SWARD STRUCTURE AND INTAKE OF RUMINANTS

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This thesis is dedicated to my wife, Miriam, and
to our children Rebecca, Thomas and Aleksis

ABSTRACT

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Advocates of mixed grazing have argued that grazing habits of different animal species tend to be complementary rather than exclusively competitive. However there were few objective data for variation in pasture intake and diet selection among species grazing the same pasture or on the extent of variation in diet selection between animals of differing age within a species on which to base this assumption.

In the three experiments in this study the objectives were to: compare species intake and diet selection in a range of sward structures; develop techniques that would enable grazing behaviour to be related to prevailing pasture conditions; test the hypothesis that the force required to sever individual bites may determine bite dimensions and resultant bite weight and intake rate, and differences in grazing strategy between animal species.

Diet selection and intake of calves, lambs and kids, simultaneously, but separately, grazing four pasture masses (3000, 3800, 4500 and 5400 kgDM/ha) on a temperate ryegrass white-clover sward, were compared in the first trial. A common pasture allowance for all species was calculated at twice the interspecies mean maintenance requirement (0.5 MJME/kg$^{0.75}$/d). Animal intake was estimated from faecal recovery using Cr_2O_3 as a marker corrected for diurnal variation. Diet composition and quality were measured in the extrusa (OE) obtained from oesophageal fistulae of four individuals of each species. A further four fistulated older goats and sheep were used to compare diet selection among animals of differing age within a species.

Mean species intake rates were 77.8, 60.0 and 48.7 gDOM/kg$^{0.75}$/d for calves, lambs and kids respectively. Lambs were the only species where intake was not affected by pasture mass (PM). All species consumed a diet of similar quality (organic matter digestibility), however botanical composition while similar at low pasture masses differed increasingly as pasture mass increased. Dietary overlap suggested the species were more competitive than complementary when grazing intensively managed pastures. Pasture and animal measures in this trial were too imprecise and/or infrequent to enable species grazing strategies to be characterized.

In the second experiment a technique involving short term grazing of pasture turfs cut from a ryegrass white clover pasture was developed to enable intake and bite variables to be related to sward structure. Two animals of each species progressively defoliated, in 4 grazing periods, 3 turfs of similar mass (4700 kgDM/ha) and composition. Intake rate (IR) of the sheep and goats was greater than that of the calves (124, 100 and 40 mgDOM/kgLW/min, respectively). Intake rate of sheep was insensitive to declining PM or pasture surface height. While goat bite weight declined with both PM and surface height it did not effect IR. Goats exhibited an aversion for older vegetative leaf and preferentially consumed young leaf while cattle preferentially consumed the second to oldest leaf. Bite depths of cattle and goats were similar and shallower than sheep (2.9 and 2.7 vs 4.0cm respectively). It was concluded that this technique, with further modifications, was suitable for identifying causal relationships between sward structure, intake and bite variables.

In the first trial of the final series of experiments pure perennial ryegrass turfs (surface area $0.1m^2$ x 0.1m soil depth) were manipulated by clipping to produce 3 pasture heights (5, 10 and 15cm) x 3 pasture structures (varying in leaf to pseudostem ratio and bulk density). Six sheep grazed 4 turfs of each height and density fixed to a force plate. Mean peak bite force, bite weight, bite depth, bite area, bite volume and grazed stratum bulk density were calculated.

Peak bite force increased with pasture surface height but significantly so only between 10 and 15cm. Pasture structure had no effect except on the 5cm pasture treatment with the highest grazed stratum bulk density. Bite depth and bite weight increased with pasture height and were not influenced by pasture structure at a constant height. Bite area was similar at all pasture heights, but decreased as grazed stratum bulk density increased. On short pastures (<10cm) proximity to the ground restricted bite depth and bite weight rather than peak bite force. Low bite weights per newton of peak bite force may constrain bite depth and weight rather than absolute peak bite force.

In a further trial the influence of sward and animal factors controlling intake rate were compared on three pasture species (ryegrass white clover, prairie grass and tall fescue) where peak bite forces were similar and not considered to be primarily involved in the control of intake rate. Four sheep grazed 4 turfs of each of the immature pasture species grown from seed in a glass house. IR on the white clover was 50% greater than on prairie grass and 46% greater than on tall fescue. Sheep did not compensate for the lower grazed stratum bulk density of the grasses (0.47, 0.56 vs 1.68 $mgDM/cm^3$ for prairie grass, tall fescue, and white clover respectively) by altering bite dimensions. Prehension rate appeared an important determinant of intake rate. In addition, dry matter content of the grazed stratum accounted for 56 and 29%, respectively, of the variation in intake rate of prairie grass and tall fescue.

Peak bite force and bite rate did not change when 150 mm ryegrass turfs were grazed a second time after all pasture above the mean BD at the first grazing had been removed. However BW (0.07 vs 0.11 gDM) and IR (4.8 vs 7.6 gDM/min) decreased in the second grazing through a reduction in bite area and bite depth. A compensatory increase in bite area (44%) occurred when a grid restricted the preferred bite depth of sheep to two thirds of a paired control turf. Such compensation maintained short term intake rate.

In the final experiment 150 mm turfs were grazed by goats and the peak bite force and intake variables compared with sheep. Peak bite force in goats was 22% of that of sheep. Goat BD was shallower than that of sheep although bite areas were similar. Goats were able to maintain a similar intake rate to goats by virtue of a greater bite rate (42.9 vs 24.6 bites/25s in goats and sheep respectively).

<u>Keywords:</u> age, bite dimensions, bite weight, bite area, bite depth, bite volume, calves, clover, complementarity, goats, grazing, grazing behaviour, grazing strategy, intake, intake rate, kid, lamb, pasture, peak bite force, sheep, selection.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF PLATES

Chapter 1

Introduction

Grasslands currently cover over a third of the world's land surface and provide the sole nutrient supply to a diverse group of herbivores. In New Zealand pasture grazed *in situ* or conserved pasture is the major feed source for the ruminant animal industry. Growth of temperate pastures is distinctly seasonal and as a consequence animal demand is adjusted to match supply by manipulating timing of physiological status and by pasture rationing. In intensive temperate grazing systems, animals are fed to appetite for very short periods. For the majority of the year they are subject to varying degrees of feed restriction to conserve feed for more critical periods of the production cycle and to improve per hectare output and overall profitability through increased pasture utilization. Such manipulation relies on an ability to accurately predict intake and dietary composition when pastures are being rationed, a very difficult if not an impossible task at present.

Sward structural characteristics have a major influence on intake as even minor changes in structure in a homogenous pasture can alter intake four fold (Hodgson 1982a). When pasture is being defoliated, daily intake is the summation of structure-induced change in ingestive behaviour. Although many studies have been conducted to investigate the influence of the spatial distribution of above-ground plant components (eg pasture mass/hectare) on ingestive behaviour and intake there is considerable variation and conflict (Hodgson 1977). Change in pasture structure is usually correlated with change in plant nutritive value which has also made interpretation of research difficult. Pastures are heterogeneous by nature so it is most likely that simple gross descriptions such as mass or height will have limitations in the prediction of intake.

The foraging strategy (motive behind and method of feed consumption, where motive does not imply conscious thought but a goal described by evolutionary fitness in physiological and ecological terms) defines the way in which each animal species selects its food. However the plant parts actually selected depend on an array of plant and animal factors largely determined by what is on offer and the animal's requirement for nutrients. Therefore for each agriculturally important animal species the pattern and sensitivity of behavioural and intake responses to sward structure and composition must be described. Only then can pasture management systems be designed to optimize animal productivity. Plant breeding and selection priorities for pasture destined for grazing may also be enhanced by such information.

Experiments in this thesis describe how structural components of the sward influence intake and attempt to isolate a possible underlying mechanism. Diet composition and intake of kids, lambs, calves and rising one year sheep and goats were compared on similar pastures at each of four pasture masses (experiment 1, chapter 3). Each animal species grazed separately. In the remaining experiments ingestive behaviour and short term rate of intake were measured in animals confined to graze homogenous swards of carefully defined structure. Techniques were developed to measure short-term rate of intake and bite dimensions in calves, sheep and kids offered boxed turfs indoors (experiment 2, chapter 4). The force or forces required by sheep to sever individual bites was measured for the first time and related to bite dimensions and sward structure, in an attempt to identify an underlying ingestive mechanism influencing pasture intake (experiment 3, chapter 5).

Chapter 2

The influence of sward structure on intake

A review

Temperate pastures are a heterogeneous mix of plant species and components which vary in chemical composition and proportions of leaf, stem, seed head and dead and senescing material with stage of maturity, season and many other factors. A wide range of animal, pasture and environmental factors determine the amounts of such pasture consumed by grazing ruminants (figure 2.1) This review of literature will concentrate only on pasture and animal factors determining daily intake where accessibility or difficulties associated with acquisition constrain intake (figure 2.2).

Intake regulation in the absence of such constraints (*ad libitum* intake) is only briefly discussed. Special attention has been focused on canopy structure and composition of temperate pastures and their influence on bite dimensions, pasture components consumed and grazing intake of sheep, cattle and where possible goats. Finally a possible mechanism determining bite dimensions is discussed.

2.1 Control of pasture intake in ruminants

Control of grazing intake in ruminants can be pictured as a balance between the drive for energy and specific nutrients (feeding drive stimuli) and the ease of acquisition of feed, both being sensitive to metabolic, physical and behavioural inhibitory stimuli (Hodgson, 1986). Animal factors determining the demand for nutrients are discussed later in this review (section 2.4). While there have been obvious advantages in expressing nutrient demand in terms of a single unit, energy, since it is the most frequently limiting nutrient, it must not be assumed that the balance of nutrients especially amino acids and trace elements are not important.

Physical regulation of intake reflects the capacity to move feed through the gastro-intestinal tract and is governed by the level of rumen fill, and the rate of disappearance of digesta by digestion and passage. This was demonstrated elegantly by Chacon and Stobbs (1976), who showed that cattle were able to fully compensate for the removal of rumen contents. On temperate pastures, rumen fill has been shown to limit intakes of grass but not legume, in lambs (Cruickshank, 1986).

Metabolic regulation of intake is important where energy is readily acquired relative to requirement (Forbes, 1988). Intake is manipulated in accordance with the balance and efficiency of utilization of absorbed nutrients (Black, 1990). Protein quality and/or quantity (Poppi, 1990), secondary compounds such as tannins and mycotoxins (Barry and Blaney, 1987) and intestinal parasites (Sykes, 1987) may inhibit intake by metabolic pathways.

Figure 2.1 Factors influencing pasture intake in grazing animals

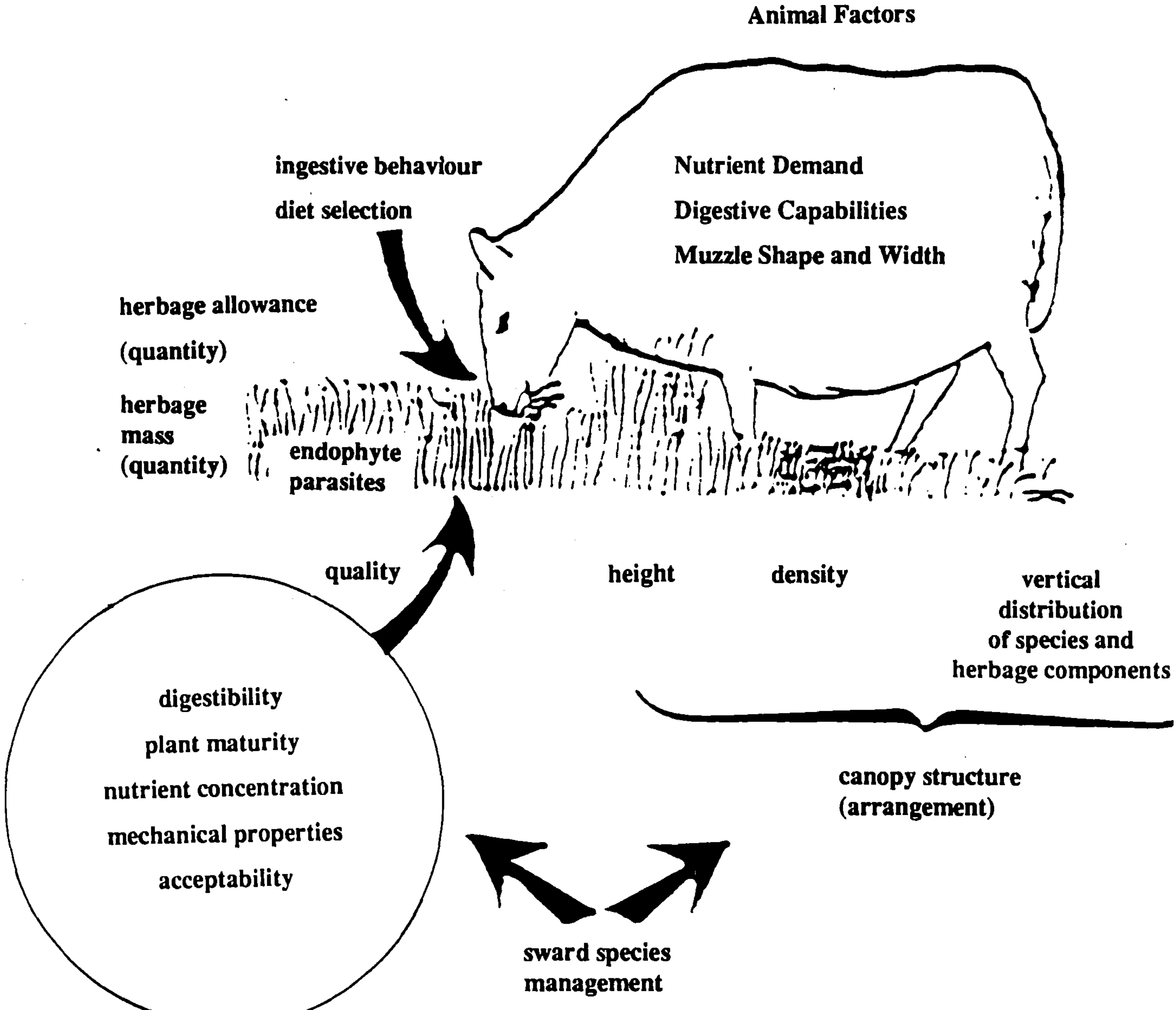
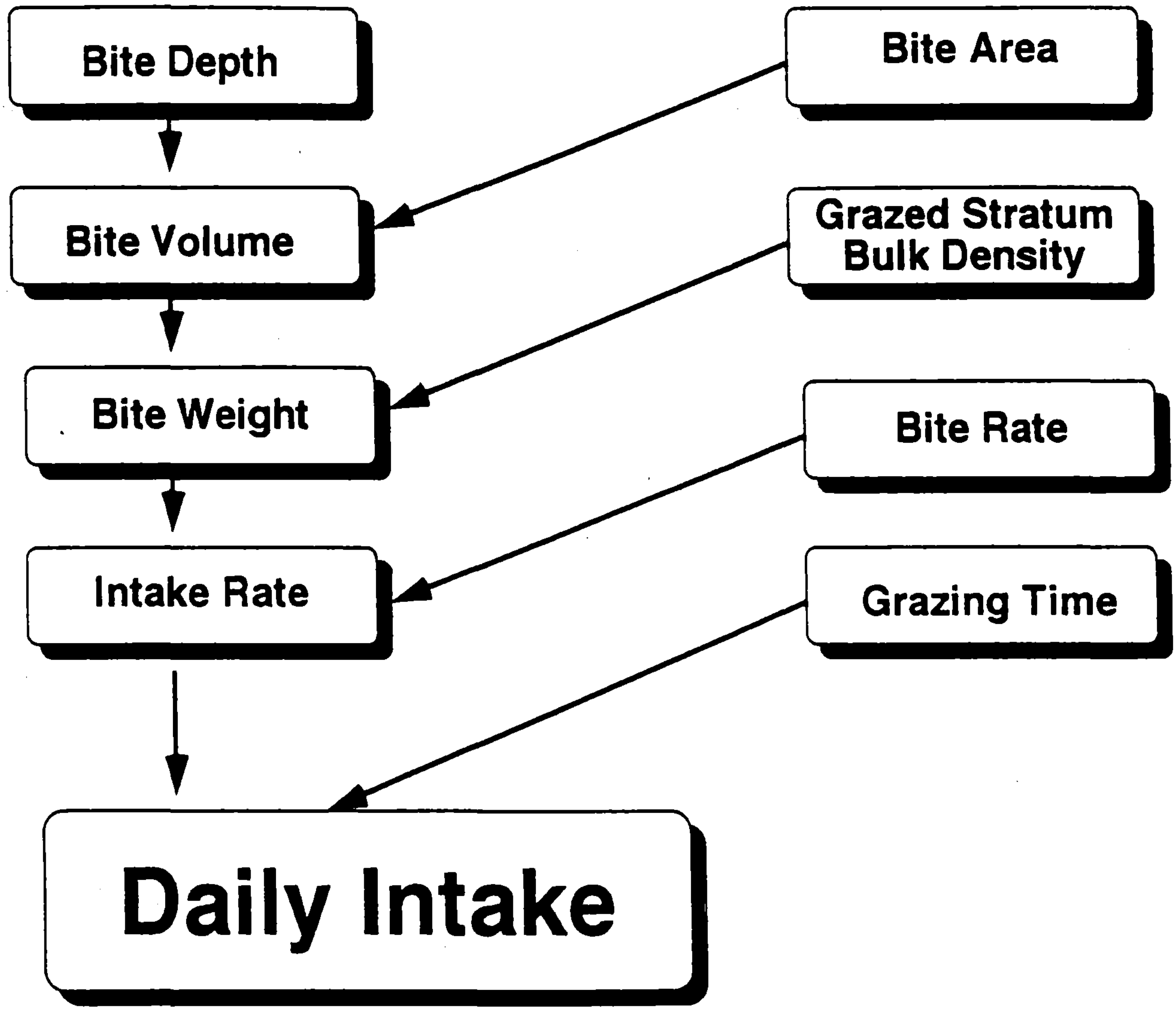


Figure 2.2 The components of daily pasture intake



Behavioural regulation of intake reflects the animals' desire to maintain short term rate of intake where accessibility and ease of acquisition of preferred pasture components is progressively reflected in its response in increasing grazing time if intake rate declines. There is no evidence that either physical and/or metabolic mechanisms are necessarily involved in intake regulation where pasture conditions are constraining acquisition and accessibility to preferred components (Weston and Poppi, 1987).

This review therefore concentrates on herbage acquisition constraints to intake. Pasture and animal components influencing intake of grazing animals have been presented hierarchically in figure 2.2. In the remainder of this review the relative importance of individual components are discussed. Gross pasture characteristics and their influence on intake are discussed initially to highlight the limitations of such measures both when predicting intake and understanding the mechanisms of intake control.

2.2 Gross pasture characteristics and intake

Pastures have been described in terms of mass per unit land area (the product of height and density) and composition (plant species or components within a species) (Thomas, 1980). The intake response to increasing pasture supply is usually curvilinear irrespective of whether supply is expressed as pasture mass per hectare (PM, the above ground dry weight of pasture per hectare, kgDM/ha), allowance (dry weight of pasture allocated per animal, or unit of animal liveweight, each day) or pasture height (above ground height of the undisturbed pasture) (Hodgson, 1977; Poppi *et al.*, 1987; Penning, 1986; figure 2.3 and 2.4). In the ascending portion of the curve where acquisition constraints prevail, intake is determined by the animals grazing strategy as modified by pasture structure (Allden and Whittaker, 1970). In the plateau region of the relationship, nutritional properties of the sward which determine physical and metabolic constraints prevail. Published estimates of the critical pasture mass below which constraints to acquisition largely determine intake vary more than four fold (Hodgson, 1977) even when only those data from trials where animals were maintained on static PM for long periods (weeks rather than days) are considered. Much of this variation was probably attributable to differences between the pastures in scope for selection. Some researchers have found no relationship between PM and intake (Wheeler *et al.*, 1963; Meijs, 1981; Havstad *et al.*, 1983), but their trials usually involved few if any treatments likely to impose acquisition constraints on the grazing animal and were therefore biased to the plateau region of the pasture allocation intake relationship.

Measurements of herbage intake and grazing behaviour have generally been related to the mean characteristics of the whole sward (Allden and Whittaker, 1970; Jamieson and Hodgson, 1979a,b). In many circumstances it is more likely that the animal reacts to conditions at the surface (Stobbs, 1975a) or within the pasture canopy (L'Huillier *et al.*,1986). Techniques which enable the sward to be vertically stratified and described (Milne *et al.*, 1982; Hodgson, 1982b) have highlighted this. In general gross sward descriptions are unable to reflect the heterogeneity of pasture components especially those confined to the grazed strata, which influence intake (for example, pseudostem height; Barthram, 1981).

2.2.1 Summary

Empirical relationships between gross sward characteristics and intake, while of great practical value to grassland farmers, have been of limited value in understanding how swards of differing canopy structure and

Figure 2.3 The relationship of pasture intake to various pasture characteristics and methods of pasture allocation

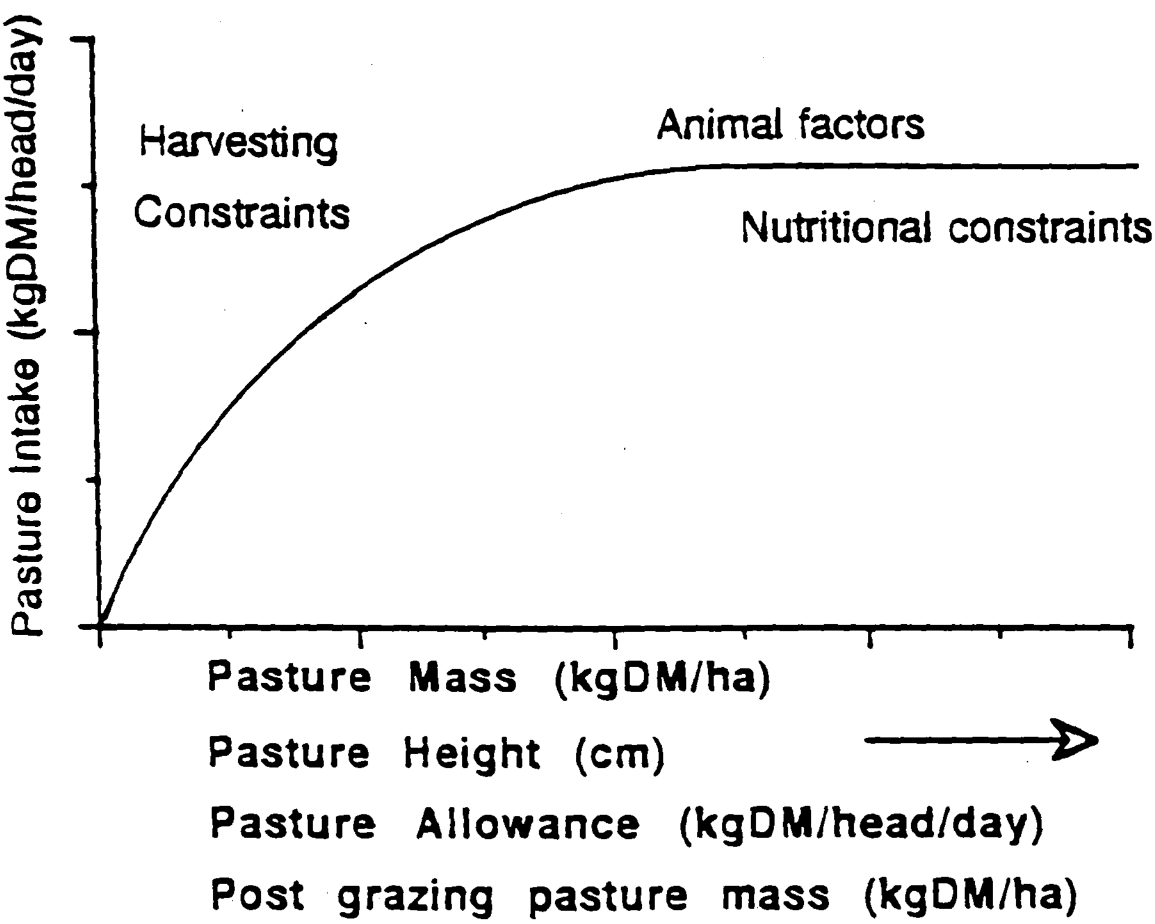
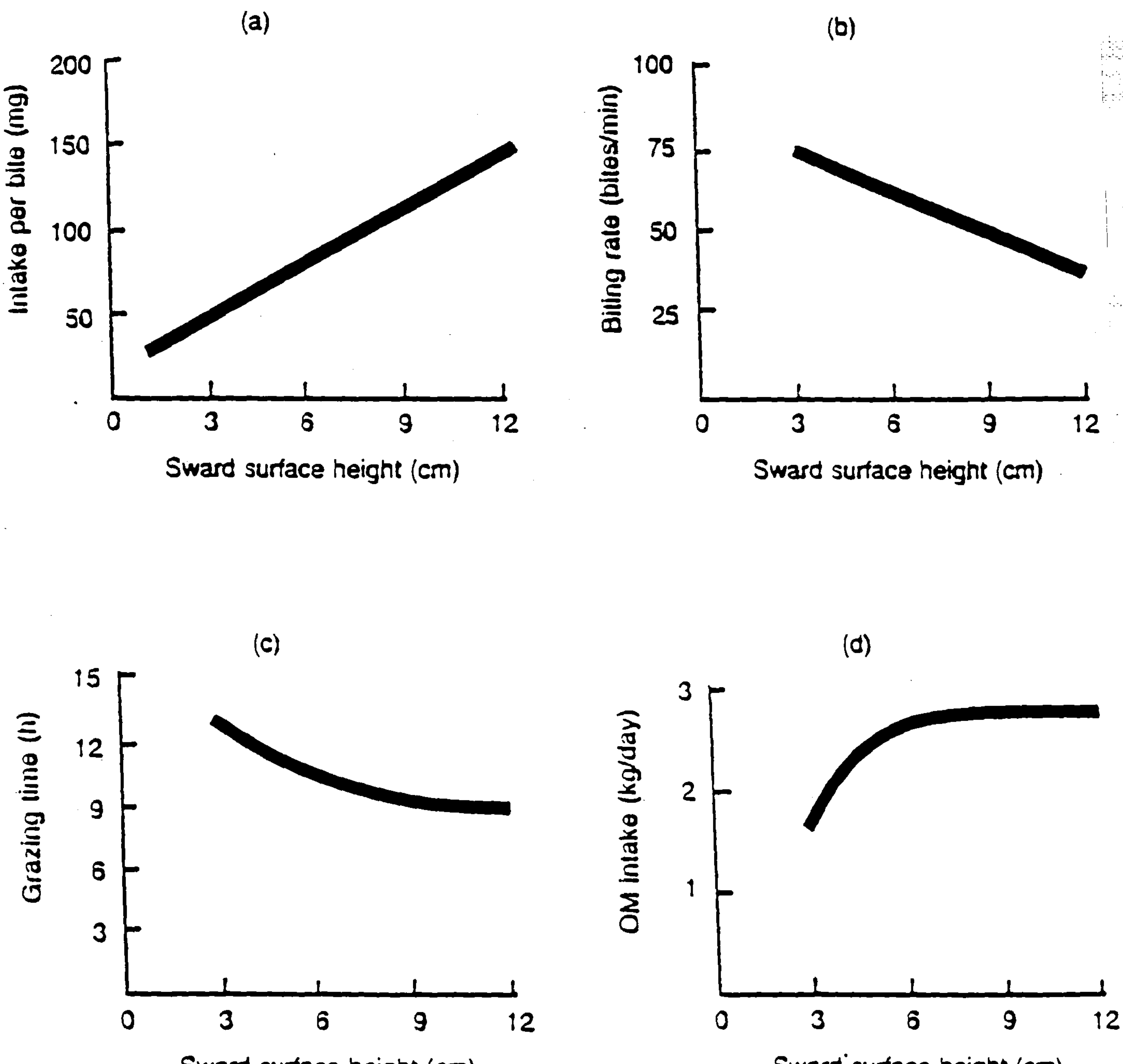


Figure 2.4 The influence of pasture height on the components of ingestive behaviour (from Penning, 1986)



composition are likely to influence diet selection and intake (Hodgson, 1977). Most pasture characteristics are inseparably correlated (for example PM = height * density) which makes it very difficult to distinguish the causative from merely correlated variables. Where swards are being grazed down (rotational grazing) they are in a dynamic state where variations in intake are difficult to attribute to pasture characteristics because height and density, as well as nutritive value undergo change. Many of the relationships between sward variables and intake have therefore been derived under steady state conditions (continuous grazing eg Hodgson, 1982b), or short term grazing of carefully manipulated or artificial swards (Black and Kenney, 1984; Burlison and Hodgson, 1985).

To improve intake predictions, pasture allocation is often assessed in terms of that which is green or alive only (Rattray and Clark, 1984). Even so, considerable variation exists in pasture intake of similar animals at equivalent allowances of green dry matter, due to differences in structural presentation, ease of harvest (ease with which plant components can be accessed and severed) and nutritive value of pasture components (Rattray and Clark, 1984). Black and Kenney (1984) found the pasture mass within the area of a bite was a better predictor of the intake response than the mean PM of the entire pasture where pastures were composed entirely of vegetative leaf. In addition, even on pure pasture species, a similar PM at a chosen bite site can be the product of a vast array of height and density combinations. Thus PM is too gross a measure to have general applicability. More progress is possible if those components of plant structure and composition influencing grazing behaviour and intake could be isolated and their mechanism of action understood.

2.3 Pasture characteristics and ingestive behaviour

Grazing behaviour represents the final compromise among the animals grazing strategy (Hofmann and Stewart, 1972), nutrient demand and prevailing pasture characteristics. Grazing strategy as discussed in section 2.4.2.1, is determined genetically through the evolutionary adaptation of an animal species' harvesting and digestion apparatus and methodology of grazing.

Grazing fatigue was proposed as a major cause of low intake and growth of beef cattle by Johnstone-Wallace and Kennedy(1944) due to the additional effort and time required for grazing as PM declined. Shortly afterwards, Hancock (1952), introduced a mechanistic view of ingestive behaviour where pasture intake was the product of the mean bite weight, rate of biting and grazing time in an attempt to explain the performance of dairy cattle grazing structurally different pastures.

Thus: Daily pasture intake = bite weight * rate of bite * grazing time ; rate of intake = bite weight * rate of bite ; total daily bites = rate of bite * grazing time

While the components of ingestive behaviour are expressed as means, they are in fact continuous variables reflecting the dynamic nature of pasture characteristics. Allden and Whittaker (1970) used the mechanistic view of grazing behaviour to establish the relative sensitivity and response pattern of sheep to pasture structure. Since then many aspects of ingestive behaviour have been comprehensively reviewed (eg Stobbs, 1975a; Arnold, 1981; Hodgson, 1977,1982a,1985,1986).

2.3.1 Grazing time

Grazing time is an important determinant of daily intake provided intake is not limited by the potential to use nutrients, rumen digesta load and the removal of digesta from the rumen by passage and digestion (figure 2.2). Pasture intake may be limited by time available for eating and ruminating when pasture conditions are constraining intake rate (IR the weight of fresh but usually dry matter consumed per minute eg gDM/min). Weston and Poppi (1987) expressed intake rate in terms of foraging rate (time spent foraging per unit feed intake). Constraints to herbage acquisition were highlighted by contrasting the foraging rate of sheep (Allden and Whittaker, 1970) of 2.5 h/kgDM versus 6.7 h/kgDM when grazing pastures of 7 - 35 cm and 3.5 cm respectively. Expressing intake rate data in terms of foraging rate immediately identifies large potential differences in the grazing time required to achieve similar daily intake. From a study of ingestive behaviour of grazing dairy cattle Phillips and Leaver (1985) related grazing time (GT) to bite weight (BW) where:

$$GT = 652 - 313*BW \ (r^2 = 0.98; RSD = \pm 46.5)$$

BW was measured in g DM. For the range of bite weights in the study (0.63 to 0.22 g DM) GT only increased by 128min/24h and BR by 7.8 bites/min yet intake declined from 16.3 kg DM/d to 8.3 kgDM/d. Such data highlight the importance of BW in determining daily intake and the relatively small compensatory increases in GT and BR.

Whether the grazing animal can effectively allocate sufficient time to grazing when foraging constraints exist will depend on time required for other essential activities, such as water acquisition, rumination, resting, social interaction, mutual grooming, predator avoidance, mating and the need to nurture. In addition it is unlikely that the grazing animal will continue to graze for any appreciable time where the energy expended is greater than the net energy consumed. In the interests of energy conservation the best strategy would be to stop grazing and minimize other activities which consume energy. The extent to which the grazing animal can manipulate the time required for these activities will depend on specific animal and pasture circumstances which determine nutrient demand and acquisition constraints to intake.

The energetic costs of grazing have been well documented (eg Osuji, 1974). In a more recent study (Adam *et al.*, 1984), it was argued that the energy cost of eating was more a function of the time spent eating than the amount of food ingested. Energy costs per minute spent eating were similar irrespective of the intake rate or the DM content of the feed (table 2.1). Cattle had a lower energy cost of eating, (expressed as J/kg liveweight) than sheep (33.0 ± 6.4 vs 40.7 ± 8.0) but when published estimates are summarized however the values for simulated grazing, (39.0 (range 31.3 - 57.2 ;Holmes *et al.*, 1978) vs 37.7 (range 20.5 - 68.6; Graham, 1964)) for cattle and sheep, respectively, were similar. Energy expended (J/kg liveweight) per g of DM ingested was considerably less for the cattle than sheep (3.4 vs 25.1). However such values are very dependent on the rate of intake and therefore the relative sensitivity of the cattle and sheep to pasture conditions constraining intake.

Feeds with low intake rate due to either problems of harvesting or mastication would, in such a scenario, incur high energy costs of ingestion per kgDM because of the extended harvesting times required. Prediction of the nutrient supply from the ingested material would depend on whether acquisition constraints, or physical and/or chemical properties of the available pasture were restricting intake. For example turnips with both a low DM content and IR (gDM/min) incurred a high cost of ingestion (1428 J/kg LW kgDM), per unit drymatter (table 2.1) yet have a high nutritive value, a situation very akin possibly to temperate spring pasture.

Table 2.1 The influence of drymatter content and intake rate on the energy cost of ingestion of five diets by cattle (from Adam *et al.*, 1984).

Food type	Dry matter content (gDM/kg)	Rate of ingestion Fresh (g/min)	Dry (gDM/min)	Energy cost of ingestion per kg live weight (J/min) spent eating	(J/kgDM) ingested
Concentrate pellets	871	149.3a	129.7a	27.6	237a
Lucerne pellets	903	149.9a	137.9a	28.9	218a
Lucerne hay, long	846	42.8b	36.8b	35.6	1029b
Dried grass, chopped	894	39.1b	38.8b	27.6	776b
Turnips chopped	136	196.2a	29.8b	34.7	1428c
s.e. of means		15	10.1	3.5	114

Subscripts that differ within columns indicate means that are significantly different ($p<0.05$)

If the energy costs of grazing pasture are indeed related to time spent grazing, then it should be possible in the future to develop and test models based on energy balances which predict grazing times from a knowledge of the decline in IR and other activities associated with grazing where acquisition constraints apply, such as time spent seeking grazing sites and standing. It is almost certain that the degree to which desired nutrient requirements of the animal in a particular physiological state have been satisfied will also influence the drive to graze and therefore grazing time (Arnold, 1981).

There is recent evidence that DM content of pastures may influence IR (gDM/min) and thus affect grazing time. Ingestion constraints rather than rumen capacity restricted the intake of sheep offered cut pasture of increasing DM content (12 to 25% DM)(John and Ulyatt, 1987). While fresh forage intake rate did not change markedly as DM content of the grass increased, the intake rate of DM increased linearly. If energy expenditure per minute spent grazing is relatively constant for animals of a given liveweight, these results suggest that intake of low DM pasture may be restricted by time available to graze, and that time constraints within the day and/or the energy cost of DM consumption may provide the control mechanism. There are as yet inadequate data to test such a hypothesis.

