily and the DM content of the silage was estimated. Group silage intakes were thus determined daily and weekly means were calculated.

The analysis of the freeze-dried forage, concentrate and faeces samples for n-alkanes was carried out as described by Mayes *et al.* (1986[a]), with the modification that the milled samples were treated directly with ethanolic potassium hydroxide solution, and a glass wide-bore capillary column (Supelco SP131 30 m x 0.75 mm o.d.; Supelco Ltd, Poole, Dorset, UK) was used for the gas chromatographic analysis ,as described in Chapter 3.

When silage was offered, the silage: total forage ratio was estimated using the odd chained n-alkanes C_{27} to C_{35}. An interactive routine (Microsoft Excel Solver) minimized the sum of squares of the discrepancy between the actual n-alkane faecal concentrations (expressed as a proportion of total alkane content and corrected for recovery) and calculated concentration from the n-alkane content of the two forage components (See Chapter 4). Total forage intakes were then estimated by calculating the C_{32} and C_{33} concentration in the diet of each animal using previously calculated silage: total forage ratios and using the formula of Dove and Mayes (1991) which takes into account the concentrate consumption. The faecal recoveries of the different n-alkanes used were those reported by Dillon (1993) which were 0.753, 0.767, 0.826, 0.861, 0.833 and 0.882 for C_{27}, C_{29}, C_{31}, C_{32}, C_{33} and C_{35} respectively. These were further validated in the experiment described in Chapter 3.

SSH was recorded twice weekly using a HFRO sward stick (Hill Farming Research Organisation, 1986) with 50 grass heights, taken in a "W" pattern across each paddock. Herbage mass was estimated fortnightly by mowing 8 random strips of 1.5 m x 0.33 m to a height of 3 cm using an Alpina Motor Scythe and collecting the cut material. Tiller density was estimated every 14 days during the experimental period. Fifteen random (20 cm^2) cores were collected from each paddock in which live and dead tillers were counted. Within each paddock the grazed area was estimated in five permanent 1 x 2m plots, the position of each plot indicated by wooden pegs at ground level. A moveable frame covered with a grid of 20 x 20 cm squares was used to estimate grazed areas, by subjective assessment, in each plot in

the experimental weeks 3, 5, 7, 10, 13 and 15. An area was judged to be rejected if no marks of recent grazing could be seen and the height was above that of areas which had recently been grazed. Samples of herbage, silage and concentrates were collected for chemical analysis each week and frozen at -20°C to await analysis. The herbage sample was obtained by taking cuts using shears in grazed areas only.

DM content of the supplemental silage was determined by oven drying at 100°C and organic matter (OM) by difference after ashing at 500°C. Herbage and silage organic matter digestibility (OMD) was determined by a modified version of the Tilley and Terry (1963) *in vitro* method (Alexander and McGowan, 1969). ME was then predicted from the equation:

$$ME\ (MJ\ kg^{-1}DM) = (OMD\ (\%) \times 0.907 + 6.03) \times (OM\ (g\ kg^{-1}\ DM)/1000) \times 0.16.$$

ME content of the concentrate was determined using the E3 equations of Thomas *et al.*, (1988) using neutral cellulase gaminase digestibility (NCGD) and ether extract (EE) content (MAFF, 1993). CP was determined by Kjeldahl (N x 6.25), acid-detergent fibre (ADF) by the method of Van Soest and Wine (1967) and neutral-detergent fibre (NDF) by the method of Van Soest *et al.* (1991).

Records of time spent grazing, ruminating, eating silage or other activities were made during 24 hour observations in weeks 4, 6, 10 and 14. Observation was aided during the night by a 6-V torch. Cows were conditioned to the presence of an observer both day and night prior to the first observation. Recordings were made of every animal on the experiment at 15-minute intervals. Rate of biting at pasture was obtained by recording the time required to take a minimum of 40 bites, where there was no interruption in the biting action for longer than 15 seconds. These measurements were taken on three occasions during the day (morning, afternoon and early evening) for each animal on either the day before or the day after the 24 hour behavioural observations. A total of 10 observations were carried out on each occasion resulting in 30 observations for each animal for each recording week.

The ME requirement of each individual animal was calculated each week using AFRC (1993) and was used in the subsequent calculations. Changes in live weight for each cow were calculated by regression of live weight on time. Average weekly live weight change was calculated and used in the ME calculations. Based on ME requirement, DM intake was calculated using group supplement intakes and the ME content of the feeds as previously described by Phillips and Leaver (1985). These were then compared with the DM intake estimates based on the n-alkane technique.

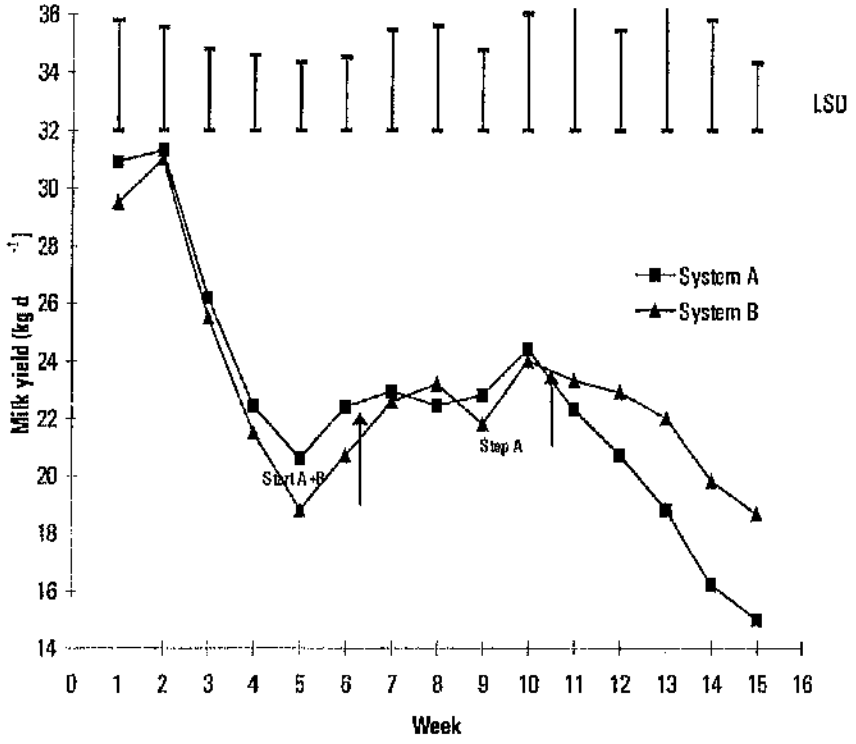
5.2.3. Statistical Analysis

The differences between treatments were examined using the statistical package Genstat 5 Release 2.2. (Lawes Agricultural Trust, 1990). Average animal performance variables were calculated for those animals which were on the experiment throughout (week 1-15). These were analysed using ANOVA. In addition, statistical comparisons of animal performance, herbage intake and animal behaviour at specific time points throughout (week 5, 7, 11, 15) the experiment were carried out using ANOVA with A and B as treatments and the animals within each group as replicates.

The statistical comparison of sward rejection and tiller density was carried out using the 5 plots in each field as replicates. A mean and s.e.d. using ANOVA were calculated for each treatment in each sampling week.

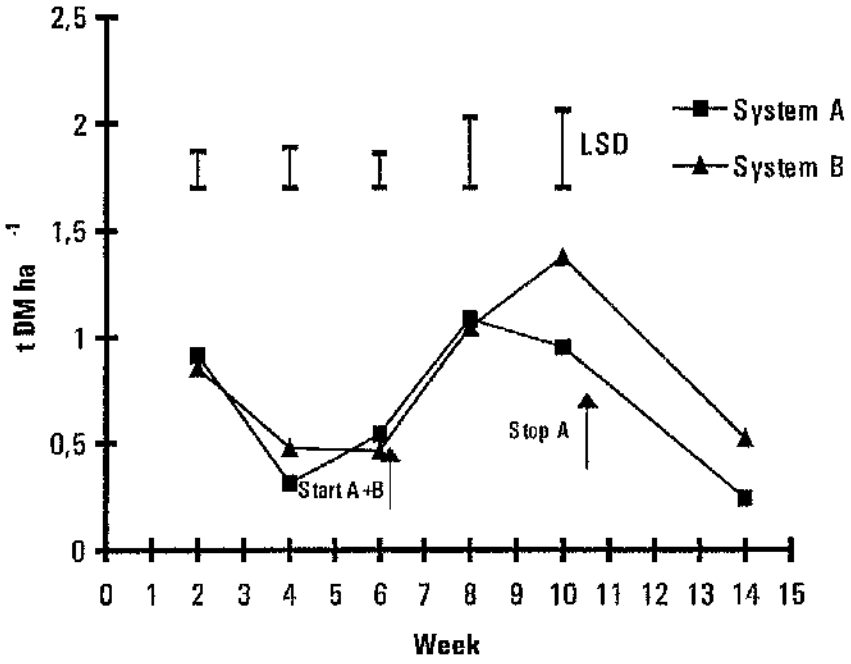
5.3.1.Sward surface height, mass, tiller density and herbage rejection

Figure 17. The change in sward surface height (weekly means) under grazing systems A and B. Arrows indicate the start and end of silage supplementation. Vertical bars represent LSD' s.



Mean SSH during the experiment was 8.6 cm for A and 9.6 cm for B. The changes in SSH during the experiment are shown in Figure 17. Silage supplementation began in week 6 in both treatments and continued until the start of week 10 for A but was continued until the end of the experiment with B. As shown in Figure 18, herbage mass followed a similar pattern to SSH (Figure 17). The variation in herbage mass within the paddocks increased with time as reflected by the higher LSD value. The differences between the two treatments in herbage mass were not significant (Figure 18).

Figure 18. Herbage mass (T DM ha-1) available over 3 cm above ground level for grazing systems A and B. Arrows indicate beginning and end of silage supplementation. Vertical bars represent LSD 's.



Tiller density gradually increased until week 10 of the experiment after which tiller numbers fell by week 15 (Table 31). Tiller density was not significantly affected by treatment (Table 31). Mean total number of tillers during the experiment were 14,400 and 14,600 tillers m^2 for A and B respectively, with a mean live to dead tiller ratio of 7.75 and 7.97 for A and B respectively

Table 31. Live and total tiller density (no.m^{-2} x 10^3) on swards under two systems of grazing (A and B)							
	Week						
	1	3	5	7	10	13	15
Live tillers							
System A	9.37	12.21	11.10	14.69	16.64	10.18	11.36
System B	9.24	10.57	12.79	14.07	15.50	11.03	12.47
s.e.d.	1.644	2.099	2.404	3.595	3.395	2.228	2.546
Total tillers							
System A	10.93	14.95	13.35	17.62	18.19	12.56	13.05
System B	10.44	12.60	16.29	15.50	18.34	13.67	15.14
s.e.d.	1.704	2.232	2.606	3.712	3.521	2.364	3.635

The estimated proportion of the area which was rejected is given in Table 32. Rejection was very low during the early part of the experiment; it reached a maximum for both treatments in week 10, and then decreased to 0.05 in treatment A but only to 0.22 in treatment B.

Table 32. Proportion of sward rejected by dairy cows. Mean values (n = 5) based on subjective assessments						
	Week					
Week	3	5	7	10	13	15
System A	0.02	0.05	0.15	0.29	0.09	0.05
System B	0.02	0.04	0.16	0.40	0.22	0.22
s.e.d.	0.025	0.029	0.091	0.224	0.101	0.108

5.3.2. Chemical composition of the feeds

The quality of the grazed herbage tended to be higher in system B compared with A (Table 33). Herbage quality, in terms of ME content, was low in week 5,especially when compared to the silage produced from the same area. The grazed sward was initially very stemy with very little leaf and this could explain the low ME values of the sward in week 5. After week 5, ME values increased gradually until week 11 after which it fell sharply in system A to 9.5 MJ kg^{-1} and only marginally on system B. Content of CP of the herbage increased from 158 and 142 g kg^{-1} DM for systems A and B respectively to 229 and 252 g kg^{-1} DM in week 11. Thereafter, CP content declined.

Contents of both NDF and ADF decreased during the experimental period. The silage used was of high quality as is shown in Table 34.