Grazing time (GT) except in extreme circumstances shows limited response to variation in pasture characteristics with most domesticated species grazing 8 - 10h/day (Arnold, 1981). Pasture conditions which influence the rate at which pasture is defoliated influence GT. On continuously grazed pastures where changes in pasture characteristic constraining intake are normally slow (occur over weeks rather than days) GT initially increased as BW declined (Bircham, 1981), however such compensatory change was limited and the decline in GT rapidly mirrored that in BW. Where pastures were strip-grazed (Jamieson and Hodgson, 1979a) or progressively grazed down (Chacon and Stobbs, 1976) both rate of intake and grazing time declined simultaneously. Animal response to changing pasture conditions in terms of GT or rate of biting was often so small that changes in daily intake reflected closely the pattern of response of BW (Bircham, 1981; Penning, 1986; Hodgson, 1986). Diurnal patterns of grazing activity and grazing times are similar for cattle and sheep grazing together a range of temperate pastures (Forbes, 1982).

2.3.1.1 Summary

Grazing time is generally negatively related to PM or pasture height (eg Forbes, 1982; Allden and Whittaker, 1970; Penning, 1986; figure 2.4). Grazing time though shows little evidence of sufficient variation to maintain intake. Other characteristics of ingestive behaviour are therefore more important in determining intake.

2.3.2 Bite weight

Bite weight may be mechanistically defined by bite area and depth, which determine the bite volume and the density of plant material in the grazed stratum, provided the animal grazes down from the pasture surface. Bite depth is defined as the difference between the pre-grazing pasture surface height and the mean height of severed plant units after one bite at the chosen bite site. Bite area is the horizontal area encompassed by a bite and bite volume the product of bite depth and area.

Neither bite area (BA) nor bite volume (BV) are necessarily confined by the anatomical dimensions of the animals mouth. Bite area is the surface area of the undisturbed pasture gathered to form a bite, which may not be closely related to that area defined by the animal's incisor breadth and width of mouth when opened. Grazing animals are able to gather pasture into the bite catchment by head, lip and tongue manipulation. In much the same way BV does not represent the volume of the buccal cavity region but the volume in the undisturbed pasture from which the bite was taken.

Bite weight (BW) is the major determinant of intake in that the grazing animal is unable to compensate fully for pasture induced reductions in selection opportunity, as indicated by declining BW, by increasing bite rate (BR) or the time spent grazing (GT) (Arnold and Dudzinski, 1969; Allden and Whittaker, 1970; Chacon and Stobbs, 1976; Forbes, 1982; see figure 2.4 a, b and c from Penning, 1986). On temperate pastures the normal range in bite weight is approximately 11-400 mg OM (0.4-2.6 mg OM kg LW^{-1}) for sheep and 70-1610 mg OM (0.3-4.1 mg OM kg LW^{-1})for cattle (Hodgson, 1986). No values were found in the literature for goats. Bite weight can either be calculated by dividing the weight of dried oesophageal extrusa (OE) by the number of ingestive bites for short term grazing periods, or daily intake by total prehending bites. The relative merits of each technique were discussed in detail by Hodgson (1982b).

Animal size is an important determinant of BW (Clutton-Brock and Harvey, 1983). On a liveweight basis there was no difference in BW between cattle and sheep either grazing a pasture down or for continuous grazing (Forbes and Hodgson, 1985). However as pastures became shorter the small animal's bite depth was relatively less restricted. On very short pastures the only bite dimension that is unrestricted is the biting width formed by the incisors; consequently BW is proportional to incisor width, which scales as body $\text{weight}^{0.36}$ for ruminants (Illius and Gordon, 1987).

On temperate pastures there is a positive and largely linear relationship between BW and pasture height or PM (eg Arnold and Dudzinski, 1969; Allden and Whittaker, 1970; Chacon and Stobbs, 1976; Forbes, 1982; Penning, 1986; figure 1a).

In contrast to temperate pastures the majority of research on tropical pastures has found density (pasture weight per unit volume of pasture canopy) rather than height to be the major determinant of BW (Stobbs, 1973a and b, 1975b; Chacon and Stobbs, 1976; Hendricksen and Minson, 1980; Ludlow *et al.*, 1982). This apparent conflict highlighted the need to develop research techniques where the independent effects of height and density could be studied (Black and Kenney, 1984; Burlison and Hodgson, 1985).

Real differences between temperate and tropical pastures in pasture-intake relationships could be anticipated as the latter generally have a lower bulk density and higher stem content (Dirven, 1977; Mott, 1983) which is also structurally stronger at the same stage of maturity, as measured by the amount of energy required required for breakdown by mechanical grinding (Weston and Poppi, 1987). As yet the relationship between comminution energy values, bite weight and intake rate has been inadequately defined, however Weston (1985) found, for a narrow range of diets, that the time taken to consume unit weight of herbage was directly related to its comminution energy. BW appears therefore dependent on the bulk density of plant components severed within the bite volume.

2.3.2 Bite dimensions and their influence on bite weight

Bite dimensions (bite volume, bite area and bite depth, figure 2.2) have a major influence on BW. Understanding how these dimensions are influenced by pasture characteristics may enable IR to be predicted with greater precision from suitable gross pasture descriptors.

Black and Kenney (1984) and Burlinson and Hodgson (1985) were the first researchers to assess the independent effects of height and density on BW and bite dimensions of sheep, the former with hand constructed artificial pastures and the latter with a range of manipulated sown swards of grass and oats (Table 2.2). By way of comparison some recently published values for cattle using techniques developed from the trials reported in this thesis have also been included.

BW in sheep was positively related to both height and density when these variables were uncorrelated (table 2.2). Surface height and grazed stratum bulk density had an independent but additive influence on BW. In earlier studies, where height and density were correlated, many researchers (Allden and Whittaker, 1970; Forbes, 1982; Penning, 1986) found positive relationships between pasture surface height and BW. Research from the tropics reported no relationship with height but a positive relationship with mean grazed stratum bulk density. Interpretation of these latter studies is made difficult by changes in nutritive value of the pasture on offer during the experiments.

Fasting cattle prior to grazing did not effect bite weight, but increased prehending bite rate and, as a consequence, intake rate (Greenwood and Demment, 1988). Mastication bites were reduced which suggests that, for short periods at least, bite type is able to be adjusted to effect a faster intake rate and that the animals normally ingest at a rate below the maximum.

Table 2.2 Comparison of bite dimensions and bite weight for sheep and cattle

Bite variable	Range of values	Relationship with Surface height	Relationship with Grazed stratum bulk density	Reference
Sheep :				
Bite depth (cm)	1.5 - 20.6	+	NS	Burlison (1987)
	9 - 16	NE	-	Black and Kenney (1984)
Bite area (cm^2)	9.0 - 35.5	+	NS	Burlison (1987)
	8.6 - 33.0	NE	-	Black and Kenney (1984)
Bite volume (cm^3)	20 - 428	+	NS	Burlison (1987)
	11 - 471	+	-	Black and Kenney (1984)
Bite weight (mg DM)	42 - 326	+	+	Burlison (1988)
	10 - 200	+	+	Black and Kenney (1984)
	25 - 420	+	NE	Hodgson (1986
Cattle :				
Bite depth (cm)	5.9 - 6.8	NS	NS	Elliott (1988)
	5.0 - 15.0	+	+	Mursan *et al.*,(1988)
Bite area (cm^2)	37 - 48	NS	NS	Elliott (1988)
	44 - 48	NS	NE	Mursan *et al.*,(1988)
Bite volume (cm^3)	244 - 287	NS	NS	Elliott (1988)
	110 - 380	+	-	Mursan *et al.*,(1988)
Bite weight (mg DM kg LW^{-1})	2.0 - 2.7	NS	NS	Elliott (1988)
	1.5 - 2.5	+	NE	Mursan *et al.*,(1988)

+ positive, - negative, NS non-significant,NE not examined

2.3.3.1 Bite depth

While BW response to changing sward structure has been widely recorded it is only in recent years that bite depth has been measured (Milne *et al.*, 1982; Forbes, 1982; Burlison and Hodgson, 1985). All found bite depth was positively related to surface height, and even though pasture conditions varied greatly between trials, the slope of the height term in the regression equations ranged only from 0.33 to 0.42. Bite depth of sheep decreased as density was increased at the same pasture height (Black and Kenney,1984) by using artifical ryegrass pastures. There is a suggestion that bite depth maybe controlled by factors other than the sward as bite depth was 9.0 cm on artificial ryegrass pasture (18 cm surface height mean sward bulk density 4.23 mgDM cm^{-3}) but only 4.6 cm on a ryegrass cage sward which was both taller and less dense (22.1 cm, grazed stratum bulk density 0.46 mgDM cm^{-3}) and should have encouraged deep bites (Burlison, 1987).

No comparison of bite depths for cattle, sheep and goats grazing identical pasture at an equal allocation were found in the literature. In the only comparison between sheep and cattle for a restricted range of pasture heights, BD was similar but more variable for sheep (Forbes and Hodgson, 1985). Anecdotal evidence to date suggests that both cattle and goats are surface grazers while sheep prefer to graze the denser intermediate pasture horizons. Sward factors controlling bite depth will be discussed in detail later in this review.

2.3.3.2 Bite area

Burlison and Hodgson (1985) were the first to measure bite area although Black and Kenney (1984) attempted to do so on a limited number of artificial pastures where the sheep had grazed them almost to the base. Bite area was positively related to pasture height which suggests the sheep were able to increase the bite catchment by some form of scooping or compressing motion rather than vertical plucking. The animals' ability to harvest short pasture has been modelled and discussed in detail by Illius and Gordon (1987).

2.3.3.3 Bite volume

BV is the product of the mean bite depth and bite area. While both Burlison and Hodgson (1985) and Black and Kenney (1984) found BV was positively related to surface height the latter authors suggested that it decreased as grazed stratum bulk density increased (table 2.2). Although the range of sward heights and density in the two papers were similar Burlison could find no relationship between BV and density.

2.3.3.4 Rate of biting and total grazing bites

Most confusion relating to bite rate and pasture conditions concerns the type of bite recorded. As discussed earlier grazing involves prehending and mastication bites. While pasture harvesting is dependent on prehending bites, intake rate is also dependent on the mastication process which permits the harvested material to be swallowed. There is a suggestion from the recent literature that the total number of prehending and mastication bites per minute is relatively constant for sheep and possibly for cattle (Chambers *et al.*, 1981; Penning, 1986). On relatively tall swards which impose no acquisition constraints reciprocal changes in prehending bite rate and BW may balance to maintain a relatively constant rate of intake. However, on short swards which impose acquisition constraints on the grazing animal, increases in bite rate are inadequate to compensate for the decline in BW, and rate of intake declines (Hodgson, 1986). In a recent paper, total jaw movements for grazing sheep were constant (149 jaw movements/min) throughout the grazing season (spring to autumn) irrespective of pasture height (30 - 120mm) (Penning *et al.*, 1991). As BW increased in this study at pasture heights above 6cm, a greater number of jaw movements were required to masticate and position the pasture prior to swallowing and thus rate of prehending bites fell while IR remained unchanged. Such data emphasize the importance of measuring total grazing bites and not just prehending bites which has been the accepted presentation format to date (Hodgson, 1986). Recommendations for measuring rate of biting are discussed in detail by Hodgson (1982b).

In a recent review Hodgson (1986), argued that prehending bite rates on sown temperate pastures were similar for sheep and cattle (22-94 and 20-96 bites min^{-1} respectively). Such data are impossible to interpret as associated total jaw movements, intake rates, animal and pasture conditions were inadequately described for any of the cited trials. As an example BR can be low because the animal is carefully consuming preferred pasture components in a heterogeneous pasture mix or because large bite weights require high numbers of mastication bites prior to swallowing. Where pasture acquisition constraints are indicated by a decline in intake rate, changes in bite rate appear to be sward induced rather than an animal response to decreasing BW in an attempt to maintain intake (Hodgson, 1986). Both sheep and cattle respond to decreasing PM or height by increasing the rate of biting and at the same time decreasing the ratio of mastication (or adjustment) to prehending bites.

2.3.3.5 Summary

Where intake of pasture is not controlled by metabolic and/or physical mechanisms and acquisition constraints prevail intake rate can be restricted by:

1) accessibility of pasture components within the potential bite catchment
2) constraints imposed on BW by either prehension and/or mastication

3) Insufficient change in BR or GT.

Properties of pasture components which may constrain IR are now discussed.

2.3.4 Structural strength of accessible plant material and intake control.

To maintain grazing momentum it is conceivable that an upper limit has evolved for force that an animal species exerts in prehension (peak bite force). Such a mechanism would minimize grazing fatigue from the exertion of variable bite forces and maintain a grazing rhythm. A consistent rate of jaw movement/minute of grazing time (harvesting plus mastication bites), has been observed when sheep graze temperate pastures (Penning, 1986). Maintenance of a grazing rhythm could depend on a close relationship between those properties of the pasture determining tensile and shear strength which would determine the ratio of prehending to mastication bites. Bite dimensions of the grazing animal would in turn depend on the tensile strength of the pasture components within the horizon being grazed so that bite force was maintained below the upper limit. Weight and tensile strength of preferred plant material would therefore determine bite size except on sparse pastures where plants are not clumped (Black and Kenney, 1984).

2.3.4.1 The influence of tensile and shear strength of pasture components on intake rate.

2.3.4.1.1 Prehension

The concept of peak bite force determining bite dimensions, and as a consequence, BW involves predominantly tensile rather than shear forces. Shear forces are also critically important in determining intake rate in that they could be expected to influence the proportion of jaw movements spent on mastication and therefore prehension bite rate, BR. If shear forces predominate in prehension then evolution has served large grazing ruminants badly as scissor-like matching incisors, as found in horses and rabbits, or mandibles in insects, would appear more effective with the ability to apply two directional compared with undirectional shear forces. In addition the extensive subsequent movement consistent with tensile breaking is not required.

The biomechanical properties of grass leaf make it well suited to severing by tensile force alone (Vincent, 1982; 1983).

Teeth may function as an edge over which to crease or bend leaves and thus reduce the force required for tensile fracture, (Bignall, 1984). In much the same way a sheet of paper is more easily ripped over a sharp edge than a rounded one. Rumination may maintain the sharp outer edge on the incisor provided these teeth are still erupting, by wear against the dental pad. If teeth are involved in prehension by shear fracture they would be more effective if they rested on the dental pad rather than marginally forward of it.

When pasture grazing was mimiced using skulls from freshly killed sheep with the outer skin removed the point of pasture grip was behind the teeth, between the upper and lower dental pad (Hughes unpublished), which again suggests teeth are present predominantly as a sharp edge to reduce the force required for tensile fracture. Biomechanically grass is notch insensitive, that is a notch in a grass leaf does not concentrate stress which reduces the effort for fracture as for example in a pane of glass (Vincent, 1983). The primary function of teeth would appear to be an edge over which to break pasture rather than any cutting process. In summary ruminant animals without interacting incisors, fracture pasture components by both tensile and shear force.

2.3.4.1.2. Mastication

Prehension can not be viewed in isolation from mastication if rate of biting is to be maintained. Conceivably grazing will involve the blend of fresh BW and BR that produces the optimal intake rate within limits imposed by pasture conditions and the biological limits of the animals ingestion mechanisms. Where preferred plant material is readily accessible and has low tensile strength (eg white clover pastures or low DM temperate spring pasture) BW may be determined by the amount of fresh material the mastication mechanism can handle. Post prehension the extent of chewing (mastication bites) prior to swallowing would depend on shear force properties of the ingested plant material, the size of ingested plant components and whether swallowing involves discrete boli or is a continuous process. Therefore it is not surprising that animal performance and intake has been related to both shear (Hendricksen and Minson, 1980) and tensile strength (Evans, 1967) of grass lamina. Greater resistance of plant components to fracture (either shear or tensile) was associated with longer grazing times in both studies. Ryegrass selected for low leaf-shear strength was consumed at a faster rate than the non selected control although rumen degradation rates were similar (MacKinnon *et al.*, 1988).

2.3.4.2 Support for the concept that intake rate is controlled by shear and tensile strength of pasture components.

For simplification and precision grazing animals may control intake by monitoring IR rather than BW (Kenney and Black, 1984; Black and Kenney, 1984). Optimal foraging as a concept (Malechek and Balph, 1987), assumes that an animal chooses grazing sites according to potential intake rate. The summit bite force and buccal cavity capacity/mastication hypotheses could explain the reduction in bite area with increasing bulk density of leaf (Burlison and Hodgson, 1985; Black and Kenney, 1984) as greater numbers of plant units would need to be severed per unit of area and/or the resultant fresh bite mass may increase the need for mastication and therefore constrain the ratio of prehension to mastication bites.

Pasture height or access to preferred plant components may limit the potential bite catchment to such an extent that force is not a factor (Illius and Gordon, 1987) because of the limited plant material within a bite catchment. Alternatively greater structural strength of pasture components in the base of the sward (stem and pseudostem) may constrain BW to ensure peak bite force is below the summit value. The reduction in bite area with declining pasture height (Burlison, 1987) supports the contention that grazing animals have progressively greater difficulty gathering plant material into the bite catchment. It is therefore unlikely that summit bite forces are restricting intake where pasture structure or composition is constraining IR.

A summit force hypothesis predicts large differences in intake rate among grasses and legumes according to the fracture strength of plant components within the potential bite catchment. Evidence is unfortunately sparse and inconclusive. Maximum IR of subterranean clover was three times greater than ryegrass where height, density and pasture mass were varied to obtain the respective optima (Kenney and Black, 1985). It is unlikely that the higher IR of the legume was related solely to prehension as processing prior to swallowing would also be reduced by the lower fibre content. Larger bite sizes were expected because of the higher concentration of leaf in the surface horizon than the grass.

2.3.4.3 Summary

Animal intake and performance has been related to both shear and tensile strength of plant components. While both tensile and shear strength appear to be involved in prehension only shear forces have been implicated in mastication. Fracture strength of pasture components may ultimately determine intake by determining bite dimensions and the ratio of prehending to mastication bites per minute. On short pasture the ability to gather and grip plant components rather than summit force may restrict intake. Mastication rate may determine intake of pasture of high density and low structural strength.

2.4 Animal factors influencing intake and diet selection

Increased physiological drive for intake - caused by high growth potential in young animals, pregnancy, lactation, poor body condition, loss of external insulation (eg shearing) - increases grazing time and rate of intake (Arnold, 1981). Intake generally decreases in late pregnancy, with increasing body condition score and in clinical disease states.

Ingestive behavioural responses of sheep and cattle to similar pasture structures differ. Under changing sward conditions the pattern of lambs and calves was similar, although lambs appeared the more sensitive as their bite rate increased more rapidly as pasture height and mass declined (Jamieson and Hodgson 1979b). Bite rate and GT of mature sheep also increased prior to those of mature cattle as pasture mass declined (Forbes and Hodgson, 1985). While Arosteguy (1982) found that sheep were better able to maintain intake on short swards than cattle, Collins and Nicol (1986) found cattle better able to maintain intake as PM declined than were sheep or goats. Goats were the most sensitive of the three species to declining PM. In many such studies it is difficult to determine whether differences recorded in species sensitivity to changing pasture conditions are real, or merely reflect inequitable pasture allocation.

When challenged by changing pasture conditions younger animals appear to be more capable of maintaining intake than their older contemporaries. Allden and Whittaker (1970) found that while yearling sheep had higher intake rates than lambs on tall pastures, on short pastures the order was reversed. Care is required in extrapolations of these data as GT was not measured. On a per kilogram liveweight basis intake increased with stage of maturity in grazing cattle (Zoby and Holmes, 1983). However, small cattle have been observed to have greater GTs and bite rates but smaller BW's yet were able to modify grazing behaviour more effectively than older cattle to maintain intake as PM fell (Zoby and Holmes, 1983). Young cattle may be less sensitive to declining sward conditions by virtue of a larger incisor breadth per kilogram liveweight (Illius and Gordon, 1987), or may be driven by a comparatively greater demand for energy. Hodgson and Jamieson (1981) found no difference in BW and intake kg^{-1} of liveweight between strip-fed calves and cows. However the calves had a longer GT and lower bite rates.

Ingestive behaviour appears responsive to previous experience of particular pasture conditions. Calves experienced to grazing had greater intakes than their less experienced younger contemporaries (Hodgson and Jamieson, 1981). Sheep accustomed to low PM had higher intakes, GT and rate of intake when compared to unaccustomed sheep (Curll and Davidson, 1983).

2.4.1 Summary

While young animals have a higher potential for growth it is unclear to what extent this influences intake rate and diet selection. Young animals appear to be able to buffer the decline in intake as pastures progressively constrain acquisition by increasing GT and BR, which may be a response to the comparatively greater demand for energy. Influence of age within a species on diet selection is conflicting. Conflicting results in the literature preclude development of a hypothesis concerning the relative sensitivity of cattle and sheep to declining pasture mass. To what extent the conflict in such data is determined by unequal opportunity and allocation of pasture needs addressing. The extent that such variable data derived from grass dominant diets can be applied to mixed grass legume pastures (which arguably provide greater opportunity for selection) is unknown.

2.4.2 Pasture components selected

The grazing ruminant uses sight, touch on the lips and in the mouth, taste and smell in diet selection (Arnold, 1981; Black, 1990). Sense of smell may be used when selecting the grazing site and that of taste to continue sampling from a site. According to Arnold (1981), the animals physiological state (whether pregnant, lactating or dry) does not appear to affect its dietary preferences and the effects of breed and age also appear small. Zoby and Holmes (1983) found the faeces from younger cattle had lower faecal ash and cellulose content than older cattle grazing the same pastures, which suggested that younger cattle grazed more selectively. In contrast Hodgson and Jamieson (1981), found no evidence of dietary discrimination, as assessed by digestibility and diet composition, between adult cattle and weaned calves. To what extent any relationship between age and diet composition is influenced by pasture acquisition constraints on pastures other than predominantly ryegrass is unknown.

Grazing involves the selection of grazing site and then a bite within a site (Hodgson, 1986). Grazing animals select pasture components given the opportunity (eg Arnold, 1981). Opportunity is crucial - reflecting pasture canopy composition and structure often termed accessibility. Selection is a function of preference modified by opportunity (Hodgson, 1979). Preference refers to the discrimination between areas of a pasture, or pasture components, and ideally is measured by relative intake given free choice (eg Kenney and Black, 1984). Although many reports describe the diet selected by animals in different environments, most provide inadequate descriptions of the animal, grazing sites and canopy structure to understand why particular plant components were selected.

Accessibility and ease of harvest under particular pasture conditions will vary among grazing animals relative to their grazing strategy and potential bite dimensions (Grant *et al.*, 1985). Accessibility remains a nebulous concept rather than an objective measure and like relative preference (measured by relative IR with free choice), it has an instantaneous time scale of a harvesting bite. In vegetative pasture, accessibility may be defined by the pasture mass within the catchment area of a bite (Black and Kenney, 1984). But such a definition does not consider the pasture determinants of bite depth which may determine whether components at various levels in the canopy are available for consumption. Moreover the determinants of bite area need further definition before such a measure can be used. Sheep were unable to discriminate between young vegetative leaf and senescing material when it was closer than 20 mm on artificially constructed pastures (Black *et al.*, 1989). Intake rate of young grass declined as the number of young grass tillers to senescing tillers in a group declined. While the young tillers were potentially within an animal's bite area they were not readily accessible because of their close proximity to senescing material against which the animal strongly discriminates.

Sheep do appear to graze unselectively in the surface horizons of vegetative ryegrass white clover pastures (Milne *et al.*, 1982), yet will graze leaf in the base when the surface horizons are predominantly dead material (L'Huillier *et al.*, 1986). However even when the diet is compared to the horizon in the sward being grazed (Milne *et al.*, 1982) there may be evidence of deliberate selection. Animals may graze at particular sites and positions within a site, in an attempt to optimize rate of intake (Kenney *et al.*, 1984). Sheep showed distinct preference for those chopped forage components they could ingest most rapidly, except where sensory factors, such as smell and taste modified potential intake rates (Colebrook *et al.*, 1985). Sensory factors were considered more likely to influence preference where potential intake rates were high, while differences in intake rate had the strongest influence where potential intake rates were low.

Both shear and tensile strength of ryegrass leaf decreased between leaf base and tip (Evans, 1967; John *et al.*, 1989). These data suggest that the physical and chemical composition of pasture components which determine shear and tensile strength of leaves may be correlated. It is difficult to imagine that the grazing ruminant has all the necessary mechanisms to make instantaneous decisions on which pasture components to consume based on nutritive value especially without regular sampling. Animal productivity was inversely related to tensile strength of leaf for a range of grass varieties (Evans, 1967), however such differences may be related as much to nutritive value as differences in intake. Preference is to a large extent determined by relative intake rates (Kenney and Black, 1984) which may be related to ease of acquisition. Sheep have shown preference for cut grass of higher DM content when offered the same material at a range of dry matters (Black *et al.*, 1987). Further studies are required to identify the relationship between water content of standing pasture, preference and intake rate of both fresh and dry matter.

Interpretation of diet selection data between animal species assumes a knowledge of the species' grazing strategy, relative preference for plant components and accessibility of pasture components relative to mouth dimensions. In many instances where cattle and sheep select for or against the same components in a sward it cannot be assumed that the two species have the same dietary preferences (Grant *et al.*, 1985). Cattle are considered to graze less selectively than sheep (Arnold, 1981) and their diet may contain a higher proportion of dead or senescing pasture. Such variation may stem from differences in the anatomy of the mouth parts and the process of grazing. Forbes and Hodgson (1985) found that sheep, when grazed with cattle on the same pastures, had a more selective grazing strategy and maintained a relatively constant nutrient concentration in the diet throughout the year. In contrast, cattle attempted to maximise their rate of intake rather than maintain a constant nutrient concentration.

Prediction of dietary composition from pasture composition and relative preference rankings has been thoroughly explored but as yet shows little consistency (Skiles, 1984). Such a lack of consistency is perhaps not surprising as preference ranking may be continuously changing as a result of :-

(1) IR (Black, 1990), and therefore all the pasture and animal factors which may influence this.
(2) Plant defences, physical or chemical, to regular or intensive grazings (Malechek and Balph, 1987)
(3) The changing proportion of the component in the pasture (eg white clover, Clark and Harris, 1985)
(4) Level of satiety (Jung and Koong, 1985).
(5) Pasture components consumed not being replaced at the same rate by similar material in the same pasture strata.

2.4.2.1 Species grazing strategies

A species grazing strategy defines the way its food is selected and considers the motive behind and method of feed consumption (grazing behaviour) rather than the result (intake). Motivation does not imply conscious thought but rather a genetically determined goal, described in physiological and ecological terms. Physiological and behavioural differences in feeding characteristics among species have arisen through evolutionary pressure resulting in a specific strategy for a particular niche within an ecosystem occupied by a species. The very survival of a species to date suggests that the grazing strategy that evolved was successful. Muzzle width and shape, and rumen size in relation to body size, are also important (eg Hofmann, 1988). For example, the muzzle of cattle is wide relative to body weight and flat while that of the goat is narrow and pointed. Goats, by virtue of their muzzle shape and dimensions, have greater potential discriminatory capabilities among pasture components in heterogeneous pasture canopies .

Current theories concerning grazing strategies of domesticated ruminants have been developed by considering that :

1) Energy requirements per unit of liveweight are greater for small than large animals to maintain the same relative nutritional status.
2) Gut size is proportional to liveweight not to metabolic demand.

Small animals have a greater need to consume higher quality pasture diets to compensate for their relatively higher energy requirements and relatively smaller gut. On the other hand large animals with both a lower energy requirement/kg liveweight (ARC, 1980), and a larger gut may be able to tolerate lower quality feeds. Goats would appear to have digestive advantages over cattle and sheep when it comes to digesting browse as their salivary proteins can nullify digestion-inhibiting tannins present in willow, gorse and other browse species (Robbins *et al.*, 1987). Insufficient evidence exists to describe the specific grazing strategies for goats, sheep and cattle.

2.5 Conclusions from literature review

Factors which control the intake of grazing ruminants can be classified into three groups where: -

1) Preferred pasture components are plentiful and accessible and intake rate is not constrained by prehension or mastication. Grazing time is usually below maximum.

2) Intake rate is constrained by the animal's ability to gather and consume sufficient preferred plant components even within an extended grazing time.

3) Preferred pasture components are either in short supply, difficult to gather or inaccessible. Both intake rate (as a result of low BW and BR) initially and grazing time eventually are severely restricted.

Intake in the first classification is controlled by reticulo-rumen capacity, rates of digestion and/or passage, nutrient supply to the small intestine and factors which determine the efficiency of utilization of the absorbed nutrients. Generous allocations of high nutritive value leaf dominant vegetative pastures (eg Cruickshank, 1986) of at least 7cm and with a canopy density of greater than 2mgDM/cm^3 would be expected to provide such conditions for lambs.

In the second classification, intake rate is restricted by either prehension constraints (eg pasture height, density, tensile strength of components); by buccal cavity capacity (eg high volumes of low DM pasture) and mastication requirements (eg ingesta particle length and shear strength) within the available grazing time. Such constraints would restrict BW and/or BR and therefore rate of intake. Pasture conditions and the resultant intake rate encourage longer grazing time. Different strategies may have evolved by which animal species maintain intake rate. For example a small muzzle would enable selection of pasture components on a fine scale yet provide limited buccal cavity capacity. One possible grazing strategy would entail small bites of low shear strength material and therefore rapid prehending bite rates. Identification of such strategies will assist in describing what pasture conditions will restrict intake.

In the final classification grazing intake is restricted as preferred plant components are either sparse compared to the potential bite area or volume of the animal, mixed with other less preferred components or difficult to gather into the bite catchment and sever. Grazing time is probably reduced by fatigue from relentless prehending bites with limited respite by way of mastication bites. A combination of low bite weights and restricted grazing time results in low daily intakes. Animal intake on short swards (eg <50mm) of predominantly pseudostem could be controlled by these later factors. In the normal sequence of rotational grazing all three intake control classifications could be encountered within 24h.

There are no clear boundaries between the classifications discussed. Bite weight appears to be of paramount importance in the control of intake through its influence on prehending bite rate and grazing time.

Chapter 3

Experiment One

3.1 Introduction

The objective of this experiment was to identify differences in grazing behaviour, intake and diet composition of recently weaned kids, lambs and calves while simultaneously but independently grazing a range of pasture masses. Effects of animal age were also investigated.

3.2 Materials and methods

Sixteen kids, 16 lambs, and 16 calves approximately four months of age and of mixed sex, were allocated hierarchically according to body weight to groups of 4 per species, each of which grazed one of four pasture masses (PM) for eight days. There were therefore 12 plots. A one year old Nui ryegrass/ white-clover pasture (*Lolium perenne/Trifolium repens*) was used. Treatment pasture masses were intended to range in 1000 kg increments from 1000 to 4000 kgDM/ha, but very favourable growth conditions in late spring meant the lower mass was almost 3000 kgDM/ha. The higher two pasture masses were prepared by intensive on-off grazing with ewe hoggets and the lower two pasture masses with a flail harvester and catcher.

A common pasture allowance (stocking rate) for all species (table 3.1) was calculated as twice the inter-species mean maintenance requirement (0.5 MJME/kg$^{0.75}$/d, from ARC, 1980; Holmes and Moore, 1981) after adjustments were made for the energy cost of grazings. Pasture energy content was assumed to be 10MJME/kgDM on all grazing sites. Appropriate areas for each animals species and treatment PM were (calculated for 4 days periods from total pasture DM requirements and initial PM) delineated and separated by electric net fencing (Gallagher Group of Companies, Hamilton, NZ).

Table 3.1 Mean herbage allowance (kgDM/hd/d) and mean liveweight (kg) of calves,lambs, and kids used in the trial.

	Calves	Lambs	Kids
Allowance	3.6	1.2	0.82
Liveweight	119.5 ± 3.1	28.5 ± 0.9	16.3 ± 0.7

A further kid, calf, lamb, calf, mature doe and ewe fitted with an oesophageal fistula (OF), grazed with its own species on each of the 4 pasture masses at all times. Thus 20 fistulated animals in total were used in the trial. At two day intervals the fistulated animals were randomly reallocated to another PM, so that during an 8 day measurement period all OF animals sampled each PM, always with their own species.

In the pre-trial period all animals were grazed together, dosed daily with Cr_2O_3 capsules and faecal sampled for 12 days. These dosing and sampling procedures continued for a further 4 days after allocation to a PM treatment, to ensure full adaptation to that PM, and throughout the subsequent 8 day measurement period.

3.2.1 Pasture Measurements

Pasture measurements were made on three occasions : on the day before grazing commenced, on day 4 (end of period 1), and at the end of the trial, day 8 (grazing period 2).

3.2.1.1 Pasture mass

A pasture electronic capacitance probe (Vickery *et al.*, 1982; supplied by Design Electronics Ltd. Palmerston North NZ ; DE 8208) was used to take 40 readings per plot from which the sites for harvest were chosen (at the mean and at one standard deviation on either side). Three quadrats ($0.2m^2$) at each plot were cut to ground level with an electric shearing hand piece and a sub-sample subsequently dried to constant weight at 70° C. The remainder was stored at -20° C for plant compositional analyses. Vertical distribution of herbage within the pasture canopy was measured by cutting a further 3 quadrats (0.19 m^2) per plot in 6 cm layers from the sward surface down to ground level (Milne *et al.*, 1982). Pasture from each quadrat horizon within a species plot was washed, if necessary, stored at -20° C and subsequently freeze dried before compositional analysis.

3.2.1.2 Pasture growth

On days 4 and 8, 5 cuts were made at each PM on an area outside that being grazed but which had received the same pre-trial treatment. Net herbage accumulation (NHA) estimated from these cuts was used in calculating agronomic intake by the apparent dry matter (DM) disappearance technique.

3.2.1.3 Pasture height

Pasture surface height (cm) - unextended height of grass and clover leaf - was measured at the beginning and end of the trial with a cut down ruler, employing 100 and 50, measurements respectively, at the beginning and end of the trial. Pasture height was that of the closest undisturbed tiller to the front of the boot after the third pace when walking the axes of the letter W through a plot.

3.2.1.4 Pasture and diet composition and digestibility

(a) Botanical analysis

Analysis of botanical compositions was performed on both pasture and oesophageal extrusa (OE) after freeze drying. A well mixed subsample of at least 250 pieces was manually separated initially into grass, clover, weeds and dead material and, in the case of all pasture cuts, into grass stem, leaf and seedhead and clover leaf, stem and seedhead. A binocular microscope was used to separate finely ground material. Separated components were then dried in a force-draught oven at 70° C to constant weight. Results were expressed as a proportion, by weight, of total subsample DM.

(b) *In vitro* digestibility

Dry matter (DMD) and organic matter (OMD) digestibilities were determined on all PM cuts by the two-stage *in vitro* procedure of Tilley and Terry (1963) on all material which had been ground sufficiently to pass a 1mm mesh. Organic matter was determined by ashing 0.5g of DM at 575°C for 6 h.

3.2.2 Animal preparation and measurements

The kids, had been weaned for at least three weeks prior to trial commencement. Pre and post trial weights for non surgically modified animals are shown in table 3.2

Table 3.2 Mean liveweight (kg) and liveweight gain (g/d) of calves, lambs and kids in trial one. (where PM is pasture mass in kgDM/ha).

PM	Species		Pretrial liveweight	post trial liveweight	liveweight gain	trial liveweight
2950	calves		117.75	134.25	1178.6	126.00
3800	calves		124.50	133.00	607.1	128.75
4500	calves		119.67	127.00	523.8	123.33
5400	calves		116.25	128.00	839.3	122.13
	calves	**MEAN**	**119.54**	**130.56**	**787.2**	**125.05**
		SEM	**3.10**			
2950	lambs		29.50	30.25	53.6	29.88
3800	lambs		27.67	27.33	-23.8	27.50
4500	lambs		28.00	30.50	178.6	29.25
5400	lambs		28.67	28.33	-23.8	28.50
	lambs	**MEAN**	**28.46**	**29.10**	**46.1**	**28.78**
		SEM	**0.90**			
2950	kids		16.00	16.13	8.9	16.06
3800	kids		16.50	15.75	-54.0	16.13
4500	kids		16.38	16.25	-8.9	16.31
5400	kids		16.50	16.63	8.9	16.56
	kids	**MEAN**	**16.34**	**16.19**	**-11.2**	**16.27**
		SEM	**0.69**			

3.2.2.1 Oesophageal fistulation - techniques and maintenance

(a) Fistulation

Four young animals from each species and four rising two year wether goats and sheep were fitted with T-shaped rubber cannulae (M^{c}Manus *et al.*, 1962) at least 3 weeks before the trial preliminary period using the surgical procedure of Bishop and Froseth (1970).