Table 33. Chemical composition of herbage on offer					
Week	5	7	11	15	Mean
System A					
DM (g kg^{-1} DM)	213	260	177	251	198
CP (g kg^{-1} DM)	158	196	229	172	184
OMD (g kg^{-1} DM)	543	639	692	625	630
ME (MJ kg^{-1} DM)	7.9	9.7	10.6	9.5	10.0
NDF (g kg^{-1} DM)	624	611	615	583	617
ADF (g kg^{-1} DM)	328	294	270	299	318
System B					
DM (g kg^{-1} DM)	254	302	174	235	202
CP (g kg^{-1} DM)	142	183	252	171	192
OMD (g kg^{-1} DM)	600	657	684	667	655
ME (MJ kg^{-1} DM)	9.0	10.4	10.5	10.4	10.2
NDF (g kg^{-1} DM)	615	586	583	566	591
ADF (g kg^{-1} DM)	322	280	259	286	311

Table 34. Chemical composition of grass silage	
DM (g kg)	204
CP (g kg^{-1} DM)	167
OMD (g kg^{-1} DM)	810
ME (MJ kg^{-1} DM)	11.6
NDF (g kg^{-1} DM)	489
ADF (g kg^{-1} DM)	271

5.3.3. Forage intake

Forage intakes from herbage and silage are presented in Table 35. Total feed intake includes 1.9 kg DM day^{-1} of concentrate fed in the milking parlour. Herbage intakes were not significantly different prior to supplementation (week 5). When cows on system B were offered silage during weeks 11 and 15, herbage intakes were significantly lower than in System A. Total feed intake was higher but not significantly different between systems in any week.

Table 35. Silage, herbage and total feed intake (kg DM d^{-1}) under two grazing systems of strategic weeks throughout the experiment					
	System	Week 5	Week 7	Week 11	Week 15
Silage (kg DM d^{-1})	A	0	7.6	0	0
	B	0	6.1	3.5	7.8
	s.e.d.	-	0.56*	0.79*	1.25*
Herbage (kg DM d^{-1})	A	13.6	7.6	15.8	13.0
	B	13.4	7.5	10.2	7.0
	s.e.d.	0.82	0.76	1.28*	1.42*
Total intake (kg DM d^{-1}) †	A	15.5	17.1	17.7	14.9
	B	15.3	15.5	15.6	16.7
	s.e.d.	0.82	0.84	1.01	1.31
† includes 1.9 kg DM from concentrate					

The total dry-matter intake calculated from ME requirements and the discrepancy from the total dry matter intake based on the n-alkane technique are presented in Table 36. Total DM intake was significantly different in week 5 when using the DM intakes based on ME requirement, while no significant difference could be established when using the n-alkane technique. The DM intakes based on ME requirement were not consistently higher or lower compared with the DM intakes estimated with the n-alkane technique. The discrepancy ranged from -3.5 to 1.7 kg DM d^{-1}

Table 36. Estimated total dry matter intake based on ME requirement and discrepancy from estimated dry matter intake using the n-alkane technique

		Week 5		Week 7		Week 11		Week 15	
	System	Predicted intake	discrepancy †	Predicted intake	discrepancy †	Predicted intake	discrepancy †	Predicted intake	discrepancy †
Total DM intake (kg DM day^{-1})	A	18.9	-3.5	16.3	0.8	15.9	1.7	17.1	-2.1
	B	15.0	0.3	16.1	-0.6	17.4	-1.7	15.9	0.7
	s.e.d	1.28**	1.19**	1.45	1.38	1.28	1.58	0.80	1.43

† n-alkane predicted herbage DM intake - predicted herbage DM intake based on ME requirement

5.3.4. Animal behaviour

Table 37. Behaviour of dairy cows during two systems of grazing and supplementation

	System	Week 5	Week 7	Week 11	Week 15
Eating silage (mln d^{-1})	A	0	121	0	0
	B	0	117	78	87.9
	s.e.d.	-	9.6	-	-
Grazing (min d^{-1})	A	620	302	508	516
	B	612	340	468	384
	s.e.d.	24.1	32.2	35.2	38.6*
Ruminating (min d^{-1})	A	543	590	480	525
	B	520	565	503	619
	s.e.d.	22.5	24.1	29.9	38.6*
Biting rate (bites min^{-1})	A	73.0	70.7	64.4	71.3
	B	72.9	69.8	60.3	66.3
	s.e.d.	1.508	1.833	1.862*	1.913*
Intake rate per bite when grazing (g DM $bite^{-1}$)	A	0.302	0.341	0.470	0.340
	B	0.275	0.234	0.239	0.323
	s.e.d.	0.024	0.068	0.031*	0.045

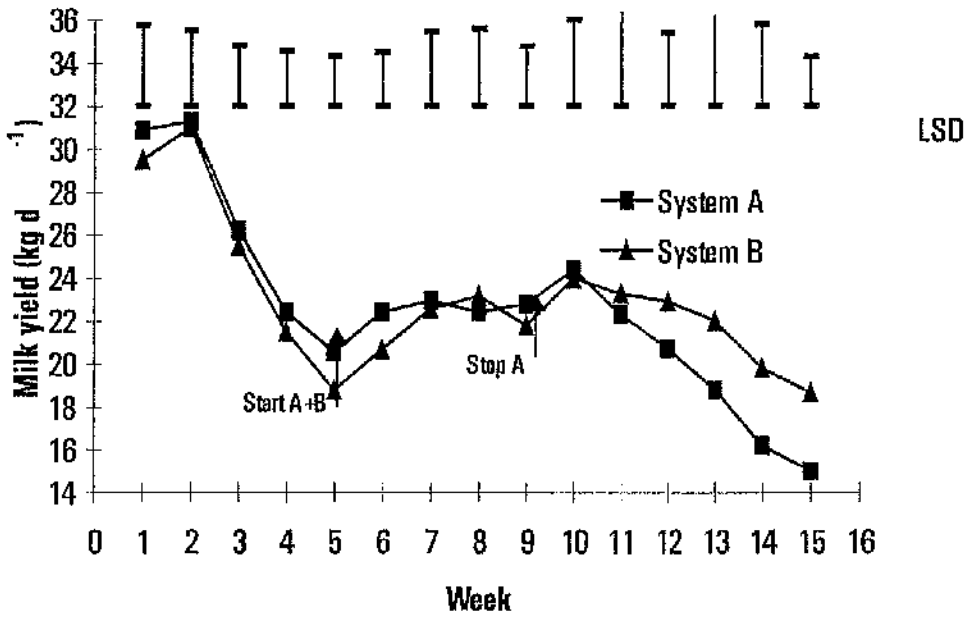
The results of the animal behaviour studies during weeks 5, 7, 11 and 15 are presented in Table 37. Grazing time was depressed by offering silage, as indicated by the difference between week 5 and 7 for both treatments and the difference between systems A and B in weeks 11 and 15. These differences were significant in week 15. When the silage supplement was offered in week 7, grazing time decreased. Grazing time was only marginally lower in B compared with A in week 11 although the animals on treatment B were offered silage. Grazing time was significantly less on B in week 15. Rumination time was affected only in week 15 when rumination time was significantly higher in B compared with A. The rate of biting when grazing, tended to be related to herbage height (Figure 18). No significant differences were detected during weeks 5 and 7 while during weeks 11 and 15 biting rates were significantly lower in B.

Table 38. Mean milk yield and composition, live weight, live weight gain and condition score for dairy cows under two systems of grazing/supplementation

	System	Week 5	Week 7	Week 11	Week 15	Week 1-15	Week 16-19
Milk yield (kg d^{-1})	A	20.6	22.9	24.4	15.0	22.2	13.8
	B	18.8	22.6	24.0	18.7	23.5	15.4
	s.e.d.	1.33	1.97	2.25	1.85	2.04	1.58
Milk composition							
Fat (g kg^{-1})	A	40.0	40.1	35.8	43.3	40.5	42.4
	B	38.5	42.8	39.9	43.4	40.4	42.4
	s.e.d.	2.66	3.19	3.73	3.05	1.95	2.54
Protein (g kg^{-1})	A	30.1	30.7	33.0	30.5	31.8	34.0
	B	29.9	31.1	32.0	35.3	31.8	34.9
	s.e.d.	1.10	1.10	1.19	1.28	1.14	1.48
Lactose (g kg^{-1})	A	44.3	45.9	45.7	42.6	44.3	42.9
	B	43.9	45.4	45.8	42.9	44.8	42.0
	s.e.d.	0.976	0.93	1.52	1.14	0.97	1.45
Live weight (kg)	A	565	570	575	606	581	619
	B	547	542	572	612	594	611
	s.e.d.	31.6	32.7	33.4	35.3	32.5	37.8
Condition score	A	1.79	1.94	1.81	1.96	1.89	1.95
	B	1.94	1.83	1.79	2.06	2.03	2.21
	s.e.d.	0.189	0.170	0.104	0.158	0.174	0.196
Live weight gain ($kg\ day^{-1}$)	A	0.24	-0.46	-0.57	0.54	0.52	0.43
	B	-0.33	-0.27	0.52	0.46	0.37	0.70
	s.e.d.	0.98	0.644	0.84	0.256	0.226	0.617

Milk yield and composition were not significantly affected by treatment (Table 38). In Figure 20 the pattern of milk production during the experiment is shown. Milk production decreased from 30 kg day^{-1} to 20 kg day^{-1} during the first 5 weeks of the experiment. The introduction of the silage in week 6 and a reduction in stocking rate resulted in an increase in milk yield until week 10, after which it declined on both treatments.

Figure 19. The weekly average milk yield (kg d -1head) of dairy cows under grazing systems A and B. Arrows indicate beginning and end of silage supplementation. Vertical bars indicate LSD



As shown in Table 38, supplementation system did not significantly affect milk composition, live weight or condition score. During the subsequent monitoring period (weeks 16-19) no carryover effects could be detected but the difference in milk yield in favour of treatment B persisted. These differences were not significant. In Table 39 the performance, in terms of milk yield, milk composition and number of days in milk is presented for the 7 animals which used throughout the experiment throughout. No significant differences were established between the two systems but lactation milk yield and fat, protein and lactose yield tended to be higher with system B, mainly as a result of increased lactation length.

Table 39. Total production of milk and milk components for dairy cows (n=7) and mean composition of milk over the complete experimental period			
	System A	System B	s.e.d
Milk yield (kg)	6131	6556	444.5
Milk composition			
Fat (g kg^{-1})	44.1	42.7	2.11
Protein (g kg^{-1})	31.2	31.7	0.78
Lactose (g kg^{-1})	45.3	45.8	0.88
Fat (kg)	269	280	22.0
Protein (kg)	191	208	13.7
Lactose (kg)	278	300	20.8
Day in milk †	266	281	13.5
† = cows were dried off either when milk yield was less than 10 kg d^{-1} or when predicted to calve within the following 65 days			

5.3.6. Overall performance of the buffer feeding systems

The total production per ha for each system is given in Table 40. The animals on system A were supplemented during weeks 6 to 9 and consumed 1,550 kg DM of silage during this period. The animals on treatment B were supplemented from week 6 until the end of the experiment and consumed 2,830 kg DM of silage. Overall differences in animal production (Table 40) were minor. The difference in milk yield was only 104 kg over a 15 week period and the differences in milk component production were also very small. Calculated energy yield was very similar for the two systems. Energy input was, however, very different between the two systems due to the different amounts of silage used for supplementation. This resulted in a higher energy yield from grazed herbage with system A

Table 40. Overall animal output per hectare for two systems of grazing/supplementation		
	System	
	A	B
Animal production		
Milk yield (kg ha^{-1})	10342	10446
Milk composition		
Fat (kg ha^{-1})	424	425
Protein (kg ha^{-1})	331	330
Lactose (kg ha^{-1})	474	471
Energy yield	82979	81836
Energy demand cows (MJ ha^{-1})	49532	49532
Energy harvested as silage (MJ ha^{-1})	132511	131368
Energy input	19589	19589
Energy concentrates (MJ ha^{-1})	18018	32858
Energy silage fed (MJ ha^{-1})	37607	52447
Energy from grazed herbage (MJ ha^{-1})	45372	29389

5.4. DISCUSSION

When the experiment was initiated, it was expected that SSH would fluctuate in a wave manner, moving several times between the upper SSH limit (11 cm) and the lower SSH limit (7 cm). When the SSH limit was reached, the forage supplement would be introduced resulting in less grazed pasture being consumed and therefore, SSH would increase. The movement of SSH was, however, very slow and therefore only once during the experimental period with A was supplementation initiated and thereafter stopped. Hutchings, Bolton and Barthram (1991) investigated potential decision rules for controlling sward heights of continuously stocked pasture and, concluded that pre-emptive adjustment of stocking density in anticipation of a change in grass growth rate, improved the control that was achieved. Furthermore, in this experiment an additional variable was the availability of a forage supplement, which could potentially reduce herbage offtake. It was only after 4 weeks of forage supplementation that the grass height had increased from the lower to the upper limit and this was accompanied by a stocking rate reduction from 6 cows ha^{-1} to 3.9 cows ha^{-1}. The changes in SSH were reflected in changes in herbage mass. Tiller density was lower than

those reported by Arriaga-Jordan and Holmes (1986) for a continuously grazed sward but comparable to the values reported by Fisher, Roberts and Dowdeswell (1995[a]) for a grazed silage aftermath.