(b) Sampling

An extrusa sample was collected daily between 0600 - 0830h during 10min. If the animal failed to graze or produced a sample with excessive saliva or rumen contamination a further sample was collected during the afternoon grazing period (1600 - 1700h). After collection OE were held in an insulated chilled container prior to storage at -20°C and subsequent freeze drying.

(c) Extrusa analysis

Diet composition and *in vitro* digestibility were determined on freeze dried extrusa as described for pasture except that the separation was limited to grass, clover, weeds and dead material and not individual species components were separated.

3.2.2.2 Faecal output

(a) Dosing

Faecal output was measured by the dilution of chromium sesquioxide (Cr_2O_3) (Kotb and Lucky, 1972). All non fistulated animals were dosed twice daily (0800 - 0930h; 1600 - 1730h) with 1g Cr_2O_3 suspended in oil within a gelatine capsule (R.P.Scherer Pty. Ltd. Australia) for 16 days prior and during the 8 day measurement period. Care was taken with such young animals to ensure the capsule was swallowed and the throat was not damaged with the balling gun.

(b) Faecal collection

One animal from each species within a PM was fitted with a harness at the start of the 4 day preliminary equilibration period (a four day familiarisation period on the allocated PM treatment prior to the 8 day measurement period) for total daily faecal collection. Total daily faecal production for bagged animals during the 8 day trial period were compared with estimates based on grab samples. Any bias between total collection and grab sample estimates of daily faecal output (due to diurnal variation in Cr_2O_3 concentration), were used to adjust all grab sample data for the day in question for that animal species and PM treatment.

Rectal faecal grab samples were obtained between 0800 and 0930h and 1600 and 1730h and bulked separately for two consecutive four day periods (period 1 and 2) in air tight containers that were stored at 4°C. A modified 20ml plastic syringe was used to obtain approximately 6ml of faeces at each sampling. Total faeces were obtained from the harnessed animals at the same time as grab samples. After weighing a well mixed subsample was retained and bulked over the two 4 day periods and stored at 4°C.

Total four day faecal samples were dried to constant weight (70°C) and ground to pass through a 1mm screen. Duplicate subsamples were dried at 100°C for 12 h, reweighed and ashed in a muffle furnace at 575°C for 6 h. Resultant ash samples were digested with hot phosphoric acid and potassium bromate (Le Du and Penning, 1982) and the chromium concentration measured by atomic absorption spectrometry (Shimadzu atomic absorption spectrophotometer, model AA-670).

3.2.2.3 Digestible organic matter intake (DOMI)

Mean DOMI was calculated from sward disappearance ($DOMI_a$) or from faecal DM output ($DOMI_c$).

$$\mathbf{DOMI_a = (DMI_a \times OM_{fd}) \times OMD_f} \quad \text{.......... 3.1}$$

Where: apparent DM intake was calculated using equation 3.2
OM_{fd} is the %OM in the feed consumed measured from the OE.
OMD_f is the *in vitro* digestibility of the feed OM

$$\mathbf{DMI_a = (PM_{t1} - PM_{t2}) \times A / (n \times 4 \times W)} \quad \text{.......... 3.2}$$

Where: PM was measured (kgDM/ha) at the start (t1) and finish (t2) of each four day grazing period.
A is the area grazed (ha).
n is the number of animals per plot including those fistulated.
W is liveweight or metabolic liveweight (kg).

$$\mathbf{DOMI_c = ((D/[Cr^2O^3]_{fc}) \times OM_{fc} \times 1000)/(1 - OMD_f)/W} \quad \text{.......... 3.3}$$

Where: D is dose of Cr^2O^3(g) administered per day.
$[Cr^2O^3]_{fc}$ is the faecal concentration of chromium sesquioxide per g of faecal DM (mg/gDM).
OM_{fc} is the faecal OM% (All other terms have been defined earlier).

3.3.1 Data handling and statistics

Lotus 123 was used for all raw data manipulation and data generation. All analyses of variance were performed with the GENSTAT package (Rothamsted Experimental Station version V. mark 4.03, 1980). Intake, digestibility, and diet composition (grass, clover and dead material) were used as variates where the source of variation was considered as animal species, date, pasture mass and animal where the error term was the three way interaction species*date*PM.

3.3.2 Pasture and diet composition

Botanical composition of pasture and OE samples was expressed as a proportion of the sample DM. Kulzinsky's coefficient of similarity, described by Holechek *et al.*,(1984) and used by Collins (1989), was used to compare diet composition between days within a grazing species, and between OE and entire or stratified pasture composition using equation 3.4. A similarity coefficient of 1 indicates complete similarity, 0 complete dissimilarity.

$$\mathbf{Similarity = W \times 2 / (A + B)} \quad \text{.......... 3.4}$$

Each diet component (%) is compared between days (or the diet and the pasture horizon in the second set of comparisons) and the lower value in each case summed to derive "W".

A is the sum of all diet components (%) on a chosen day (or in the diet in the second set of comparisons).

B is the sum of all diet components (%) on a day where the diet is compared with the chosen day (or in a particular horizon of the pasture).

3.4 Results

The sward preparation techniques produced pastures of significantly different PM and height but somewhat greater than had been projected. Estimates of net herbage accumulation (NHA) were very high possibly because climatic conditions favoured the accumulation of dead material which under normal circumstances would be incorporated in soil organic matter.

With the exception of one young kid all the animals remained healthy throughout the trial. One kid scoured for two days but after the removal of the faecal collection harness it made a rapid recovery.

3.4.1 Pasture height

Pasture heights at the beginning and end of the trial are given in table 3.3.

Table 3.3 Mean pasture height (cm) at each pasture mass (PM) at the beginning and end of the trial for each animal species.

Pasture mass kgDM/ha	Start Day 1	Finish (day 8) Calves	Lambs	Kids
(PM 1) 2950	12.4 ± 0.46	7.1 ± 0.21	10.9 ± 0.37	10.4 ± 0.26
(PM 2) 3800	19.3 ± 0.68	8.3 ± 0.28	15.2 ± 0.64	11.7 ± 0.42
(PM 3) 4500	31.6 ± 1.26	13.8 ± 0.69	15.7 ± 1.12	14.5 ± 0.66
(PM 4) 5400	41.5 ± 1.86	12.9 ± 0.66	18.3 ± 1.10	15.6 ± 0.80

Pasture height decreased on all pastures, the greatest reduction occurring on those grazed by calves. PM grazed by lambs underwent the least change in height while those grazed by kids were intermediate between lambs and calves. Final leaf height was less than half the initial height on the higher PM (3 and 4), however on the lower PM (1 and 2) the relative reduction in height was far less, except for the calves.

3.4.2 Pasture mass

Estimates of PM derived from summation of horizon PM were consistently lower than those from ground level cuts probably because drill rows were still present and inter row plant material was therefore difficult to harvest at ground level. Horizon cuts were made by a shearing hand piece mounted on a guide frame that was only capable of cutting as low as the first soil contact point, in this instance the elevated drill rows. Pasture which had tillered out from the drill rows could not be harvested at ground level.

Table 3.4 Pasture mass (kgDM/ha) at the start (day 0), midpoint (day 4) and end of the trial (day 8) by grazing site for calves, lambs and kids.

	PM 1	PM 2	PM 3	PM 4
Start	2950 ab	3797 b	4477 a	5362 c
Calves (1)	2477 bc	3351 b	4290 a	4087 b
Calves (2)	1967 c	2096 a	3935 a	2951 a
Lambs (1)	2747 ab	3364 b	4152 a	4525 bc
Lambs (2)	3419 a	3473 b	4009 a	4597 bc
Kids (1)	2950 ab	4223 c	6039 b	5393 c
Kids (2)	3084 ab	3326 b	4631 a	3640 a
Mean	**2793**	**3319**	**4505**	**4365**
$LSD_{0.05}$	689	414	838	873

(within columns, values with different letters differ; P<0.05)

Pasture mass was unchanged throughout the trial on PM 3 and only declined after day 4 for calves on PM 2. A reduction in pasture mass occurred on PM 1 and 4 grazed by calves and during period 2 on PM 4 grazed by goats. Sampling error probably contributed to some of the fluctuation in pasture mass as some plots became increasingly heterogeneous as the trial progressed.

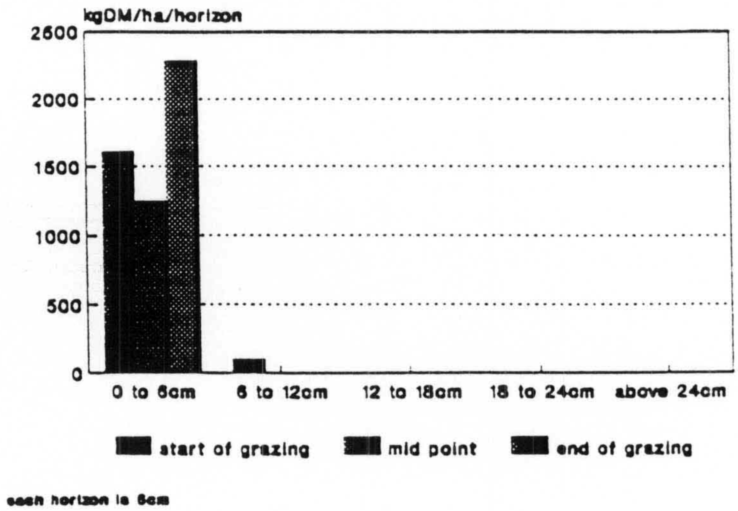
Distribution of PM by horizon changed significantly during the grazing periods (figures 3.1.1 to 3.1.4) even where PM did not change (PM 2 and 3). Animal species appeared to employ different grazing strategies. For example on PM 1 where full opportunity of expression of differences in grazing strategies may have been constrained by inadequate height, PM was maintained in the 0 to 6cm horizon under lambs, while that under calves and kids increased. Calves and kids on PM 1 were either reluctant to graze into the 0 to 6cm horizon or were meeting their grazing objectives in the upper horizons. Grazing strategy was influenced by PM but identification of a pattern was difficult. There was no clear pattern of change in PM distribution by horizon under lambs on any treatment pasture mass (figures 3.1.1 to 3.1.4) even though PM did not change for lambs.

3.4.3 Digestible organic matter intake

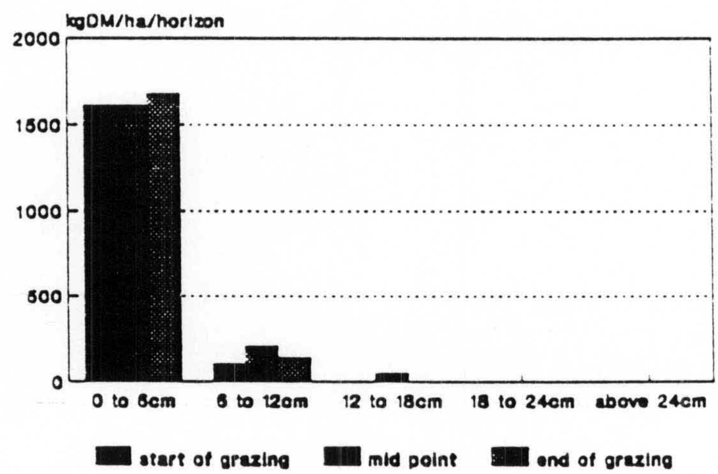
(a) Intake derived from pasture disappearance

Accurate estimation of intake by the agronomic technique depended to a large extent, on the factor used to convert undisturbed pasture growth rates measured outside the trial area to those within the grazed area. Difficulties commonly occur where time between cuts exceed a day and where the PM within the grazed area may be declining or less photosynthetically active (Meijs *et al.*, 1982). PM

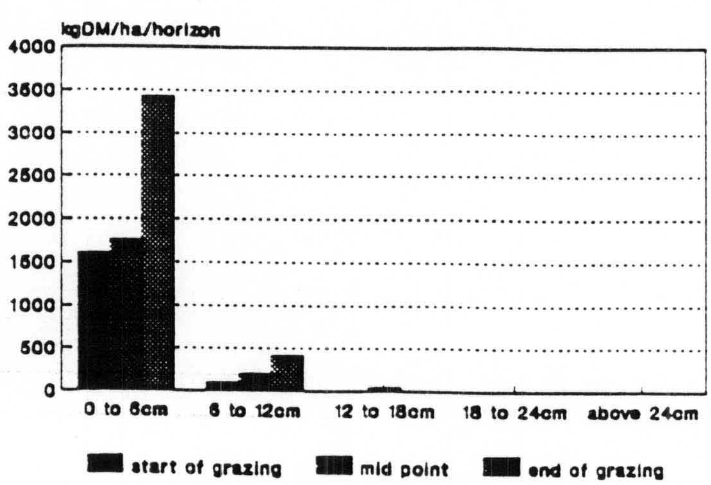
Figure 3.1.1 Pasture mass distribution by sward horizon for (a) calves, (b) lambs and (c) kids grazing ryegrass-white clover swards on PM1.



(a) calves

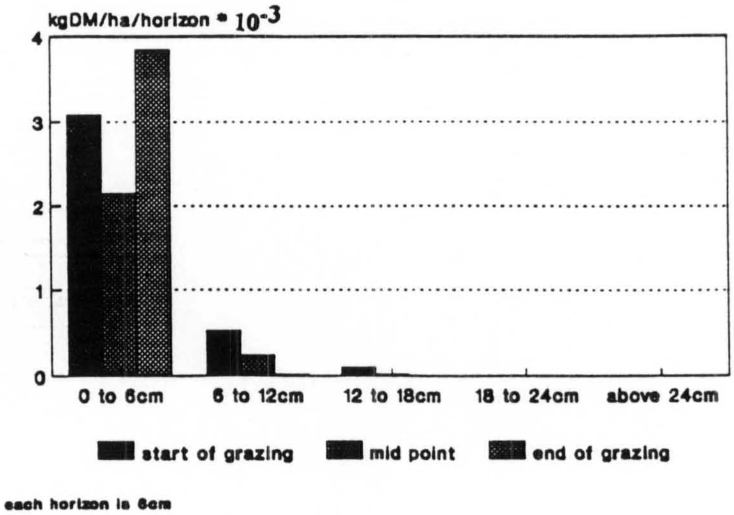


(b) lambs

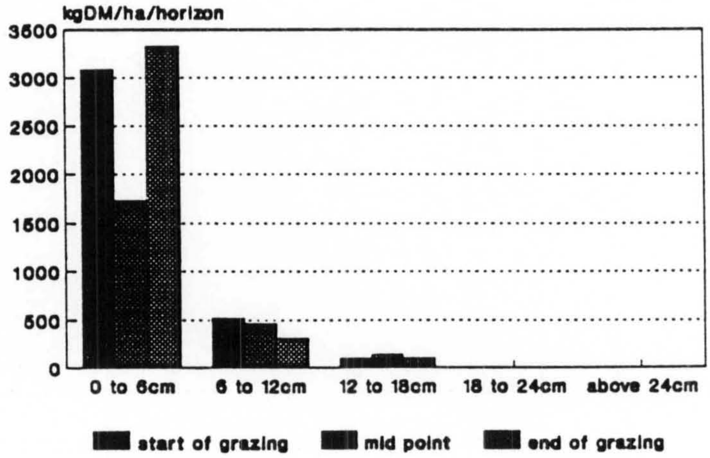


(c) kids

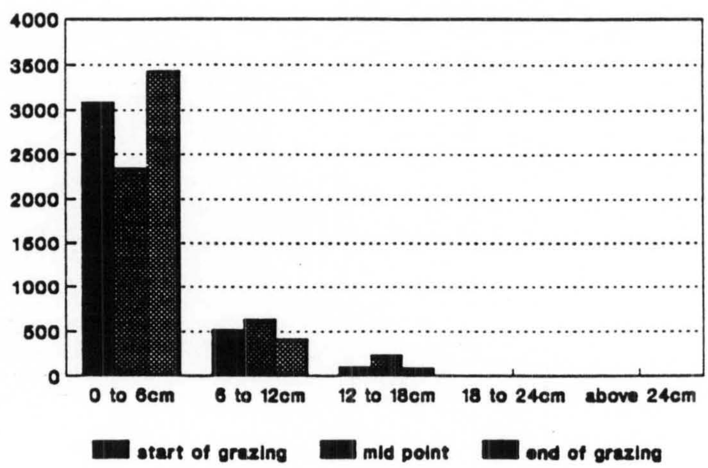
Figure 3.1.2 Pasture mass distribution by sward horizon for (a) calves (b) lambs and (c) kids grazing ryegrass-white clover swards on PM2.



(a) calves

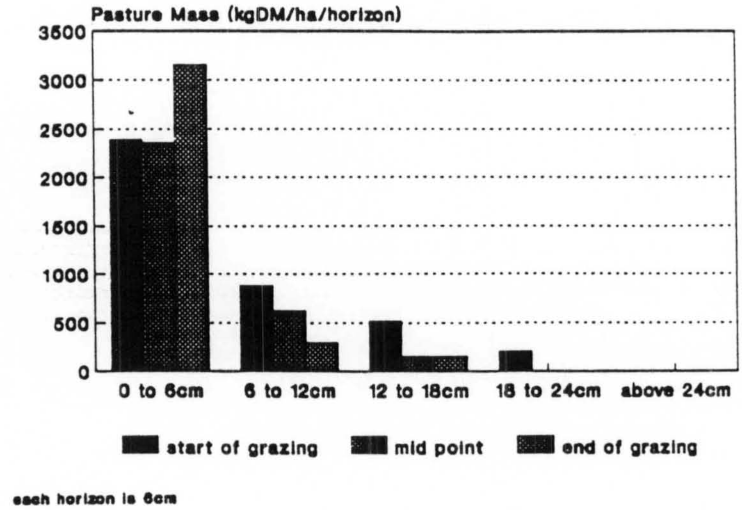


(b) lambs

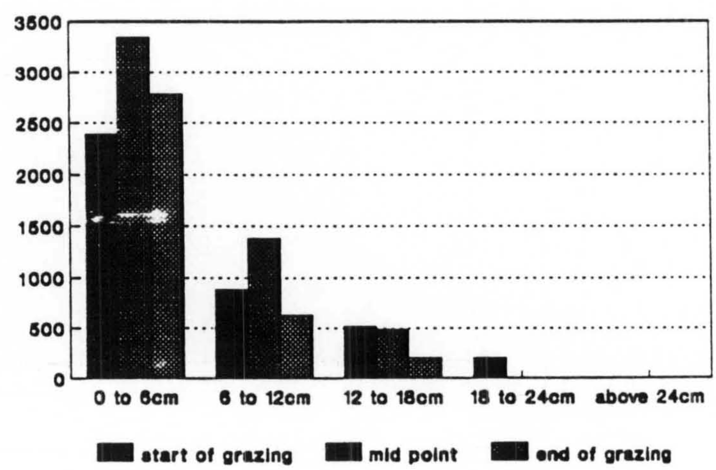


(c) kids

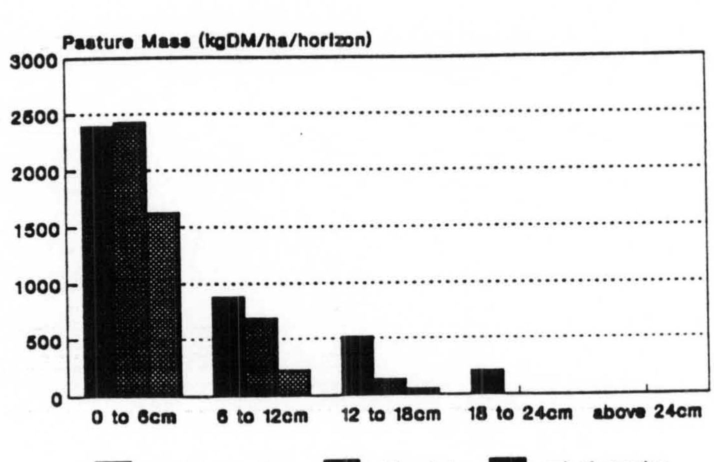
Figure 3.1.3 Pasture mass distribution by sward horizon for (a) calves, (b) lambs and (c) kids grazing ryegrass-white clover swards on PM3.



(a) calves

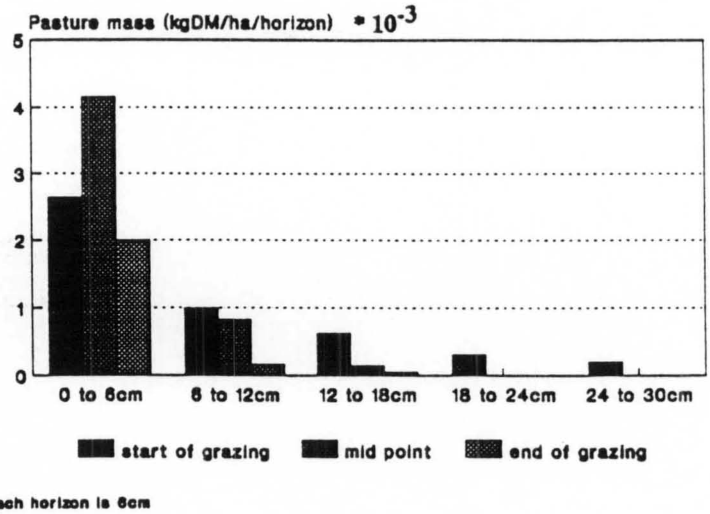


(b) lambs

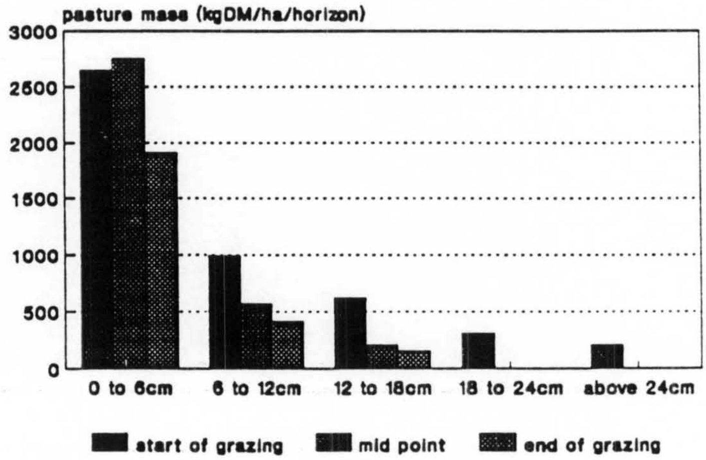


(c) kids

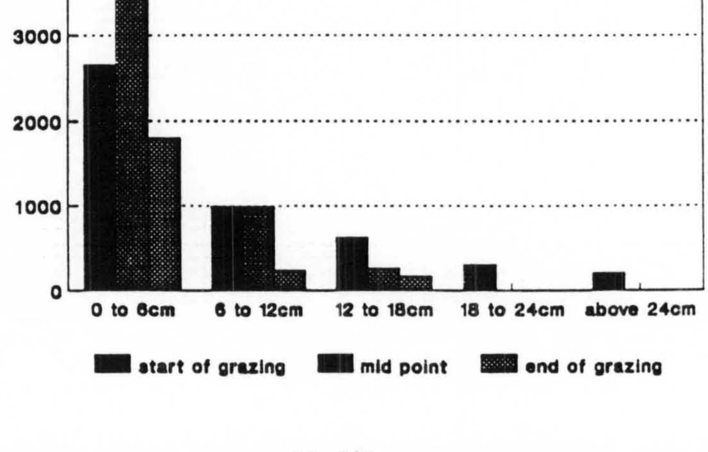
Figure 3.1.4 Pasture mass distribution by sward horizon for (a) calves, (b) lambs and (c) kids grazing ryegrass-white clover swards on PM4.



(a) calves



(b) lambs



(c) kids

decreased on PM 1 and 4 grazed by kids and calves. No adjustments were made for net herbage accumulation over the 4 days in the grazed areas.

Table 3.5 Apparent DOMI(g/kgLW/d and g/kg$^{0.75}$/d) of calves lambs and kids during two four day periods on four pasture masses (kgDM/ha).

Pasture mass	Species	Day 1-4 g/kgLW/d	Day 4-8 g/kgLW/d	Day 1-4 g/kg$^{0.75}$/d	Day 4-8 g/kg$^{0.75}$/d
2950 (PM 1)	calves	26.7	28.1	89.4	94.2
3800 (PM 2)	calves	15.6	19.3	51.4	63.7
4500 (PM 3)	calves	6.6	7.9	22.2	26.5
5400 (PM 4)	calves	9.5	10.0	31.7	33.1
2950 (PM 1)	lambs	29.8	9.4	68.3	21.4
3800 (PM 2)	lambs	19.1	6.6	43.7	15.0
4500 (PM 3)	lambs	9.6	7.1	22.2	16.5
5400 (PM 4)	lambs	10.3	3.0	23.7	6.8
2950 (PM 1)	kids	28.4	24.5	56.9	49.1
3800 (PM 2)	kids	6.2	26.8	12.3	53.5
4500 (PM 3)	kids	-10.9	23.7	-22.0	47.8
5400 (PM 4)	kids	5.2	19.1	10.4	38.5

Apparent $DOMI_a$ intakes were generally higher during day 4-8 than day 1-4, except for the lambs. Within an animal species intake also decreased with increasing PM, however intakes were erratic and lower than expected.

(b) Intake derived from faecal output

Intake was calculated for the calves, lambs and kids as outlined in 3.2.2.2 (b).and the results are presented in table 3.6 and 3.7 for DOMI (g/kgLW/d) and (g/kg$^{0.75}$/d) respectively and in figure 3.2.

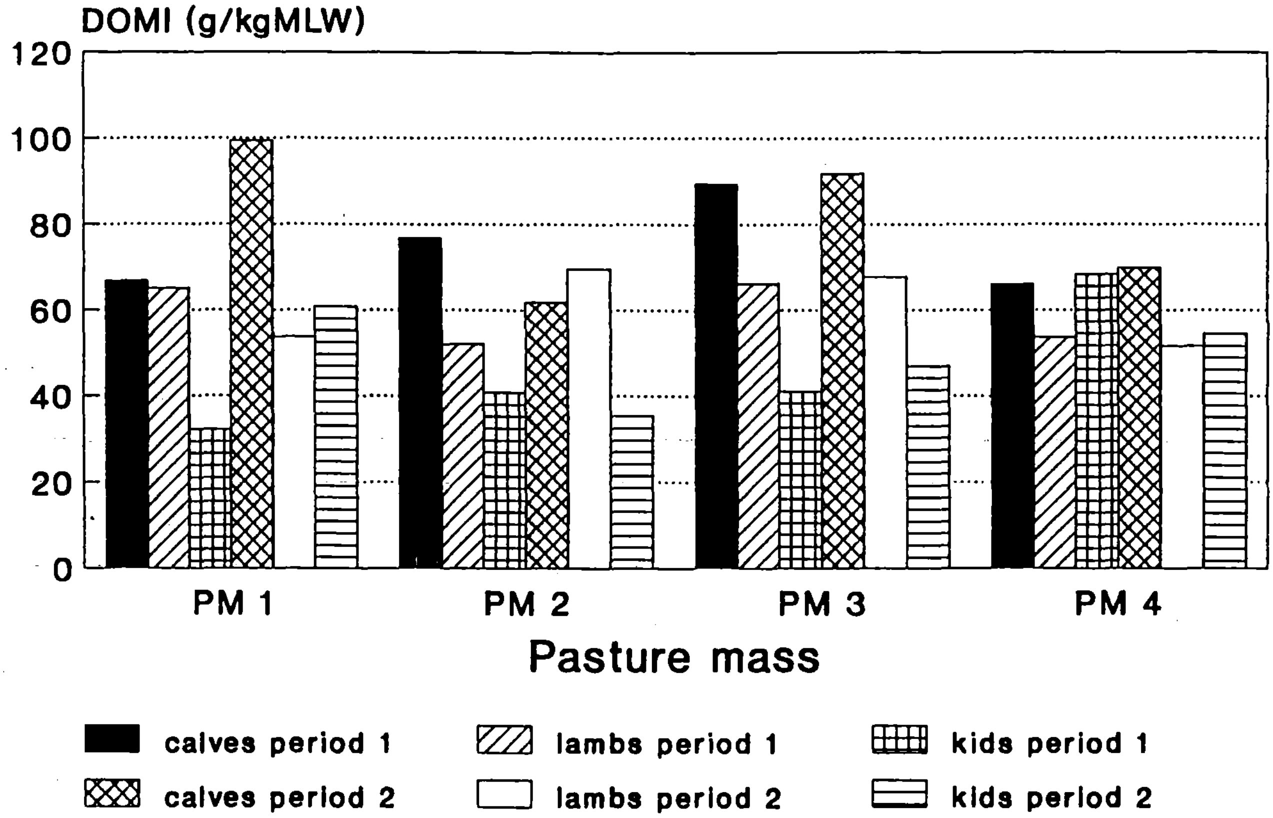
Table 3.6 Digestible organic matter intake (gDOM/kgLW/d) of calves, lambs and kids for the four pasture masses and two intake periods.

	Calves			Lambs			Kids		
Days	1-4	4-8	Mean	1-4	4-8	Mean	1-4	4-8	Mean
PM 1	19.9a	29.5c	24.7a	28.7a	23.2ab	26.0a	16.3a	30.7b	23.5ab
PM 2	23.2a	18.6a	20.9a	22.7a	30.4b	26.6a	20.4a	17.5a	19.0a
PM 3	26.8a	27.5bc	27.2a	28.5a	29.2ab	28.9a	20.6a	23.6ab	22.1a
PM 4	19.9a	21.0ab	20.5a	23.3a	22.4a	22.9a	33.9b	27.0b	30.5b

SED = 3.60 $LSD_{0.05}$ = 7.51
(within columns, values with different letters differ; P<0.05)

Mean intake changed between days 1-4 and 4-8 for calves and kids on PM1 and lambs on PM2. In the remaining 9 comparisons intakes did not change during the period of the trial. Mean intakes for the 8 days were therefore calculated. Intake both within species for all pasture masses and among

Figure 3.2 Digestible organic matter intake (g/kg0.75/d) of lambs calves and kids grazing ryegrass-white clover swards on four different pasture mass treatments in two four day periods.



species within a pasture mass were similar. The only exception was the apparently higher intake of kids grazing PM4 when compared with both calves and lambs and to kids grazing all other pasture masses. No obvious reason could be found for the high intake of kids on PM4, especially during days 1-4. Intake did not respond to PM for any of the animals species if it is assumed that the intake of kids on PM4 was a chance effect. Maximum intakes for calves, lambs and kids were comparable (29.5, 30.4 and 33.9 gDOM/kgLW/d respectively, table 3.6).

Similar intake response patterns were also apparent when intake was expressed on a metabolic liveweight basis (table 3.7).

Table 3.7 Digestible organic matter intake ($g/kg^{0.75}/d$) of calves, lambs and kids for the four pasture masses and two intake periods.

	Calves			Lambs			Kids		
Days	1-4	4-8	Mean	1-4	4-8	Mean	1-4	4-8	Mean
PM 1	66.8a	99.4c	83.1ab	65.1a	53.8a	59.5a	32.2a	60.8b	46.5ab
PM 2	76.8ab	61.9a	69.4a	52.1a	69.7b	60.9a	40.8a	35.4a	38.1a
PM 3	89.4b	91.9c	90.7b	66.2a	67.7b	67.0a	41.1a	46.9ab	44.0a
PM 4	66.1a	69.9a	68.0a	53.6a	51.6a	52.6a	68.4b	54.4b	61.4b

SED means = 7.60 $LSD_{0.05}$ =15.9
(within columns, values with different letters differ; P<0.05)

Mean calf intake showed no consistent response to pasture mass (table 3.7). If the high intake on day 4-8 on PM1 is considered a chance effect, then intake increases with pasture mass until PM3 and declines between PM3 and 4. Mean intake of lambs on all PM treatments were similar possibly because PM did not decline as the trial progressed in contrast to sites grazed by kids and calves (table 3.4). There was a suggestion that lamb intake like that of the calf also declined beyond PM3. Mean intake of kids was similar from PM 1 to 3 and then contrary to the trend for calves and lambs increased between PM3 and 4. However the higher intake of kids on PM4 was largely due to a high intake on day 1-4 which may be a chance effect as it was not repeated on days 4-8. While calves generally had the greatest mean intake on all pasture masses, - although not always significantly so - kids had consistently lower intakes than lambs with the possible exception of PM4.

Maximum intake values for the young kids, calves and lambs of 68.4, 99.4, and $66.2g/kg^{0.75}$, respectively, fall within published values (eg Collins, 1989; Forbes, 1982). These represent, on a DM basis, an intake of 3.4, 3.0 and 2.9% of average body weight for the kids, calves and lambs respectively. As these values are consistent with *ad libitum* values in the literature, $DOMI_c$ intakes were used as a bench mark for comparison with $DOMI_a$.

$DOMI_a$ (table 3.5) was consistently lower than $DOMI_c$ (table 3.7) especially for the lambs and calves. Intake of calves on PM 3 in periods 1 and 2 was 22 and 27 for $DOMI_a$ (table 3.5) and 89 and 92 for $DOMI_c$ ($g/kg^{0.75}/d$) (table 3.7). While $DOMI_c$ for calves reached its highest values on PM 3 (table

3.7), that calculated from pasture disappearance was the lowest for the four pasture masses grazed (table 3.5). In the remainder of chapter 3 all intakes discussed are $DOMI_c$.

3.4.4 Ingested diet

(a) Digestibility of oesophageal extrusa

Calculation of intake ($DOMI_c$) is particularly sensitive to any errors in the estimation of *in vitro* digestibility, OMD. Such error can arise when the OE sample size is small and/or is contaminated heavily with saliva (Le Du and Penning 1982). With a few exceptions all fistulated animals provided large samples with only 23 samples missed from a potential collection of 160 during the trial. While *in vitro* digestibility (OMD) was determined on all OE, values were averaged for the 2 day period which each fistulated animal spent on a particular PM. As a consequence there were only 2 PM-species associations with no OMD values. These missing values were estimated from regression analyses using Genstat.

Organic matter digestibility of OE was not influenced by PM or by day of sampling on a pasture even though PM declined for some species during the trial (table 3.4). There was no significant difference in the OMD of the diet consumed by calves, lambs and kids (table 3.8) even though there were differences in botanical composition of extrusa but rising 2 year goats had a higher OMD (0.83) than similarly aged sheep (0.76). Age of animal within a species did not influence oesophageal extrusa OMD (table 3.8).

Table 3.8 Digestibility of organic matter (OMD) in oesophageal extrusa (OE) from calves, kids, goats, lambs and sheep grazing four pasture masses on a ryegrass white clover pasture.

	Mean of ungrazed PM	Calves	Kids	Goats	Lambs	Sheep
OMD	0.71	0.76b	0.81ab	0.83a	0.77ab	0.76b

Means followed by the same letter do not differ; ($P<0.05$)

The decline in digestibility of OE from all animal species with increasing PM was linear (equation 3.5) and followed that of the OMD of the whole sward (table 3.9).

$$\mathbf{OMD = -2.41 \times 10^{-5}\ PM\ (\pm 7.1 \times 10^{-7}) + 0.87} \quad (P<0.001) \quad \ldots\ldots\ldots\ldots\ldots \mathbf{3.5}$$

adj $R^2 = 0.35^{***}$

Similarity coefficients were calculated between the *in vitro* digestibility (OMD) of the whole pasture and that of the OE at the beginning and end of the trial (table 3.10). While initially the OE digestibility reflected very closely the mean digestibility of the available pasture the two values became more dissimilar with time. Dead material as a proportion of the available PM may have increased as the trial progressed (appendix Table 2) as OE digestibility did not change.

Table 3.9 Mean organic matter digestibility of oesophageal extrusa from all species at each of the four pasture masses (kgDM/ha).

	Pasture mass (kgDM/ha)			
	PM 1 2950	PM 2 3800	PM 3 4500	PM 4 5400
Sward prior to grazing	0.76	0.77	0.75	0.68
Mean post grazing	0.65	0.68	0.53	0.52
Oesophageal extrusa	0.82b	0.81b	0.78ab	0.74a
	$LSD_{0.05}$ =0.053			

Table 3.10 Coefficients of similarity between organic matter digestibility (OMD) of oesophageal extrusa (OE) and the whole pasture for each pasture mass and animal species.

		Similarity coefficients	
Pasture mass	Species	Day 1	Day 8
2950 (PM 1)	calf	0.90	0.88
3800 (PM 2)	calf	0.96	0.92
4500 (PM 3)	calf	1.00	0.84
5400 (PM 4)	calf	0.98	0.90
2950 (PM 1)	lamb	0.94	0.80
3800 (PM 2)	lamb	0.98	0.88
4500 (PM 3)	lamb	0.94	0.74
5400 (PM 4)	lamb	0.94	0.82
2950 (PM 1)	kid	0.96	0.80
3800 (PM 2)	kid	0.96	0.92
4500 (PM 3)	kid	0.92	0.82
5400 (PM 4)	kid	0.92	0.80

3.4.5 Botanical composition of pasture and the ingested diet.

(a) Pasture botanical composition

A general pattern of change in botanical composition emerged during the 8 day grazing period. With the exception of PM 1, the upper horizon, or horizons in the case of PM 4, were removed in the first grazing period. Pasture mass in the 6cm horizon at ground level increased, and the proportion of dead material progressively rose especially in those horizons above 6cm. Grass and clover leaf generally decreased in all horizons above 6cm although the extent of the change was species and pasture mass dependent (figures 3.1.1, 3.1.2, 3.1.3, 3.1.4). For example on PM 4 (figure 3.1.4) sheep

Figure 3.3.1 Botanical composition of the pasture horizon below 6cm on PM 3 before grazing commenced and for each species site at the end of the trial.

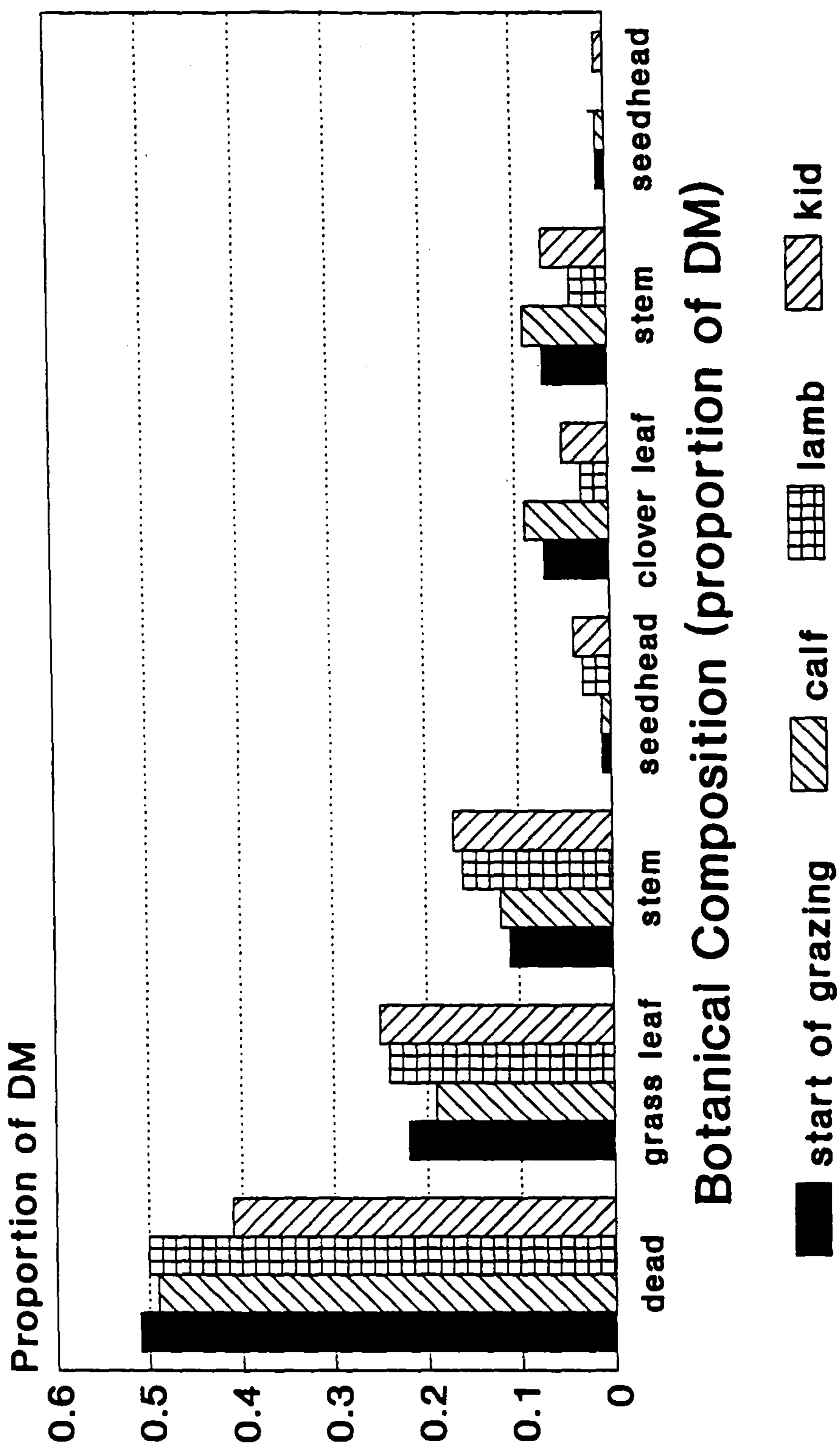


Figure 3.3.2 Botanical composition of the pasture horizon between 6 and 12 cm on PM 3 before grazing commenced and for each species site at the end of the trial.

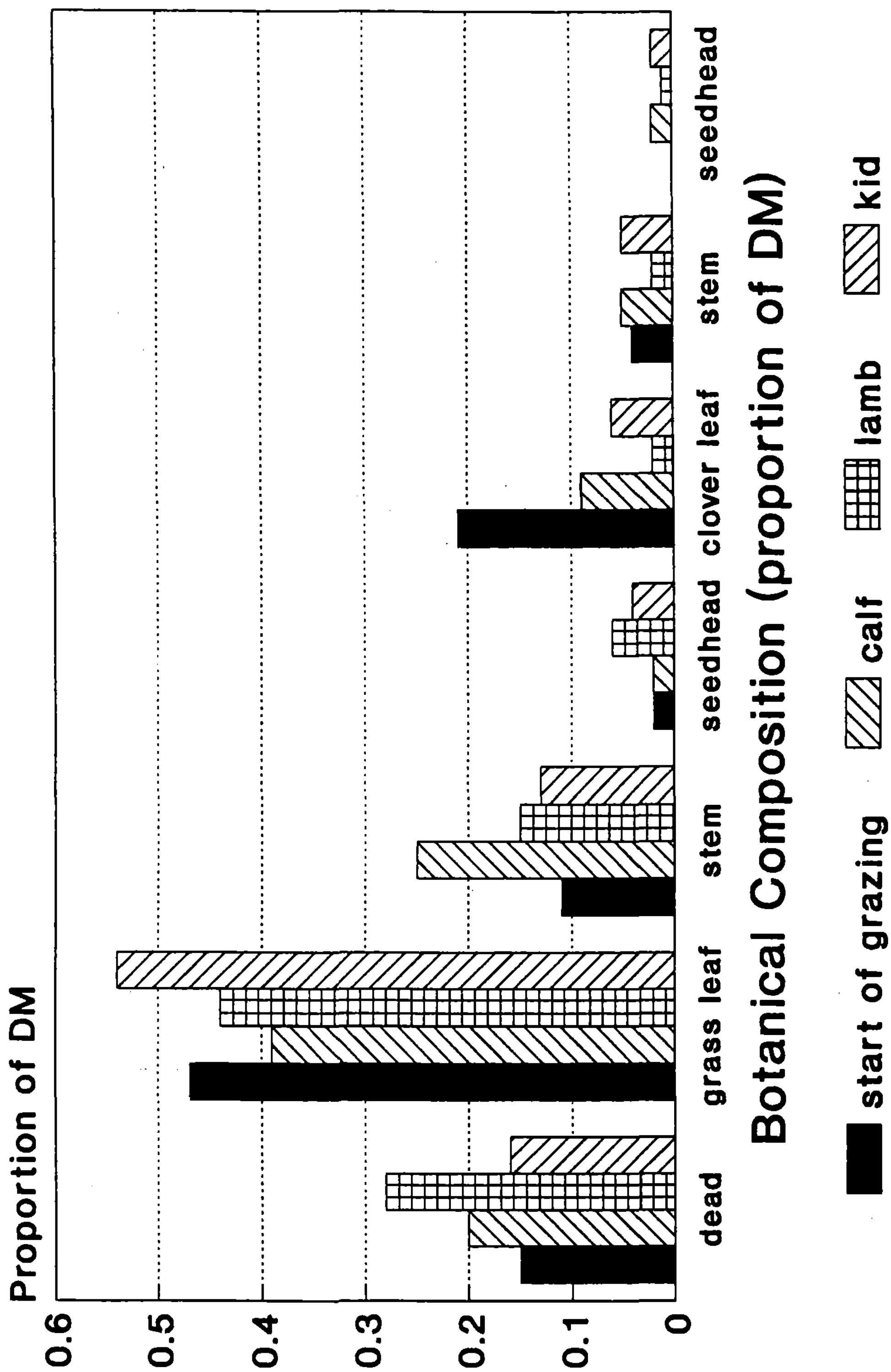
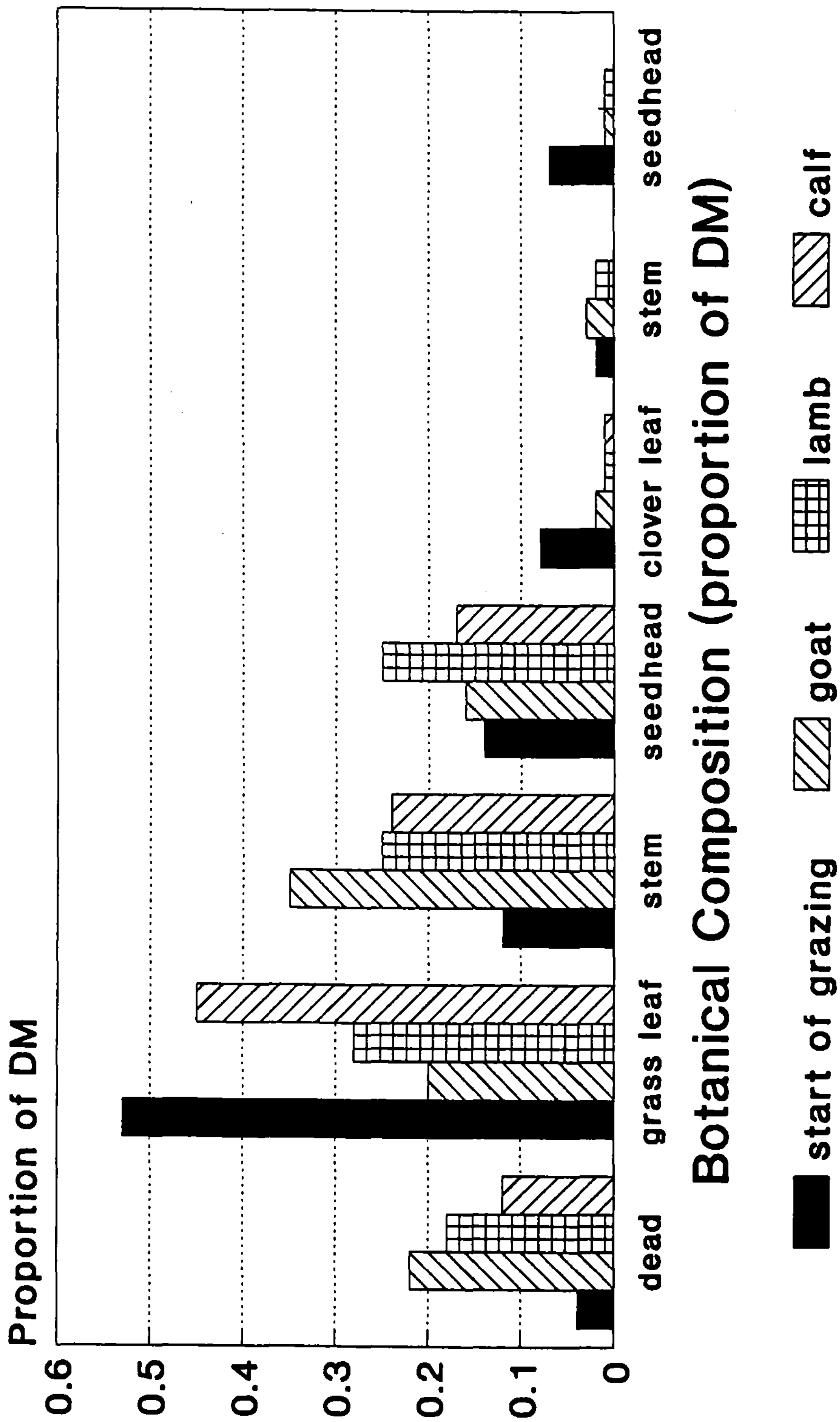


Figure 3.3.3 Botanical composition of the pasture horizon between 12 and 18cm on PM 3 before grazing commenced and for each species site at the end of the trial.



grazed the 6 to 12 cm horizon in the first grazing period while goats and calves only grazed this horizon in the second grazing period.

A comparison of changes in botanical composition of the pasture horizons for PM 3, where PM was unchanged during the grazing period (table 3.4), are presented in figures 3.3.1 to 3.3.3. The 18-24cm horizon was completely consumed and/or compressed into lower horizons by all animal species during the first grazing period, and is not presented. Botanical composition of the ground horizon appeared largely unchanged (figure 3.3.1). Although white clover content apparently declined for all species grazing sites in the 6-12cm horizon (figure 3.3.2), the decrease was greater for lambs. Grass leaf may have declined and stem content increased on the PM grazed by calves. In the surface horizon - 12-18cm (figure 3.3.3) - the decline in clover content and the increase in dead material was similar for all species grazing sites. Grass leaf decreased markedly for calves and lambs and remained unchanged for goats.

(b) Botanical composition of oesophageal extrusa

There were significant species x PM and PM x date interactions for the percentage of legume and grass in the diet (table 3.11). In the latter interaction only three pasture mass x day combinations differed significantly. As no biological reason for these interactions was found the latter interaction has not been discussed.

3.4.5.1 Clover composition

Clover content of OE from both the kid and goat increased from PM1 to PM4 however on PM3 it was lowered than predicted by the general trend. . Pasture mass on PM3 grazed by kids increased during the experiment (table 3.4) which may have provided both kids and goats with greater opportunity to consume grass. Clover content in the calf diet - in contrast to the kid and goat - gradually declined as PM increased (ie from PM1 to PM4). Clover content of both the lamb and sheep diet also declined as pasture mass increased apart from a temporary increase on PM2. On PM1 clover content was similar for all species irrespective of age. It is difficult to believe that goats on PM1 only harvested 2% clover (table 3.11) so this value has been considered a chance effect. If this value for older goats on PM1 is discounted clover composition of the diet is not influenced by age for either the caprine or ovine species.

In general the OE of lambs and kids contained a greater proportion of clover than that of calves. This difference increased from PM1 to 4 where the diet of the kid contained a significantly greater proportion of clover than that of the calf (table 3.11). Contrary to expectations the proportion of clover in the diet of kids and lambs were similar at all PM. However sheep consumed a higher proportion of clover than goats on all but the highest PM where the order was reversed (table 3.11).

3.4.5.2 Grass

PM x species interactions for grass were the inverse of those obtained for clover as OE composition consisted of only one other minor component - dead material - as weeds were very rarely present.

3.4.5.3 Dead material

The proportion of dead material in the diet of all species increased with PM (PM 1 to 4) and day of sampling (table 3.12). Calves consumed a greater proportion of dead material than kids or goats although apparent discrimination against dead material was very high for all species.

Table 3.11 Animal x PM and PM x date interactions for the clover and grass components (%) of the diet of calves, kids, goats, lambs and sheep grazing four separate pasture masses of ryegrass white-clover.

Animal x PM **Clover**	PM 1	PM 2	PM 3	PM 4
calves	26.5ac	17.4bc	18.5bc	9.5b
kids	31.6a	37.6ac	19.4bc	46.7a
goats	2.2bc	18.0bc	18.9bc	44.0a
lambs	37.7a	61.3a	40.1ac	28.3ab
sheep	36.5a	49.8a	44.6a	11.9b
Grass	PM 1	PM 2	PM 3	PM 4
calves	64.0b	80.1a	74.8a	78.2a
kids	66.4b	60.3ac	76.4a	45.3bc
goats	97.7a	77.6a	76.3a	51.4bc
lambs	61.5b	35.3b	52.1ac	64.0ac
sheep	60.7b	46.1bc	47.0bc	75.8a
PM x date **Clover**	PM 1	PM 2	PM 3	PM 4
day 1-2	13.3b	44.6a	32.1a	35.5a
day 3-4	32.0ab	35.6a	28.2a	25.4ac
day 5-6	20.4ab	22.0a	22.2a	45.0a
day 7-8	38.5a	45.1a	30.8a	6.3bc
Grass	PM 1	PM 2	PM 3	PM 4
day 1-2	84.7a	52.4a	63.8a	60.4ab
day 3-4	65.4ab	61.4a	66.8a	68.8ab
day 5-6	75.2ab	74.8a	71.7a	47.2b
day 7-8	56.4b	50.8a	58.9a	75.3a

Means in columns followed by the same letter do not differ significantly ($P<0.05$).

3.5 Comparison of oesophageal extrusa and pasture horizon botanical composition

Similarity coefficients were calculated between the botanical composition of the diet and that of the pasture horizons for each pasture mass, species and period, in an attempt to identify those horizons making the largest contribution to the animals diet. These coefficients were derived from two independent (OE and horizon botanical composition) but auto-correlated data sets. In addition within the horizon data the composition on any day in the trial is a function of the composition on the previous day. These limitations within the data used to derive the coefficients impose serious restrictions on the reliability of any subsequent statistical analyses. When interpreting the analyses that follow consideration must be given to these limitations.

Table 3.12 Percentage (%) of dead material in oesophageal extrusa dry matter as influence by pasture mass (kgDM/ha), animal species and day of pasture sampling.

Pasture mass	Dead	Species	Dead	Day	Dead
2950	1.5b	calves	5.4b	1-2	0.8b
3800	1.4b	kids	0.8a	3-4	1.6b
4500	3.5ab	goats	0.9a	5-6	3.3ab
5400	4.8a	lambs	1.8ab	7-8	5.6a
		sheep	5.1b		

Means in columns followed by the same letter do not differ significantly (P<0.05).

Pasture mass and horizon were the only significant predictor variables (appendix table 3.1) of the similarity coefficient between the botanical composition of OE and pasture horizons (table 3.13). Regression analyses was used as numbers of 6cm horizons were greater for the higher pasture masses. Surprisingly no animal species effects were detected.

Table 3.13 Similarity coefficients between oesophageal extrusa and pasture horizon botanical composition for pasture mass and horizon.

	PM 1	PM 2	PM 3	PM 4
Horizon				
Entire pasture	0.64a	0.58a	0.61b	0.61b
0-6cm	0.62a	0.55a	0.52a	0.55a
above 6cm	0.80b	0.69b	0.78c	0.73c
6-12cm	0.97c	0.72b	0.76c	0.73c
above 12cm	0.95c	0.67b	0.77c	0.76c
12-18cm			0.94d	0.91d
above 18cm			0.91d	0.96d
18-24cm				0.92d

Means in columns followed by the same letter do not differ significantly (P<0.05).

Interpreting the similarity coefficients between OE and pasture horizon botanical composition is difficult if not impossible without bite depth data which identifies the horizon grazed. High similarity coefficients in the surface horizons can be interpreted as largely indiscriminate sampling from these horizons. They may however simply have a composition similar to that of the horizon where the animal grazed. Similarly, progressively lower similarity coefficients closer to ground level may reflect considerable discrimination if these horizons were indeed grazed or may simply suggest their composition was markedly different to other horizons in the pasture and they were not grazed.

3.6 Discussion

3.6.1 Equality of pasture allocation

Interpretation of results from multi species grazing trials depend on all species having "equal grazing opportunity" throughout the trial period. In this trial the interspecies mean maintenance requirement was used as a means of equilibration for determining pasture allocation (table 3.1). Unless all animal species select similar amounts of each pasture component from the same horizon there can never be equal opportunity except for a short period at the start of the trial. All trials of this nature are destined to be flawed in this way. For mixed pasture (for example ryegrass white-clover) where the opportunity exists to selectively graze alternate pasture species as well as individual plant components within species, stable conditions are impossible to meet especially if the grazing species have unique grazing strategies. Describing mixed pastures in terms of PM alone therefore, provides only a crude measure of the structure and composition of pasture. For example, on PM 3 mean mass did not change during the trial (table 3.4), but the distribution (figure 3.1.3) and botanical composition (figures 3.3.1 to 3.3.3) differed among the animal species treatment sites. Pasture components in the diet also differed among the three animal species (table 3.11).

3.6.2 Species intake

Mean herbage intakes in this trial (77.8, 60.0 and 48.7 ± 2.67 gDOM/kg$^{0.75}$/d for calves lambs and kids respectively, table 3.7) were similar to those of comparable animals grazing temperate pastures of equivalent digestibilities at corresponding grazing pressures (Collins, 1989; Forbes, 1982; Jamieson and Hodgson, 1979b). For example the intake of the calves and lambs of similar age grazing pure ryegrass pastures were 85.6 and 77.7 ± 3.22 gDOM/kg$^{0.75}$ (Jamieson and Hodgson, 1979b). No comparable data was found for young goats. In all cited trials, animals were at least three months older than those used in this study.

Mean intake of calves was generally greater than lambs on all PM, although not always significantly. The mean intake of goats was consistently lower than lambs. Although pasture mass declined for most PM grazed by calves and kids (table 3.4) there was no consistent evidence of a decline in intake in the second 4 day measurement period. Intake within the species did not change markedly with as PM increased. However the lowest PM on day 8 was almost 2000kgDM/ha and all pastures were still predominantly vegetative.

3.6.3 Composition of the diet

Botanical composition of the diet differed among animal species (table 3.11, 3.12). The grazing strategy of all species appeared to be one of avoiding ingestion of dead material and although calves were apparently less successful than kids or lambs the amounts consumed were still very small (table 3.12). A wider muzzle and a tongue harvesting mechanism may have disadvantaged calves when compared to goats and sheep. However dead material was more difficult to avoid on the higher pasture masses and as the trial progressed (table 3.12). Collins (1989) also found that dead material increased in the diet of goats cattle and sheep as mixed pastures were progressively defoliated.

While botanical composition of diet selected by all species was similar on PM 1 (table 3.11), it differed as pasture mass increased. The low surface height of PM1 possibly constrained all species to graze the same horizon. Kids and lambs consumed similar proportions of grass and clover on all pasture masses. However calves consistently consumed the lowest proportion of clover and the highest proportion of grass although such differences were not always significant. It remains a point for speculation as to whether further dissection of oesophageal fistula boli into grass and clover subcomponents would have assisted the interpretation of these results. Collins (1989) found that cattle and goats were predominantly surface horizon grazers while sheep grazed the intermediate horizons where, it was speculated, they optimized the consumption of DOM. Unfortunately horizon cuts were not obtained regularly enough to allow such conclusions to be supported or refuted in this experiment.

3.6.4 Age of animal species and botanical composition

Age had no influence on dietary discrimination in either goats or sheep although there was a consistent trend at all PM for the diet of the younger animal in each species (ie kids and lambs) to contain more clover(table 3.11). Age was also found to have no effect on the botanical composition of the diet of sheep and cattle grazing predominantly ryegrass pastures (Hodgson and Jamieson, 1981; Hodgson, 1986), however no comparative information was found for goats. Older cattle were not included in the age comparison in this experiment because of the extra fencing and handling facilities that would have been required and because previous comparisons had found little differences in the botanical composition of the diet (eg Hodgson and Jamieson, 1981). As age of animal does not appear to influence either botanical composition or the digestibility of the diet (table 3.8), mature fistulated animals which are more robust and easier both to manage and obtain samples from could be used when the intake of young animals is being measured.

3.6.5 Diet quality

The similarity of the digestibility (OMD) of the diet selected by the three animal species (0.77, 0.81, 0.76 respectively; calves, kids and lambs, table 3.8) was unexpected. Sheep have generally been observed to consume a diet of higher digestibility than cattle (Jamieson and Hodgson, 1979b; Langlands and Sanson, 1976; Dudzinski and Arnold, 1973; Forbes, 1982). The mixed pasture in the present studies should have provided greater opportunity for selection and enhanced any differences in selectivity among animal species. On the other hand Collins (1989) found the digestibility of the sheep diet greater than that of the goat which was in turn greater than cattle. Similar mixed pastures and comparable pasture masses were used and although all the sheep, cattle and goats were at least 8 months older, age is not expected to have influenced diet quality or botanical composition. Diet quality in the current experiment was similar for all species probably because there was not sufficient difference in digestibility between components selected (clover vs grass, table 3.11) and because all species consumed very little dead material. In addition differences in botanical composition among species were not large.

Age within a species had no influence on diet digestibility (table 3.8). Generally only small differences have been found between diets selected by animals differing in age (Hodgson, 1986).

3.6.6 Identification of grazing strategies

While significant changes occurred in both the pasture mass and botanical composition of horizons grazed by all species at each pasture treatment (figures 3.1.1 to 3.1.4 and 3.3.1 to 3.3.4) the results were difficult to interpret. There was evidence that the animal species were employing different grazing strategies based on diet composition and changes in the mass and composition of the pasture canopy, however characterization of such strategies was not possible. More regular and representative sampling of the pasture horizons would have been required. Collins (1989) subsequently overcame many of the limitations noted here by sampling a more representative area at daily intervals and relating the horizon changes to daily intake.

3.7 Conclusions

While differences in intake and diet composition occurred, isolating cause and effect was impossible due to the heterogeneous nature of the mixed pastures which required a greater number and frequency of pasture canopy measurements. It was, however the first trial in which the grazing strategy of goats were compared with sheep and cattle under a range of pasture conditions.

The diet of the kid was intermediate between that of the lamb and calf and of a similar digestibility. On intensively managed temperate pastures the dietary overlap of the three species suggests competition rather than complementarity. For example on PM 1 the young of all species consumed a similar diet. Such a finding is probably more a reflection of lack of opportunity on this the lowest PM rather than a reflection of species grazing or selection strategy. However the importance of understanding the influence of structure was highlighted by the trend for clover content in the diets of kids and goats to rise as PM increased while that of lambs, sheep and calves appeared to decrease. It was not possible to equate grazing opportunity for the three species, nor was it possible to identify unique species grazing strategies. On a metabolic liveweight basis calves had the highest intake followed by lambs and kids although the latter species did not always differ.

Progress in grazing studies requires a detail understanding of pasture induced modifications of an animal's grazing strategy via changes in grazing behaviour. Such conditions can only be adequately satisfied where pasture composition and structure are related to bite and intake variables over grazing periods of short duration.

Chapter 4

Experiment Two

Sward structure and grazing behaviour

4.1 Introduction

In experiment one the diet composition and intake of the three animal species responded differently to variation in pasture mass, implying different grazing strategies. Such strategies could not be related to pasture conditions, because of the imprecise nature of the animal and pasture measurements used. The objective of this trial was to develop techniques that would enable the effect of changes in pasture conditions on ingestive behaviour to be measured more directly.

4.2 Materials and methods

In early autumn two rising one year calves, two 14 month old goats and two similarly aged ewes were penned separately indoors and fed *ad libitum* on lucerne hay and a pelleted concentrate. Both calves and both goats had similar bodyweights 92, and 20kg respectively but one sheep weighed 45 and the other 57kg. Prior to being brought indoors, all animals grazed together on a fenced off area of the pasture used during the trial. Once indoors animals were accustomed for one week to grazing turfs cut from this pasture. Three animals from each species were originally introduced and those which consistently grazed the edges or destroyed turfs were rejected.

Each animal grazed 3 freshly cut turfs (0.35m^2, mean height 12.8cm mean PM 4718kgDM/ha) for at least 4 successive grazing periods and in some instances six, with the exception of calf 100 which in two instances demolished the turf, hence the missing values (appendix table 4). All animals willingly grazed the turfs at all times even though other feed sources were not removed. If the turf broke up or the animal pulled up roots and soil all measurements on that particular turf were abandoned. When time allowed this turf was replaced and all four grazings repeated. Detailed agronomic measures between grazings normally meant animals grazed their first turf about 10.30h their second around 13.30h and their final turf at about 15.45h. Only one of the 6 animals grazed turfs each day during the 6 day measurement period.

The turf was weighed to the nearest 0.5g, before and after grazing and the grazed status and height of 40 representative labelled tillers and stolons was recorded and the number of prehending bites and the duration of each grazing period was noted. In an attempt to keep errors associated with estimating intake to below 5% the period of grazing was increased with each successive grazing period on a turf so that where possible 20 to 30g of fresh pasture was consumed at each grazing. Intake and bite variables (BW, IR, BD, BA) were related to pasture mass and height (PM and SH) for each grazing period.

4.3 Pasture preparation

The pasture a 5 year old ryegrass-dominant ryegrass-white clover (*Lolium perenne/Trifolium repens*) of unknown endophyte status, was prepared by mowing to ground level eight weeks prior to the start of the trial and irrigating as required. Each day during the measurement period 5 turfs 45 x 35cm (0.158 m^2) were cut (soil depth 15cm) using a guide frame (46 x 36cm) and two people with spades. Swards were then wedged into cardboard boxes (dimensions 45 x 35 x 15cm) with soil to prevent disintegration during grazing, and then transported to the pens.

4.3.1 Botanical composition

At least 100 contacts with an inclined point hit quadrat device (Grant, 1981) was used to estimate botanical composition of turfs prior to grazing. At least six quadrats were taken diagonally in each corner and at the midpoint on the long sides of the turf, with minimal disturbance of the sward. The pasture was parted using a brass needle to record hits especially in close proximity to the soil. Contacts were divided into grass leaf, stem and seed head and clover leaf, petiole, stolon and flower, and dead material.

Each boxed turf was divided into an imaginary grid based on 8 sectors by length (commencing 2.5cm in from each end) and 5 sectors by width. The side of the box was marked to identify individual grids. A representative tiller or stolon was chosen within each of the 40 areas defined by the grids prior to grazing and labelled at ground level with plastic coated wire (< 1mm diameter). The highest point of each component of grass tillers above ground level was measured with a cut down ruler. Height of pseudostem between the ground and the first leaf (PS1), pseudostem between the two lowest leaves (PS2), and height of all leaves numbered from the ground up (L1, L2, L3, L4) were measured. In the case of clover, leaf height only was measured prior to grazing and petiole height once the leaf had been removed by the grazing animal.

Such a system of identification of individual plant units in a regular pattern over the entire turf reduces the opportunity for animals to graze areas where pasture conditions have been inadequately described. It should then be possible to extrapolate from the changes that have occurred between successive grazings in the labelled tillers to estimate diet composition. In addition, changes in sward structure and composition can be related to behavioural components of intake.

Botanical composition of the plant material consumed at each grazing was estimated by disappearance of components of the labelled tillers. Comparisons of the estimated botanical composition of the diet and that of the horizons grazed have also been based on labelled tiller components.

4.3.2 Pasture mass

Pasture mass was estimated by eye on a site of uniform height (approximately 15cm) and composition for the paddock before the turf was cut. In addition to the 3 turfs cut daily for grazing a further two were cut, one for calculating insensible weight loss (the standard turf) during grazing and the other for estimating the dry matter percentage (DM%) of the grazed horizon and PM. The latter was calculated by cutting to ground level after grazing and drying to constant weight at 70°C then adding back the dry weight of the grazed material estimated from corrected turf weight changes due to grazing and the DM% of the grazed horizon. Thus PM could be calculated at the start of each individual grazing on a turf. PM of turfs prior to grazing did not differ significantly during the 6 day trial (grand mean 4718 ± 149 kgDM/ha). Each day one of the boxed turfs was cut in 3cm horizons (with horizon cutting equipment previously described in section 3.2.1.1) from the sward surface to ground level. A subsample of each horizon was weighed and dried to constant weight at 70°c.

4.3.3 Pasture height

Pasture surface height (SH) was the mean of the highest component on each of the forty labelled plant units (tillers or stolons). Height above ground level of each component of the labelled plant units was measured with a cut down ruler to the nearest 0.5 cm and recalculated at the start of each grazing period.

4.3.4 Grazed height

Grazed height (GH) was calculated as the mean height of all plant components of the forty labelled plant units which had decreased in height during a grazing and/or had been assessed as grazed. The height of grazed plant components did not always decrease, especially the upper leaves of the labelled tillers which had been semi-prostrate prior to grazing and assumed a more erect habit when a considerable portion of their mass was removed. Such an effect was generally confined to the first two grazings.

4.3.5 Bite depth

Bite depth (BD) was calculated as the difference between SH at the start and the GH at the completion of a grazing period. Such a calculation assumes that an animal grazes uniformly down from the top of a pasture and takes only one bite at a particular bite site between measurements. As the turfs were not subject to treading, grazing was the only means by which reduction in height could occur.

An alternative measurement of bite depth was investigated where the change in height for all recorded plant components grazed at a particular grazing was used as an indicator of grazed depth (GD). As for BD, this measure of GD was also hampered by leaf that had been freshly grazed increasing rather than decreasing in height even though most of the leaf had been consumed. This alternate measure does not assume that grazing starts from the surface of the pasture but does assume that the reduction in height is due to a single bite and not successive bites at the one site between measurements. Thus this measure of GD is a mean of the reduced height of grazed plant units in the pasture and does not reflect length of plant units removed except in upright uniform swards.

4.3.6. Bite weight

Bite weight (BW) was the difference between pre and post grazing turf weight corrected for insensible weight loss divided by the number of prehending bites during the grazing period. Each day a spare ungrazed turf (standard turf) similar to those allocated to be grazed was weighed at noted times encompassing all turf grazings so that insensible weight loss could be calculated.

$$BW = ((W_1 - W_2)+(W_3 - W_4)/(T_4 - T_3)*(T_2 - T_1))/(NPB)$$

Where: BW is bite weight (g)

W_1 pre-grazing turf weight at time T_1.

W_2 post-grazing turf weight at time T_2.

W_3 weight of the standard turf at time T_3.

W_4 weight of the standard turf at time T_4.

NPB number of prehending bites in the period $(T_2 - T_1)$.

Time was measured in seconds and weight in g. BW was initially expressed in g of fresh material and subsequently converted to DM (mgDM/kg and mgDM/$kg^{0.75}$) to enable comparisons between species and with published data. Bite depth was used to identify the horizons which the animal grazed and the appropriate DM% for these horizons from the sampled turf were used. Liveweight was the mean liveweight during the measurement period.

4.4 Animal measurements

All animals used were selected initially on liveweight and finally selected on their adaptability to the penned conditions and their readiness to graze turfs. With the exception of the goats all had extensive previous handling and were accustomed to being confined indoors.

4.4.1 Bite rate

Bite rate (BR) was recorded (where both sound and head movement indicated a prehending bite) by playing back a video of each grazing filmed less than 50cm from the turf being grazed. BR is expressed in prehending bites per min.

4.4.2 Intake rate

Intake rate (IR) is the product of BW and BR and was calculated as g fresh material per animal min^{-1}, mgDM kg^{-1} min^{-1} and mgDM $kg^{-0.75}$ min^{-1}.

4.4.3 Bite area

Bite area (BA) cm^2 was calculated by dividing the pregrazing PM gDMcm-^{2} above the grazed height calculated from inclined hit quadrat data by BW. Hits by height were weighted by the DM% of the horizon corresponding to that height relative to the mean DM% for each turf. It was assumed that all plant hits (contacts) had equal mass. PM above the grazed height (gDM cm^{-2}) prior to grazing was the product of the proportion of total hits above the grazed height and the total turf PM. Finally BA was calculated as

$$BA = BW/D$$

Where: BA is bite area, cm^2.

BW is bite weight gDM

D is PM above the grazed height $gDMcm^{-2}$

BA could be calculated for each grazing on a turf by reducing the PM in the grazed horizon by the corrected change in turf weight and adjusting this for changes in grazed height. These results have not been presented in the later grazings of a turf (beyond grazing 3) as the PM remaining in the horizon being grazed was often nil yet BW data indicated otherwise. As suggested earlier there are large inherent errors in estimating both grazed height and PM above the grazed height. For these reasons BA has been presented only for the first grazing of a turf.

4.5 Statistical analysis

Raw data manipulation, analyses of variance (ANOVA) and regression analyses were performed with the STATISTIX II interactive statistical analysis program for microcomputers (NH Analytical Software, Roseville, Minnesota 1985). As only one animal grazed on any day, it was not possible to estimate variation due to day of grazing. In ANOVA's the animal * grazing * turf interaction was used as the error mean square term.