Due to of the expense and logistical problems of undertaking replicated experiments with continuously grazing dairy cows, the experiment reported here had no field replication. Thus, results of sward characteristics should be treated with caution and it must be noted that statistical analysis of animal performance was derived from using animals as replicates However, this type of experimental design has been shown to provide evidence of the effects of sward treatments on the performance of continuously grazed animals (Arriaga-Jordan and Holmes, 1986, Kibon and Holmes, 1987, Fisher and Dowdeswell, 1995[b], Fisher *et al.* 1995[a]).

The digestibility and ME values of the herbage are low compared with values reported by others (Phillips and Leaver 1985, Roberts 1989), probably because the sward used was a silage aftermath which contained stemmy material, resulting in low ME values as shown by Fisher *et al.* (1995[a]). The samples used were taken by cutting and therefore may not represent the material actually consumed by the animals, as was shown by Hodgson and Jamieson (1981). It may be more appropriate in future experiments to analyse samples obtained by hand plucking, as with the samples used for the n-alkane analysis, although this would not provide an indication of the quality of the herbage on offer but of the herbage potentially consumed.

Supplement intake tended to be highest when SSH were lowest in agreement with the results of Roberts and Leaver (1986). However, in this experiment, even when sward height was high, the animals still consumed 3.5 kg DM of silage (week 11) without any response in animal performance. This contrasts with responses to concentrates, where even when sufficient herbage is available, responses to supplementation, in most cases, can be observed (Meijs and Hoekstra, 1984; Arriaga-Jordan and Holmes, 1986).

Although differences in sward rejection existed these were not significant. System B (continuation of forage supplementation) appeared to result in increased rejection of herbage and increased SSH. This did not however result in increased intake rates per bite (g DM bite^{-1}), in contrast with Stobbs (1974) and Rook, Huckle and Penning (1994), who indicated that intake rate per bite was related to sward height and sward characteristics. This experiment indicates that when animals are not supplemented and therefore have a greater requirement for herbage (hunger drive), they tend to compensate not only with increased bite size but also with increased bite rates. Hodgson (1985) and Phillips and Leaver (1986) both reported a maximum of 66 bites minute^{-1} in dairy cows in a paddock grazing system and continuous grazing systems. In this study, mean biting rates of up to 73 bites minute^{-1} were observed and appear to be high but are similar to values reported by Kibon and Holmes (1987). A possible explanation could be that the swards used were silage aftermath's, which have low tiller densities (Fisher *et al.,* 1995) and the high biting rate probably reflects the greater difficulty of harvesting the herbage. The calculated intake rates per bite are comparable to values reported by Phillips and Leaver (1985) and Roberts (1989) for a continuous stocked grazing system. It should be noted that these values were based on ME balance calculations while in this study actual intakes were measured using n-alkanes. When comparing the two techniques for estimating total DM intake it was shown that total DM intake was both, over-estimated and under-estimated when the ME requirement based technique is compared with the n-alkane technique.

On average the ME requirement based technique tended to overestimate total DM intake by about 0.5 kg DM day^{-1} compared to the n-alkane based technique.

The grazing times recorded indicate that the animals had to graze for a long period to achieve their required intake in the beginning of the experiment (week 5). Hodgson (1985) reported a range of grazing times from 350 min d^{-1} to 650 min d^{-1}. The values found in this study in week 4 were near the upper limit, indicating a low rate of intake and therefore attempts by the animals to compensate not only by high biting rates but, also by increasing grazing times. This indicates the difficulty that dairy cows have in achieving sufficiently high intakes from recently regrown silage aftermath's. Forage supplementation reduced grazing time dramatically when weeks 5 and 7, are compared and grazing time for the supplemented animals was reduced throughout the experiment.. Animal performance was not significantly affected by treatment during the experimental period at grass and no significant differences could be detected during the carry-over period (weeks 16-19) when the animals were fed silage and housed. When total lactation length and production are compared, the animals on system B tended to produce more milk and had a longer lasting lactation, indicating that system B may result in a higher persistency of milk production as was found by Pinares and Holmes (1996). When the overall performance of animals per ha are compared, there are only small differences. This is in contrast to responses ranging from 0 to 2.3 kg day^{-1} milk reported by Phillips and Leaver (1985), Roberts (1989) and Leaver and Campling (1993). However, in these latter experiments, grazing area was not kept constant but was used as a variable to control herbage height. The estimated total metabolizable energy yield of each system was very similar to the yields reported by Kibon and Holmes (1987) who reported a total utilised metabolizable energy yield of 130 GJ ha^{-1} for a system with dairy cows grazing continuously stocked pastures.

This experiment indicates that the use of forage supplementation between pre-determined lower and upper limits of grass height could be a valid system which should achieve similar production, reduce herbage rejection and reduce need for silage during the grazing season. Adaptation of this practice should result in improved efficiency for grass based dairy production systems.

CHAPTER 6. THE EFFECTS OF SUPPLEMENTING GRAZING DAIRY COWS WITH STRAW BASED MIXTURES OF DIFFERING COMPOSITION

6.1. INTRODUCTION

Forage supplementation is a widely used strategy in dairy production systems to achieve increased dry matter intakes in grazing dairy cows. Various authors (Stockdale, King, Patterson and Ryan, 1981; King and Stockdale, 1981; Phillips and Leaver, 1985[a]; Roberts, 1989) reported on the benefits to animal performance from forage supplementation. Benefits have been investigated with relation to stage of lactation (Stockdale *et al.*, 1981, King and Stockdale 1981), and the interaction between forage supplementation and season (Phillips and Leaver, 1985b). However none of these studies compared the effect of different forage supplements in terms of energy content or dry matter (DM) degradability when access to the forage supplement is relatively short (for example one hour after each milking).

Aston *et al.* (1990), Roberts (1989) and Roberts and Kelley (1990) compared forage supplements of different energy content within a system of partial storage feeding in which the animals had access to the forage supplement during the whole night. Increased energy content of the buffer feed within a partial storage feeding system resulted in increased consumption of the forage supplement, but this was not always accompanied by an increase in animal performance. In the typical forage supplementation situation (buffer feeding) where access periods to the forage supplement are short the energy content or dry matter degradability of the supplement could have a greater effect since these factors could affect the potential intake of the supplement and as a consequence, this could influence the potential benefits from forage supplementation. Therefore, two experiments were carried out to examine the effects of two forage supplements which were differed in straw and sugar beet content and therefore in energy content and dry matter degradability. In the first experiment the animals had access to the feeds for one hour after each milking and were allowed *ad libitum* consumption during this period while in the second experiment the feeds were restricted to an equal level in order to evaluate the impact of forage supplement energy content and DM degradability at equal intake.

6.2. Materials and methods

6.2.1. Design

Two forage supplements, with either a low straw content (LS) or high straw content (HS) were evaluated. Two experiments were carried out, both of a continuous design, each lasting 4 weeks. In experiment one, which was carried out from 4 to 29 May 1992, 20 Holstein/Friesian cows were paired on the basis of milk production, live weight, lactation number and calving date. The animals consisted of 16 multi parous and 4 primi parous cows which were 75.3±4.16 days calved at the start of the experiment and had an average live weight of 551±11.2 kg and an average milk production of 25.6±0.77 kg day^{-1}. Each animal of a pair was then randomly allocated to one of the two treatments; grazing and a low straw content forage supplement (LS1) or grazing and high straw content forage supplement (HS1). Access to the forage supplement was allowed for one hour after each milking. In the second experiment the same group of cows was used as in Experiment 1 but half of the pairs on the different treatments were exchanged to form two new groups. In the second experiment, which was carried out from 1 to 26 June, 1992, access to the forage was as in Experiment 1 but the amount of the LS forage offered, was restricted to the amount of the HS forage eaten. This resulted in two treatments in which the same amount of forage supplement was eaten of either a high energy/high degradability (LS2) or low energy/low degradability (HS2).

6.2.2. Dairy cow management and supplement composition

During both experiments the cows were milked each day at about 7:15 and 15:30 hours. The animals had access to their appropriate forage supplements for one hour after each milking in a cubicle shed, in a feed passage in separate treatment groups. The animals had access to drinking water but not to cubicles. The forage supplements were prepared daily and offered at 10% (DM basis) above the amount eaten the previous day, for both treatments in experiment 1 and on the HS2 treatment in experiment 2. The amount offered in experiment 2 for the LS2 treatment was dependent on the amount consumed the previous day on the HS2 treatment. The forage supplements consisted of barley straw, sugar beet pulp, cane molasses, urea and a standard mineral (Maxcare, BP Nutrition Ltd). The LS mixture contained 310 g kg^{-1}DM, 592 g kg^{-1} DM, 65 g kg^{-1} DM, 9 g kg^{-1} DM and 24 g kg^{-1} DM of barley straw, sugar beet pulp, cane molasses, urea and minerals respectively.

The HS mixture contained 540 g kg^{-1} DM, 359 g kg^{-1} DM, 65 g kg^{-1} DM,12 g kg^{-1} DM and 24 g kg^{-1} DM of barley straw, sugar beet pulp, cane molasses, urea and minerals respectively. Before mixing the straw was chopped to lengths of approximately 7 cm. The mixtures were prepared daily using a Cornall Mixer.

During both experiments the same 3.3 ha field was used containing predominantly perennial ryegrass (*Lolium perenne* cv. Primo) originally sown in 1974. The sward received a spring application (28 March) of 110 kg N ha^{-1} in the form of urea and during the experiments an additional 129 kg N and 11 kg K_20 ha^{-1} in 3 equal applications. The field was split into two equally sized plots which were grazed by both groups on a daily change over basis in order to achieve equal grazing conditions. In order to maintain a target grazing height of 7 cm, the stocking rate was changed by adding or removing additional dairy cows during the grazing periods.

6.2.3.Measurements

During the last two weeks of each experiment milk yields were recorded daily and samples for milk composition were collected on one day of the last week from a consecutive am and pm milking for the analysis of fat, protein and lactose contents (Biggs, 1979). Live weights (LW) were measured weekly and on the last day of each experiment following afternoon milking and the animals were condition scored (CS) at the same time using the tail head system (Mulvany, 1977). In addition yields and milk composition, LW and CS were estimated in the week before the start of the experiment which were used as covariates.

Individual grazed herbage and forage supplement intakes were estimated using the n-alkane technique (Mayes *et al.*, 1986) during the last two weeks of each experiment. Animals were dosed twice daily after milking with paper pellets containing dotriacontane (C_{32}) impregnated into shredded paper. During the last 5 days of the 11 day dosing period faecal grab samples were taken from each animal after am and pm milking but before there supplementation period. The samples were bulked up to a 5 day sample which was frozen at -20°C before analysis. During these 5 days, daily herbage and forage supplement samples were collected. Herbage samples were collected by hand plucking, to simulate grazing. Grazing animals were observed and samples were collected by hand plucking in that same area. The individual samples were then frozen at -20°C awaiting analysis.

The frozen samples for n-alkane analysis were freeze-dried and were analysed as described by Mayes *et al.* (1986), with the modification that the milled samples were treated directly with ethanolic K0H solution and a glass wide-bore capillary column (Supelco SPB1 30 m x 0.75 mm o.d.) was used for the gas chromatographic analysis as described in Chapter 3. The proportion of supplement consumed from the total forage intake was calculated using a minimisation routine as described in Chapter 4. The proportion supplement to total forage intake was estimated using the odd-chained n-alkanes C_{27} - C_{35}. An interactive routine (Microsoft Excel Solver) minimised the sum of squares of the discrepancy between the actual *n*-alkane faecal concentrations (expressed as a proportion of total alkane content corrected for recovery) and calculated concentration from the *n*-alkane content of the two forage components. Total forage intakes were then estimated by calculating the C_{32} and C_{33} concentration in the diet of each animal using previously calculated silage:total forage ratios and using the formula of Dove and Mayes (1991). The faecal recoveries of the different *n*-alkanes used were those reported by Dillon (1993)and validated in Chapter 3.

Sward surface height (SSH) was recorded 3 times a week using a HFRO sward stick (Hill Farming Research Organisation, 1986) with 50 random grass heights being taken in a "W" pattern across each paddock. Herbage mass was estimated once a week during the last two weeks of each experiment by mowing 8 random strips of 1.5 x 0.33 m to a height of 3 cm using an Alpina Motor Scythe and collecting the cut material. A herbage sample and forage supplement sample was collected weekly during the last two weeks of each experiment and frozen at -20°C awaiting analysis. Herbage samples were obtained by taking cuts using shears in grazed areas.