4.6 RESULTS

All animals grazed their turfs eagerly even though other feed was not withdrawn. One of the calves (calf 100), was over-vigorous when grazing, uprooting grass on three occasions.

4.6.1 Pasture mass

Pre-grazing PM and SH was similar for all turfs (4718 ± 149kgDM/ha; 12.8 ± 0.3cm). Both PM and SH were significantly reduced by grazing but the reduction in PM between grazings and mean PM after 4 grazings were similar for all species (table 4.1). Intake and bite variables among animal species were therefore compared at each of the four grazings.

Table 4.1 Mean pasture mass (kgDM/ha) of turfs at the beginning of each of four grazings for calves, sheep and goats.

	Animals								
Grazing	Calf 100	Calf 104	Mean Calf	Sheep 141	Sheep 26	Mean Sheep	Black Goat	Brown Goat	Mean Goat
1	4477a	5090a	4783a	4477a	4657a	4567a	4748a	4860a	4804a
2	4030a	4650ab	4342ab	3880ab	4287ab	4083ab	4223ab	4470ab	4347ab
3	3470ab	4170ab	3770bc	3257bc	3837ab	3547bc	3787ab	4130ab	3958bc
4	2881b	3727b	3335c	2640c	3503b	3072c	3483b	3710b	3597c
Mean	3715	4410	4057	3563	4071	3817	4060	4292	4176

Means in columns with the same letter do not differ ($P<0.05$)

4.6.2 Bite weight

Mean bite weights have been expressed as mgDM per kg metabolic liveweight for each species (table 4.2). The pattern of reduction in bite weight with successive grazings were not similar for all species. Mean bite weights of calves were consistently lower than the sheep and goats at all grazings. Sheep had a similar BW for the first 3 grazings and cattle for the first 2, but goat BW declined significantly after grazing 1 (eg BW decreased by 31% between grazing 1 and 2) but was similar for grazings 2, 3 and 4. The decline in cattle bite weight appeared gradual with each successive grazing. Bite weight of individual sheep and cattle differed significantly.

Table 4.2 Mean bite weights (mgDM/kg$^{0.75}$) of calves, sheep and goats over four grazings on three turfs each of the same pregrazing height, composition and mass.

	Animals								
Grazing	Calf 100	Calf 104	Mean Calf	Sheep 141	Sheep 26	Mean Sheep	Black Goat	Brown Goat	Mean Goat
1	6.7a	8.8a	7.7a	15.3a	7.8a	11.5a	15.5a	13.2a	14.3a
2	6.5a	6.5b	6.5ab	13.5b	7.8a	10.7a	10.8b	8.9b	9.9bd
3	5.0b	3.7c	4.3bc	12.3b	5.3b	8.8a	6.3c	8.6b	7.5cd
4	4.6b	2.7c	3.7c	5.8c	4.2b	5.0b	4.8d	6.8c	5.8d
Mean	5.7	5.4	5.6	11.7	6.3	9.0	9.4	9.4	9.4

Means in columns followed by the same letter do not differ (P<0.05)

4.6.3 Bite rate

Bite rate was greater (29.7 prehending bites/min) on the third turf grazed each day than the previous two (25.7 and 25.2 for turf 1 and 2 respectively). Turf effects on BR may reflect a diurnal pattern as grazing on turf 3 was normally not completed until late afternoon. It may, however, simply reflect familiarity with turf grazing or an increase in DM content of the pasture as the day progressed.

There was a significant species*grazing interaction for BR (table 4.3). Both sheep and goats maintained a similar BR at all grazings although the mean BR of sheep was consistently higher than that of goats. While BR at grazing 3 for sheep was significantly lower than at grazing 1, this has been considered a chance effect as it increased at grazing 4. Calves maintained a higher BR than goats for the first 2 grazings (not significantly so), but this declined rapidly at successive grazings. Although the mean BR of calves at grazing 4 was lower than that of goats the difference was not significant. There were no differences between animals within species in BR.

Table 4.3 Mean bite rate (prehending bites/minute) of calves, sheep and goats over four grazings on three turfs, each of the same pregrazing height composition and mass.

	Animals								
Grazing	Calf 100	Calf 104	Mean Calf	Sheep 141	Sheep 26	Mean Sheep	Black Goat	Brown Goat	Mean Goat
1	32.4a	24.6b	28.5a	43.6a	38.1a	40.8a	25.1ab	18.6b	21.8a
2	26.7b	29.1a	27.9a	35.6b	37.0ab	36.8ab	27.7a	23.7a	25.7a
3	16.8c	17.5c	17.1bc	33.0b	33.7b	33.3b	23.7b	22.6a	23.1a
4	7.0d	19.5c	13.2c	40.1a	27.9c	34.0ab	16.9c	23.2a	20.0a
Mean	23.4	22.0	22.7	38.2	34.2	36.3	23.4	22.0	22.7

Means in columns followed by the same letter do not differ ($P<0.05$)

4.6.4 Intake rate

As expected there were only minor changes in rankings when IR was expressed on a metabolic liveweight versus a liveweight basis (ie mgDM/kg$^{0.75}$/min vs mgDM/kg/min). Mean intake rate has been presented (table 4.4) on a liveweight basis, as the majority of the published literature is also in this format.

Table 4.4 Mean intake rate (mgDM/kgLW/min) of calves, sheep and goats over four grazings on three turfs each of the same pregrazing height, composition and mass.

	Animals								
Grazing	Calf 100	Calf 104	Mean Calf	Sheep 141	Sheep 26	Mean Sheep	Black Goat	Brown Goat	Mean Goat
1	70a	67a	68a	250a	107a	178a	185a	112a	149a
2	56ab	61a	58ac	183b	102a	143ab	134b	100ab	117ab
3	27b	20b	24bc	158b	61b	109b	72c	92ab	82bc
4	10b	18b	14b	91c	42b	67c	38c	72b	55c
Mean	41	41	40	170	78	124	107	94	100

Means in columns with same letter do not differ ($P<0.05$)

Mean IR of sheep was greater than that of goats which in turn was greater than that of calves (124 vs 100 vs 40mgDM/kg/min respectively, table 4.4). Although IR also declined between successive grazings (139 vs 112 vs 73 vs 43mgDM/kg/min) the pattern of decline in IR for all species was similar for successive grazings. However while the decline in IR was similar for sheep and goats between grazing 1 and 4 (IR at grazing 4 was 38 and 37% respectively of that a grazing 1), for cattle it declined to only 21% of that at the first grazing. Differences in IR between individual animals within species (eg the calves) were detected.

4.6.5 Grazed height

Grazed height was lower on turf 1 than on turfs 2 and 3 (7.5 vs 8.1 and 8.0cm respectively). While species and grazing both influenced GZH the species*grazing interaction just failed to attain significance (ie P<0.06). Cattle and goats grazed to a similar height but sheep grazed consistently lower (9.0, 8.5 and 6.1cm respectively Table 4.5). Grazing height decreased progressively with successive grazings (9.8, 8.4, 6.9, 6.3cm for grazing 1, 2, 3 and 4 respectively). Apart from initial species differences the pattern of decline in GZH with successive grazings was similar.

Table 4.5 Mean grazed height (cm) of three turfs of similar pregrazing height, composition and mass when grazed by calves, sheep and goats in four grazing periods.

	Animals								
Grazing	Calf 100	Calf 104	Mean Calf	Sheep 141	Sheep 26	Mean Sheep	Black Goat	Brown Goat	Mean Goat
1	11.8a	11.3	11.5a	6.3	9.2	7.7a	10.2	10.3	10.2a
2	9.17b	9.7	9.4b	6.8	7.3	7.0a	9.3	8.3	8.8b
3	8.0	7.1	7.5c	5.1	5.7	5.4b	8.8	6.9	7.9bc
4	7.8d	7.0	7.4c	3.9	4.5	4.2c	8.4	5.9	7.1c
Mean	9.2	8.8	9.0	5.5	6.7	6.1	9.2	7.8	8.5

Means in columns with the same letter do not differ (P<0.05)

4.6.6 Bite depth

While SH was effected by both animal species and grazing, the species*grazing interaction was not significant. Surface height was higher on turfs grazed by calves than by goats, which in turn was higher than on turfs grazed by sheep (11.7, 11.2 and 10.0cm on calf goats and sheep turfs respectively, Table 4.6).

Table 4.6 Mean surface height (cm) on three turfs of the same pregrazing height, composition and mass when grazed by calves, sheep and goats in four grazing periods.

	Animals								
Grazing	Calf 100	Calf 104	Mean Calf	Sheep 141	Sheep 26	Mean Sheep	Black Goat	Brown Goat	Mean Goat
1	13.5	13.1	13.3a	12.0	13.9	12.4a	13.0	12.3	12.6a
2	12.5	12.6	12.5a	9.7	12.3	11.0b	12.4	11.4	11.9a
3	10.6	11.5	11.0b	8.4	10.2	9.3c	11.4	10.0	10.7b
4	9.7	9.7	9.7c	6.9	8.0	7.5d	10.5	8.5	9.5c
Mean	11.6	11.7	11.7	9.0	11.1	10.0	11.8	10.6	11.2

Means with the same small letter do not differ (P<0.05)

Surface height decreased with successive grazings and was 12.8, 11.8, 10.5 and 9.1cm on turfs at grazing 1 to 4 respectively. The pattern of decline in surface height was similar for all species although SH differed among species. Individual animals within a species did not influence SH.

Bite depth (BD) was similar for goats at all four grazings, gradually decreased in sheep with each successive grazing and increased for calves from grazing 1 to 3 and then decreased (table 4.7).

Table 4.7 Mean bite depth (cm) of calves, sheep and goats grazing three turfs of the same pregrazing height, composition and mass.

Grazing	Mean Calf	Animals Mean Sheep	Mean Goat
1	1.8b	4.7a	2.4a
2	3.1ac	4.0ab	3.1a
3	4.0a	3.9ab	2.8a
4	2.7bc	3.2b	2.4a
Mean	2.9	4.0	2.7

Means in columns with the same letter do not differ (P<0.05)

Bite depth was also estimated from the reduction in grazed labelled plant unit height between successive grazings. Grazed depth were similar for all species (0.5, 0.3, 0.6cm for calves, sheep and goats respectively) and was not influenced by grazing, turf or animal within species. Many GD values were negative as post grazing height - especially of grazed leaf - was greater than that pregrazing.

4.6.7 Bite area

Bite area (BA) was only calculated for the first grazing on a turf to minimize potential errors. Two and half-fold differences in BA between animals were not significant (table 4.8) which is not surprising when coefficients of variation were 34, 81 and 24% in goats, calves and sheep respectively. Considerable improvements in the accuracy are required in the techniques used to measure grazed height and pasture mass per unit area above the grazed height, if accurate estimates of bite area are to be obtained. Calf 100 destroyed 2 turfs during the trial and may have been a more cautious grazer as a result. Turf destruction occurred because the turfs were not sufficiently heavy or packed tightly enough into the box to prevent disintegration while grazing with the associated loss of soil.

4.6.8 Regression analyses of major bite and intake variables

Bite weight, BR and IR of calves sheep and goats were regressed against PM and SH (table 4.9). Neither the range of PM or SH in this experiment influenced BW, BR or IR of sheep. While goat BW decreased as PM declined, neither BR or IR were responsive. Similarly when SH was substituted for PM, BW was the only variable which responded, decreasing as SH decreased. In contrast to goats, cattle BR rather than BW decreased with declining PM and IR also decreased. Cattle were more sensitive to the decline in SH than PM as BW, BR and IR decreased.

Table 4.8 Bite area (cm^2) for calves, sheep and goats grazing three separate turfs of similar pregrazing height and mass.

	Animals		
	Goat	Calf	Sheep
Mean	14.1	35.0	17.8
		SED 9.0	

Table 4.9 Regression relationships between bite and intake variables and pasture mass and height for calves, sheep and goats.

Species	Regression equation	Significance	R^2 (adjusted)
cattle	BW = 0.54 + 0.00302 ± 0.00021PM	NS	4.3%
sheep	BW = 1.71 + 0.00043 ± 0.00008PM	NS	0.9%
goat	BW = - 2.76 + 0.00171 ± 0.0005M	***	33.6%
cattle	BR = - 4.54 + 0.00653 ± 0.0021PM	***	29%
sheep	BR = 41.8 - 0.00146 ± 0.0017PM	NS	0.0%
goat	BR = 27.9 - 0.00124 ± 0.0019PM	NS	2.6%
cattle	IR = - 26.2 + 0.0167 ± 0.007PM	**	18.3%
sheep	IR = 87.3 + 0.0097 ± 0.004PM	NS	0.0%
goat	IR = - 29.2 + 0.0311 ± 0.016PM	0.06	10.8%
cattle	BW = 1.45 + 0.275 ± 0.092SH	***	28.1%
sheep	BW = 2.57 + 0.079 ± 0.028SH	NS	0.0%
goat	BW = - 1.01 + 0.480 ± 0.220SH	**	14.0%
cattle	BR = - 17.3 + 3.390 ± 1.020SH	***	33.5%
sheep	BR = 34.5 + 0.163 ± 0.126SH	NS	0.0%
goat	BR = 19.0 + 0.325 ± 0.781SH	NS	0.0%
cattle	IR = - 98.5 + 12.0 ± 2.827SH	***	46.0%
sheep	IR = 95.3 + 2.89 ± 1.213SH	NS	0.0%
goat	IR = - 36.5 + 12.2 ± 6.455SH	0.07	10.1%
Where	BW = bite weight mgDM/kgLW		
	BR = bite rate bites/min		
	IR = intake rate mgDM/kgLW/min		

4.6.9 Botanical composition

There was no significant difference in the mean botanical composition of the three turfs offered to each animal. Means and standard errors were respectively; green grass leaf 41.2 ± 2.6%, pseudostem 11.5 ± 0.7%, grass seed head 0.0%, clover leaf 7.3 ± 1.3%, clover petiole 10.0 ± 1.0%, clover flower 1.0 ± 0.2%, dead matter 29.0 ± 2.2%. Although turfs contained considerable amounts of dead material, a normal feature of such PM in early autumn, it was confined to the lower 5cm.

4.6.9.1 Botanical composition of the diet

Dietary composition, estimated from the sum of plant components grazed at the first grazing only, were used to compare dietary composition among species and at all four grazings for within species comparisons. There were no significant differences between species (table 4.10) after the first grazing. Although sheep consumed greater proportions of grass leaf 1 and pseudostem 2, than goats or calves such differences did not attain significance. No further comparisons were made between species as diet composition may have increasingly reflected between species differences in pasture allocation and the amount and composition of material consumed at previous grazings rather than grazing strategies peculiar to a species. Within species differences occurred between the sheep and the goats and were related to differences in the grazed height for pseudostem above leaf 1.

4.6.9.2 Diet composition relative to that of the grazed horizon

When the botanical composition of the diet was compared with the horizon grazed (above the grazed height) at the first grazing only, species differences arose. Goats consumed a smaller proportion of leaf 1 and calves more of leaf 2, than that present in the grazed horizon. The two sheep differed in their response. Sheep 141 consumed a greater proportion of pseudostem 2 while sheep 26 consumed a smaller proportion of pseudostem and leaf 1, but greater proportions of leaf 2 than the mean proportions in the horizon being grazed (table 4.10).

Coefficients of similarity imply goats were least discriminating but paucity of animal replication makes further extrapolations unwise.

4.7 Discussion

4.7.1 Bite weight

Sheep bite weight (range 90 to 210 mgDM grazing 4 vs.1) were similar to those published for predominantly pure grass pastures (eg 10 - 200, Black and Kenney, 1984; 25 - 420 mgDM Hodgson, 1986). Although the cattle bite weights were low compared with the other species (mean 1.75mgDM/kgLW or 5.6mgDM/kg$^{0.75}$ table 4.2) they are very similar to those reported for young cattle grazing pure ryegrass (0.63 - 1.26 Jamieson and Hodgson, 1979b; 0.99 - 1.17 mgOM/kgLW Forbes and Hodgson, 1985), if OM is assumed to be 0.90 * DM. The published data were obtained from longer term trials where intake was measured over days rather than seconds and where pasture, weather and soil conditions may have changed appreciably during the measurement period. No comparative data were located for goats.

Table 4.10 Mean botanical composition of the diet selected and of the pasture at the start of grazing on offer above the mean grazed height (cm) and similarity coefficients for calves, sheep and goats.

Animal		grazed height	leaf 1	leaf 2	leaf 3	leaf 4	legume	pseudostem 1	pseudostem 2	Similarity coefficient
calf 100	diet		0.07	0.48*	0.36	0.01	0.05	0.0	0.03	0.81
	sward	9.2	0.16	0.29	0.37	0.03	0.08	0.01	0.06	
calf 104	diet		0.11	0.51*	0.30	0.03	0.05	0.00	0.00	0.74
	sward	8.8	0.15	0.35	0.37	0.02	0.08	0.00	0.03	
sheep 26	diet		0.12	0.34	0.30	0.02	0.07	0.02	0.14*	0.88
	sward	6.7	0.17	0.38	0.33	0.01	0.06	0.01	0.04	
sheep 141	diet		0.08*	0.41*	0.34	0.04	0.06	0.01	0.06*	0.81
	sward	5.5	0.16	0.28	0.29	0.03	0.06	0.02	0.16	
black goat	diet		0.07*	0.37	0.44	0.03	0.04	0.01	0.04	0.87
	sward	9.2	0.18	0.32	0.39	0.01	0.06	0.00	0.03	
brown goat	diet		0.07*	0.38	0.35	0.03	0.05	0.00	0.12	0.91
	sward	7.8	0.14	0.31	0.34	0.05	0.04	0.00	0.12	

* difference between diet and horizon composition significant (P<0.01).

Goat bite weight was very sensitive to changing pasture conditions declining by 31% between grazing 1 and 2, unlike calves and sheep where BW did not decline until at least the third grazing and even then only gradually (table 4.2). In the regression analyses (table 4.9) goats were the only species where declining pasture mass reduced BW. It is difficult to imagine that the goat removed all preferred pasture components at this first grazing as there was only minimal evidence that it preferentially consumed horizon components (table 4.10) or that a PM in excess of 4000kgDM/ha, 40% of which was leaf, constrained intake. Goats may prefer to consistently graze fresh pasture.

When pasture allocation was expressed as SH, BW of both cattle and goats decreased as SH was reduced. Cattle BW appears more sensitive to a reduction in SH than PM. Such an effect cannot be explained by a bigger proportional change in SH versus PM in this experiment as the reduction in both over the first 3 grazings was identical (29%). Sheep bite and intake parameters were insensitive to both declining PM and SH.

4.7.2 Prehending bites

The range of bite rates for sheep and cattle (table 4.3) fall within the lower end of the published range (22 - 94; and 20 - 66 bites/min for sheep and cattle respectively (Hodgson, 1986)), probably as a consequence of the large bite weights. The goat was apparently unwilling to compensate for declining BW at the second and subsequent grazings by increasing BR, even at what are considered high pasture masses (table 4.1). Bite rate of both sheep and goats were unchanged as both PM and SH decreased. As pasture conditions restrict BW, animals normally respond initially by increasing BR in an attempt to maintain IR (eg Hodgson, 1986). Although goat BW decreased significantly over the 4 grazings there was no evidence of a compensatory increase in BR. Cattle were the only species where BR decreased significantly as pasture mass and surface height declined (table 4.14). Again it is unclear why BR declined especially as BW was unaffected by the decrease in PM and SH and BR was already at the low end of the expected range (22 vs 20-66 table 4.3 and Hodgson, 1986). It seems unlikely that mastication requirements restricted BR especially as BW was unchanged, even though bite depth increased with successive grazings increasing the possibility that structurally stronger plant material was harvested.

4.7.3 Intake rate

While the IR for cattle falls within the reported range (13 - 204 mgOM/kgLW/min Hodgson, 1986) the mean for sheep (124 mgDM/kgLW/min or 328mgDM/kg$^{0.75}$/min, table 4.4) is considerably greater than the recently reviewed range (22 - 80 mgOM/kgLW/min, Hodgson, 1986) even if allowance is made for the conversion of DM to OM. However considerably higher rates have been recorded for sheep on mixed ryegrass white clover pastures (109 mgDM/kgLW/min, Milne *et al.*, 1982) or on pure subclover artificial pastures (350 - 600 mgDM/kgLW/min, Kenney and Black, 1986) assuming sheep liveweight is 40kg. No comparative data were found for goats which on a metabolic liveweight basis had IR intermediate between that of sheep and goats (213 vs 328 and 112mgDM/kg$^{0.75}$/min for goats, sheep and cattle respectively, table 4.4).

Cattle were the only species whose IR declined as PM and SH were reduced (table 4.10). Again such a result was unexpected as SH and PM even after at the final grazing would not normally be considered to constrain intake rate.

4.7.4 Within species variation in bite and intake variables.

Although not emphasised during this discussion the turf technique is sensitive enough to identify within species variation in grazing behaviour (eg table 4.2) as it enables rapid grazings of similar pastures by a representative group of animals. As only two animals of each species were used in this trial, to enable all measures to made on pasture of similar structure and maturity, and the emphasis was on among species differences, little can be said about the differences identified between animals within a species in grazing behaviour.

4.7.5 Sensitivity of goat bite variables to defoliation

As discussed in section 4.6.1, goats were the only species whose bite weight declined with pasture mass (table 4.10). The major component of this decline occurred between the first and second grazings which suggests that goats were sensitive to even the smallest decline in SH and PM or that they had removed the preferred components and desired fresh pasture. Collins (1989) also found goat intake to be very sensitive to very small changes in pasture mass on similar pastures and suggested that the grazing strategy of goats may involve the harvesting of new plant growth. Goats appeared reluctant to sample different horizons as grazings progressed as their bite depth did not change (table 4.7).

Goats showed a reluctance to graze the oldest leaf, leaf 1, within the horizon being grazed. Such a rejection of older leaf again suggests that part of the grazing strategy of goats may be the avoidance of older plant material as leaf one contributed between 14 and 18% of the pasture on offer in the grazed horizon (table 4.11). It may be, however, that the harvesting mechanism of the goat is not well suited to prehending the structurally stronger older leaf.

4.7.6 Bite dimensions

Goats had the smallest bite depth of all species and this was unchanged as PM and SH declined(table 4.7). Mean bite depth of sheep gradually declined with successive grazings which suggest a lower barrier below which sheep were reluctant to graze. However this was not so as sheep decreased grazed height from grazing 1 to 4 more than any other species (54% vs 68 and 70% for sheep vs cattle and goats respectively table 4.5) even after grazing initially closer to the ground at the first grazing. Burlison and Hodgson (1985) predicted a bite depth for sheep of 4.2cm on 13cm all grass pasture, almost identical to the mean (4.0 cm table 4.7) obtained in this trial. Cattle may have increased BD with successive grazings (table 4.5) in a futile attempt to maintain IR as the bulk density of the surface horizon declined with successive grazings.

Bite areas were only presented for the first grazing (table 4.8) on a turf because of the difficulties in obtaining accurate estimates at subsequent grazings. Bite area for the sheep fell within the range of 9 - 35 cm^2 reported by Burlison and Hodgson (1985) and that calculated from the data of Black and Kenney (1984) 8.6 - 33 cm^2. Bite area for the calves was almost identical to those of rising two year Friesian cattle grazing similar pastures, 44 - 48 cm^2 (Mursan *et al.*, 1989). No comparative data was found for goats.

Illius and Gordon (1987) modelled the grazing process where bite area was a function of incisor width and did not change with pasture conditions, and suggested that mature animals of large species must experience a more severe intake restriction when grazing short swards than small species, because of greater restrictions in bite dimensions. The model identified bite depth as the major determinant of intake where pasture height was restricted. In the current trial the IR of goats the species with the smallest incisor width were contrary to predictions almost as sensitive as cattle to a reduction in surface height of the pasture (table 4.10). Goats may have evolved as a browsing animal that grazes.

4.7.7 Limitations of the turf technique

The turf technique did enable pasture structure to be more closely related to intake and bite variables than was possible in experiment 1 (chapter 3). However limitations in some measurement techniques (eg calculation of grazed depth or bite area) do not justify general extrapolation of the results. Bite depth could be calculated more accurately if all plant units were erect and the surface horizon was of uniform height, although it could be argued that such pastures are not "real". Calculation of bite area by the techniques outlined in this trial (section 4.4.4) have two major limitations:-

a) plant material contacted by the inclined point hit equipment is assumed to be of similar mass irrespective of its position in the pasture canopy.

b) measurements of grazed depth are not considered to be influenced by post grazing increases in plant height, even though height of some individual leaves increased when grazed.

An alternative method of calculating bite area is required even if it is destructive and prevents any subsequent grazing of a turf. Pastures ideally should be mono-cultures until the fundamental mechanisms by which the animal modifies grazing behaviour in response to changes in pasture structure are understood. After the completion of this trial polystyrene boxes were evaluated for turf packaging rather than cardboard. Turfs in such boxes did not disintegrate when grazed even by cattle as the turf could be tightly wedged in. In the future turfs should be wedged into polystyrene boxes thus preventing disintegration during grazing.

4.8 Summary experiment two

Grazing turfs for short time periods overcame the problem of unequal allocation of pasture among species and more importantly identified differences in grazing behaviour. All turfs pregrazing were of similar mass, height and composition and after 4 grazings of similar residual pasture mass. Weighing turfs pre and post grazings and the videoing of the grazing allowed BW, BR and GT to be accurately measured. Sheep grazed to a greater depth (mean grazed height 6.1cm vs 8.5 and 9.1cm for goats and calves respectively) than calves or goats. By recording the height and grazed status of individual leaves of 40 representative labelled tillers, differences in the botanical composition of the diet at the first grazing were identified. Goats preferentially consumed the youngest leaf avoiding old leaf even though it contributed over 30% of the leaf on offer in the grazed horizon. Calves preferentially grazed the second to oldest leaf; sheep, pseudostem above leaf 1. In terms of intake rate, cattle were the most sensitive species to declining PM or pasture surface height, followed by goats then sheep. Goats BW decreased between the first and second grazings when only minor changes in structure and composition had occurred which suggests factors unrelated to pasture structure were restricting intake, for example a desire to sample fresh pasture. Grazing in the field, such sensitivity may be masked by small modifications of grazing time.

The turf technique with modifications has the capacity to identify differences in some aspects of grazing strategy. However the extent to which pasture structure and/or composition can influence these differences is unknown. In the final series of experiments the turf technique was modified to investigate possible pasture responsive mechanisms determining intake rate for sheep and goats.

Chapter 5

Experiment Three

Sward structure, bite dimensions and bite force

5.0 Introduction

In this final experiment the techniques developed in the second experiment (chapter 4) to measure bite dimensions were refined. In addition, turfs were fixed to a modified force plate which enabled measurement of both the magnitude and direction of the resultant force used to sever each bite. The relationships between the force required to sever individual bites, bite dimensions and resultant bite weight and intake rate were studied. To maintain grazing momentum it is conceivable that an upper limit has evolved for force that an animal species exerts in prehension (peak bite force). Such a mechanism would avoid grazing fatigue from the exertion of variable bite forces and maintain a grazing rhythm. A consistent rate of jaw movement/minute of grazing time (harvesting plus mastication bites), is regularly observed when sheep graze temperate pastures (Penning, 1986). Bite dimensions of the grazing animal would in turn depend on the tensile strength of the pasture components within the horizon being grazed so that bite force was constrained below the upper limit.

Pasture components are likely to vary in tensile strength. For example, pseudostem would be expected to be more difficult to break than leaf and old leaf more difficult than new, assuming similar cross sectional area (Bignell, 1984). Therefore 4 trials were devised to provide such pasture conditions. In the first trial six sheep grazed turfs of three heights and three pasture treatments within a height designed to expose more pseudostem at a particular height. In the second, bite parameters of four sheep were compared for three pasture cultivars (immature white clover, prairie grass and tall fescue) where force to sever a bite was considered unlikely to restrict intake and bite variables; while the third examined the ability of sheep to alter bite dimension and biting behaviour when a grid was used to restrict bite depth during two consecutive grazings of 15cm ryegrass turfs. The final trial examined the comparative bite parameters of goats and sheep when grazing 15cm ryegrass pastures, in an attempt to explain the grazing strategies of these species.

All trials in the last experiment were performed at the Scottish Farm Building Research Centre in Aberdeen Scotland while on sabbatical leave at Hill Farming Research Organization in Edinburgh.

5.1 Materials and methods

Six healthy Scottish Blackface hoggets, sound of mouth and foot and of similar age, body weight (63.6 ± 2.1kg), birth status and body condition were selected for use in the first three trials. The four goats used in the final trial were Scottish feral adult females of unknown age and breeding but of similar weight (22.8 ± 0.8kg) and condition, with sound mouths.

In early summer, six weeks prior to the start of the first trial, 216 ryegrass (*Lolium perenne*) dominant turfs (area 0.1m^2, soil depth, 10cm), 72 at each of three heights (5, 10 and 15cm, measured with a HFRO sward stick), were carefully cut from an area of silage aftermath using a grid guide and wedged into polystyrene boxes and packed with soil, if necessary, to produce an even ground surface.

All harvested turfs received two dressings of nitrogen (equivalent to 80kgN/ha in total), one immediately after harvesting and the other two weeks prior to grazing. The 72 turfs at each pasture height were divided randomly into three groups of 24. One group was maintained at the harvested height by regular trimming (M), the second group cut 5 cm below the harvested height and allowed to regrow to the harvest height (G), while the third was permitted to grow 5cm beyond the harvested height and cut back to the desired height the day prior to grazing (C). These different pasture treatments (M,G,C,) were chosen to simulate common grazing practice. Treatment M mimiced continuous grazing; C, the midpoint of grazing down through a pasture; and G entry to regrowth, stages within a rotational grazing system. A rectangular grid (60 x 40cm) mounted on adjustable tripod legs was positioned at the desired height above the soil surface of the turf when trimming or cutting was required. Stiff wires were then threaded through guide holes at 2cm intervals from one side of the grid to the other causing a minimal disturbance to the pasture so that material above the wire could be removed by clippers and a vacuum cleaner.

All turfs were stored in a green-house and trimmed and watered as required. At least six spare turfs were prepared for each pasture height and pasture (M, G, C) treatment. Such turfs not used for animal familiarisation were used in trials three and four.

Pastures for the second trial were grown from certified seed (supplied by the DSIR Grasslands Division, Palmerston North, New Zealand) in a mixture of soil and potting mix in the same size polystyrene boxes as used for the pasture turfs in trial one. These pastures germinated and grew in a heated glass house. Pastures were at least 10 weeks old and 10cm high at grazing. Where possible, all such pastures were trimmed at least once prior to grazing to encourage root development.

5.2 Trial one - The influence of pasture height and density on bite dimensions and bite force.

The six sheep used in trial one were blocked into two groups of three. Treatments consisted of a 3 x 3 (height x pasture treatment) factorial experiment replicated four times to each of the two blocks of three sheep over six days. Each of the six days were split into 6 equal periods and the sheep were fed within their block in the same sequence within each period to minimize possible confounding effects of time of grazing, time since last grazing and level of satiety at a grazing on grazing behaviour. Animals were not fasted in any of the trials in this trial having a concentrate pelleted ration and chaffed hay available *ad libitum* at all times during the day except when temporarily required for turf grazing.

5.2.1 Animal measurements

Prior to grazing, the boxed turfs were fixed to a standard Kistler force plate (Kistler 2581, Kistler Instrumente AG, Eulachstr. 22, Postfach 304 CH-8408 Winterhur, Schweiz)by an overlapping top plate that encroached 2cm in from the edge of the turf and was fixed down tightly with wing nuts (see plates 5.1 to

5.3). Technical specifications of the force plate have been described in detail by Scott (1985) and Webb and Clark (1981). The operation of the force plate depends on the properties of piezo-electric quartz crystals which are fixed to the four corner columns supporting the rectangular plate to which the turfs were fixed. These piezo-electric crystals were mounted in both the vertical and horizontal plane on each pillar and changed their electrical properties in a known pattern depending on the extent of distortion under force. An attached computer integrated the resultant forces in both horizontal (X and Y direction) and vertical axes (Z direction). Angle of application of the force in both the horizontal and vertical axes was also calculated. After calibration, the equipment measured force in all axes to ± 0.1N. Forces in all three directions were measured each millisecond and the equipment used was claimed by the manufacturer to have minimum susceptibility to harmonic motion especially in the force range predicted for grazing sheep (< 30N).

This force equipment generated vast amounts of data during a grazing bout which were reduced by up to 80% by eliminating records between bites. Initially force in all axes (X Y and Z) and their resultant were plotted at 0.02 second intervals for a representative group of turf heights and pasture treatments. Interbite noise in the data often caused the resultant force to approach 1 newton. Bite numbers recorded the operators and the video were checked with those shown by the force plate graphical outputs. An algorithm which identified genuine bites but eliminated the vast number of records between bites was written and tested. A bite was identified where at least two successive records showed resultant forces of greater than 1N. For each 10s grazing the number of bites, as shown by the force plate, and their duration was recorded and checked against visual and video records. In addition, impulse (the area under the force-time curve, Ns) and the smoothed peak force for each bite (1/3){F_{xyz}peak + F_{xyz}peak-1 + F_{xyz}peak+1})) were recorded. All forces at 0.02s intervals and their angle of application contributing to a bite were also stored. Genuine bites continued for varying degrees of time up to 1.5 seconds.

All sheep underwent a preliminary training period of 5 days where they grazed turfs fixed to the force plate and became familiar with the nearby video camera. This training period also enabled personnel to become familiar with the force plate and the associated equipment.

Grazing commenced during the trial period at 0800h and was generally completed by 1800h. The grazing of a turf was achieved in two 10 second grazing runs as the computer was incapable of handling more than 10 seconds of data at a time. During grazing, the number of prehending bites (BN) was recorded by two observers independently and this was checked against a video of the grazing if their observations differed. Overnight all animals were returned to the field. All sheep gained considerable weight and condition over the two week period of the first trial and were healthy throughout.

5.2.2 Pasture measurements

Prior to grazing all turfs were trimmed as uniformly and close to the desired height as possible using the tripod grid described above (section 5.1). This procedure increased the accuracy with which bite dimensions (area and volume) could be calculated. Very little of such trimming was required except for turfs designated in the (C) pasture treatment category. Pasture height was then measured to the nearest mm (H_1) at 20 sites over the surface of the turf with a cut down ruler. Prior to grazing each turf was weighed to the nearest 0.1g

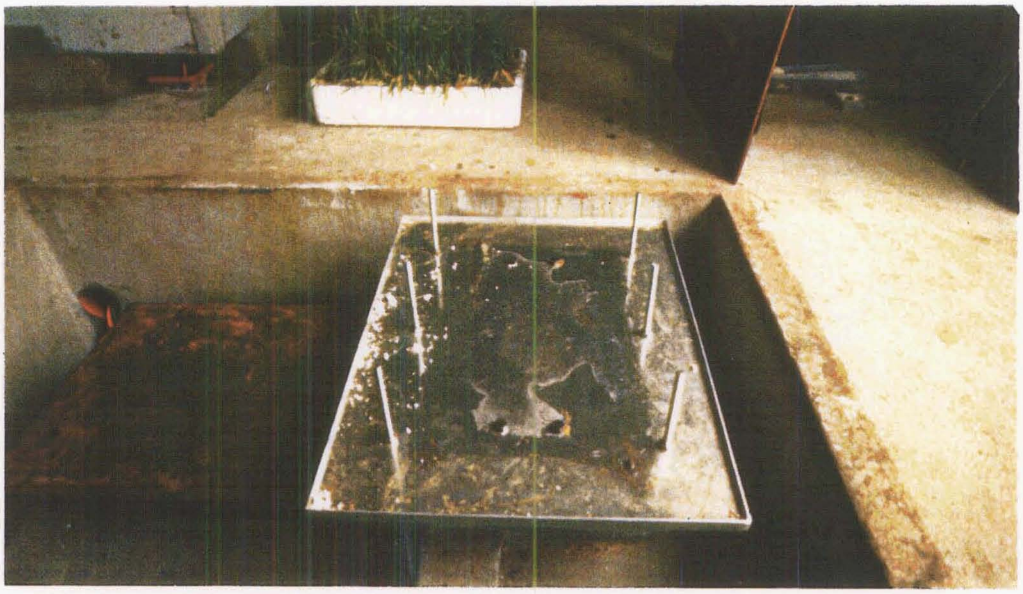


Plate 5.1 The force plate exposed at ground level with the protective base on which the turf was secured.

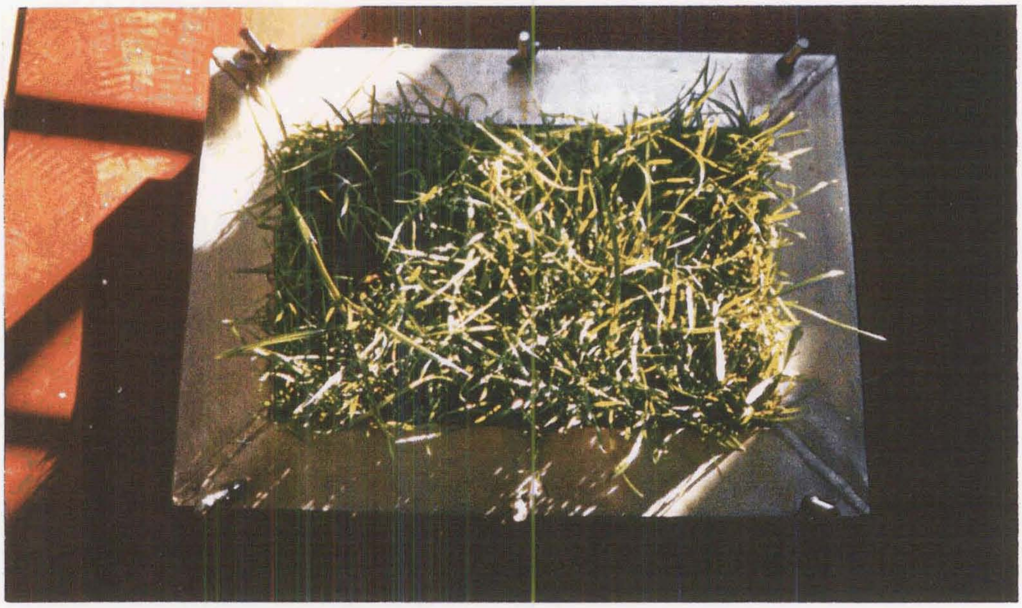


Plate 5.2 The turf fixed to the force plate prior to grazing

Plate 5.3 A grid positioned over the turf regulating bite depth

and the time noted. A second similar turf was also immediately weighed and the time noted so that insensible weight loss (W_{ins}) could be calculated.

The turf destined for grazing was then firmly attached to the force plate, the video activated and the animal introduced to graze. After ten seconds grazing the animal was temporarily prevented from grazing while the force plate was discharged prior to a second 10s measurement period. Grazing time for each turf averaged 25 seconds (checked by time track on video), the additional time being the time for animal removal at the end of a grazing bout. There were occasions when the force plate was not correctly activated, the computer malfunctioned or when the sheep or goat stood on the turf and the grazing run had to be repeated. If the turf was still fit for grazing, grazing time on these turfs exceeded 25s and the necessary adjustments were made in subsequent calculations.

At the completion of grazing, the turf was detached from the force plate, reweighed (W_2) and the elapsed time since first weighing (W1) noted. The paired ungrazed turf was also weighed again. Grazed stratum bulk density (GSBD) was calculated by setting the grid at the mean grazed height, (the mean height of 20 grazed plant units (H_2)) and removing all grass above this height with cutters and a vacuum cleaner. The difference between the original turf weight pre-grazing (W_1) and the weight of this freshly trimmed turf (W_3), corrected for insensible weight losses, divided by the turf surface area and the mean bite depth gave grazed stratum bulk density. An ungrazed representative sample of the pasture removed from the grazed stratum was kept for pasture DM estimation and to calculate the mean weight of plant units in this horizon (the mean of 100 ungrazed plant pieces). Mean bite weight and dimensions were then calculated as detailed in Table 5.1.

Table 5.1 Derivation of intake and bite variables for all four trials in experiment three.

Fresh bite weight (FBW) g	=	$(W_1 - W_2 + Wins)/(BN)$ (BN = number of prehending bites in the period, T2 - T1; where T1 is the time when grazing started and T2 the time it stopped)
Bite weight (BW) gDM	=	FBW * (DM% in grazed stratum)
Intake rate (IR) g/min	=	BW * BN * 60/(T2 - T1) (the grazing time T2 - T1 is measured in seconds)
Bite depth (BD) mm	=	$(HT_1 - HT_2)$
Grazed stratum bulk density (GSBD) g/cm^3,	=	$(W_1 - W_3 + W_{ins})/(BD)$*turf Area (turf area = 1000cm^2)
Bite volume (BV) cm^3	=	FBW/(GSBD)
Bite area (BA) cm^2	=	BV/(BD/10)
Proportion of the turf grazed (PNG)	=	BA * BN/Turf Area
Plant pieces per bite (PLB)	=	FBW/(Mean weight of plant unit in the grazed stratum)

Intake and bite variable units are consistent for all tables and regressions in chapter 5. Dry matter content of the grazed stratum was expressed as a proportion of fresh forage weight.

5.3 Statistical analyses

In all four trials data were subjected to ANOVA and where appropriate regression analyses (Genstat version 5 1988 Lawes Agricultural Trust, Rothamsted experimental station, England). Periods, animal group and animals were blocked and day, run and height*pasture treatment considered initially as treatments. Initial analyses found no significant difference between runs in impulse, mean maximum force per bite and the standard deviations of individual mean maximum force per bite in a run. This enabled force data for the two runs to be combined. Adjusted R^2 have been used as measure of the goodness of fit of regression models. This overcomes the potential problem with R^2 (1 - RSS/TSS) which always increases as new independent variables are included in the model even if they possess no relationship with the dependent variable. Adjusted R^2, (1 - (n - 1)RMS/TSS), corrects for this potential problem where n is the number of cases in the regression (where RSS refers to the residual sums of squares, TSS to treatment sums of squares and RMS to residual mean square).

On the last day of the trial (day 6), time constraints required some rationalization of the number of measurements on each turf if the building and equipment was to be returned to its original state for other unrelated trial work. The techniques used to measure agronomic and animal variables related to intake rate could be readily performed at a later date with the exception of force to sever a bite. It was therefore decided to concentrate on measuring only force and the simple agronomic and animal measurements necessary for calculating FBW, HT1 and BN. By day six all animals had grazed at least 3 replicates of each height*pasture treatment. However there were 38 missing values in all for BW, IR, GSBD, BV, BA, PNGD and PLB, but only 2 for all other variables.

5.4 Results, Trial one

5.4.1 Pregrazing height

The pasture heights (HT1) aimed for were achieved, mean values being 56.4, 102.2 and 146.3 mm for the 50, 100 and 150mm treatments, respectively (table 5.3). Although pasture height of the three pasture treatments (C,G,M) differed by as little as 5.3mm (table 5.3) this difference was significant because of the large number of samples per treatment (72). It is extremely doubtful, however, whether these latter height differences are of any practical significance as this would require an accuracy of greater than 0.25cm when measuring and interpreting pasture height.

5.4.2 Bite number

Mean number of prehending bites (BN) was not influenced by pregrazing height or pasture treatment and corresponded to a bite rate (BR) of 67 bites per minute as the average grazing time was 25s for the 28.1 bites.

5.4.3 Bite depth

There was a strong simple linear relationship (equation 5.1) between bite depth (BD) and pasture height (HT1). Equation 5.1 was significantly improved by fitting grazed stratum bulk density (GSBD) (equation 5.2).

$$BD = 0.530(\pm 0.017)HT1 - 10.83(\pm 1.84) \quad \text{adjusted } R^2 = 0.73^{***} \quad \text{.........(5.1)}$$

$$BD = 0.524(\pm 0.023)HT1 - 451.5(\pm 227.6)GSBD - 7.05 \quad adj.R^2=0.79^{***} \quad \text{.........(5.2)}$$

$$BD = 0.523(\pm 0.018)HT1 + 0.326(\pm 0.119)FRC - 13.86 \quad adj.R^2=0.76^{***} \quad \text{.........(5.3)}$$

(BD and HT1, mm; GSBD, g/cm^3; FRC, N)

Table 5.2 Simple correlations between animal and pasture variables determining intake and bite dimensions for trial one.

	HT1	BN	BD	FBW	BW	IR	DM
HT1	1.0000						
BN	-0.1687	1.0000					
BD	0.8892	-0.0853	1.0000				
FBW	0.7421	-0.2632	0.7382	1.0000			
BW	0.6697	-0.1929	0.6688	0.9050	1.0000		
IR	0.5601	0.3011	0.5953	0.7076	0.8499	1.0000	
DM	-0.1381	0.1218	-0.1063	-0.0739	0.3285	0.3997	1.0000
GSBD	-0.3896	0.2234	-0.4091	-0.0554	-0.0069	0.0949	0.2003
BV	0.7836	-0.3608	0.7915	0.7830	0.7012	0.4515	-0.1224
BA	-0.0861	-0.5262	-0.2347	0.1359	0.1062	-0.1709	-0.0526
PNGD	-0.2486	0.3382	-0.3562	-0.0974	-0.0769	0.0823	0.0320
PLB	-0.3307	-0.0125	-0.3406	-0.0351	0.1573	0.1700	0.4889
FBN	-0.3074	0.2394	-0.2499	-0.2714	-0.2472	-0.1263	0.0519
IMP	0.4622	-0.1834	0.4850	0.5072	0.5085	0.3693	0.0322
FRC	0.4578	-0.1564	0.4839	0.5159	0.5271	0.3887	0.0584
	GSBD	**BV**	**BA**	**PNGD**	**PLB**	**FBN**	**IMP**
GSBD	1.0000						
BV	-0.5224	1.0000					
BA	-0.2401	0.3309	1.0000				
PNGD	-0.0505	-0.0235	0.5638	1.0000			
PLB	0.2353	-0.1463	0.3914	0.4159	1.0000		
FBN	0.0794	-0.2641	-0.0776	0.2043	0.1481	1.0000	
IMP	-0.1130	0.4830	0.0071	-0.1817	-0.2142	-0.4592	1.0000
FRC	-0.0293	0.4547	-0.0261	-0.2142	-0.1672	-0.4586	0.8682

correlation significantly different to zero ($P<0.05$) when $r > 0.148$
Code as for table 5.1

Bite depth on the 5 and 10cm pastures was 38% of pregrazing pasture height (HT1) while on the 15cm pastures it was 47% of HT1. This increase in bite depth with height was highly significant ($p<0.001$). Mean peak force (FRC) was also associated with bite depth (BD, equation 5.3).

5.4.4 Bite weight

Fresh bite weight (FBW) was significantly influenced by both height and pre grazing pasture treatment (table 5.3). FBW increased 23% for the first 5cm increment in height and by 78% for the second 5cm from 10 to 15cm which suggests the response with height is not linear. Unexpectedly FBW was greatest on the pasture which had the upper 5cm removed (C) immediately prior to grazing.

Table 5.3 Mean pre grazing height (HT1), bite depth (BD), bite weight (FBW and BW) intake rate (IR), plant units per bite (PLB), and the proportion of the surface area grazed by sheep grazing ryegrass pasture turfs of three heights and pasture treatments within height.

Variable	Height(mm)					Pasture treatment				
	50	100	150	SED		C	G	M	SED	
Height HT1	56.4a	102.2b	146.3c	1.39	p<0.001	104.1b	98.8a	102.1b	1.39	p<0.001
Bite No.	29.04	28.40	26.90	1.269	NS	28.29	28.89	27.17	1.269	NS
Bite depth	21.2a	39.2b	69.1c	1.93	p<0.001	42.08	44.90	42.43	1.93	NS
Fresh BW	0.392a	0.481b	0.858c	0.0259	p<0.001	0.609e	0.543d	0.58de	0.0259	p<0.05
Bite weight	0.088a	0.095b	0.179b	0.0073	p<0.001	0.124	0.113	0.126	0.0073	NS
Intake rate	6.70a	7.14a	12.56b	0.585	p<0.001	9.11	8.16	9.13	0.585	NS
Plant units/bite	86.2c	63.9b	50.5b	7.39	p<0.001	60.0	68.6	72.0	7.3	NS
Proportion of area grazed (%)	49.5a	50.6a	42.7b	1.958	p<0.001	42.6b	50.1a	50.1a	1.958	p<0.001
Bite area	18.55	18.46	17.22	0.864	NS	16.5a	19.3b	18.5b	0.864	p<0.05
Force bite number	15.9b	14.9b	13.1a	0.62	p<0.05	14.25	15.08	14.59	0.62	NS
BW/FRC	0.012a	0.013ab	0.0148b	0.0010	p<0.05	0.0130	0.0129	0.0138	0.0010	NS

Bite weight (BW) was significantly influenced by pasture height (table 5.3 equation 5.4). For the first 5cm increment, BW increased by only 8% but for the second increment BW was 11 fold greater. With only three data points (ie 5,10,and 15cm pastures) it is impossible to speculate whether BW had peaked at 15cm. Both grazed stratum bulk density and DM content of the grazed were significant predictors of BW (equation 5.6).

$$BW = 0.0010(\pm 0.00008)HT1 + 0.012(\pm 0.009) \quad \text{......(5.4)}$$
$$\text{Adj } R^2 = 0.45^{***}$$

$$BW = 0.0012(\pm 0.00009)HT1 + 4.62(\pm 0.88)GSBD - 0.05(\pm 0.01) \quad \text{......(5.5)}$$
$$\text{Adj } R^2 = 0.52^{***}$$

$$BW = 0.0013(\pm 0.00007)HT1 + 3.57(\pm 0.74)GSBD + 0.50(\pm 0.06)DM - 0.15(\pm 0.16) \quad \text{......(5.6)}$$
$$\text{Adj } R^2 = 0.68^{***}$$

The adjusted R squared improves by 0.01 if the square of surface height was used (ie HT1*HT1) in equation 5.4 instead of the linear term.

5.4.5 Rate of intake

Intake rate (IR) was not influenced by pasture treatment but increased with pasture height (table 5.3). Intake rate increased by 7% and 76%, respectively as pasture height increased from 5 to 10cm and 10 to 15cm.

5.4.6 Proportion of the turf surface grazed

The proportion of the turf surface grazed (PNG) was influenced by both the height and pasture treatments (table 5.3). Sheep grazed a smaller portion of the available surface of the tallest pasture (15cm). Although this difference was only 6% it was significant. The magnitude of the difference in PNG between pasture treatments C on one hand and G and M on the other was again small (7%), but significant (table 5.3).

5.4.7 Grazed stratum bulk density

There was an interaction between height (HT1) and pasture treatments (C,G,M) for grazed stratum bulk density (GSBD) (table 5.4). Grazed stratum bulk density declined as pasture height increased at all pasture trêatments, except the 100mm * G and 150mm * G treatments where grazed stratum bulk density was unchanged. Within a height, grazed stratum bulk density was influenced by pre grazing pasture treatments with C > M > G. Again the exception to this general trend occurred in the 10cm pasture treatments where grazed stratum bulk density did not differ between 10M and 10G treatments.

5.4.8 Bite volume

Bite volume (BV) was influenced by both height and pasture treatment and the interaction was highly significant (table 5.4). Bite volume was highest on those treatment combinations with the lowest grazed stratum bulk density. Thus BV increased within all pasture treatments with height and within a height from C to M to G.

$$BV = 0.877(\pm 0.053)HT1 - 15.7(\pm 5.75) \quad \text{......(5.7)}$$
Adj. R^2 0.61 ***

$$BV = 0.66(\pm 0.058)HT1 - 3221.9(\pm 522.4)GSBD + 1.20(\pm 0.33)FRC + 22.3(\pm 8.4) \quad \text{......(5.8)}$$
Adj. R^2 0.69***

In the regression analysis (equation 5.8), peak bite force was a significant predictor of BV.

5.4.9 Bite area

Bite area was significantly influenced by pasture treatment but not pre -grazing height (table 5.3). Bite area was inversely related to grazed stratum bulk density, bite number, dry matter and pre-grazing height (equation 5.9). The best unweighted least squares linear regression of bite and intake variables associated with bite area accounted for little variation (equation 5.9), with most of the coefficients negative.

$$BA = -376.6(\pm 83.6)GSBD - 0.35(0.004)BN + 0.07(\pm 0.009)PLB - 24.5(\pm 7.17)DM - 0.18(\pm 0.008)HT1 + 33.3(\pm 2.09) \quad (5.9)$$

Adj. R^2 0.51***

5.4.10 Number of bite records on the force plate.

The number of bites, as indicated by the force plate (FBN), decreased as pasture height increased (table 5.3). This result is in conflict with that for bite number which was not influenced by treatment. In addition, bites recorded by the force plate were only half the corresponding bite number. A considerable component of this difference is due to biting that occurred at the end of the two force measurement runs before the animal could be removed, generally a time interval of up to 7 seconds. The remaining portion may relate to the algorithm used to identify bites as it only successfully identified those bites whose peak force exceeded 1 N. Incorrect identification of prehending bites can not be ruled out as an additional potential source of error.

Table 5.4 Mean grazed stratum bulk density (GSBD), bite volume (BV), bite impulse (IMP), peak bite force (FRC), and the standard deviation of peak bite force (SDF) for sheep grazing ryegrass turfs of three heights and methods of preparation within height.

Variable	Treatment	Preparation C	G	M	S.E.D.
Grazed stratum bulk density (g_{fresh}/cm^3)	height (mm)				
	50	0.0144g	0.0086cd	0.0112f	0.00045 $p<0.05$
	100	0.0092e	0.0066b	0.0060a	
	150mm	0.0090de	0.0065ab	0.0083c	
Bite volume (cm^3)	height				
	50	34.9a	41.3a	37.9a	7.59 $p<0.05$
	100	62.0b	75.6c	68.7b	
	150mm	95.4d	136.7f	115.0e	
Impulse (Ns)	height				
	50	1.30c	0.66a	0.93b	0.123 $p<0.05$
	100	1.15bc	0.76a	0.96b	
	150	2.11d	2.59e	2.60e	
Peak bite force (N)	height				
	50	10.7c	6.4a	7.5ab	0.57 $p<0.05$
	100	8.0b	6.9ab	7.7b	
	150	13.1d	14.1d	14.0d	
Standard deviation of peak bite force (N)	height				
	50	7.0c	3.9a	3.8a	0.410 $p<0.05$
	100	5.0b	4.3ab	4.8b	
	150	8.1d	9.4e	8.1d	

5.4.11 Mean bite impulse

The interaction between height and pasture treatments significantly influenced mean bite impulses (IMP), the area under the force time curve for each bite (table 5.4). Impulses for pasture treatment G were lower at heights 5 and 10cm than for M which in turn was lower than for C. This trend was not evident on 15cm pastures where G and M pasture treatments required a similar but greater impulse each bite than C. Within pasture treatments impulse increased only as height increased from 10 to 15cm.

5.4.12 Mean peak force to sever a bite

There was a height x pasture treatment interaction for the mean peak force to sever a bite (FRC) (table 5.4). Within pasture pasture treatments there were no differences in force between the 5 and 10cm heights. The one exception was the C treatment where peak bite force measured to sever a bite at 5cm was greater than at 10cm (table 5.4). Peak bite force almost doubled as height was increased from 10 to 15cm. On the 15cm pasture peak bite force was similar for all pasture treatments. Although force was associated with height (HT1), grazed stratum bulk density and force bite number, these variables while highly significant explained very little of the variability in peak bite force (equation 5.10).

$$FRC = 0.068(\pm 0.011)HT1 - 0.69(\pm 0.13)FBN + 261.9(\pm 110.07)GSBD + 6.15(\pm 2.24) \quad \text{..........(5.10)}$$
Adj. R^2 0.33^{***}

5.4.13 Standard deviations of the mean peak forces to sever a bite.

Standard deviations of the mean peak forces to sever a bite (SDF) were studied to see if they were influenced by height and pasture treatment since the mean may be less important than the distribution of force in determining grazing strategy. There was a height x pasture treatment interaction in the standard deviation of the peak forces (table 5.4). Within the 5cm height the standard deviation of peak bite force for C was 81% greater than for G and M, while within the 10cm height, pasture treatment did not influence peak bite force (table 5.4). At 15cm, standard deviation of peak bite force was greater for G than the other two pasture treatment treatments. Within pasture treatment standard deviation of peak bite force generally increased with pasture height. On the 10cm C treatment standard deviation of peak bite force was less ($p<0.05$) than that for 5cm. Greatest variation in the mean peak force to sever a bite occurred on the 5cm C and on all pasture treatment treatments at 15cm.

5.4.14 Bite weight per newton of peak force

Bite weight per newton of peak force (BW/FRC) was significantly influenced by height (table 5.3). On the 150mm pastures sheep were able to harvest a greater weight for each newton of bite force expended. Although the trend was present also as height increased from 50mm to 100mm, this was not significant.

5.5 Trial 2. Comparison of pasture species

Where pasture is dense, of low tensile strength and easily gathered into the bite catchment, rate of mastication rather than summit force may be the most important determinant of bite dimensions, BW and intake rate. Prehending bite rate may be restricted if mastication bites increase if it is assumed that jaw movements per minute are relatively constant. This second trial investigated the relative importance of peak bite force in determining bite dimensions and intake of such pastures. In trial two, three pasture species-

Huia white clover (*Trifolium repens*), Roa tall fescue (*Festuca arundinacea*) and Matua prairie grass (*Bromus willdenowii*)- were grown from seed in a $0.1m^2 * 0.15m$ deep polystyrene boxes in a green house. Dense pastures of immature leaf which presumably could be easily harvested were produced.

5.5.1 Materials and methods

Forty eight boxed pastures (16 each of white clover, tall fescue and prairie grass) were offered to 4 sheep (64.3 ± 1.8kg) over 4 days in 3 periods within each day. Treatments (pasture species) were arranged in such a way that animal, period and day effects were balanced and could be blocked so that treatment effects were estimated entirely on the interaction term (A/P/D). Pastures were to be at the same height (above 10cm) if possible at grazing. As this second trial followed within a week of the end of the first, the 4 sheep selected from trial one required no further familiarisation with the grazing methodology and were offered turfs of all three pasture species during the four days prior to the start of the trial.

5.5.2 Pasture and animal measurements

Pasture and animal measurements were the same as for trial one (sections 5.2.1 and 5.2.2).

5.5.3 Results

Intake and bite variables for the three pasture species are presented in appendix table 5.2. Pre grazing height of white clover was below that of the two grass species (table 5.5).

Table 5.5 Short term intake and bite variables of sheep grazing immature pastures of white clover, tall fescue and prairie grass.

Pasture	Clover	Prairie	Fescue	S.E.D	Signif.
Pregrazed height (mm)	98.2	147.2	139.2	5.35	***
Bite depth (mm)	45.0	74.8	77.1	5.19	***
Bite number	27.3	22.7	23.7	1.84	**
Fresh bite weight (g)	0.81	0.84	0.65	0.082	**
Dry matter (%)	0.207	0.121	0.169	0.013	***
Bite weight (gDM)	0.16	0.11	0.11	0.015	***
Intake rate (gDM/min)	7.81	5.19	5.35	0.744	***
Grazed stratum bulk density (g fresh/cm^3)	0.0081	0.0039	0.0033	0.0005	***
Bite volume (cm^3)	106.2	212.9	195.0	14.24	***
Bite area (cm^2)	24.1	28.5	25.5	1.54	**
Proportion of turf surface area grazed	0.635	0.636	0.598	0.0396	NS
Plant units per bite	71.2	36.5	56.5	9.06	***
Impulse (Ns)	0.93	0.84	0.88	0.127	NS
Mean peak bite force (N)	7.68	6.86	7.63	0.704	NS
Standard deviation of the maximum forces	4.70	4.64	4.68	0.568	NS
BW/FRC	0.021	0.016	0.014	0.002	**

5.5.3.1 Force and Impulse

As in trial one the force data for the two grazings of each turf on the force plate were compared and then combined as they did not differ significantly. The mean maximum force and impulse, and the distribution of individual maximum forces did not differ among the pasture species (table 5.5). Intake variables and bite dimensions in these circumstances were responding to other pasture and animal attributes.

5.5.3.2 Intake rate

Pasture height prior to grazing differed significantly between the white clover and the grasses (table 5.5). It proved impossible to produce white clover pastures of 150mm, partially because swards were trimmed during the growth period to encourage root development in an attempt to prevent plants being uprooted during grazing (table 5.6).

Table 5.6 Mean, maximum and minimum values for pregrazing height (HT1), grazed stratum bulk density (GSBD) and bite number (BN) for sheep grazing (a) white clover, (b) prairie grass and (c) tall fescue pasture turfs.

Variable	minimum	maximum	mean
(a)white clover			
HT1	73.6	125.0	91.6
GSBD	0.0056	0.0134	0.0077
BN	13.0	46.0	27.4
(b)prairie grass			
HT1	135.0	157.0	146.3
GSBD	0.0028	0.0049	0.0040
BN	17.0	28.0	22.4
(c)tall fescue			
HT1	105.0	153.0	137.9
GSBD	0.0021	0.0046	0.0034
BN	18.0	31.0	23.8

Intake rate of the clover pasture was 50% greater than that of prairie grass and 46% greater than that of tall fescue (table 5.5). Sheep grazing the white clover had the lowest bite depths and the largest bite weight and bite number (table 5.5). There were small differences in bite number between white clover and the grasses (27.3 vs 22.7 and 23.7). Although significant, bite area differences between grass and white clover pastures (28.5 and 25.5 vs 24.1 cm^2) were relatively small (table 5.5).

In the 25s grazing period sheep apparently grazed a similar surface area on all three pasture species. Sheep grazing legume pastures appeared to sever more plant units in the grazed stratum than when grazing either prairie grass or tall fescue (71.2 vs 36.5 and 56.5). Mean number of plant units severed each bite reflect relative weight of plant units and the fresh bite weight.

The simple correlations between animal and pasture variables influencing intake for all pasture species (table 5.7) and the individual pastures (table 5.8) highlight the major variables associated with bite dimensions and intake with pasture species.

Table 5.7 Simple correlations between pasture and animal variables influencing intake for sheep grazing white clover, prairie grass and tall fescue turfs.

	HT1	BN	DM	DBW	IR	BD	GSBD
HT1	1.0000						
BN	-0.2384	1.0000					
DM	-0.4198***	0.2315	1.0000				
DBW	-0.0354	0.3871***	0.5478***	1.0000			
IR	-0.0350	0.3865***	0.5480***	1.000***	1.0000		
BD	0.917***	-0.1133	-0.4080***	0.0153	0.0160	1.0000	
GSBD	-0.4778***	0.4697***	0.5255***	0.615***	0.615***	-0.548***	1.0000
BV	0.897***	-0.2802**	-0.4617***	0.0121	0.0129	0.915*	*0.59***
BA	0.544***	-0.463***	-0.0764	0.1908	0.1908	0.332**	-0.0383
PNGD	0.4206***	0.4859***	0.0974	0.550***	0.549***	0.340**	0.3356
PLB	-0.0701	0.3481**	0.4345***	0.754***	0.753***	-0.217	0.47***
FBN	0.0758	0.2426	0.2124	0.2917**	0.2915**	0.1589	0.2572
IMP	0.0126	0.0768	0.0903	0.0494	0.0494	-0.0504	0.1642
FRC	0.0625	0.1918	0.2145	0.1987	0.1979	-0.0348	0.2733

	BV	BA	PNGD	PLB	FBN	IMP	FRC
BV	1.0000						
BA	0.5665***	1.0000					
PNGD	0.3804***	0.5143***	1.0000				
PLB	-0.0220	0.1197	0.4453***	1.0000			
FBN	0.0429	0.0642	0.2855**	0.2053	1.0000		
IMP	-0.0844	0.0140	0.1383	0.1133	-0.0474	1.0000	
FRC	-0.0567	0.1113	0.3277**	0.319**	-0.0250	0.905***	1.0000

(df for comparison = 46)
Critical values of r; r=0.285 ($P<0.05$); r=0.370 ($P<0.01$)

All subset regressions of intake rate (IR) on predictor variables gave the following linear relationships for white clover, prairie grass and tall fescue (equation 5.11, 5.12, 5.13).

(a) white clover

$$IR = 0.069(\pm0.013)HT1 + 22.6(\pm7.0)DM + 0.17(\pm0.05)BN - 8.10(\pm2.38) \quad \text{.........................(5.11)}$$

Adj. R^2 0.75***

(b) prairie grass

$$IR = 50.4(\pm12.3)DM + 981.0(\pm282.8)GSBD - 5.04(1.53) \quad \text{.........................(5.12)}$$

Adj. R^2 0.75***

(c) tall fescue

$$IR = 2509(\pm 359)GSBD + 36.6(\pm 4.9)DM + 0.1(\pm 0.02)HT1 - 0.14(\pm 0.05)BN - 19.9(\pm 3.8) \quad ...(5.13)$$

Adj. R^2 0.75***

Table 5.8 Simple correlation between pasture and animal factors influencing intake for (a) white clover, (b) prairie grass and (c) tall fescue.

(a) white clover

	IR	BA	BD	BN	BV	DM	GSBD
IR	1.0000						
BA	0.4093	1.0000					
BD	0.7337***	0.2751	1.0000				
BN	0.4110	-0.3198	0.1844	1.0000			
BV	0.6820***	0.4254	0.9518***	0.0738	1.0000		
DM	0.3481	0.2770	-0.1955	-0.0714	-0.2517	1.0000	
GSBD	0.5699**	0.4455	0.1596	0.4433	0.0620	0.5087	1.0000
HT1	0.6889***	0.5679**	0.8894***	0.0147	0.855***	-0.0466	0.3802
DBW	1.0000***	0.4098	0.7344***	0.4118	0.682***	0.3472	0.571**

	HT1	DBW
HT1	1.0000	
DBW	0.6896***	1.0000

(b) prairie grass

	IR	BA	BD	BN	BV	DM	GSBD
IR	1.0000						
BA	0.1760	1.0000					
BD	0.1698	-0.3858	1.0000				
BN	0.0695	-0.5684**	0.5206**	1.0000			
BV	0.3184	0.5979**	0.5057**	-0.0837	1.0000		
DM	0.7583***	0.0141	0.1015	0.1650	0.0998	1.0000	
GSBD	0.703***	-0.2518	-0.1169	0.1359	-0.3236	0.3746	1.0000
HT1	-0.1303	-0.3735	0.4356	0.4952	0.0463	0.0847	-0.2121
DBW	0.9999***	0.1772	0.1651	0.0669	0.3155	0.755***	0.71***

	HT1	DBW
HT1	1.0000	
DBW	-0.1349	1.0000

(c) tall fescue

	IR	BA	BD	BN	BV	DM	GSBD
IR	1.0000						
BA	0.6269**	1.0000					
BD	0.1037	-0.1838	1.0000				
BN	-0.0323	-0.4767	0.3649	1.0000			
BV	0.5196**	0.6085**	0.662***	-0.0643	1.0000		
DM	0.6679***	0.3555	0.1355	0.2366	0.3457	1.0000	
GSBD	0.3617	0.0553	-0.5105	-0.1752	-0.3891	-0.2153	1.0000
HT1	0.0772	0.0818	0.7667***	0.3617	0.682***	0.3141	-0.75***
DBW	1.0000***	0.6263**	0.1025	-0.0301	0.5182**	0.668***	0.3630

	HT1	DBW
HT1	1.0000	
DBW	0.0777	1.0000

(df for comparison = 14)

Critical values of r; r=0.514 (P<0.05); r=0.641 (P<0.01)

DM content of pasture was a significant term for all species. Grazed stratum bulk density, while important for the grasses, was not a significant predictor variable of IR for white clover. Grazed stratum bulk density varied almost three fold for the white clover pasture but even the minimum was greater than the maximum for either grass (table 5.6).

5.6 Trial 3 Consecutive grazings of ryegrass with and without a grid restricting bite depth.

This small trial had two objectives. The first was to study whether sheep were able to make adjustments to either bite area and/or BN to maintain IR if a grid was used to restrict bite depth. Consecutive grazings on the same turf enabled bite variables to be compared when sheep were grazing predominantly leaf (grazing 1), and pseudostem (grazing 2) when all pasture above the mean grazed depth at the first grazing was removed.

5.6.1 Material and Methods

Four sheep each grazed two paired 15cm ryegrass pasture turfs for two consecutive grazings periods each of 20s duration. Bite dimensions and intake variables were measured as for trial 1 (section 5.2). Bite depth measured after grazing 1 and 2 on the first turf grazed (P1), was used to position a grid in the pasture which restricted bite depth for both grazings on the second turf (P2), to two thirds of that at the corresponding grazing on turf 1. The second of the paired turfs, with the grid, was grazed immediately after the first.

Eight 15cm ryegrass turfs (pasture treatment G, section 5.2), surplus to requirements in trial one (section 5.2) were paired on appearances and pasture height and allocated at random to be grazed unimpeded (P1) or with the grid in place (P2). Each pair of turfs was grazed in a set sequence, (P1 followed by P2) on two occasions (G1 and G2) by one of 4 sheep over a 3 hour period. In a preliminary period of two days, each sheep grazed 15cm ryegrass turfs with and without the grid restricting bite depth.

During the trial, bite depth was restricted to two thirds of that measured on the first of the paired turfs grazed (P1), using the grid designed for trimming pastures (section 5.2). When grazed stratum bulk density had been measured after the first grazing period (G1), by removing all pasture above the mean bite depth, the turf was returned to the force plate for a second grazing (G2). This sequence occurred for turfs grazed without (P1) and with (P2) the grid restricting bite depth. The same intake variables measured in trial 1 (section 5.2) were again measured.

Data from this trial (appendix table 5.3) were analysed by simple ANOVA using the animal/grazing/grid interaction term to test for significance.

5.6.2 Results

Pre grazing pasture height and post grazing bite depth for both grazings (G1 and G2) with (P2) and without the grid (P1) demonstrate the degree to which a second grazing and the grid restricted bite depth (table 5.9). The impact of these results is diminished by a technical oversight during this trial where the (P2) turf to be grazed for the second time (G2) was not trimmed to the same postgrazing height as the paired turf (P1,G1) before the grid was inserted but left at the trimmed bite depth determined by the grid setting for G1. The new grid setting was still set at two thirds of the bite depth measured on the P1 turf for G2. Unfortunately this difference in pre grazing height (P2,G2 vs P1,G2 ;126.8 vs 110.4 S.E.D. 6.45) was just significant ($P<0.05$). Thus mean height of turfs grazed with the grid (P2) was also significantly greater than those grazed without (P1) (table 5.9) and possibly, even with a grid in place, more leaf was available.

Table 5.9 Pasture height and bite depth for sheep grazing 15cm ryegrass for two consecutive grazings (G1, G2) with and without a grid inserted (P2, P1) to restrict bite depth.

grid	No Grid (P1)		With Grid (P2)	
Grazing	height	bite depth	height	bite depth
First G1	147.2 ±4.5	74.6 ±6.4	150.0 ±2.3	45.3 ±7.6
Second G2	73.7 ±3.2	26.0 ±2.3	103.6 ±9.4	33.4 ±5.5

(height s.e.d. 5.34; L.S.D. 17.00)
(bite depth s.e.d. 5.86; L.S.D. 18.64)

Table 5.10 Animal and pasture intake variables for 15cm ryegrass pasture turfs each grazed twice (G1, G2) with and without a grid inserted (P2, P1) to restrict bite depth.

Treatment	FRC	FBN	Bite area	PNGD	PLB	IR	BW	BN
grazing G1	8.41	13.3	20.1	0.58	39.5	7.6	0.11	31.0
grazing G2	8.03	13.1	11.1	0.39	29.2	4.8	0.07	35.3
SED	1.09	2.06	2.18	0.05	5.7	1.17	0.017	5.30
	NS	NS	***	***	NS	**	NS	NS
No grid P1	9.54	14.0	12.8	0.38	39.0	7.2	0.09	31.1
Grid P2	6.91	12.4	18.4	0.60	29.7	5.2	0.08	35.1
SED	0.50	2.06	2.18	0.05	5.7	1.17	0.017	5.30
	**	NS	***	***	NS	NS	NS	NS

For both grazed stratum bulk density (GSBD) and bite volume (BV) the G * P interaction was significant (table 5.11).

Table 5.11 Interaction between grazing (G1, G2) and bite depth restriction (P1, P2) for grazed stratum bulk density (GSBD) and bite volume (BV) when sheep grazed 15cm ryegrass pasture turfs.