Food DM content was determined by oven drying at 100°C, organic matter (OM) by difference after ashing at 500°C. Crude protein (CP) was determined by Kjeldahl (N x 6.25) using selenium dioxide as a catalyst. The *in vitro* digestibility's (OMD) of the forages were determined by a modified version of Tilley and Terry (1963) as described by Alexander and McGowan (1969). Metabolisable energy content (ME) was then predicted from the equation:

$$ME\ (MJ\ kg^{-1}\ DM) = (OMD\ (\%) \times 0.907 + 6.03) \times (OM\ (g\ kg^{-1}\ DM)/1000) \times 0.16.$$

Acid-detergent fibre (ADF) was determined using the method of Van Soest and Wine (1967) and neutral-detergent fibre by the method of Van Soest, Robertson and Lewis (1991). In addition DM and protein degradability of the forages were estimated using Suffolk male wether sheep each fitted with a rumen cannula and fed a basal diet of hay. The methods used to obtain the degradability characteristics were as described by Ørskov and McDonald (1979).

In each experiment two 24 hour behaviour studies were carried out in weeks 3 and 4. Recordings were made of every animal on the experiment at 10 minutes intervals during day light hours and at 15 minute intervals during darkness. Observation was aided during the night by a 6-v torch. Cows were conditioned to the presence of an observer both day and night prior to the first observation. Recordings of grazing, ruminating, eating forage supplement , milking or other activities were made. Rate of biting at pasture was obtained from recording the time required to take a minimum of 40 bites, where there was no interruption in the biting action longer than 15 seconds. These measurements were taken at three occasions during the day (morning, afternoon and evening) for each animal on either the day before or on the day after the 24 hour behaviour observation. A total of 10 observations were carried out during each experiment for each animal on each treatment.

6.2.4. Statistical analysis

Changes in live weight were calculated for each animal by regression of live weight from week 3 of each experiment to the last day of each experiment. The variables used for statistical analysis were the mean of the observations collected during the last week for each experiment except for the forage intake variable, were only one value per animal was estimated. The differences between treatments in the first experiment were examined using ANOVA with the statistical package Genstat 5 release 2.2 (Lawes Agricultural Trust, 1990) using the covariate if available, pair as block and the different forage supplement treatments as treatments resulting in 8 residual degrees of freedom (r.d.f.) when a covariate was available and 9 r.d.f. if no covariate was available. In the second experiment the differences were examined using pair as block, the covariate if available and the forage supplement treatments in experiment 1 x the forage supplement in experiment 2 as treatment resulting in 6 r.d.f. with the covariate and 7 r.d.f. without the covariate.

6.3.RESULTS

6.3.1.Sward surface height and chemical and degradability characteristics of the feeds

Mean SSH was 7.5 cm and 6.9 cm for experiments 1 and 2 respectively. Average herbage mass (above 3 cm) was 563 kg DM ha^{-1} and 412 kg DM ha^{-1} in experiment 1 and 2, respectively. The chemical and degradability characteristics of the feeds are presented in Table 41. The forage supplements as expected were different in energy (ME) content, fibre content (ADF and NDF) and DM degradability characteristics. The herbage in the second experiment was of lower CP, energy content (ME) compared to the herbage on offer in the first experiment.

Table 41. Chemical and degradability characteristics of the foods

	Forage supplements		*Herbages*	
	LS	HS	Exp 1	Exp 2
Chemical analysis	(*n*=8)	(*n*=8)	(*n*=4)	(*n*=4)
DM (g kg^{-1})	694 ± 3.3	703 ± 4.6	181 ± 7.7	329 ± 28.2
CP (g kg^{-1} DM)	109 ± 2.9	96 ± 5.8	200 ± 4.7	167 ± 11.9
OM (g kg^{-1} DM)	901 ± 1.9	913 ± 2.4	884 ± 5.5	906 ± 1.2
IVOMD (g kg^{-1} DM)	721 ± 11.3	592 ± 12.0	763 ± 9.0	707 ± 4.0
ME (MJ kg^{-1} DM)	10.4 ± 0.17	8.4 ± 0.20	11.5 ± 0.10	11.0 ± 0.10
NDF (g kg^{-1} DM)	502 ± 12.5	627 ± 9.4	574 ± 9.6	573 ± 9.3
ADF (g kg^{-1} DM)	314 ± 9.8	394 ± 6.3	248 ± 4.6	255 ± 5.0
DM Degradability	(*n*=3)	(*n*=3)	(*n*=3)	(*n*=3)
a	0.30 ± 0.020	0.25 ± 0.028	0.27±0.005	0.25±0.022
b	0.54 ± 0.023	0.50 ± 0.030	0.67±0.013	0.50±0.013
c	0.04 ± 0.002	0.04 ± 0.009	0.06±0.0004	0.04±0.001
Calculated Degradability ††	0.480	0.417	0.587	0.453
CP Degradability †				
a	0.41 ± 0.036	0.47 ± 0.021	0.34±0.005	0.23±0.019
b	0.59 ± 0.063	0.42 ± 0.039	0.61±0.006	0.67±0.019
c	0.03 ± 0.09	0.04 ± 0.007	0.13±0.001	0.09±0.001
Calculated Degradability ††	0.571	0.575	0.718	0.585

†a,b and c are the three constants when fitting $dg=a+b\{1-e^{(-ct)}\}$ as in Orskov and McDonald (1979)
†† calculated degradability = a+ (b*c)/(c+r), r=0.08

6.3.2. Forage intake and diet composition

Forage intakes from herbage and forage supplement and resulting overall diet composition are presented in Table 42. In experiment 1 the herbage intake ($P<0.01$) and forage supplements intake ($P<0.001$) were significantly different between treatments but total DM intake was the same .

This did result in significant differences in CP content ($P<0.001$) and NDF content ($P<0.001$) of the diet of the animals on the two treatments in Experiment 1. In Experiment 2 no significant differences with regard to forage DM, buffer feed DM or total DM intake between treatments were detected. The fact that no significant differences in DM intakes were detected resulted in significant differences in terms of ME content ($P<0.001$), NDF content ($P<0.001$), ADF content ($P<0.001$) and DM degradability ($P<0.001$) of the diet.

Table 42. Treatment effects on forage intakes and resulting diet composition

	Experiment 1			*Experiment 2*		
	LS1	HS1	s.e.d	LS2	HS2	s.e.d
Intakes						
Herbage (kg DM^{-1} day)	11.5	14.5	0.77**	13.0	13.2	1.10
Buffer feeds (kg DM^{-1} day)	5.3	2.3	0.51***	2.8	2.8	0.25
Total intake (kg DM^{-1} day)	16.9	16.7	1.01	15.8	16.0	1.24
Diet composition						
CP (g kg DM)	172	187	0.31***	156	155	0.6
ME (MJ kg^{-1} DM)	11.3	11.2	0.13	11.0	10.5	0.02*
NDF (g kg^{-1} DM)	549	589	8.2***	562	582	0.7***
ADF (g kg^{-1} DM)	265	272	4.5	268	279	1.2***
DM Degradability (%)	53.3	54.4	0.68	45.8	44.7	0.04***

*p<0.05
**p<0.01
***p<0.001

6.3.3.Animal behaviour and forage intake rates

Cow behaviour in terms of time spent on a certain activity was not significantly affected by treatment in experiment 1 as shown in Table 43. However, due to the significant differences in herbage and forage supplement intake this resulted in significant differences in both herbage ($P=0.05$) and forage supplement intakes rates ($P<0.001$). Biting rate during grazing was not significantly affected by treatment. In experiment 2 grazing time and rumination time were not significantly affected by treatment, but forage supplement time was ($P<0.05$). Herbage intake rate was not significantly affected by treatment but forage supplement intake rate was ($P<0.05$).

Table 43. Animal behaviour and forage intake rates						
	Experiment 1			*Experiment 2*		
	LS1	HS1	s.e.d.	LS1	HS1	s.e.d.
Grazing time (min day^{-1})	486	499	23.6	453	480	7.54*
Rumination time (min day^{-1})	506	495	28.3	566	574	15.1
Supplement eating time (min day^{-1})	63	56	5.0	51	65	5.8*
Herbage intake rate (g DM min^{-1})	23.8	29.2	2.19*	28.8	27.7	2.45
Supplement feed intake rate (g DM min^{-1})	89.5	40.3	10.4**	55.9	43.2	4.82*
Grazing biting rate (bites min^{-1})	68.5	66.9	1.89	70.8	65.5	1.63*
Intake per bite (g DM $bite^{-1}$)	0.35	0.44	0.037*	0.41	0.42	0.036
*p<0.05 **p<0.01						

6.3.4.Animal Performance

The animal performance results are presented in Table 44. No significant differences due to treatment could be detected in either experiment on any of the variables measured. The level of production was higher in experiment 1 compared to experiment 2 while live weights were higher in experiment 2.

Table 44. Animal production						
	Experiment 1			*Experiment 2*		
	LS1	HS1	s.e.d.	LS1	HS1	s.e.d.
Milk yield (kg day^{-1})	25.0	23.3	1.17	20.5	19.5	1.1
Fat (g kg^{-1})	40.0	43.6	1.75	37.7	37.3	2.2
Protein (g kg^{-1})	30.6	31.2	0.51	30.9	29.6	1.7
Lactose (g kg^{-1})	46.4	46.2	0.56	45.7	46.7	0.53
Fat yield (kg day^{-1})	1.003	1.007	0.0540	0.763	0.730	0.0296
Protein yield (kg day^{-1})	0.762	0.726	0.0345	0.626	0.575	0.0439
Lactose yield (kg day^{-1})	1.159	1.075	0.0572	0.942	0.908	0.0508
Live weight (kg)	553	552	5.9	565	572	6.5
Live weight gain (kg day^{-1})	-0.15	0.23	0.397	0.28	0.56	0.326
Condition score	2.20	2.20	0.033	2.12	1.92	0.043
*p<0.05 **p<0.01 ***p<0.001						

6.4.DISCUSSION AND CONCLUSION

The optimum grass height for continuously stocked swards is considered to be 6-8 cm (Le Du and Hutchinson, 1982). The average grass heights in the experiments described here were 7.5 and 6.9 cm. It seemed that herbage availability was not limiting potential herbage intake since in the first experiment the animals on the HS treatment were able to consume an additional 3 kg DM day^{-1} (Table 42) of herbage without increasing their grazing time significantly (Table 43). Phillips and Leaver (1985[a]) showed that the amount of forage supplement consumed was dependent on stocking rate. However, it seems that in the current experiments it can be assumed that the amount of forage supplement eaten was independent of herbage availability. This implies that other factors, in addition than stocking rate , determine intake from forage supplements which are different in composition. Factors which could be involved are DM-contents, digestibility, degradability, fibre length and density of the products used for forage supplementation.

Roberts (1990) when using a partial storage feeding system, fed mixtures of increasing energy content, achieved by decreasing the amount of barley straw in the mixtures. He demonstrated that decreasing the amount of straw in a mixture increased estimated ME and DM intakes. This is in contrast with the results of the first experiment reported here where forage supplements of different straw content resulted in equal levels of total DM and energy intake (Table 42). The animals on the HS1 treatment compensated their reduced DM intakes from the forage supplement with increased intakes from grazed herbage and this resulted in an overall diet composition equal compared to the LS1 treatment in terms of ME content, ADF content and DM degradability of the diet.

Intake of mixture HS was similar in both experiments (Table 42). Short term fill effects as described by Balch and Campling (1962) and Mbanya, Anil and Forbes (1993), probably determined maximum levels of HS mixture intake. Short term fill could be defined as the regulation effect caused by consuming in a short period a meal resulting in rumen distension or chemostatic control of intake (Forbes, 1995). Short term fill is the factor controlling meal size. In contrast, long term fill could be defined as the regulation mechanism which control intake over a whole day. For example when a highly fibrous food is consumed, its disappearance from the rumen sets a limit on what can be eaten during a day. Mertens (1987)

showed that if low degradable material was fed to ruminants, effective rumen fermentation volume could be reduced and this in turn could reduce potential DM intake. This is not confirmed with the results of both experiments presented here in which (in both cases) equal levels of total DM intake were achieved. However, since the amount of HS mixture eaten was low and therefore formed a low proportion of the diet (13.6 and 17.5% of total DM intake in experiment 1 and 2, respectively), it could be expected that these levels are too low to expect differences in total DM intake as described by Mertens (1987). It seems, therefore, that in this experiment when using HS forage supplements short term fill factors prevent long term fill effects from effecting total intake and this might explain the differences in results compared to Roberts (1990) who used a partial storage feeding system and hence a longer access time to the supplement.

The behaviour observations (Table 43) show no main differences due to treatments in the two experiments and are within the range reported by Hodgson (1985). Animals on the HS2 treatment did spend more time eating supplement compared to the animals on the LS2 treatment. This effect is not surprising since the amount of forage supplement available on the LS treatment was restricted to that consumed by animals given HS.

The combination of forage DM intake results with the behaviour data resulted in some interesting significant differences in intake rates. During the first experiment the animals on the HS1 treatment consumed 3 kg DM day^{-1} more herbage than the animals on the LS1 treatment (Table 42). The cows achieved this higher intake not by increasing their grazing time but by increasing their intake rate and this was not accompanied by an increase in biting rate (Table 43) and therefore the higher intake would have been achieved by increasing bite size. This is in contrast with Jamieson and Hodgson (1979) who suggested that bite size is only related to animal size/type and herbage mass. In these experiments, the swards the animals were grazing were the same swards and the difference between the two treatments was only with respect to a difference in forage supplement intake. Animals would have to increase bite depth or bite area to achieve different intakes per bite. A measurement of tillers pre- and post grazing would have been of value and could have explained the origin of the increase in bite size. However since these differences where not anticipated, these measurements where not carried out.

The rate at which the forage supplements were consumed was markedly different with 89.5 g DM min^{-1} for the LS forage supplement compared to 40.3 g DM min^{-1} for the HS forage supplement. Roberts and Kelly (1990) also reported differences in intake rates and resulting total mixture intakes, when comparing a straw mixture with a silage mixture in a partial storage feeding system. They suggested that intake rate could be an indicator of potential intake. In the experiments reported here intake rate in the second experiment, when intake from the forage supplement was equal the intake rate from the LS forage supplement was still significantly higher although much lower than in the first experiment (Table 43).

No significant effects on animal performance was detected (Table 44) in either of the experiments. In experiment 1 when intake from the forage supplement was determined by access time the animals on the HS1 treatment were able to compensate for the reduced forage supplement intake by consuming more herbage. This resulted in a final diet of remarkably equal composition as shown in Table 42. Not surprisingly this resulted in, no significant differences in being detected in terms of animal performance. In the second experiment the difference in ME intake was only 5 MJ day and this difference is probably too small to enable differences in terms of animal performance to be detected.

One interesting speculation remains and that is why did the animals choose to eat the supplements because in both experiments on both treatments if the animals would have eaten herbage only they would have maximised energy intake. It seems however from this experiment that short term fill, which could be associated with short term comfort feeling for the animal, seems to drive the intake from the forage supplement. An pasture only treatment would have been extremely interesting in this experiment since it could have explained some of the questions which this experiment has generated. In this case a pasture only treatment was not possible due to a lack of experimental animals.

The use of a high energy/higher degradable forage supplement compared to a lower energy/lower degradable forage supplement resulted in increased intakes from the high energy/high degradable forage supplement. However, when herbage is readily available the animals receiving the lower degradable forage supplement were able to increase their herbage intake by increasing the bite size. This resulted in an equal diet composition and animal performance. When the intake of the LS forage supplement was restricted to

the level of the HS forage supplement (experiment 2) no significant differences were detected. Within systems of twice daily access to supplement short term fill factors seem to determine the level of intake from the forage supplement. It was shown that although the forage supplements were of lower energy content than the herbage on offer the animals still consumed substantial (up to 5.3 kg DM day^{-1}) amounts of the lower quality forage supplement. This could potentially result in reduced daily energy intakes and poorer animal performance.

CHAPTER 7. THE EFFECTS OF SUPPLEMENTING GRAZING EARLY AND LATE LACTATION DAIRY COWS WITH STRAW MIXTURES OF DIFFERENT DRY MATTER CONTENT

7.1. INTRODUCTION

Supplementing grazing dairy cows with a forage is a commonly used strategy to increase dry matter (DM) intakes. Mayne (1990) in a review of the use of supplements to grazing cattle, suggested that supplementation with forages of grazing dairy cattle results in high substitution rates with grazed herbage. Substitution rate is dependant on herbage availability as shown by Phillips and Leaver (1985[a]) and they suggested that substitution rate was in addition dependant on the level of production of the animal. However, in this study, actual forage supplement intake and herbage intakes were not measured, but were predicted by metabolisable energy (ME) balance calculations. Stockdale *et al.* (1981) and King and Stockdale (1981) studied the response to forage supplementation in early and late lactation cows, respectively, and speculated that the response to forage supplementation might be dependent on stage of lactation.

Ulyatt and Waghorn (1993) suggested that one of the main limitations to high levels of dairy production from pastures is the water content of the herbage, which is predominantly intra cellular and therefore contributes to the bulk of the diet. Jackson and Forbes (1970) suggested that DM intakes from grass silages peak at 320 g kg^{-1}. Various authors (Stockdale *et al.*, 1981; King *et al.*,1981; Phillips and Leaver, 1985 [ab] and Roberts, 1989) have investigated the benefits of forage supplementation in relation to stocking rate and season. None of these compared different forage supplements in terms of DM content and the interaction with stage of lactation.

This paper describes an experiment carried out to investigate the interactions between forage supplement DM and the interaction with the stage of lactation of dairy cows. The n-alkane technique is used to measure intake of supplement and herbage and therefore comparisons between individuals are possible.

7.2. MATERIALS AND METHODS

7.2.1. Design

Three forage supplement treatments were compared to a control, non-supplemented treatment, within a continuous design experiment, which was carried out over a 5 week period (1 week for covariate measurements and 4 weeks for the experimental treatments) from 3 May until 4 June 1993. During the covariate period all animals received 1.8 kg DM per day of a standard dairy concentrate and were grazing the paddocks used in the experiment. The treatments in the experiment were a control (C) non-supplemented treatment and forage supplements with DM contents of 300 g kg^{-1} (B30), 550 g kg^{-1} (B55) and 800 g kg^{-1} (B80). Half the animals on each treatment were either in early lactation (E) or late lactation (L) resulting in a total of 8 treatments. Forty multiparous Holstein/Friesian cows were allocated to groups of four on basis of milk production, live weight, lactation number and calving date. The twenty early lactation animals were 71.8 ± 3.95 days calved, with an average live weight of 602 ± 8.3 kg and an average milk production of 32.9 ± 2.79 kg day^{-1} at the start of the experiment. The twenty late lactation animals were 218.5 ± 17.1 days calved, with an average live weight of 611 ± 11.7 and an average milk production of 23.3 ± 0.75 kg day^{-1} at the start of the experiment. Access to the forage supplements for the appropriate treatment groups was for one hour after each milking while the non-supplemented group remained in a similar area for 1 hour after each milking.

7.2.2. Dairy cow management and supplement composition

During the experimental period the cows were milked each day at approximately 07:15 and 15:30 hours. The animals had access, according to protocol to the forages supplements for one hour after each milking in a feed passage in separate treatment groups. The animals had access to drinking water but not cubicles. As a consequence, animals which did not recieve a forage supplement were also kept in a feed passage for one hour in order to achieve equal acces times to grazed herbage. The forage supplement was prepared daily and offered at 10% (on a DM basis) above the amount eaten the previous day.

The forage supplement contained 330 g kg^{-1} DM, 572 g kg^{-1} DM, 72 g kg^{-1} DM, 11 g kg^{-1} DM and 15 g kg^{-1} DM of barley straw, sugar beet pulp, cane molasses, urea and minerals (Maxcare, BP Nutrition Ltd), respectively. The difference in dry matter was achieved by soaking the sugar beet pulp in differential amounts of water. Before mixing, the straw was chopped to a length of approximately 7 cm. The mixtures were prepared daily using a Cornell mixer and covered by plastic sheets during the periods when the animals had no access. No parlour concentrate was fed to any of the animals.

The animals grazed 4 plots of 2 ha each in groups of 10 animals per forage supplement treatment on a daily rotational basis. The grazing area was a perennial ryegrass sward (*Lolium perenne* cvs Merlinda, Morgana, Condessa) which received a spring dressing of 110 kg N ha^{-1} in the form of urea and during the experiment 2 additional dressings of 30 kg N ha^{-1}. The sward was grazed by dairy cows from 23 april untill the start of the experiment at a stocking density to attempt to maintain a sward height of 7 cm. The objective in using a daily rotational system was to prvide equal swards for all experimental animals. The objective was to evaluate the effects of the supplementaion treatments and not the interaction between treatment and the sward.

7.2.3. Measurements

During the last two weeks of the experiment milk yields were recorded daily on one day per week from a consecutive am and pm milking, samples were taken for the analysis of fat, protein and lactose contents (Biggs, 1979). Live weights were measured weekly and on the last day of the experiment following afternoon milking.

Individual grazed herbage and forage supplement intakes were estimated using the n-alkane technique during the last two weeks of the experiment. Animals were dosed twice daily after milking with paper pellets containing dotriacontane (C_{32}) impregnated into shredded paper. During the last 5 days of the 11 day dosing period faecal grab samples were taken from each animal after am and pm milking, but before forage supplementation. The samples were bulked up to a 5 day sample which was frozen at -20°C before analysis. During these 5 days, daily herbage and forage supplement samples were collected. Herbage samples were collected by hand plucking, to simulate grazing. Grazing animals were observed and samples

were collected by hand plucking in that same area. The individual samples were then frozen at -20°C awaiting analysis. The frozen samples for n-alkane analysis were freeze-dried and were analysed as described by Mayes *et al.* (1986), with the modification that the milled samples were treated directly with ethanolic KOH solution and a glass wide-bore capillary column (Supelco SPB1 30 m x 0.75 mm o.d.) was used for the gas chromatographic analysis. The proportion of forage supplement from the total forage intake was calculated using a minimisation routine as described in Chapter 4. An interactive routine (Microsoft Excel Solver) minimised the sum of squares of the discrepancy between the observed n-alkane faecal concentrations (expressed as a proportion of total alkane content and corrected for their recovered) and expected faecal n-alkane concentration (not corrected for recovery) calculated from the n-alkane content of the two forage components Total forage intakes were then estimated by calculating the C_{32} and C_{33} concentration in the diet of each animal using previously calculated silage: total forage ratios and using the formulae of Dove and Mayes (1991). The faecal recoveries of the different n-alkanes were those reported by Dillon (1993). These were validated in Chapter 3

Sward surface height (SSH) was recorded twice per week using a HFRO sward stick (Hill Farming Research Organisation, 1986) with 50 random grass heights being taken in a "W" pattern across each paddock. Herbage mass was estimated once a week during the last two weeks of the experiment by mowing 8 random strips of 1.5 x 0.33 m to a height of 3 cm using an Alpina Motor Scythe and collecting the cut material.

A herbage sample and forage supplement sample was collected weekly during the last two weeks of each experiment and frozen at -20°C awaiting analysis. Herbage samples were obtained by taking cuts to a height of approximately 3 cm, using shears, in grazed areas.

Food DM content was determined by oven drying at 100°C and organic matter (OM) by difference after ashing at 500°C. Herbage and silage digestibility (OMD) was determined by a modified version of the Tilley and Terry (1963) *in vitro* method (Alexander and McGowan, 1969). ME was then predicted from the equation

ME (MJ kg^{-1} DM) = (OMD (%) x 0.907 + 6.03) x (OM (g kg^{-1} DM)/1000) x 0.16.

Crude protein (CP) was determined by kjeldahl (N x 6.25).

Two 24 hour behaviour studies were carried out in weeks 4 and 5. Recordings were made of every animal on the experiment at 10 minute intervals during day light hours and at 15 minute intervals during darkness. Observations was aided during the night by a 6v torch. Cows were conditioned to the presence of an observer both day and night prior to the first observation. Recordings of grazing, ruminating, eating forage supplement, milking or other activities were made. Rate of biting at pasture was obtained from recording the time required to take a minimum of 40 bites, where there was no interruption in the biting action longer than 15 seconds. These measurements were taken at three occasions during the day (morning, afternoon and evening) for each animal on either the day before or on the day after the 24 hour behaviour observation. A total of 10 observations were carried out for each animal on each treatment.

7.2.4. Statistical analysis

The animal production data were corrected for covariate using the data collected in the week before the experiment. Changes in live weight were calculated for each animal by regression of live weight from week 3 to the last day of the experiment. The variables used for statistical analysis were the mean of the observations collected during the last two weeks except for the forage intake variable, were only one value per animal was estimated. The differences between treatments were examined using ANOVA with the statistical package Genstat 5 release 2.2 (Lawes Agricultural, Trust 1990) using the covariate (if available), allocation group as block and the forage supplement *x* stage of lactation as treatments using ANOVA resulting in 23 residual degrees of freedom. The substitution rate and response to forage supplementation were calculated within each allocation group of four and then analysed using ANOVA with allocation group as block and forage supplementation treatments x stage of lactation as treatments resulting in 23 residual degrees of freedom.

7.3.RESULTS

7.3.1.Sward surface height, herbage mass and chemical composition of feeds

Mean SSH was 10.0 cm while average herbage mass was 1066 kg DM ha^{-1}. The chemical composition of the feeds is presented in Table 45. As shown the herbage was of higher ME and CP content compared to the straw mixture while the forage supplements DM contents were near to their target values.