Bite depth restriction	Grazing	Mean GSBD gfresh/cm^3	Mean BV cm^3
P1	G1	0.0044a	121.9c
P1	G2	0.0159b	22.4d
P2	G1	0.0040a	97.7c
P2	G2	0.0069a	45.0d
	(S.E.D.	0.0015	8.00)

Means in columns with the same letter do not differ ($P>0.05$)

As in trial one and two the force data for the two runs within each grazing were compared and as they were not significantly different they were combined. Pasture height differed significantly between grazing 1 and 2 (table 5.9) and with and without the grid (P2 127, P1 110mm sed 6.5). Ideally for a valid comparison the pregrazing height for the grid treatments should have been similar.

5.6.3 The influence of grazing treatment on bite and intake variables.

Mean peak bite force did not differ between grazing one and two, nor did bite weight (BW gDM) or the number of bites taken on the force plate (FBN) (table 5.10). Intake rate (IR gDM/min) decreased by 37% (table 5.10) in spite of a 361% increase in grazed stratum bulk density (table 5.11). Bite area declined by 45% and as a consequence the proportion of the turf grazed also decreased significantly (table 5.10). Sheep did not compensate for the reduced potential bite depth by increasing bite area and/or rate of biting.

5.6.4 Bite depth restriction

Mean peak bite force decreased significantly when a grid restricting bite depth was inserted in the pasture (table 5.10). It could be argued that even though pregrazing heights differed for P1G2 and P2G2 treatments the grid was probably restricting bite depth to a greater extent on the taller more leafy P2G2 treatments. Grazed stratum bulk density was reduced by 47% by the restricted bite depth. However a 44% increase in bite area almost compensated for this so that BW and IR where not affected (table 5.10). Bite number did not change.

Different grazing strategies were identified among the 4 sheep used in this trial. Sheep 2 grazed a larger proportion of each turf, harvested more plant units per bite, yet expended less peak force each bite. There were also significant sheep * grid treatment influences on force and the proportion of the turf grazed, with sheep 2 and to a lesser extent sheep 4, sampling a larger surface area compared to the other two sheep.

No clear cut pattern emerged in terms of whether tillers were severed above or below the grid, indicating predominantly shear or tensile breaking (appendix table 5.3). On the taller pre-grazing heights (P2G1) mean bite depth occurred below the grid on 2 occasions and above the grid on the other 2. When grazing lower in the pasture strata, bite depth was consistently above the grid which suggested plant material broke close to or at the point of grip.

5.7 Trial four

In this final trial the intake rate, bite variables and bite force of goats and sheep were compared on 15cm ryegrass pasture turfs.

5.7.1 Materials and methods

Four feral goats each successively grazed two 15cm ryegrass turfs (15M turfs surplus to trial 1, turfs maintained at 15cm by regular trimming) during a three hour period. The goats were trained for a week to graze turfs indoors and to become familiar with the procedures employed. Intake and bite variables were compared with sheep (1 to 4) grazing 15M turfs on the first two occasions in trial 1. There was a period of 4 weeks between trial one and four during which the turfs used in this final trial were kept in a glass house and watered and trimmed regularly.

The techniques used to measure bite and intake variables were the same as those in trial one (section 5.2). Goats used in this trial and the sheep used for comparison purposes 23.5 ± 0.8 and 64.0 ± 3.1kg, respectively. Pre grazing turf heights (HT1) were 146.1 ± 4.1 and 144.3 ± 2.9mm for the goats and sheep, respectively.

5.7.2 Results

All bite and intake variables are presented in appendix table 5.4. Bites detected by the force plate were considerably fewer for goats than sheep which may reflect the low mean peak bite force employed by goats relative to the accuracy of the algorithm used to detect bites. Video images of the goats while grazing were used to check for potential errors in bite number and bites identified by the force plate. A time scale on the video suggested many records not identified as bites by the force equipment involved almost a chewing rather than a biting motion. In similar circumstances mean peak bite force (FRC) of sheep was almost five fold greater than that of goats (table 5.12). Sheep also had a greater bite depth (7.2 vs 5.9cm) similar bite areas and volumes (16.0 vs 13.7cm^2; 113.7 vs 79.6 cm^3) but a lower bite number (24.6 vs 42.9) than goats.

Table 5.12 Intake and bite variables of goats grazing 15cm ryegrass pasture turfs compared with those of sheep grazing similar turfs in trial one.

	IR/MLW	FRC	%FRC<10	PNGD	BD	BN	GSBD	BV	BA	PLB
Goat	0.366	3.24	100	0.51	59.1	42.9	0.0029	79.6	13.7	20.6
sheep	0.456	14.7	57	0.38	71.8	24.6	0.0076	113.7	16.0	44.1
S.E.D	0.067	1.67	14.0	0.05	4.7	5.7	0.0007	19.8	2.7	7.6
	NS	***	***	**	**	***	***	NS	NS	**

Where :-

IR/MLW = intake rate (gDM/kg$^{0.75}$/min).
FRC = mean peak bite force (N).
%FRC<10 = percentage of peak bite forces below 10N.
PNGD = proportion of turf surface area grazed.
BD = bite depth (mm).
BN = total number of bites from turf.
GSBD = grazed stratum bulk density (gfresh/cm^3).
BV = bite volume (cm^3).
BA = bite area (cm^2).
PLB = plant pieces per bite.

Both bite number (BN) and, as a consequence, the proportion of the turf grazed (PNGD) by goats was greater than for sheep (table 5.12). The shallow grazing of goats also restricted the grazed stratum bulk density. When intake rates were expressed on a liveweight or a metabolic liveweight basis there was no difference between the goats and the sheep (0.167 vs 0.161gDM/kg/min; 0.366 vs 0.456 gDM/kg$^{0.75}$/min). Unfortunately, goats were not offered a second grazing on a turf to test their response once the easily harvested leaf had been removed.

5.8 Discussion

5.8.1 Trial one

The objective of this trial was to determine the role of force in prehension on components of intake. An upper limit to the force animals exert to sever a bite may be important in maintaining grazing momentum. If an upper limit does exist, the animal could be expected to adjust bite dimensions in response to pasture structure, especially where the pasture is tall, dense, and preferred components are accessible. This trial demonstrated for the three pasture heights and pasture treatments that intake rate was influenced only by bite weight. Bite weight increased with height, grazed stratum bulk density and to a lesser extent dry matter content of the grazed stratum. Bite depth increased with pasture surface height. Greater bite depths were associated with greater mean peak bite forces. At a given pasture height bite area increased as grazed stratum bulk density decreased. Larger bite weights per newton of peak bite force were obtained on the tallest pasture.

5.8.2 Intake rate

Bite number, and consequently bite rate, was not influenced by either the height or pasture treatment (table 5.3). Therefore any effects of treatment on intake rate are a consequence of their effect on bite weight. Intake rates (gDM/min) were similar to those reported by Black and Kenney (1984) on artificial ryegrass pastures at heights of 50 and 100mm but were almost double those of Black and Kenney at 150mm (12.6, table 5.3 vs 6.0 gDM/min). When converted to mgDM/kgLW/min (105 - 197 mgDM/kgLW/min) intake rates were higher than the recently reviewed range for sheep (22 - 80 mgOM/kgLW/min Hodgson, 1986) even after allowance was made for the conversion of DM to OM. The mean intake rates in the present data set were obtained from almost 200 individual estimations and were measured directly. No surgical modification of animals was required and sheep had access to feed at all times. The data well may reflect for a short time period response of animals given the opportunity to graze rather than consume concentrates and hay before settling to lower mean IR levels. Furthermore the 25s grazing period in this trial may be too short for such behaviour to be appreciably diluted by normal grazing behaviour. Animals were at no stage constrained by grazing opportunity as only a maximum of 51% of the surface area of any treatment turf was grazed (table 5.3).

Intake rate was influenced by pasture height, grazed stratum bulk density, bite number and DM content of the grazed stratum although the latter two predictor variables had a relatively minor effect when compared with that of height and density (appendix table 5.4).

5.8.3 Bite weight

Bite weight was positively related to pasture height (section 5.4.4) confirming conclusions in recent experiments and reviews of the literature (table 2.1). While grazed stratum bulk density was important in determining bite depth and area in this trial it did not independently significantly influence bite weight. When GSBD was included along with pasture height in the regression equation it was significant and improved the overall adjusted R^2 (equation 5.5). In those experiments where both height and density independently influenced bite weight (Black and Kenney, 1984; Burlison, 1987) pasture height and density were not correlated, unlike this experiment. For the current narrow range of pasture heights and densities it was impossible to speculate on whether the relationship was curvilinear at higher pasture heights or grazed stratum bulk densities. On 55cm tall oat swards Burlison (1987) still found the relationship between height and bite weight strongly linear. However at very high grazed stratum bulk densities (> 2.0 mgDM/cm^2) Black and Kenney (1984) found an asymptotic relationship with only marginal increases in bite weight for two fold increases in GSBD.

The dry matter content of the pasture horizon consumed also appeared to have an influence on bite weight in the current range of grazed stratum DM contents (0.13 - 0.43, mean 0.21). The relative influence on bite weight at the mean DM level was small as the coefficient for DM (equation 5.6) accounted for less than 5% of BW for pastures of 150mm.

5.8.4 Bite depth

There was a positive relationship between bite depth and pasture surface height (equation 5.1). However, bite depth in the current study was greater than predicted by Forbes (1982), Milne *et al.* (1982) and Burlison (1987) as the regression coefficient (0.52 vs. 0.37 - 0.42) was larger. Differences in BD could be explained by differences in GSBD of the grazed horizons (Black and Kenney, 1984) between trials provided the published data were derived from more dense pastures. However, in the current trial the range of GSBD (1.17 - 3.28mgDM/cm^3) was narrower but higher than that of Burlison *et al.*, (1991) (0.44 - 2.04mgDM/cm^3) and only represented a small portion of the range of Black and Kenney (1984)(0.46 - 4.23mgDM/cm^3). Although sheep were grazing more deeply into the pasture on this trial it is difficult to compare across trials as the pastures and pretrial preparation were different. For example, only 6 of the 17 pastures were ryegrass in the study of Burlison (1987). In spite of the negative correlation between pasture height and grazed stratum bulk density (table 5.2) the inclusion of the latter term significantly improved the prediction of bite depth (equation 5.2). Although Black and Kenney (1984) did not explore the relationship between bite depth and surface height, bite depth decreased as grazed stratum bulk density increased. The coefficient for grazed stratum bulk density (equation 5.2) was also negative in spite of a narrower range of pasture heights (50 - 150 vs. 10 - 180mm) and grazed stratum bulk densities (1.17 - 3.28 vs. 0.46 - 4.23 mgDM/cm^3) when compared to those of Black and Kenney. Unlike the present study and that of Black and Kenney, Burlison (1987) found no relationship between grazed stratum bulk density and bite depth. The reduction in bite depth in the current study and that of Black and Kenney could be explained if the animal was adjusting bite dimensions to maintain a grazing rhythm.

Mean peak force increased with bite depth (equation 5.3). Sheep exerted greater force when they grazed more deeply on taller pastures, as peak bite force increased with pasture height (table 5.4). Such an increase may have arisen because the tensile strength of the pasture increased with depth and because bite depth had been restricted on shorter pastures. On the 50mm pasture bite depth was not influenced by pasture treatment yet the mean peak bite force was significantly greater for the C than either the G or M pasture treatments (10.7 vs. 6.4 and 7.5N table 5.4) which suggests predominantly pseudostem material was more difficult to sever. Sheep were able to maintain bite depth over the range of pasture conditions in this trial by increasing the peak force exerted per bite and/or by reducing bite area (table 5.3). Similar numbers of plant units were severed per bite on all pasture treatments within a height (table 5.3) even though the plant units on the 50mm C treatment required greater force to sever (table 5.4). As pasture height increased the number of plant units severed at each bite decreased (table 5.3) yet the peak bite force increased suggesting that more force was required to break off individual plant units possibly reflecting a greater cross sectional area of individual plant units and/or greater amounts of structural fibre.

It is still unclear which pasture characteristics limited sheep bite depth. Why did sheep grazing the 100mm pastures not increase the force exerted per bite and decrease bite area to take a bite of similar depth to those of sheep on the 150mm pasture (ie. increase BD from 39 to 69 mm)? If force to sever a bite was determining bite depth sheep might be expected to regularly sample the lower horizons. Such a sampling strategy would be expected to increase the standard errors about the mean bite depth (table 5.3) or the standard deviations about the peak bite force (table 5.4). The standard deviation of bite forces about the peak bite force increased as the pasture became taller which suggests the sheep may have been regularly sampling the available horizons either adjusting bite area or depth or both. Certainly as pasture height decreased there appeared to be less variability about the mean bite force to sever a bite. Further experimentation is required where force to sever bites are measured as a turf is progressively grazed down, so the force to sever mainly pseudostem material can be compared with that for leaf.

Bite depth has been shown to be linearly related to pasture height over a range of heights beyond those used in this trial (50 - 2200mm, Burlison, 1987) yet the slope coefficient is less than 0.5. If length of leaf requiring processing prior to swallowing is a constraint, a sudden cut off point would be expected at some critical leaf length and corresponding pasture height, producing a curvilinear rather than a linear relationship between BD and pasture height. In addition, factors other than pasture structure related to the sheep's overall grazing strategy may contribute to bite depth control, such as the avoidance of dead material and the ingestion of fungal endophytes, internal and external parasites or chemicals within the plant in higher concentrations in old plant tissue than young. It is difficult to imagine that the latter factors impose a major constraint during the short grazing period in the current trial.

5.8.5 Bite Area

Bite area was significantly influenced by pasture treatment which altered bulk density but not by pasture height (table 5.3). Although there was a small decline in bite area with height this was not large enough to attain significance. Burlison (1987) found a positive relationship in sheep between pasture height and bite area (Burlison, 1987) where bite area was measured directly on nine pastures. The upper limit of pasture height in Burlisons trial (22 vs.15cm) was greater but the grazed stratum bulk density (2.04 vs 3.28 mgDM/cm^3) was lower than in the current data. Burlison did however produce swards where height and density where not correlated as in the current data. Given the lower grazed stratum bulk densities of the majority of the pastures that Burlison used it is difficult to offer an explanation for the difference between the trials. There is no cause to doubt the methodology for calculating bite area (section 5.2.2) and it is highly unlikely an unintentional bias could selectively allocate itself through nine pasture treatments. The standard error of the difference among means was also small suggesting consistency of measurement and/or little variability about means. In the only two experiments where measurements have been made in cattle, bite area was not influenced by pasture height between 5 and 15cm (Mursan *et al.*, 1989; Elliott, 1988) for three pasture species even though grazed stratum bulk density decreased. It could also be argued that cattle harvest predominantly with their tongue and therefore can not be directly compared with sheep except on very short pastures.

Bite area (BA) was negatively correlated with grazed stratum bulk density (table 5.2) which was a significant predictor variable in the best fit regression of bite and intake variables predicting bite area (equation 5.6). Sheep may have adjusted BA in response to grazed stratum bulk density (table 5.3 and 5.4) as the lowest BA (16.5 cm^2 table 5.3) corresponded to that treatment with the highest mean GSBD at all heights, viz. pasture treatment C (table 5.4). As bite depth was not effected by pasture treatment the significant response in bite volume (BA * BD) is a direct consequence of changes in bite area.

With the exception of pasture treatment C (at the 50mm height) adjustments in bite area in response to pasture treatments ensured peak bite force at a height, bite weight and intake rate were the same irrespective of pasture treatment (table 5.3 and 5.4). It is possible to speculate that sheep attempt to maintain a grazing rhythm and have thus developed some mechanism by which BA is manipulated to meet some longer term grazing goal. Such a mechanism may involve monitoring bite rate, peak bite force or variability of peak bite force, the use of lips as pressure sensors which record the number of contacts and their structural rigidity (a crude measure of stratum bulk density) as well as feed back from post harvest buccal cavity sensors determining mastication bites.

5.8.6 Bite weight per newton of mean peak bite force

Bite weight per newton of peak force was greatest on the 150mm pasture height (table 5.3). The additional force required to break fewer plant units (table 5.3) was more than compensated for by the greater mass of plant material harvested each bite. If it is assumed that peak force is positively correlated with energy expenditure per bite and sheep seek to harvest the greatest mass of nutrients per unit of energy expenditure they should show preference for tall (150mm) rather than short (50mm) pastures.

5.8.7 Conclusions Trial one

Bite weight at low pasture height was not constrained by peak bite force, but rather the animal's ability to gather and prehend pasture and to increase bite depth as suggested by Illius and Gordon (1987). On the

15cm pasture sheep maintained a similar peak bite force but adjusted bite dimensions, primarily bite volume dependent on sward bulk density. On the taller pastures (>10cm) peak bite force increased but so also did bite weight per newton of bite force. Low bite weights/N bite force may constrain bite weight rather than peak bite force and partially determine bite dimensions. Pasture height was the best predictor of short term intake rate.

5.9 Comparison of bite and intake variables for three pasture species (trial 2).

In the second trial bite and intake variables and mean force to sever a bite were measured using the force plate on immature pastures of white clover, prairie grass and tall fescue. The expectation was that on dense immature pasture force to sever a bite would not constrain bite dimensions and bite weight and, in such circumstances mastication rate may determine BR and possibly bite dimensions. Pasture and animal factors other than mean peak force restricted intake rate on these immature pastures. Intake rate on white clover was almost 50% greater than that on the two grasses. Sheep grazing the low bulk density grass did not adjust bite dimensions so that resultant bite weights were equal to those on clover. In addition the low dry matter content restricted intake rate of grass but not clover.

5.9.1 Force to sever a bite

Unfortunately clover turf pastures could not be generated at the target 15cm and were significantly shorter than either of the two grasses (table 5.5). There were no differences in the mean prehension force amongst pasture species (table 5.5) whether expressed as mean peak bite force, mean impulse or as the standard deviation of peak bite forces. The mean peak bite forces measured for white clover, prairie grass and tall fescue (7.68, 6.86 and 7.63 N) were similar to those recorded at 100mm on ryegrass (table 5.4). Mean peak bite forces of the same sheep on 150mm ryegrass pastures (13.7N) were almost twice those in this trial which suggested that there was considerable scope to increase bite force. Intake rate (although higher than in trial 1, table 5.4) was limited by pasture bulk density and the inability of the animal to gather sufficient pasture into the potential bite catchment and/or buccal cavity post harvest processing.

5.9.2 Intake rate

Rate of intake (gDM/min) of white clover pastures was 50% greater than that of prairie grass and 46% greater than that of tall fescue (7.81 vs. 5.19 and 5.35 gDM/min; Table 5.5). Black and Kenney (1984) and Kenney and Black (1986), using artificial pastures of ryegrass and subterranean clover, reported maximum intake rates of 6.0 and 25 gDM/min respectively. White clover appears to have three advantages over the prairie grass and tall fescue; a greater grazed stratum bulk density (0.0081 vs.0.0039 and 0.0033 g/cm^3) a significantly higher DM content in the grazed stratum (0.21 vs. 0.12 and 0.17. table 5.5) and properties related to ease of mastication which allowed it to be consumed at a faster rate (27.3 vs. 22.7 and 23.7 bites/25s table 5.5) in spite of larger bite weights. Unfortunately X-ray devices at airports between the United Kingdom and New Zealand ruined the video tapes of the grazings which meant the ratio of prehending to mastication bites could not be investigated. Bite rate normally declines as bite weight increases reflecting the greater need for processing prior to swallowing. However clover in this trial appeared not to stimulate this expected reaction as bite rate was 20 and 15% greater than on prairie grass or tall fescue despite a 45% larger bite weight.

Intake rate is a measure of the combined effect of prehension, mastication and swallowing. On sparse pastures prehension rate limits intake but as pasture becomes more plentiful the latter factors, processing and swallowing probably assume the dominant roll. Clover is possibly more amenable to rapid processing prior to swallowing predominantly because of its low fibre content.

5.9.3 Limits to the manipulation of bite dimensions

If it is assumed that the shape of bites does not change, a bite can be considered to be cylindrical in shape and described by three measures viz, bite depth (a linear measure), bite area (some function of a linear measure squared) and bite volume (bite area * bite depth, some function of a linear measure cubed). A 50% increase in bite volume (ie new BV = 1.5 x original BV) will not lead to similar increases in bite area and depth as a cubic dimension can not be compared directly with a linear (bite depth) or a square dimension (bite area). The increase in bite depth will equal the cubed root of 1.50 or a 14% increase in bite volume. Bite area is the square of this linear measure (ie. 1.145^2) which corresponds to a 31% increase in bite area. If these increased dimensions are checked, a 14% increase in bite depth times a 31% increase in bite area produces a 50% increase in bite volume provided bite shape remains the same (1.14BD * 1.31BA = 1.5BV). This concept of linear, square and cubic dimensions has been used to compare bite dimensions among clover and grasses to ensure equitable comparisons.

Lower bite weights in the grasses compared with the clover are a reflection of lower grazed stratum bulk densities and dry matter contents (table 5.5). To what extent do grass bite dimensions need to change so that the resultant bite weights equal those on clover? Are such changes biologically and practically feasible? The development of the following argument assumes that the differences in relative grazed stratum bulk density between white clover and the grasses hold for all height strata. If it is assumed that bite shape does not change, the increase in bite dimensions on prairie grass and tall fescue necessary to produce bites of the same weight can be calculated (table 5.13). This approach suggests that bite volumes on the grasses need to increase 3.57 and 3.0 fold if bite weights are to be equal to those on white clover to enable compensation for the lower grazed stratum bulk densities (0.47 and 0.56 vs. 1.68mgDM/cm^3 table 5.13). Assuming bite shape is unchanged the increase in bite depth and area necessary to produce the relevant change in bite volume can be calculated.

Table 5.13 Mean bite dimension and adjustments (shown in brackets) required to equate bite weight of prairie grass and tall fescue with white clover.

	White clover		Prairie grass		Tall fescue	
Bulk density (mgDM/cm^3)		1.68		0.47		0.56
Bite volume (cm^3)	(1)	106	(3.57)	378	(3.0)	318
Bite depth (cm)	(1)	4.5	(1.53)	6.9	(1.44)	6.5
Bite area (cm^2)	(1)	24.1	(2.34)	56.4	(2.08)	50.1

The bite volume required on the two grasses to produce bites of equal weight to white clover are considerably greater than the range of those recorded in practice (table 5.5). Bite depth seems capable of expansion with the range recorded greater than the theoretical requirement (6.9 and 6.5 vs actuals of 7.5 and 7.7cm table 5.5). However the need for a 130% and 108% increase in bite area appears to be biologically impossible for sheep.

Bite areas on these immature grasses (25.5 - 28.5cm^2) were probably very close to the maximum as the highest recorded value in the literature is 35.5cm^2 (table 2.2). Bite areas were 57% greater than those on 15cm ryegrass turfs (17.2 cm^2 table 5.3). It could be argued that immature grass could be more easily gathered and manipulated into the bite catchment area than more mature grass of greater structural rigidity and fibre content. If it is assumed that the current bite area for the two grasses reflect the potential and therefore cannot change, then the entire adjustment in bite dimensions to achieve the desired bite volume must occur through bite depth. Therefore required bite depth on the Prairie grass would need to be (3.57 * 4.5cm) 16.0cm and that on the tall fescue (3.00 * 4.5cm) 13.5cm. With pregrazing heights of 14.7 and 13.9cm for prairie grass and tall fescue respectively (table 5.5) the desired bite depths could not have been achieved even if there was no increase in peak bite force required to harvest a bite. It appeared impossible for sheep grazing the grasses to adjust bite dimensions to equate bite weight with that on clover.

Grazed stratum bulk density in the lower pasture horizons could be expected to increase and thus reduce the necessity for increase in bite depth, but it is highly unlikely that this would occur in practice. Sheep seem therefore probably unable to compensate for the greater grazed stratum bulk density of the white clover pasture by altering bite dimensions. Given that post harvesting problems associated with processing large bite weights of the two grasses are unlikely, either taller pastures or a vast improvement in dry matter bulk density is required before bite weights can equate with those from white clover. As bite rate on clover was some 15-20% greater than that on the grasses even when mean grass BW was lower (0.15 vs 0.11 gDM table 5.5), it is difficult to imagine that this advantage to clover would not increase if grass bite weights were increased. Fresh bite weights of the clover and prairie pastures were identical while that for fescue was significantly lower (0.81 and 0.84 vs 0.65g, table 5.5).

It therefore seems unlikely that grass structure can ever be manipulated to such an extent that resultant intake equal those on white clover. A recent novel approach has been the selection of ryegrass for low and high leaf shear strengths (Mackinnon *et al.*, 1988). In their experiment low leaf shear strength grasses were consumed at a faster rate than control grass although rumen degradation rates were similar. The improvement in intake rate could be due to an improvement in buccal cavity processing of the grass prior to swallowing which may allow the animal to handle larger bite weights and/or increase the rate of prehending bites.

If it is assumed that the density of pasture is 1 then sheep grazing clover harvest 1g of fresh pasture per 100cm^3 of bite volume while those grazing prairie grass and tall fescue harvest 1g per 215 and 197cm^3 of bite volume respectively (fresh bite weight divided by grazed stratum bulk density, table 5.5) which does not appear to represent a very effective harvesting mechanism on a weight basis and may explain why grazing animals appear eager under many pasture conditions to substitute supplements that can be consumed more rapidly for pasture (eg Mayne *et al.*, 1990).

5.9.4 The influence of dry matter content of the grazed stratum on intake rate.

The importance of dry matter content of the grazed strata is often overlooked as a possible factor limiting intake. John and Ulyatt (1987) using 3 ryegrass and 2 tall fescue cultivars found that the intake of fresh forage was limited by mechanisms regulating intake of wet feed, rather than feed DM, and that DM content may be an important factor limiting nutrient intake. Voluntary consumption of feed DM was positively correlated (r = 0.89) with forage DM content at all stages of forage maturity over a wide range of DM contents (12 - 25%). In addition, they demonstrated that intake inhibition was not due to negative feed back from rumen distension as such fresh feed rapidly disintegrated in the rumen and the water so released was quickly absorbed. Such results suggest that intake was restricted by post prehension processing prior to boli formation and swallowing.

Intake rates of sheep grazing ryegrass pastures were significantly influenced by the diurnal variation in DM content (range 11.9 - 17.0%) (Penning and Hooper, 1987). Pasture structure and mass did not change significantly during the measurement period and time of day had no influence on intake rate. In the present study (DM range for grasses 10 - 27%), IR (gDM/min) was positively correlated with DM content of the pasture (0.76 and 0.67 for prairie and fescue respectively, table 5.8). It is likely that rate of intake was controlled by post prehension buccal cavity processing as there was considerable scope for larger bite weights before the peak bite force measured with the same sheep on ryegrass in trial one (14.1 N, table 5.4), was exceeded. Regression relationships between intake rate and dry matter content (table 5.14) highlight the potential importance of dry matter as a predictor of intake. The proportion of dry matter in the grazed stratum alone accounted for 56 and 29%, respectively, of the total variation in intake rate on prairie grass and tall fescue (table 5.14, figure 5.1). Kenney *et al.*, (1984) found that IR of Kikuyu grass decreased as the DM content of the fresh pasture was reduced. The large effect of DM content on the IR of prairie grass may simply reflect a lower DM content in the grazed stratum (0.12 vs 0.17 and 0.20 for prairie grass, fescue and white clover respectively).

Table 5.14 Regression relationships between grazed stratum dry matter content (%) and intake rate (gDM/min) for (1) ryegrass pasture (trial 1), (2) all grass species (trial 2), (3) white clover, (4) prairie grass, and (5) tall fescue.

1	IR =	38.3 ± 6.61 DM + 0.68 ± 1.4	Adj R^2 =	0.15	$p<0.01$
2	IR =	25.7 ± 4.02 DM + 1.72 ± 0.71	Adj R^2 =	0.29	$p<0.01$
3	IR =	19.1 ± 9.38 DM + 3.47 ± 1.94	Adj R^2 =	0.09	$p<0.05$
4	IR =	66.3 ± 10.4 DM - 3.08 ± 1.31	Adj R^2 =	0.56	$p<0.01$
5	IR =	33.5 ± 6.81 DM - 0.25 ± 1.19	Adj R^2 =	0.29	$p<0.01$

5.9.5 Conclusions Trial 2

Intake of immature prairie grass, tall fescue and white clover was probably influenced by pasture structure but by post harvest buccal cavity capacity and processing. Peak bite force were similar for all immature pastures and less than half that recorded for ryegrass of a similar height in trial one. Although considerable scope existed to increase bite dimensions other factors appeared to influence intake rate. Intake rate of the white clover was some 50% greater than that of the grasses. The majority of this advantage appeared to be due to the superior rate at which clover was processed and swallowed and the smaller influence of DM content on intake rate. Fresh bite weight of the clover and prairie grass were identical yet the prehending bite rate was greater on clover. While the DM content of the grazed horizon accounted for almost 50% of the variation in intake rate for grasses, it accounted for only 9% for the clover. In the current circumstances (trial 2) bite dimensions on the grasses may be limited more by the ability to process large bites and maintain the desired grazing rhythm than any structural features of the pasture associated with the ease of harvest.

5.10 Response of intake and bite variables to successive grazings of ryegrass pastures (trial 3).

This small trial had two objectives :-

1) To compare bite and intake variables for two successive grazings on the same turf.
2) To study the elasticity of bite and intake variables when a grid restricted bite depth in both the predominantly leaf and pseudostem strata.

The trial demonstrated that:

1) Mean peak bite force and bite rate did not change during two successive grazings of a turf although intake rate and bite weight declined.
2) Where a grid restricted bite depth, bite dimensions were manipulated to maintain intake rate.

5.10.1 The influence of successive grazings on bite and intake variables

Although peak bite force did not change during the second grazing, both intake rate and bite weight declined markedly (7.6 vs. 4.8 gDM/min; 0.11 vs. 0.07 gDM table 5.10). While the grazed stratum bulk density was greater at the second grazing (table 5.11) any such advantage was more than offset by a significant reduction in both bite area and depth. Maintenance of a grazing rhythm appeared to be of paramount importance. Thus peak bite force and bite rate were constrained to the same level as for first grazing. As there was no reduction in BN it appears intake was limited primarily by gathering and prehension characteristics rather than post harvest mouth processing.

In the previous trials (1 and 2 Chapter 5) grazing was restricted predominantly to the leaf horizons of the pastures, thus making comparisons with the current trial difficult. There was evidence, however, that bite dimensions were manipulated within the pasture treatments above 10cm which maintained intake rate (table 5.3). However bite weight and intake rate both declined.

5.10.2 Bite and intake response when bite depth was restricted

Neither intake rate or bite weight was significantly altered by the insertion of a grid which restricted sheep bite depth to two thirds of that on a previously grazed paired turf. Bite area appeared to increase by 44% (table 5.10) to compensate for the reduction in bite depth and bite rate was maintained. Peak bite force was reduced when the grid was inserted yet the sheep were able to maintain intake rate, but in so doing grazed significantly more of the turf surface area (60 vs 38% table 5.10).

5.10.3 Conclusions Trial 3

Insertion of a grid restricted BD and thus left only BA as means by which BV could be increased to maintain intake. As neither peak bite force (it decreased when the grid was inserted), nor post harvest processing (prehending BR of 74 vs 55 for grass in trial 2, table 5.5) limited intake, the animals appeared to attempt to gather as much leaf as possible by increasing BA. Leaf with low structural rigidity was gathered into the bite catchment by an increase in head movement. Where neither prehension force nor mastication constrains intake, accessibility of preferred plant components and elasticity of bite dimensions determine intake rate.

5.11 Mean peak bite force and intake and bite variables of goats grazing 15cm ryegrass turfs (Trial 4)

In this final trial the bite and intake variables of goats were compared with those of sheep when grazing similar turfs to those used in trial one (chapter 5). The objective was to compare the ingestive behaviour and intake parameters of the goat with sheep. The trial demonstrated that goats grazed in the top horizons of the pasture and exerted approximately 20% of the mean peak bite force of sheep on 15cm pastures.

5.11.1. Grazing strategy of goats

Goats maintained a similar intake rate (section 5.7.2) to sheep even though, because of their shallower bite depth (table 5.12), they grazed a stratum of lower bulk density. Intake rate was maintained by a greater bite rate although with similar bite areas the preferred horizon would become rapidly depleted. It might be, at this stage, that the goat is unwilling to adjust mean peak bite force to graze a lower horizon and like sheep (section 6.5) bite weight and intake rate declines. Goats with their relatively narrow incisor breadth, when compared to sheep, and absence of a tongue gathering grazing mechanism appear poorly equipped to graze in the least dense pasture horizon, that is at the sward surface. If the relative difference between sheep and goat peak bite force for the pasture conditions in this trial extend to a wide range of pasture conditions, the goat may have difficulty severing bites in the lower sward profiles especially if grazing rhythm is to be maintained. The grazing strategy of the goat may therefore be one of harvesting plant material of the highest quality in the surface horizon. In trial one (chapter 3 table 3.11) goats consumed the highest quality diet although not significantly greater than the lamb or calf.

5.11.2 Conclusions Trial 4

Goats appear to have a different grazing strategy to sheep. Intake rate is maintained by a rapid prehension rate. Unfortunately no grazing behaviour data was located for goats to assess whether their rate of biting per minute was different to sheep. If rate of total biting (prehension and mastication) is similar to sheep, then the goats could be expected to adjust bite dimensions to restrict the need for mastication. Selection of such material may be aided by a low peak bite force. More research is required to verify this hypothesis.

Chapter 6

Discussion

The objectives of the three trials in this thesis were :-

1) To compare the diet and intake of calves, kids and lambs over a range of sward structures and identify a grazing strategy or method of grazing for each species.
2) Develop a technique which overcame the problem of inequitable allocation and allowed grazing behaviour to be related to pasture structure.
3) To determine the role of force in prehension on components of intake.

6.1 Identification of grazing strategies.

Trial one provided good evidence that young calves, kids and lambs vary in their sensitivity to pasture structure and/or composition. The extent of dietary overlap under such conditions suggested the three species would be competitive when grazing together. However the results from this first experiment were largely descriptive and did not enable the methodology of grazing used by the three species to be identified to test hypotheses on complementarity, that is where the intake and performance of both species may be enhanced by grazing together. Differing animal species sensitivity to pasture mass and structure was indicated by differences in intake, diet composition and residual canopy structure, mass and composition at the completion of experiment one. It is essential that we have a more comprehensive picture of the grazing strategy of an animal species if the species * pasture mass interaction (table 3.11) for botanical composition is to be untangled. It is rather to simplistic for example to argue that goats discriminate against clover (eg Clark *et al.*, 1982). Depending on which PM was chosen both goats and kids could be shown to apparently select (PM 4) or reject clover (PM 3) relative to the diet composition of other species. Collins (1989) used cattle, goats and sheep to graze down similar ryegrass white-clover pastures but overcame the problem of inequitable allocation of pasture among species. She proposed a grazing strategy for the goat with a motive of maximizing the consumption of new growth and a method encompassing surface grazings, frequent moves to new sites and avoidance of contamination. It was suggested that goats would harvest a variable diet (from a quality perspective), and their intake would be very sensitive to a decline in pasture height or mass. However the results in the current trial do not fully support all aspects of the proposed strategy.

In experiment one, goats selected the highest quality diet (OMD, table 3.8) irrespective of its botanical composition however differences between species were small. Goats avoided grazing older leaf even though it made up over 30% of the grazed horizon (experiment 2, table 4.10) and concentrated on consuming the younger leaves. In the first trial goats and kids were able to discriminate more effectively against dead material (table 3.12) than other species, possibly as a consequence of their pointed muzzle. Goats exerted only 20% of the prehension bite force of sheep on 15cm ryegrass pastures (experiment 3, trial 4). However of more interest was their ability to maintain a similar intake rate to sheep by maintaining a very rapid prehending bite rate even though bite weight and depth were considerably less. While the narrow pointed muzzle of goats may assist in fine scale selection, the capacity of the mouth to handle ingesta prior to swallowing may be compromised. To overcome this possible limitation goats may ingest small shallow bites which restrict the particle length and thus require little pre swallowing mastication. Unfortunately no other grazing behaviour data for goats on temperate pastures were found in the literature. More such behavioural data from a range of controlled pasture structures and compositions is required to verify or refute the proposed ingestive mechanism for the goat.