Table 45. Chemical analysis of feeds

	Herbage	Straw mixture
DM (g kg^{-1})	166	303/541/798*
CP (g kg DM^{-1})	198	103
OM (g kg DM^{-1})	908	902
OMD (g kg DM^{-1})	746	711
ME (MJ kg^{-1} DM)	11.6	10.3

* DM for mixture B30, B55, B80 respectively

7.3.2. Forage intake and diet composition

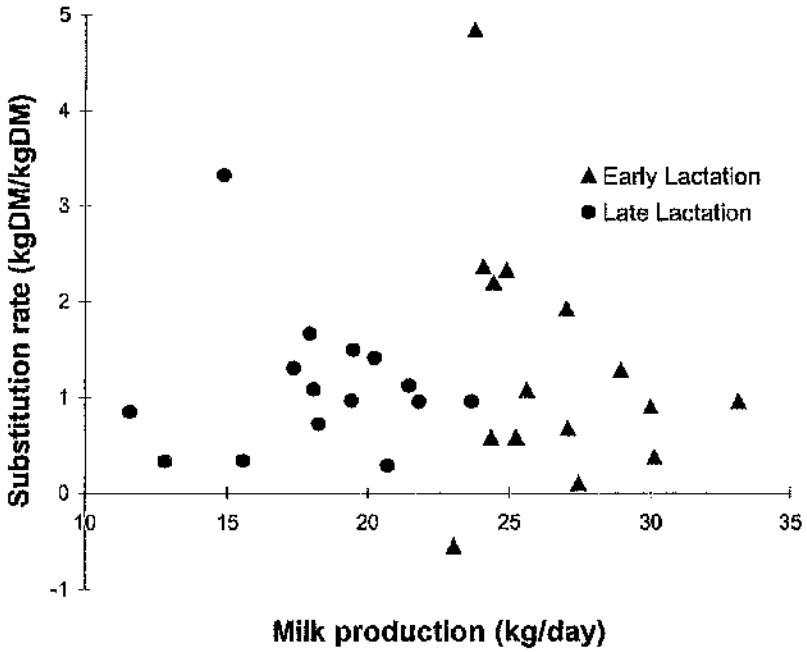
Table 46. Forage Intakes and Substitution Rates

		Buffer treatments					s.e.d.		
	Stage of lactation	C	B30	B55	B80	Mean	Forage supplement	Lactation	Interaction
Herbage Intake (g kg^{-1} DM)	E	15.5	9.3	10.5	10.4	11.4^{a}	0.884***	0.676*	1.276
	L	12.9	6.8	10.1	7.6	9.3^{b}			
	mean	14.2^{a}	8.0^{b}	10.3^{c}	9.0^{bc}				
Buffer Intake (g kg^{-1} DM)	E	0	4.0	5.0	5.8	3.7	0.679***	0.533	0.988
	L	0	5.0	4.3	5.1	3.6			
	mean	0^{a}	4.5^{b}	4.7^{b}	5.5^{b}				
Total forage Intake (g kg^{-1} DM)	E	15.5	13.3	15.7	16.2	15.1^{a}	1.15	0.67***	1.57
	L	12.9	11.8	14.4	12.7	12.9^{b}			
	mean	14.2	12.5	15.0	14.4				
Substitution rate	E	-	1.90	1.20	0.82	1.31	0.370	0.259	0.499
	L	-	1.51	0.74	1.10	1.10			
	mean	-	1.71	0.97	0.96				

* $p < 0.05$
***$p<0.001$

Herbage intake (Table 46) was significantly affected by forage supplement treatment ($P<0.001$) and stage of lactation ($P<0.05$). Although no significant difference existed between the forage supplements in terms of DM intake. Total forage DM intake was significantly different between early and late lactation cows ($P<0.001$), but was not affected by the different forage supplement treatments. The sed values in this experiment were high, although simular to the values obtained in the experiments reported in Chapter 5 and 6. Other statistaical methods (regression analysis) were used with this data set but did not result in a reduction in the variation. The resulting substitution rates (Table 46) which ranged from 1.90 to 0.74 in which substitution rate is "decrease in herbage intake divided by the forage supplement intake". However these differences were not significant.

Figure 20. Forage substitution in early and late lactation



In figure 20 the forage substitution rate for early and late lactation cows are presented in relation to their level of production. Regression lines where fitted but the resulting R2 were very low and therefore the regression lines were omitted from the graph since no relation existed between level of production and forage substitution rate.

The herbage and forage supplement intakes (Table 46) resulted in a diet composition as presented in Table 47. No significant differences due to stage of lactation were detected but forage supplementation treatment affected DM, CP, OMD and ME contents of the diet significantly (P<0.001). Treatment C resulted in the lowest DM content and highest CP, OMD and ME contents of the diet.

Table 47. Chemical Composition of the Consumed Diet

		Buffer treatments					s.e.d.		
	Stage of lactation	C	B30	B55	B80	Mean	Forage Supplement	Lactation	Interaction
DM (g kg^{-1})	E	166	221	225	231	208	9.46**	8.34	14.28
	L	166	236	217	250	217			
	mean	166^{a}	223^{bc}	221^{c}	241^{b}				
CP (g kg^{-1}DM)	E	198	169	168	165	175	3.5***	3.15	5.3
	L	198	159	169	159	172			
	mean	198^{a}	164^{b}	169^{b}	162^{b}				
OMD (g kg^{-1}DM)	E	745	735	735	733	737	1.2***	1.1	1.9
	L	745	731	735	732	736			
	mean	745^{a}	733^{bc}	735^{c}	732^{b}				
ME (MJ kg^{-1}DM)	E	11.6	11.2	11.2	11.1	11.3	0.05***	0.05	0.08
	L	11.6	11.0	11.2	11.0	11.2			
	mean	11.6^{a}	11.1^{b}	11.2^{b}	11.1^{b}				

** p < 0.01
***p<0.001

7.3.3.Animal behaviour and forage intake rate

The early lactation animals spent significantly (P<0.001) more time grazing compared to the late lactation animals (Table 48). Forage supplementation affected grazing time significantly (P<0.05) with a significant reduction in grazing time for the animals on the B80 treatment compared to the C and B30 treatment. No significant interactions between the forage supplement treatments and stage of lactation were detected. Rumination time was not significantly affected by the treatments. Forage supplement eating time was significantly affected by forage supplement treatment (P<0.001). Herbage intake rate was not affected by

stage of lactation but was significantly decreased ($P<0.01$) by forage supplementation. Forage supplement intake rate and grazing biting rate were not significantly affected by the treatments but herbage intake per bite was significantly ($P<0.001$) affected by forage supplementation treatment.

Table 48. Animal Behaviour and Forage Intake Rates

		Treatments					s.e.d.		
	Stage of lactation	C	B30	B55	B80	Mean	Forage supplement	Lactation	Interaction
Grazing time (min day^{-1})	E	479	458	422	417	444^{a}	25.1*	10.9***	32.6
	L	431	386	404	314	383^{b}			
	mean	455^{a}	422^{a}	413^{ab}	365^{b}				
Rumination time (min day^{-1})	E	473	510	509	479	492	22.5	15.7	31.7
	L	454	473	488	524	484			
	mean	463	491	498	501				
Supplement eating time (min day^{-1})	E	0	83	75	96	64	13.9***	11.1	20.3
	L	0	127	75	108	77			
	mean	0^{a}	105^{b}	75^{c}	102^{b}				
Grazed herbage intake rate (g DM min^{-1})	E	33.2	20.5	24.9	25.0	25.9	2.47***	1.44	3.35
	L	30.7	17.5	24.5	24.3	24.4			
	mean	31.9^{c}	19.0^{a}	24.9^{b}	24.6^{b}				
Forage supplement intake rate (g DM min^{-1})	E	-	48.5	67.3	60.9	58.9	8.43	3.75	10.43
	L	-	48.9	62.5	47.2	52.9			
	mean	-	48.7	64.9	54.1				
Grazing bite rate (bites min^{-1})	E	70.7	67.2	68.3	67.6	68.4	2.69	1.35	3.56
	L	67.6	65.8	67.1	62.5	65.8			
	mean	69.2	66.5	67.7	65.0				
Grazed herbage intake per bite (g bite^{-1})	E	0.47	0.30	0.37	0.37	0.38	0.039***	0.0021	0.052
	L	0.46	0.27	0.38	0.39	0.37			
	mean	0.46^{c}	0.28^{a}	0.37^{b}	0.38^{b}				

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$

7.3.4.Animal production and production response to forage supplementing

Milk yield was significantly different (P<0.001) between early and late lactation animals but no significant differences due to the forage supplement treatments could be detected (Table 49). Milk fat and lactose content were not significantly affected while milk protein content was significantly affected by stage of lactation (P<0.001). Fat yield was significantly (P<0.05) affected by the forage supplement treatments and stage of lactation (P<0.001). Protein yield was significantly higher in early lactation animals compared to late lactation animals (P<0.001).

The increase in fat and protein corrected milk (FPCM) was signficantly(P<0.01) affected by stage of lactation (Table 50). Forage supplementation resulted in a negative production response in late lactation cows and in a positive production response in early lactation. However, this response was not significantly different. The increase in FPCM per kg forage supplement consumed was significantly (P=<0.05) different between early and late lactation cows.

Table 49. Animal Production									
		Buffer treatments					s.e.d.		
	Stage of lactation	C	B30	B55	B80	Mean	Forage supplement	Lactation	Interaction
Milk yield (kg day^{-1})	E	24.3	25.1	27.1	27.8	26.0^{a}	1.23	0.58**	1.62
	L	18.1	18.3	17.5	18.7	18.2^{b}			
	mean	21.2	21.7	22.3	23.2				
Fat (g kg^{-1})	E	39.6	35.5	39.6	44.6	39.8	1.83	1.14	2.51
	L	41.4	39.6	40.0	40.8	40.4			
	mean	40.5	37.5	39.8	42.7				
Protein (g kg^{-1})	E	31.8	32.2	31.7	32.3	32.0^{a}	0.48	0.37**	0.70
	L	34.5	34.2	35.3	34.1	34.5^{b}			
	mean	33.1^{ab}	33.2^{b}	33.5^{a}	32.2^{b}				
Lactose (g kg^{-1})	E	45.5	46.6	46.4	46.5	46.3^{a}	0.54	0.22*	0.69
	L	44.7	45.1	44.8	45.0	44.9^{b}			
	mean	45.1	45.9	45.6	45.8				
Fat yield (kg day^{-1})	E	0.971	0.846	1.088	0.622	1.037^{a}	0.0588*	0.0188**	0.0739
	L	0.741	0.722	0.702	0.756	0.731^{b}			
	mean	0.856^{ab}	0.784^{a}	0.895^{ab}	1.000^{b}				
Protein yield (kg day^{-1})	E	0.761	0.805	0.876	0.889	0.830^{a}	0.0369	0.0240***	0.0513
	L	0.630	0.613	0.635	0.638	0.625^{b}			
	mean	0.696	0.709	0.750	0.755				
Liveweight (kg)	E	599	587	603	603	596^{a}	9.1	4.9**	12.5
	L	607	606	627	623	616^{b}			
	mean	603	597	615	613				
Liveweight gain (kg day^{-1})	E	0.93	0.20	0.78	1.07	0.75	0.369	0.264	0.524
	L	0.88	0.45	0.75	1.13	0.80			
	mean	0.91	0.33	0.77	1.10				

* $p < 0.05$
** $p < 0.01$
***$p<0.001$

Table 50. Production response to forage supplementation									
		Treatments					s.e.d.		
	Stage of lactation	C	B30	B55	B80	Mean	Forage supplement	Lactation	Interaction
FPCM † (kg day^{-1})	E	24.2	22.9	26.9	29.1	25.8^{a}	1.432	1.200***	2.125
	L	18.4	18.3	17.8	18.9	18.3^{b}			
	mean	21.3	20.6	22.4	24.0				
Increase in FPCM † (kg day^{-1})	E	-	1.22	3.43	5.37	3.34^{a}	1.285	1.258	1.817
	L	-	-0.48	-0.50	-0.45	-0.48^{b}			
	mean	-	0.37	1.46	2.46				
Response †† (kg day^{-1})	E	-	0.250	0.77	1.30	0.75	0.361	0.719	0.510
	L	-	-0.39	-0.30	0.12	-0.21			
	mean	-	-0.10	0.24	0.71				

FPCM = fat protein corrected milk = (0.337 + (0.116* fat %) + (0.06 * protein %) * my
***$p<0.001$
†† response = increase in fat and protein corrected milk per kg forage supplement consumed

7.3.5. Discussion and Conclusions

The mean SSH was 10 cm in this experiment which is within the range of optimum grass heights for continuously stocked swards, considered to be 8-10 cm (Hogdson, 1995). It could therefore be assumed that herbage availability was not limiting herbage intake. This is further supported by the fact that total forage intake was not significantly affected by the treatments although the water content of the grazed herbage was only 166 g kg^{-1} DM. Vérité and Journet (1970) reported that the critical DM intake of the grazed herbage was 180 g kg^{-1} DM with an estimated depression of 0.34 kg DM intake per 1% fall in herbage DM below this level. However, when water was added to the rumen of dairy cows *per fistula*, no detrimental effect on the intake of forages could be found (Thomas *et al.*, 1961) and therefore the effect of herbage DM depressing forage intake might be a palatability effect. This is supported by the work of Combellas *et al.* (1979) who reported reduced biting rates and intakes per bites when herbage dry matters were low. If palatability decreases herbage intake this should be equal to all animals in the experiment presented here. Forage supplementation increased the DM content of the diet eaten (Table 47) above the critical threshold of 180 g kg DM but this did not result in increased total forage intakes (Table 46). Two factors did affect herbage intake, stage of lactation and the forage supplement treatments but an interaction between the two could not be established (Table 48).

The s.e.d of total DM intake are high and could not be reduced using different statistical methods (e.g. regression analysis). In none of the in this thesis reported experiments sed's smaller than 0.8 were obtained. The reason for the high sed is that the experiments are of a continuous design and therefore, in the statistical analysis, the effect of individual cows can not be separated from treatment effects as would be the case in a change-over design. Experiments carried out, in the same time period, using a continuous design, at Crichton Royal Farm, but indoors, resulted in similar sed values (Hameleers *et al.*, 1995). A change over design would allow the reduction of the sed but this is not acceptable in grazing experiments since the grazed sward would change during the experimental period and it would be impossible to separate sward effects from treatment effects.

Forage supplement intake was not significantly affected by its DM content or the stage of lactation of the animal (Table 46). This has important practical implications since this means that dairy cows, regardless of the nutrient demands, will eat the same amount of forage supplement. The resulting substitution rates of grazed herbage for forage supplement were not significantly different. Actual individual substitution rates for grazing dairy cows receiving a forage supplement have not been reported before. Previous studies (Phillips and Leaver, 1985[ab]; Roberts, 1989) have reported substitution rates but these were based on ME - balance calculations, ignoring the potential effect of nutrient interactions between the different feeds and the various other sources of error associated with these calculations as discussed by Dove and Mayes (1991). This study suggests that substitution rates for grazed forage supplemented cows is independent of the level of milk production. Thomas (1987) discussed difference which exist in terms of substitution rate in early and late lactation cows when feeding concentrates. It seems clear that characteristics of the cow influence voluntary intake, however it appears that information on the animal factors which affect substitution rate is limited. In the case of forage supplementation, no difference does not seem to exist between early and late lactation dairy cows.

Grazing times were significantly shorter for late lactation cows compared to early lactation cows and this was related to forage supplementation (Table 48). Phillips and Leaver (1985 [b]) and Roberts (1989) reported reductions in grazing time when supplying forage supplements. In both these studies high DM content forage supplements were used. In the experiment presented here only supplementation with the highest DM forage (B80) significantly reduced grazing time. This was combined with a large increase in rumination time compared to the control treatment. Herbage intake rates were similar to those reported by Phillips and Leaver (1985 b), Roberts (1989) and Rook *et al.* (1994). Intake rate was significantly affected by forage supplementation. The control animals increased their intake rate but not their biting rate suggesting that the bite size must have been increased. Rook *et al.* (1994) when supplementing animals with concentrate did not find a decrease in bite size due to supplementation which is in contrast with the results presented here. Hodgson (1985) suggested that intake per bite is primarily a response to variation in the physical characteristics of the sward canopy. The animals on the experiment presented here were all grazing the same sward but were different in terms of supplementation. This tends to indicate

that intake per bite is not only affected by the physical characteristics of the sward canopy but also by the supplementation (forage supplementation in this case). Bite size was shown to be independent of stage of lactation in this experiment. No significant differences in terms of supplement intake rate could be detected (Table 48) although there was a large increase in intake rate from B30 to B55 and B80. Butris and Phillips (1987) added surface water to cut herbage fed to steers and this resulted in an overall reduction in herbage intake but not in herbage intake rate. In the case of forage supplementation the addition of water to the forage supplement did not affect supplement intake or total forage intake as shown in Table 48.

Animal performance (Table 49) was not affected by forage supplementation. The control animals were in this case able to compensate by consuming extra herbage. The only significant differences which did exist were due to stage of lactation. Although the differences in milk yield were large, ranging from 24.3 to 27.8 between the early lactation animals, the high s.e.d. value prevented significant differences to be established due to the different forage supplement treatments. The response to forage supplementation increased from B30 to B80. As shown forage supplementation early lactation cows can result in large responses in terms of milk yield and in order to achieve the largest responses, high DM forage supplements (DM>550 g kg^{-1})should be used. The responses reported are important since they were achieved in a situation when herbage intake was probably not limited by herbage height.

As shown the response to forage supplementation of late lactation animals was negative and tends to agree with the work of Phillips and Leaver (1985b) and Roberts (1989), when supplementing in spring using mainly mid and late lactation animals. Since the supplement intakes for early and late lactation animals are similar, a response of 0.75 kg FPCM can be expected per kg forage supplement consumed while in late lactation cows this value was -0.21 kg FPCM. It is therefore of importance for future forage supplementation experiments that only animals of equal stage of lactation should be used since their responses are so different.

It was shown that the DM content and stage of lactation did not affect forage supplement intake. Forage supplementation when the grass height was not limiting herbage intake did not result in increased herbage intake in either early or late lactation animals and the resulting substitution rates were dependent on total forage intake. Substitution decreased with increased total DM intakes.

The response to forage supplementation was different for early and late lactation dairy cows. Forage supplementation resulted in an increase in milk yield in early lactation and a decrease in milk yield in late lactation dairy cows. The response to forage supplementation was shown to be related to the level of production with the highest response in terms of FPCM for the animals with the highest level of production.

CHAPTER 8. GENERAL DISCUSSION AND CONCLUSIONS

8.1. EVALAUATION OF THE N-ALKANE TECHNIQUE

The objective of the series of experiments discussed in this thesis was firstly to evaluate the use of the n-alkane markers to measure herbage intake and forage supplement intake, and then to use the technique to evaluate forage supplementation strategies.

In the first study (Chapter 3) the use of n-alkanes was evaluated using a freshly cut ryegrass/white clover sward. The study shows that DM intakes can be estimated with high accuracy. The proportional discrepancy was 0.004 when using AM faecal samples , 0.002 when using PM faecal samples and 0.013 when using the combination of AM and PM samples. No effects were detected, in terms of level of intake, concentrate supplementation or the faecal sampling routine (am, pm). The limitation of the study, is that since the animals were housed, no problems occurred in terms of obtaining a representative sample of the herbage consumed. The animals consumed what was offered. In the grazing situation this not always the case as the animal are able to select for certain components of the sward (e.g. leaf). This could result in that the n-alkane patterns and concentrations of the herbage consumed are different from that of the herbage on offer. As shown by Laredo *et al.* (1991), the concentrations of the n-alkanes for different components (e.g. leaf and stem) are different.

In the experiment (Chapter 3) presented within this thesis, animals were fed 4 times a day, thereby reducing the potential for diurnal variation of n-alkane excretion. It is possible that under certain grazing management strategies (e.g. a one day paddock system), intakes occur in one or two large meals a day, which could result in larger diurnal variation in the excretion of n-alkanes. Pigden and Minson (1969) showed that the Cr_2O_2 concentrations in the faeces follows a cyclical pattern throughout the day, even when dosing twice daily. Dove (1991) reported diurnal variation in faecal n-alkane content when using sheep dosed once daily but, not when dosed twice daily. Dillon and Stakelum (1988) also reported significant diurnal variation in the faecal n-alkane concentration but found that the variation in the faecal ratios between pairs was not significantly affected by diurnal variation.

This demonstrates the potential advantage of using the n-alkane technique (using an internal marker) to other techniques (e.g. Cr_2O_2) as the intake estimate partly depends on the ratio between dosed and natural n-alkanes and therefore, the effect on the accuracy will be minimal.

A more recently available option to further reduce diurnal variation is the use of a controlled release device (CRD). Dove *et al.* (1991) evaluated the release rates and showed that these were constant. A constant release rate of artificial n-alkanes may reduce further the diurnal variation and, as a result further improve the accuracy of the DM intake estimate.

The clover proportion in the diet was predicted accurately using three different methods of calculation. However, in this experiment no range of clover proportions was evaluated. Others (Newman *et al* ,1995) have shown that if proportions of clover are very low, certain methods of calculating dietary proportions could give non-meaningful answers when using simple linear mathematics. Non negative least squares mathematical methods could potentially overcome this problem and should in the future be used to calculate dietary proportions of different forages in the diet. However, further investigation with a large range of grass/clover proportions is required to fully test the mathematical methods available. If very low levels of certain components are part of the diet, the accuracy of the chemical analysis may influence the results of the mathematical solutions.

Using the n-alkane recoveries reported by Dillon (1993) based on experiments using grass silage, allowed for accurate prediction of total DM intake. In the experiments (Chapter 3+4) presented here, a fresh forage was used consisting of two plant species. It could therefore be suggested that recovery of naturally occurring n-alkanes is independent of plant species as was suggested by Dove and Mayes (1996). When comparing the n-alkane-based intakes with intakes calculated on the basis of ME-requirements, large discrepancies occurred (Chapter 5, Table 34). However, no consistent over or under estimation of total DM intake was found in comparison to the n-alkane technique. The variation in calculated total DM intake, was greater when intake was estimated on the basis of the ME-requirement.

The use of n-alkanes to estimate forage supplement intake was shown to work well if the estimation was based on the naturally occurring n-alkanes (Chapter 4). Further more, if artificial alkanes were used in the calculation of forage supplement intake, the intake of the supplement was over estimated. This limits the use of the n-alkane technique for forage supplement intake to forage supplements which have sufficiently high concentrations of naturally occurring n-alkanes. In order to be able to use the n-alkane technique with more types of supplemental forages or feeds, improved techniques need to be developed to bind the artificial n-alkanes to these feeds.

On the basis of the literature review and experiments presented in this thesis, it can be concluded that herbage intake can be accurately estimated in grazing dairy cows as long as a representable sample of the herbage consumed can be collected. It was also shown that the n-alkane technique can be used to estimate supplementary forage intake as long as the forage supplement itself contains sufficient naturally occurring n-alkanes. A number of areas for future investigation were also identified and further experimentation is required in these areas, as presented in Paragraph 8.5.

8.2. SWARD CONDITIONS AND BUFFER FEEDING

In the literature review undertaken (Chapter 2), a number of sward factors have been identified which are important in determining the potential intake from a given sward. These factors are:

1) Digestibility of the herbage on offer
2) DM content of the sward
3) Sward density
4) Sward height
5) Herbage allowance

These factors will have an impact on the intake from the sward but also the intake of the supplement. Evaluating the literature for information on buffer feeding and, partial storage feeding, concluded was that few studies have evaluated buffer feeding while many evaluated partial storage feeding (Chapter 2).

Two main factors were identified as having an important influence on the intake and response to buffer feeding:

1) Sward surface height
2) Season

When SSH decreases, intake from the forage supplement increases. As the grazing season progresses intake from the forage supplement increases (Table 12).

In the case of concentrate supplementation, mathematical relationships exist to predict substitution rates for a given herbage allowance (Grainger and Mathews, 1989; Meijs and Hoekstra, 1984). For buffer feeding, these relationships do not exist. To date, no experiments have been carried out in which a range of herbage allowances were evaluated while buffer feeding. In addition, the buffer feeding experiments reported in the literature (Table 12+13) all used a continuos grazing system and, only report average herbage heights while not presenting the proportion of herbage rejected. It is therefore difficult to identify how much herbage was actually available for grazing and, which proportion was rejected.

The results from the experiment reported in Chapter 5, do suggest that buffer feeding can result in increased rejection of the sward. Cows which are buffer fed do reduce both biting rate and bite size which may be due to a reduced hunger drive. The latter suggesting that both bite size and biting rate are not only related to SSH as suggested by Stobbs (1974) and Rook *et al.* (1994*). The relationship of this to sward rejection is not clear from the literature and the experiments presented within this thesis. A second interesting perspective is to investigate how effective buffer feeding could be in a rotational paddock grazing system. The result of paddock grazing, is that animals, during certain period of the day, have a large amount of herbage available while at other times of the day, have small amounts of herbage available for grazing. The impact of buffer feeding could therefore be very different in a continuous grazing system compared to a rotational grazing system.

The experiments presented in this thesis used the buffer feeding strategy of allowing access to the forage supplement twice daily (After am and pm milking). In almost all previously experiments carried out, access to the forage supplement was once daily. Only Roberts (1989), used the strategy of access twice daily. Experimentation investigating the effect of

access strategy has to date not been carried out. If, as the results of the experiments in Chapter 6 and 7 suggest, supplement intake is determined by short term fill effects (the control mechanisms that control meal size), this could have important implications for forage supplement intake. On basis of this theory, supplement intake could be doubled by giving access twice daily, at a given sward height.

Table 51. Effect of sward height on forage supplement intake in grazing dairy cows

	SSH (cm)	Forage supplement intake (kg DM day^{-1})
Experiment Chapter 5		
Week 5	6.7	6.9
Week 11	14	3.5
Week 15	8.8	7.8
Experiment Chapter 6		
Experiment 1, LS	7.5	5.3
Experiment 1, HS	7.5	2.3
Experiment 2, HS	6.9	2.8
Experiment Chapter 7		
Treatment B30	10.0	4.5
Treatment B55	10.0	4.7
Treatment B80	10.0	5.5
Roberts (1989)		
Spring	7.5	3.0
Mid Summer	< 12.0	4.1
Late season/ autumn	< 12.0	3.9

In Table 51 the effect of sward height on forage supplement intake is shown from the experiments which used the strategy of supplementing twice daily. No clear relationship seems to exist between sward height and forage supplement intake. This suggest that using sward surface height as an indicator is not sufficient to predict forage supplement intake and, its potential impact on animal performance. Other factors such as animal or forage supplement characteristics affect the intake from the forage supplement.

The evaluation of the literature (Table 12+13), suggests that buffer feeding high productive cows, results in the lowest forage substation rates and highest milk yield responses. In the experiment presented in Chapter 7, no significant differences in substitution rate, between high and low productive dairy cows could be established. Significant differences were established, in terms of response to buffer feeding, in that high productive animals, increased

their production of milk as a result of buffer feeding. On the other hand in low productive animals, buffer feeding did not result in a production increase. The most important result from this experiment was that the low and high productive animal consumed equal amounts of forage supplement. This implies that the level of production does not affect forage supplement intake but does affect the response to supplementation. The implication of the latter is that when sufficient herbage is available, low productive animals should not be supplemented, as no response can be expected.

Peyraud *et al.* (1996[b]), showed that although a high herbage allowance is required to achieve maximum intakes per cow, herbage intake does not seem to be overly restricted as long as the herbage allowance is equal to 18 kg day^{-1} cow $^{-1}$ (herbage above 5 cm ground level). Herbage intake increased slowly (+0.04 kg DM day^{-1} per kg increase in herbage allowance) but decreased sharply for lower herbage allowances (-0.35 kg DM day^{-1}). Therefore it appears logical that buffer feeding should be initiated if herbage allowances fall below 18 kg day^{-1} cow $^{-1}$ and stopped if herbage allowances are available of more than 18 kg day^{-1} cow ^{1}. Starting and stopping buffer feeding does not appear to affect the response to buffer feeding and, can result in large savings in forage supplement use and increased grazed herbage utilisation as demonstrated in Chapter 5. However, as shown in Chapter 7, it is questionable if this will be economically viable when supplementing low productive cows, as the response, in terms of milk yield, was negative. It should be mentioned that the quality of the forage supplements was lower than that of the herbage on offer and therefore, buffer feeding resulted in a reduction of the ME content of the overall diet. Additional research should investigate the potential impact, in terms of production response to buffer feeding, when using supplements which are equal or higher in energy contents.

The evaluation of the literature (Table 12+13) indicates that buffer feeding in late season consistently results in a positive total DM intake response combined with a positive response in terms of milk yield with low (< 25kg day $^{-1}$) productive dairy cows. From the experiments presented in this thesis, only the experiment presented in Chapter 5 was partly carried out in late season. The animals on treatment B (continious forage supplementation) produced in week 15, 3.7 kg milk day^{-1} more than the animals on treatment A (intermitted

buffer feeding). A number of explanations could be brought forward to explain the effect of this consistent response to buffer feeding:

1. Decreased herbage quality
2. Increased water content of the herbage
3. Increased rejection and therefore reduced actual grazing heights

Herbage quality decreases during the season. This is mainly due to a change in the plants from a vegetative stage to a reproductive stage. This change from a vegetative to reproductive stage is associated with a change in the sward of less leaf and more stem (Hodgson, 1995). As shown in Figure 7, herbage digestibility can have an important effect on the intake potential of the sward. However, this does not explain why positive responses to buffer feeding can be expected when herbage digestibility is low. The only possible explanation could be that in all experiments reported in the literature, low quality forage supplements were used and therefore the difference between ME- content of the forage supplement and that of the grazed herbage was smaller in late season. Buffer feeding therefore resulted, to a lesser extent, in a reduction of the overall diet ME-content.

Vérité and Journet (1970) reported that the critical DM for grazed herbage was 180 g kg^{-1} with an estimated depression of 0.34 kg DM intake per 10 g kg^{-1} decrease in herbage DM. Herbage DM decreases during the season (Table 31; Chapter 5) and can reach values below the critical value of 180 g kg^{-1} . The buffer feeds used in the experiments reported on in the literature (Table 12), did contain high dry matters (hay and straw mixtures were used). Buffer feeding could therefore result in an overall increase of the total diet DM. In the experiment presented in Chapter 7, total diet DM was manipulated by offering forage supplements differing in DM- contents. However, in all cases, the resulting overall DM contents of the diet was above the critical value of 180 g kg^{-1} (Vérité and Journet ,1970). Although significant differences did occur in herbage intake, total DM intakes were not significantly affected and this occurred while the herbage DM was only 166 g kg^{-1}. This appears to suggest that herbage DM content is not an important factor in explaining why positive responses to buffer feeding can be expected in late season.

During the grazing season, the proportion of the sward which is rejected gradually increases to up to 43% of the grazing area (March and Campling, 1970). This could mean that the actual amount of herbage which the animal is willing to consume is limited. Although, herbage availability is high (above the critical value of 18 kg DM per animal; Peyraud *et al.* , 1996), the animal is prepared to consume only a limited amount. This could explain the observed responses to buffer feeding in late season.

8.3. CHARACTERISTICS OF THE FORAGE SUPPLEMENTS

In none of the experiments presented in the literature (Table 12 and 13) were different buffer feeds evaluated within the same experiment. The highest intakes tended to be obtained when using hays (Phillips and Leaver, 1985[a]). In, the experiment presented in chapter 6, two mixtures, differing in straw content and resulting ME content were evaluated. The results tend to indicate that short term fill effects (factors controlling meal size), determine the potential intake of the forage supplement. A large number of factors have been identified to control meal size (Forbes, 1995). Factors which could be involved in the case of forage supplementation are:

1. DM contents
2. Digestibility/degradability
3. Density
4. Fibre length.

In Chapter 7, it was shown that the DM content of the forage supplement will affect its intake. From the experiments presented in this thesis, two factors have been identified as determining the intake potential from the forage supplement:

1. ME- content
2. DM- content

The difficulty in evaluating the impact of these factors is that in the case of ME-content (Chapter 6), no control (no buffer feeding) treatment was employed. The impact of the DM content of the forage supplement,was evaluated in Chapter 7 and resulted in an increase in milk production with increasing DM content of the forage supplement. However these differences were not significant. There exists a need to investigate in the future different

buffer feeds within the same experiment, to evaluate potential impact on total herbage intake and responses to buffer feeding with these supplements.

8.4. BUFFER FEEDING STRATEGIES

As shown in the literature review, buffer feeding will result in increased total DM intake (Table 12) and increased animal performance (Table 13) even when buffer feeds are used with a ME-content lower than that of the herbage on offer. However relatively high substitution rates result compared to concentrates. On basis of the evaluation of the literature, substitution rates seem to be related to stage of lactation and herbage availability. The experiments presented in this thesis showed that, even if herbage availability is high (Chapter 7) , animals will still consume up to 5.8 kg DM day^{-1} of forage supplement. Forage supplement intake was shown to be independent of the energy requirement/ stage of lactation of the animal. Late lactation grazing dairy cows consumed equal amounts of forage supplement compared to early lactation animals. Forage supplement intake per day was shown (Chapter 6) to be related to the quality (ME-content or degradability) of the forage supplement. Short term fill factors seem to regulate forage supplement intake. In all the experiments carried out within this series of supplementation experiments, the ME-content of the supplement was lower than the herbage on offer. Since animals always consumed some forage supplement , forage supplementation resulted in net decrease of the ME- content of the diet.

Future experimentation should investigate the resulting effect if the ME content of the forage supplement was of equal or higher ME content compared to the herbage on offer. Total DM intake was shown to be related to stage of lactation of the cow (or level of production) but, was independent of forage supplementation, as long as herbage availability did allow the animal to compensate with additional herbage intake.

This work has resulted in three important conclusions. Forage supplement intake is independent of the energy requirements of the animal and therefore, if grazing animals can obtain their requirements from grazing only, these animals should not be offered a forage supplement. Secondly the quality of the forage regulates its potential intake as a forage supplement. It appears that short term intake factors are involved. Thirdly, it has been shown

that by relating access to the forage supplement to herbage availability, increased herbage utilisation can be obtained.

However, further work is required to develop a complete system of guidelines which is able to determine at which point herbage availability is limiting potential maximum total DM intake for a specific animal at a certain level of production , so the grassland manager than can decide to start offering a forage supplement. Additional work is required to determine potential forage supplement intake from a range of feeds but also access systems strategies, e.g. in this series of experiments access was twice a day but access for once a day or continuios in the field are other options in order to manipulate potential intake from a forage supplement. The work presented here does suggest that a start and stop system , with reference to access to the buffer feed, does not seem to affect animal performance but this requires further investigation.

Production responses to forage supplementation, ranged from –0.21 kg FPCM to +0.75 kg FPCM per kg DM of forage supplement consumed for early and late lactation animals respectively. Since forage supplements where used with a lower ME-content than the herbage on offer, the response of the late lactation animals in not surprising. However, the response of the early lactation animals is strange and more difficult to explain.

For the grassland manager to implement a buffer feeding strategy , he needs to evaluate a number of factors:

1. Quality of the herbage on offer
2. Amount of herbage available
3. The condition of the sward (rejection, density etc.)
4. The forage supplements available
5. Level of production of the animals to be supplemented

On basis of these factors, the grassland manager then can decide to commence or cease buffer feeding. If the quality of the herbage is low, results from the literature review suggest that a positive response to buffer feeding can be expected. If herbage available, corrected for rejected areas is below the critical values of 18 kg DM cow $^{-1}$ or below a SSH of 8cm, buffer feeding should be initiated to maintain or increase production. It should then be decided which supplement to use. If possible, the grassland manager should use supplements which have an ME-value are equal or higher than that of the herbage on offer to maximise the potential response. However, to date no experimentation exists in which dairy cows were supplemented with forage supplements with a ME contents were higher than of the grazed forage on offer. It has however been shown that when supplementing with buffer feeds with an ME-value below that of the herbage on offer, positive responses can be expected. The results from this thesis suggest that the highest response can be expected in high productive animals and these animals should be prioritised. However, when buffer feeding, care should be taken that buffer feeding does not result in excessive rejection as the results from this thesis suggest that buffer feeding can result in increased sward rejection.

The impact of buffer feeding on overall sward utilisation and performance of the grazed pasture will depend on the decisions of the person managing the system. A number of basic physical objectives can be achieved when buffer feeding grazing dairy cows:

1. Stocking density can be increased
2. The variability in forage supply can be overcome
3. The total nutrient intake of the grazing animal can improved

The results from the literate review and the work in this thesis presented experiments can form the basis to effectively implement buffer feeding strategies. However, the final factors driving a grassland based dairy system are economic and, regular economic evaluation will be required to develop economically sustainable buffer feeding strategies.

8.5. FUTURE RESEARCH

The review of the literature and the experiments presented in this thesis have resulted in the identification of a number of areas in which further research and evaluation is required or will prove beneficial:

With reference to the n-alkane technique

1) The impact of different meal patterns (especially extreme patterns which can occur in paddock grazing) on diurnal excretion of n-alkanes needs to be evaluated.
2) Different dosing techniques should be evaluated within the same experiment. A comparison between paper pellets, powdered cellulose in a gelatine capsule and the controlled release device, should be undertaken using different dosing strategies.
3) Methodology should be developed to bind accurately artificial n-alkanes to forage/food particles so they can be used as markers for the supplements
4) The n-alkane technique should be evaluated to measure both intake and proportion of grass and clover over a range of grass/clover proportions. Particulary the range of currently available mathematical techniques should be evaluated and the impact of error in the chemical analysis.
5) The possibility of dairy cows selecting within the sward for certain plant parts and its impact on the accuracy with which DM intake can be predicted should be evaluated.

With reference to buffer feeding:

1) Evaluation of the effect of access strategy to the forage supplement (twice daily, once daily, continuos access in the grazing area)
2) The potential impact of concentrate feeding when buffer feeding should be evaluated
3) The impact of the characteristics of the buffer feed should be evaluated (ME- content, degradability, fibre length, density etc.)
4) The relationship between animal production potential and the impact of buffer feeding
5) Relationships should be developed predicting substitution rates when buffer feeding for a range of sward heights or herbage allowances
6) The impact buffer feeding can have on persistency of lactation
7) The interactions which could exist between hunger drive, sward rejection and buffer feeding
8) The impact buffer feeding has on overall system efficiencies in terms of sward utilisation

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