6.2 Separation of pasture and animal characteristics influencing intake rate

The turf grazing technique developed in experiment 2 and further modified in experiment 3 enabled pasture components affecting bite and behavioural components of intake to be identified and characterized. Detailed characterization of sward structure and measurement of grazing behaviour, the avoidance of surgically modified animals (Burlison, 1987), the ability to manipulate pasture height and density by sowing rate and plant removal and the control over bite depth possible with the grid will make this a very useful technique for future research on ingestive behaviour. For example it should be possible to investigate the importance of grazed stratum fresh weight density by preparing pastures of the desired range of densities and then drying representative paired turfs rapidly at 70°C to varying DM contents in a force dry oven. As the technique is non destructive it could be used at early stages of plant selection programmes to classify pasture genotypes on intake rate and therefore likely preference, especially if paired turfs representing different genotypes were offered. No special equipment is required other than a grid (plate 5.3) and scales with a sensitivity of 0.1g over a 40kg range.

6.3 The role of prehension in determining intake rate

Bite weight at low pasture height was not constrained by peak bite force, but rather by the animals ability to gather and prehend pasture and to increase bite depth as suggested by Illius and Gordon (1987) from a theoretical model. Prehension bite force was not influenced by pasture treatments within a pasture height designed to alter grazed stratum bulk density at a height and to simulate common pasture management practices. Unfortunately the upper range of grazed stratum bulk densities in this trial (3.3 mgDM/cm^3) was lower than that of Black and Kenney (4.23mgDM/cm^3) who found a negative relationship between GSBD and bite depth. While the trend was similar in trial 1 of experiment 3, it never attained significance. Pasture treatments designed to alter GSBD sufficiently to alter BD and therefore test the summit force hypothesis were not produced. In such circumstances it is difficult to conclude that prehension force influenced bite dimensions or weight. The increase in force with height could simply reflect the greater scope for bite depth offered by the taller swards with the likelihood that tensile strength of pasture increases progressively from the pasture surface horizon to ground level. The question still remains as to what pasture or animal factors determine bite depth? Bite area and as a consequence BV may be manipulated to optimize bite weight per N of peak bite force as these were similar in trials one and two in experiment three for grasses (table 5.3 and 5.5). Bite depths in the current study were considerably greater than previously measured and may reflect the pre trial turf treatments, for example their growth in green-house conditions. It is still possible that bite depth and therefore bite dimensions are determined by prehension force but pastures of greater density and/or tensile strength are needed to test such a hypothesis.

It would appear that prehension forces may not be involved in control of intake rate in many commonly encountered pasture situations. As previously discussed, grazing strategy may determine a method of grazing which is impaired by pasture conditions. It did not appear that sheep had the elasticity of bite dimensions to compensate for the low GSBD (expressed as either g fresh or DM/cm^3) of prairie and fescue pastures when compared to white clover. There appeared to be no role for peak bite force as these same sheep had, in the previous experiment, exerted considerably more force to sever ryegrass at a similar grazed height. Bite weight per newton bite force was similar for all pasture treatments at 150mm (table 5.3) and for the 3 pasture species of similar height (table 5.5). Sheep may attempt to optimize bite weight per newton of peak force and let mastication rate adjust bite rate. The apparently higher bite weight per unit of force for legumes (0.021g/N) compared with the range for grass of similar height in trial one and two (0.0.14 - 0.016g/N table 5.3 and 5.5) may reflect a lower tensile strength and/or greater grazed stratum bulk density.

Unfortunately the DM content of the grazed strata of the three pasture species while similar for white clover and fescue (mean of 0.20 vs 0.17), was considerably lower for the prairie grass. It is only recently that DM content of the ingested pasture, whether vegetative or mature, has been shown to restrict intake rate (John and Ulyatt, 1987) prior to swallowing, rather than in the rumen. It would appear that DM content of the white clover had less effect on IR than similar levels in fescue (table 5.14). As the same sheep grazed both pastures, buccal cavity capacity differences can be eliminated. Bite rate as indicated by bite number in 25 seconds was significantly greater for the clover than either grass in agreement with Kenney and Black (1986). Such data suggest the shear strength of legume was less than that of fescue and therefore less effort was spent masticating. Kenney and Black (1986), found the rate of mastication and swallowing so much faster than for ryegrass, even though prehension rate was also greater, that intake rate did not plateau until herbage available in the grazed stratum was twice that for grass (2t DM/ha vs 1t DM/ha). In the current trial, prehending bite number was not correlated with DM for either the clover or the fescue. Selection of ryegrass for low leaf shear strength (MacKinnon *et al.*, 1988) increased intake rate by 17% over control lines. It is possible that differences in shear strength of leaf may account for a portion, at least, of the almost 50% higher IR of legume compared to grasses in this study.

Dry matter content probably influences intake rate through buccal cavity capacity as it was negatively correlated with bite volume and bite depth but not correlated at all with bite number as a measure of prehending of bite rate (table 5.7). Sheep grazing low DM pastures may increase bite dimensions in an attempt to maintain IR. Fresh bite weight for prairie grass was similar to that of white clover even though dry matter content was considerably lower (21% vs 12%DM table 5.5). Understanding which factors determine intake rate could be improved if fresh bite weight and grazed stratum bulk density data and all bites irrespective of type were recorded during grazing.

6.4 Future research directions

The turf technique offers the opportunity to provide answers to the many questions posed by the work described in this thesis. Areas identified as requiring further research are : -

1) The importance of tensile strength in determining bite dimensions especially at high pasture densities.
2) The relative importance of plant component DM content on bite and intake variables.
3) The place of shear strength in the control of pasture intake.
4) The height*pasture species interaction of GSBD on the components of intake.
5) The importance of mouth anatomy and ingestive behaviour in determining the intake rate of different animal species for a range of pasture structures and compositions.

Chapter 7

Summary

7.1 Introduction

Since the grazing process was first expressed mechanistically as the product of bite rate, bite weight and grazing time (Hancock, 1952) the relationship between sward structure and intake has been extensively studied. Few such studies have identified those pasture components influencing grazing behaviour, intake and diet selection as many pasture characteristics change rapidly and simultaneously. Separation of cause and effect has therefore been very difficult. Short term grazings of pasture turfs where pasture characteristics could be related to bite dimensions were developed in this study to overcome many of these former limitations.

7.2 Intake and diet selection of young ruminants at pasture

Dietary overlap suggests the species are more competitive than complementary when grazing intensively managed swards. Composition of the diet was not influenced by age in goats or sheep. Although species specific differences occurred in diet composition and in the composition and distribution of pasture between grazed horizons, it was not possible to identify cause and effect because of infrequent and/or imprecise measurements.

7.3 Short term grazings of pasture turfs

Short term grazing of pasture turfs overcame the problems of unequal grazing opportunity among species in experiment 2 (chapter 4) and enabled bite and intake variables to be related to pasture structure. Sheep intake did not decline as PM or surface height was reduced, while the intake rate of cattle declined with both PM and SH. Although goat BW was sensitive to PM and SH, IR was not significantly affected. Goats discriminated against old tillers in the grazed horizon preferring the youngest tiller while calves preferentially consumed the second to oldest tiller. Sheep grazed deeper in the pasture canopy than goats and cattle.

7.4 Sward structure, bite dimensions and peak bite force.

In the final experiment, four trials investigated the effects of prehension force on bite dimension and components of intake. Bite weight at low pasture heights did not appear to be constrained by peak bite force, but rather the animal's ability to gather and prehend pasture. Peak bite force increased with height but the extent to which this reflected the greater opportunity to increase bite depth and the increase in tensile strength with depth is unknown. At a particular height bite depth increased where pasture treatment decreased grazed stratum bulk density, although this trend was not significant. Within a pasture height it appeared that bite area was manipulated so that BW was similar on all pasture treatments. Low bite weights/N of bite force may constrain bite dimensions and BW rather than peak bite force. Pasture height was the best predictor of intake for these pure ryegrass pastures. When bite depth was restricted by imposing a grid in the pasture, intake rate was maintained temporarily by a 44% increase in bite area.

Buccal cavity processing capacity and/or structural attributes of the pasture influenced IR of immature pastures. Intake rate of clover was greater than that of either grass. Sheep were unable to compensate for the lower grazed stratum bulk density of grass when compared to white clover by increasing bite dimensions or bite rate. Dry matter content of the pasture within the grazed stratum was also a major source of variation in intake rate in the two grasses.

Goats appeared to have a grazing strategy quite different to that in sheep. Mean peak bite force in goats appeared to be only 20% of that those in sheep, bite area was similar, but bite depth was shallower. Goats were, however, able to maintain, for a short period at least, a similar intake rate to that of sheep because of a higher bite rate.

It was concluded that the grazing strategies of goats, sheep and cattle are different under intensive grazing. Induced changes in bite and intake variables could be related to sward structure. Gathering and retaining pasture components within the bite catchment until severed controlled bite weight and intake rate on short pastures. Peak bite force failed to respond to pasture treatments which increased GSBD and presumably tensile strength of plant components at similar pasture heights. Sheep maintained similar bite weights at all pasture heights by manipulating bite area. Shear strength and the DM content of plant components in the grazed stratum appeared to control intake where peak bite force was not implicated. If intake rate in grass is ever to match that in white clover, the grazed stratum bulk density of high DM leaf of low shear strength must be improved. Grazing animals may monitor BW/FRC when determining bite dimensions, while prehending bite rate will depend on ease of boli formation and swallowing. Careful monitoring of intake rate may be the means by which grazing intake is controlled.

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Appendix

Table 1 Mean botanical composition (proportion of dry weight) of oesophageal extrusa from kids, lambs, calves, ewes and does grazing with their own species on a ryegrass white-clover pasture at four pasture masses and a common allowance.(trial 1 chapter3).

pasture mass	date	animal	species	DOM dig	grass	clover	weeds	dead
4	1	18	1	83.6	0.634	0.345	2.100	1.600
4	2	20	1	84.9	0.482	0.481	0	0.027
4	3	24	1	80.7	0.038	0.943	0	0.019
4	4	56	1	76.6	0.754	0.215	0	0.031
4	1	46	2	76.3	0.266	0.734	0	0
4	2	42	2	70.0	0.907	0.093	0	0
4	3	43	2	68.5	0.697	0.273	0	0.030
4	4	45	2	71.3	0.835	0.106	0	0.059
4	1	54	3	69.4	0.829	0.132	0	0.039
4	2	51	3	64.7	0.824	0.148	0	0.028
4	3	53	3	72.6	0.896	0.014	0.029	0.061
4	4	52	3	67.5	0.600	0.119	0.044	0.237
4	1	22	11	78.0	0.760	0.237	0	0.003
4	2	23	11	83.4	0.486	0.503	0	0.011
4	3	25	11	84.7	0.055	0.932	0	0.013
4	4	21	11	76.9	0.843	0.105	0	0.052
4	1	50	22	74.2	0.629	0.371	0	0
4	2	47	22	68.8	0.818	0.143	0	0.039
4	3	48	22	67.6	0.748	0.117	0	0.136
4	4	44	22	62.7	0.697	0.206	0	0.097
3	1	20	1	82.8	0.752	0.235	0.014	0
3	2	18	1	77.1	0.960	0.040	0	0
3	3	56	1	73.6	0.935	0.037	0	0.028
3	4	24	1	84.3	0.481	0.482	0	0.037
3	1	42	2	79.1	0.529	0.453	0	0.018
3	2	46	2	74.8	0.511	0.469	0	0.020
3	3	45	2	73.7	0.596	0.354	0	0.050
3	4	43	2	78.3	0.596	0.396	0	0.008
3	1	51	3	71.6	0.820	0.164	0.002	0.014
3	2	54	3	77.4	0.732	0.267	0	0.001
3	3	52	3	75.8	0.823	0.127	0	0.05
3	4	53	3	76.9	0.648	0.217	0	0.135
3	1	23	11	84.4	0.772	0.228	0	0
3	2	22	11	75.9	0.822	0.172	0	0.006
3	3	21	11	87.4	0.804	0.186	0	0.001
3	4	25	11	82.2	0.715	0.257	0	0.028
3	1	47	22	75.5	0.398	0.593	0	0.009
3	2	50	22	78.4	0.407	0.570	0	0.023
3	3	44	22	72.7	0.427	0.573	0	0
3	4	48	22	74.9	0.399	0.601	0	0
2	1	24	1	84.6	0.325	0.669	0	0.006
2	2	56	1	81.4	0.802	0.179	0.009	0
2	3	18	1	*	*	*	*	*
2	4	20	1	82.1	0.375	0.625	0	0

continued . . .

. . . Table 1 continued . . .

pasture mass	date	animal	species	DOM dig	grass	clover	weeds	dead
2	1	43	2	79.0	0.301	0.695	0	0.005
2	2	45	2	81.7	0.364	0.626	0	0
2	3	46	2	77.9	0.350	0.620	0	0.020
2	4	42	2	82.8	0.462	0.537	0	0.001
2	1	53	3	83.3	0.933	0.057	0	0.010
2	2	52	3	77.6	0.816	0.134	0	0.050
2	3	54	3	81.7	0.856	0.130	0	0.014
2	4	51	3	76.3	0.470	0.502	0	0.028
2	1	25	11	83.5	0.828	0.156	0	0.016
2	2	21	11	8.01	0.876	0.111	0	0.013
2	3	22	11	76.0	0.899	0.075	0	0.026
2	4	23	11	85.3	0.690	0.310	0	0
2	1	48	22	79.7	0.407	0.593	0	0
2	2	44	22	78.9	0.275	0.707	0	0.018
2	3	50	22	82.3	0.578	0.386	0	0.036
2	4	47	22	81.1	0.637	0.339	0	0.024
1	1	56	1	75.5	0.933	0.046	0	0
1	2	24	1	83.4	0.525	0.475	0	0
1	3	20	1	86.6	0.662	0.322	0	0.016
1	4	18	1	86.2	0.569	0.429	0	0.001
1	1	45	2	81.8	0.626	0.354	0	0.020
1	2	43	2	82.6	0.551	0.449	0	0
1	3	42	2	74.6	0.909	0.075	0	0.016
1	4	46	2	80.1	0.460	0.538	0	0.002
1	1	52	3	84.3	0.775	0.161	0.013	0.051
1	2	53	3	72.6	0.818	0.099	0.023	0.060
1	3	51	3	78.6	0.518	0.398	0	0.084
1	4	54	3	80.1	0.507	0.456	0	0.037
1	1	21	11	87.7	0.893	0.107	0	0
1	2	25	11	89.8	0.790	0.209	0	0.001
1	3	23	11	88.9	0.984	0.016	0	0
1	4	22	11	*	*	*	*	*
1	1	44	22	79.0	0.624	0.366	0.001	0
1	2	48	22	82.3	0.618	0.379	0	0.003
1	3	47	22	80.1	0.775	0.223	0	0.002
1	4	50	22	81.7	0.455	0.510	0	0.035

Date: 1 mean for OE for the 27 and 28 December
2 mean for OE for the 29 and 30 December
3 mean for OE for the 1 and 2 January
4 mean for OE for the 3 and 4 January

Species: 1 Kids; 2 lambs; 3 calves; 11 does or goats; 22 ewes

Pasture mass: 1 5400; 2 4500; 3 3800; 4 2950kgDM/ha

Table 2 Pasture mass (kgDM/horizon/ha) and mean botanical composition (proportion by weight of DM) of horizon cuts (6cm deep) by pasture mass and animal species. (Trial 1 chapter 3).

pm	period	species	pasture mass (pm)	total pm	horizon cm	grass	clover	dead	grass leaf	grass stem	grass seed	clover leaf	clover stem	clover seed
4	1	4	2652	4784	0	0.37	0.26	0.37	0.19	0.16	0.02	0.11	0.14	0.01
4	1	4	988		6	0.48	0.42	0.11	0.37	0.09	0.03	0.25	0.13	0.04
4	1	4	624		12	0.47	0.50	0.03	0.37	0.09	0.01	0.35	0.10	0.07
4	1	4	312		18	0.50	0.48	0.03	0.30	0.12	0.09	0.26	0.04	0.18
4	1	4	208		24	0.90	0.06	0.04	0.37	0.09	0.44	0.00	0.00	0.05
3	1	4	2392	4004	0	0.34	0.15	0.51	0.22	0.11	0.01	0.07	0.07	0.01
3	1	4	884		6	0.60	0.25	0.15	0.47	0.11	0.02	0.21	0.04	0.00
3	1	4	520		12	0.79	0.17	0.04	0.53	0.12	0.14	0.08	0.02	0.07
3	1	4	208		18	0.93	0.07	0.01	0.57	0.03	0.33	0.03	0.00	0.04
2	1	4	3084	3708	0	0.34	0.23	0.43	0.26	0.08	0.00	0.14	0.08	0.01
2	1	4	520		6	0.63	0.28	0.09	0.54	0.08	0.01	0.23	0.03	0.02
2	1	4	104		12	0.85	0.06	0.09	0.49	0.06	0.30	0.03	0.01	0.02
1	1	4	1612	1716	0	0.33	0.33	0.34	0.29	0.04	0.00	0.26	0.06	0.01
1	1	4	104		6	0.91	0.06	0.03	0.77	0.07	0.06	0.06	0.00	0.00
4	2	1	3640	4888	0	0.28	0.28	0.44	0.20	0.06	0.02	0.10	0.13	0.05
4	2	1	988		6	0.46	0.30	0.24	0.30	0.11	0.05	0.12	0.11	0.07
4	2	1	260		12	0.50	0.13	0.36	0.29	0.18	0.04	0.04	0.08	0.02
4	2	2	2756	3536	0	0.40	0.13	0.48	0.26	0.10	0.04	0.05	0.06	0.02
4	2	2	572		6	0.56	0.18	0.25	0.38	0.12	0.04	0.06	0.06	0.04
4	2	2	208		12	0.64	0.12	0.24	0.32	0.13	0.19	0.05	0.05	0.02
4	2	3	4160	5148	0	0.35	0.15	0.50	0.23	0.09	0.02	0.07	0.07	0.01
4	2	3	832		6	0.62	0.19	0.19	0.43	0.11	0.08	0.11	0.05	0.03
4	2	3	156		12	0.74	0.14	0.12	0.42	0.17	0.15	0.07	0.03	0.04
3	2	1	3344	5216	0	0.33	0.03	0.65	0.19	0.13	0.01	0.03	0.00	0.00
3	2	1	1388		6	0.67	0.06	0.27	0.55	0.08	0.04	0.04	0.02	0.01
3	2	1	484		12	0.83	0.09	0.09	0.66	0.10	0.07	0.05	0.01	0.02
3	2	2	2356	3136	0	0.42	0.10	0.48	0.26	0.14	0.02	0.05	0.03	0.02
3	2	2	624		6	0.75	0.12	0.13	0.55	0.14	0.06	0.06	0.02	0.04
3	2	2	156		12	0.83	0.07	0.10	0.52	0.18	0.12	0.02	0.02	0.03
3	2	3	2428	3260	0	0.47	0.11	0.43	0.33	0.12	0.02	0.05	0.05	0.01
3	2	3	692		6	0.69	0.20	0.11	0.54	0.12	0.02	0.14	0.03	0.03
3	2	3	140		12	0.73	0.21	0.06	0.51	0.13	0.09	0.17	0.02	0.02
2	2	1	2340	3219	0	0.43	0.19	0.38	0.34	0.07	0.02	0.11	0.07	0.01
2	2	1	640		6	0.60	0.32	0.08	0.47	0.09	0.04	0.28	0.04	0.01
2	2	1	239		12	0.86	0.08	0.06	0.41	0.11	0.32	0.05	0.01	0.03
2	2	2	1732	2340	0	0.54	0.20	0.26	0.44	0.08	0.02	0.12	0.07	0.02
2	2	2	468		6	0.69	0.25	0.06	0.54	0.12	0.03	0.18	0.02	0.05
2	2	2	140		12	0.91	0.03	0.05	0.44	0.10	0.37	0.02	0.00	0.01
2	2	3	2148	2409	0	0.45	0.15	0.41	0.39	0.06	0.00	0.10	0.05	0.00
2	2	3	244		6	0.64	0.28	0.08	0.56	0.08	0.01	0.24	0.01	0.02
2	2	3	17		12	0.95	0.01	0.04	0.12	0.05	0.79	0.01	0.00	0.00
1	2	1	1768	2028	0	0.51	0.30	0.19	0.42	0.08	0.01	0.22	0.07	0.02
1	2	1	208		6	0.59	0.38	0.03	0.48	0.07	0.04	0.30	0.02	0.06
1	2	1	52		12	0.73	0.08	0.19	0.55	0.04	0.13	0.05	0.01	0.02
1	2	2	1612	1872	0	0.55	0.30	0.15	0.50	0.04	0.01	0.23	0.05	0.02
1	2	2	208		6	0.71	0.22	0.06	0.60	0.07	0.04	0.19	0.02	0.02
1	2	2	52		12	0.76	0.16	0.09	0.50	0.02	0.24	0.13	0.03	0.00
1	2	3	1248	1248	0	0.40	0.30	0.30	0.36	0.04	0.00	0.23	0.06	0.01
1	2	3	0		6	0.43	0.27	0.30	0.11	0.32	0.00	0.00	0.03	0.24
4	3	1	1804	2220	0	0.30	0.17	0.54	0.24	0.05	0.01	0.04	0.12	0.00
4	3	1	244		6	0.48	0.21	0.30	0.36	0.10	0.01	0.03	0.11	0.07
4	3	1	172		12	0.55	0.19	0.26	0.21	0.13	0.17	0.02	0.10	0.07

continued . . .

. . . Table 2 continued . . .

pm	period	species	pasture mass (pm)	total pm	horizon cm	grass	clover	dead	grass leaf	grass stem	grass seed	clover leaf	clover stem	clover seed
4	3	2	1908	2480	0	0.25	0.15	0.60	0.15	0.08	0.02	0.03	0.09	0.03
4	3	2	416		6	0.51	0.08	0.42	0.33	0.11	0.08	0.01	0.07	0.00
4	3	2	156		12	0.65	0.09	0.26	0.26	0.19	0.20	0.02	0.04	0.03
4	3	3	1992	2215	0	0.29	0.17	0.54	0.18	0.10	0.02	0.06	0.09	0.02
4	3	3	172		6	0.58	0.18	0.24	0.43	0.12	0.04	0.10	0.05	0.03
4	3	3	52		12	0.66	0.10	0.25	0.30	0.20	0.16	0.03	0.07	0.00
3	3	1	2782	3614	0	0.46	0.12	0.41	0.25	0.17	0.04	0.05	0.07	0.00
3	3	1	624		6	0.71	0.14	0.16	0.54	0.13	0.04	0.06	0.05	0.02
3	3	1	208		12	0.86	0.02	0.12	0.45	0.24	0.17	0.01	0.00	0.00
3	3	2	3156	3609	0	0.43	0.07	0.50	0.24	0.16	0.03	0.03	0.04	0.00
3	3	2	296		6	0.65	0.06	0.28	0.44	0.15	0.06	0.02	0.02	0.01
3	3	2	156		12	0.78	0.04	0.18	0.28	0.25	0.25	0.01	0.02	0.01
3	3	3	1628	1903	0	0.32	0.19	0.49	0.19	0.12	0.01	0.09	0.09	0.01
3	3	3	224		6	0.66	0.15	0.20	0.39	0.25	0.02	0.09	0.05	0.02
3	3	3	52		12	0.71	0.06	0.22	0.20	0.35	0.16	0.02	0.03	0.01
2	3	1	3432	3936	0	0.50	0.10	0.40	0.35	0.15	0.01	0.06	0.04	0.00
2	3	1	416		6	0.75	0.18	0.07	0.60	0.13	0.03	0.13	0.03	0.02
2	3	1	88		12	0.92	0.03	0.06	0.29	0.32	0.32	0.01	0.00	0.02
2	3	2	3328	3744	0	0.32	0.17	0.51	0.19	0.12	0.02	0.06	0.09	0.02
2	3	2	312		6	0.70	0.12	0.18	0.50	0.12	0.08	0.06	0.02	0.04
2	3	2	104		12	0.88	0.02	0.10	0.24	0.20	0.44	0.01	0.01	0.00
2	3	3	3848	3848	0	0.25	0.23	0.52	0.18	0.07	0.00	0.12	0.10	0.01
1	3	1	3432	3848	0	0.33	0.21	0.47	0.27	0.06	0.00	0.13	0.08	0.01
1	3	1	416		6	0.65	0.25	0.10	0.59	0.03	0.03	0.19	0.02	0.05
1	3	2	1680	1820	0	0.44	0.16	0.40	0.33	0.11	0.01	0.10	0.06	0.00
1	3	2	140		6	0.84	0.04	0.12	0.66	0.05	0.13	0.04	0.00	0.00
1	3	3	2288	2288	0	0.29	0.21	0.50	0.23	0.06	0.00	0.12	0.08	0.01

Where:

Pasture mass (kgDM/ha):	1 corresponds to PM 1
	2 corresponds to PM 2
	3 corresponds to PM 3
	4 corresponds to PM 4
Period :	1 Start
	2 Midpoint, day 4
	3 End of trial, day 8
Species :	1, kid; 2, lamb; 3, calf.

Table 3 Pasture mass (kgDM/ha) and botanical composition (proportion of DM) of ground level cuts at the start midpoint and end of the experiment for all animal and pasture mass combinations (experiment 1 chapter 3).

pasture mass	period	animal species	PM kgDM/ha	SEM	weed	dead	grass leaf	grass stem	grass seed	clover leaf	clover stem	clover seed
4	start		5451.3	127.4	0.0	0.34	0.21	0.15	0.05	0.10	0.13	0.02
3	start		4476.8	560.0	0.0	0.24	0.27	0.17	0.05	0.13	0.14	0.01
2	start		3797.3	179.9	0.0	0.38	0.24	0.12	0.02	0.12	0.12	0.01
1	start		2950.0	385.2	0.0	0.34	0.25	0.09	0.01	0.13	0.13	0.00
4	1	G	5393.2	191.9	0.0	0.41	0.18	0.15	0.04	0.04	0.16	0.00
4	1	L	4525.8	881.6	0.0	0.07	0.19	0.24	0.10	0.02	0.09	0.02
4	1	C	4086.9	414.2	0.0	0.41	0.12	0.15	0.03	0.07	0.20	0.03
3	1	G	6039.6	187.6	0.0	0.34	0.29	0.28	0.02	0.02	0.06	0.00
3	1	L	4127.8	61.8	0.0	0.26	0.20	0.27	0.09	0.04	0.14	0.02
3	1	C	4263.1	109.7	0.0	0.33	0.22	0.27	0.03	0.07	0.08	0.01
2	1	G	4221.8	238.4	0.0	0.37	0.21	0.16	0.02	0.10	0.13	0.01
2	1	L	3164.5	329.7	0.0	0.30	0.30	0.17	0.03	0.08	0.11	0.01
2	1	C	3118.4	132.5	0.0	0.34	0.25	0.17	0.00	0.10	0.11	0.02
1	1	G	2905.1	428.5	0.0	0.39	0.26	0.10	0.00	0.16	0.10	0.00
1	1	L	2747.4	412.3	0.0	0.29	0.33	0.12	0.01	0.14	0.10	0.01
1	1	C	2477.1	210.4	0.0	0.45	0.21	0.08	0.00	0.12	0.13	0.00
4	2	G	3639.9	150.6	0.0	0.48	0.14	0.14	0.01	0.03	0.20	0.00
4	2	L	4597.1	380.0	0.0	0.04	0.15	0.20	0.03	0.01	0.08	0.00
4	2	C	2863.8	15.7	0.0	0.40	0.13	0.24	0.03	0.05	0.15	0.00
3	2	G	4631.3	61.8	0.0	0.31	0.22	0.25	0.03	0.07	0.12	0.00
3	2	L	4009.0	313.5	0.0	0.38	0.23	0.20	0.06	0.03	0.10	0.00
3	2	C	3937.8	613.7	0.0	0.41	0.17	0.21	0.01	0.06	0.14	0.00
2	2	G	3326.9	112.1	6.7	0.27	0.32	0.15	0.00	0.11	0.09	0.01
2	2	L	3473.2	107.4	0.0	0.40	0.22	0.20	0.03	0.05	0.11	0.00
2	2	C	2060.6	141.5	0.0	0.39	0.20	0.14	0.00	0.12	0.15	0.00
1	2	G	3084.2	171.5	0.0	0.29	0.29	0.13	0.01	0.13	0.13	0.00
1	2	L	3420.5	91.7	0.0	0.38	0.24	0.13	0.00	0.08	0.16	0.01
1	2	C	1964.6	4.8	0.0	0.43	0.16	0.09	0.00	0.12	0.18	0.01

where G = kid, L = lamb, and C = calf

Where:

Pasture mass (kgDM/ha): 1 corresponds to PM1
2 corresponds to PM2
3 corresponds to PM3
4 corresponds to PM4

Period
1 Midpoint,day4
2 End of trial, day8

Table 3.1 Unweighted least squares linear regression of similarity coefficient - between oesophageal extrusa and pasture horizon - and pasture mass (PM), horizon, animal species and stage of trial (days).

Predictor variable	Coefficient	Standard error	Probability
Constant	0.402	0.036	0.0000
Pasture Mass	0.026	0.007	0.0003
Horizon	0.062	0.004	0.0000
Species	0.007	0.005	0.2152
Time	0.015	0.009	0.0900

Degrees of Freedom	370
Overall F	62.85
Adjusted R squared	0.3981
R squared	0.4046

Residual mean square 0.002

Table 4 Intake and bite variables for goats lambs and calves grazing turfs of ryegrass white-clover (trial 2 chapter 4).

animal	turf	Grz	PM	BW	BR	IR	DM%	LW	BW1	IR1	SH	GD	BD	DEN	BA
1	1	1	4335	0.46	20	9.2	20	21.5	4.28	85.6	13.7	8.9	4.8	0.05	9.0
1	1	2	3970	0.5	25.7	12.9	20	21.5	4.65	119.5	12.4	8.2	4.2		
1	1	3	3510	0.2	19.4	3.8	20	21.5	1.86	36.1	10.9	7.4	3.5		
1	1	4	3280	0.29	13.1	3.7	20	21.5	2.70	35.3	9.8	8.9	0.9		
1	2	1	4950	1.02	21.2	21.7	20	21.5	9.49	201.2	12.1	11	1.1	0.048	21.3
1	2	2	4260	0.69	21.5	14.8	20	21.5	6.42	138.0	11.9	9	2.9		
1	2	3	3730	0.37	21.8	8	20	21.5	3.44	75.0	10.9	9.1	1.8		
1	2	4	3390	0.25	24	6.1	20	21.5	2.33	55.8	10.1	8	2.1		
1	3	1	4960	0.85	34	29	20	21.5	7.91	268.8	13.2	10.6	2.6	0.071	12.0
1	3	2	4440	0.43	36	15.6	20	21.5	4.00	144.0	13	10.6	2.4		
1	3	3	4120	0.38	30	11.3	20	21.5	3.53	106.0	12.4	9.9	2.5		
1	3	4	3780	0.18	13.6	2.5	20	21.5	1.67	22.8	11.7	8.4	3.3		
2	1	1	5540	0.55	20	11	23.3	21	6.10	122.0	10.9	9.3	1.6	0.037	14.9
2	1	2	5160	0.38	16.2	6.1	23.3	21	4.22	68.3	10.5	7.4	3.1		
2	1	3	4840	0.29	18.6	5.4	23.3	21	3.22	59.8	9.8	6.2	3.6		
2	1	4	4340	0.36	18.7	6.7	23.3	21	3.99	74.7	8.7	5.4	3.3		
2	1	5	3630	0.17	18.8	3.2	23.3	21	1.89	35.5	6.4	4.8	1.6		
2	2	1	5030	0.63	12.6	7.9	23.3	21	6.99	88.1	13.5	10.3	3.2	0.036	17.5
2	2	2	4590	0.3	25.4	7.6	23.3	21	3.33	84.5	13.1	9.2	3.9		
2	2	3	4280	0.4	19.4	7.8	23.3	21	4.44	86.1	11.6	7.5	4.1		
2	2	4	3870	0.23	24.2	5.6	23.3	21	2.55	61.8	9.6	5.8	3.8		
2	2	5	3590	0.23	14.1	3.3	23.3	21	2.55	36.0	8	5	3		
2	3	1	4010	0.49	23.2	11.4	23.3	21	5.44	126.1	12.4	11.2	1.2	0.05	9.8
2	3	2	3660	0.45	29.4	13.3	23.3	21	4.99	146.8	10.5	8.3	2.2		
2	3	3	3270	0.39	29.7	11.7	23.3	21	4.33	128.5	8.7	7.1	1.6		
2	3	4	2920	0.27	26.6	7.2	23.3	21	3.00	79.7	7.3	6.4	0.9		
3	1	1	4253	1	29.5	29.5	19.5	93	2.10	61.9	15.1	11	4.1	0.059	16.9
3	1	2	3860	1.28	26.7	34.1	19.5	93	2.68	71.7	13.1	9	4.1		
3	1	3	19.5	*	*	*	*	93	0.00	0.0	*	*	*		
3	1	4	19.5	*	*	*	*	93	0.00	0.0	*	*	*		
3	2	1	4530	1.03	32	33	19.5	93	2.16	69.1	12.9	12.6	0.3	0.044	23.4
3	2	2	4070	0.78	26	20.2	19.5	93	1.64	42.5	12.2	9.2	3		
3	2	3	3480	0.75	20	15	19.5	93	1.57	31.5	10.9	7.8	3.1		
3	2	4	2930	0.85	5.2	4.4	19.5	93	1.78	9.3	9.7	8	1.7		
3	3	1	4650	1.06	35.7	37.8	19.5	93	2.22	79.3	12.6	11.7	0.9	0.044	24.1
3	3	2	4160	0.94	27.5	25.9	19.5	93	1.97	54.2	12.2	9.1	3.1		
3	3	3	3720	0.68	9.1	6.2	19.5	93	1.43	13.0	10.3	7.7	2.6		
3	3	4	19.5	*	*	*	*	93	0.00	0.0	*	*	*		
4	1	1	4550	1.67	20.7	34.5	21.9	98	3.73	77.3	12.4	10.1	2.3	0.019	87.9
4	1	2	3980	1.28	32	41	21.9	98	2.86	91.5	11.8	9.8	2		
4	1	3	3460	0.52	14.1	7.4	21.9	98	1.16	16.4	11.1	6.8	4.3		
4	1	4	3070	0.3	8	2.4	21.9	98	0.67	5.4	9.9	7.5	2.4		
4	2	1	4880	1.08	22.4	24.1	21.9	98	2.41	54.1	12.7	12.1	0.6	0.032	33.8
4	2	2	4440	0.67	32.1	21.4	21.9	98	1.50	48.1	12.3	10.2	2.1		
4	2	3	4100	0.6	17.3	10.4	21.9	98	1.34	23.2	11.9	7.1	4.8		
4	2	4	3580	0.46	26.4	12.2	21.9	98	1.03	27.1	9.3	6.8	2.5		
4	3	1	5840	1	30.6	30.6	21.9	98	2.23	68.4	14.1	11.6	2.5	0.064	15.6
4	3	2	5540	0.81	23.1	18.7	21.9	98	1.81	41.8	13.6	9.1	4.5		
4	3	3	4950	0.46	21	9.8	21.9	98	1.03	21.6	11.6	7.5	4.1		
4	3	4	4530	0.38	24	9.1	21.9	98	0.85	20.4	10	6.7	3.3		
5	1	1	4920	1.3	40	52	23.1	48	6.26	250.3	11.3	7.6	3.7	0.074	17.6
5	1	2	4240	1.2	32.4	38.9	23.1	48	5.78	187.1	10.5	7.1	3.4		
5	1	3	3410	1.1	33.6	36.8	23.1	48	5.29	177.9	9	5.5	3.5		
5	1	4	2630	0.48	37.1	17.3	23.1	48	2.31	85.7	7.5	4	3.5		
5	1	5	2150	0.33	21.1	7	23.1	48	1.59	33.5	5.3	3.5	1.8		
5	2	1	4780	1.22	37.6	46	23.1	48	5.87	220.8	11	6.8	4.2	0.057	21.4
5	2	2	4220	0.9	30	27.1	23.1	48	4.33	129.9	9.8	7.2	2.6		
5	2	3	3740	0.8	26.4	21.1	23.1	48	3.85	101.6	8.5	5.2	3.3		

continued . . .

. . . Table 4 continued . . .

Animal	trf	Grz	PM	BW	BR	IR	DM%	LW	BW1	IR1	SH	GD	BD	DEN	BA
5	2	4	3200	0.37	39.1	14.5	23.1	48	1.78	69.6	7.2	4.1	3.1		
5	2	5	2820	0.26	22.2	5.8	23.1	48	1.25	27.8	5.6	3.5	2.1		
5	3	1	3730	1.1	52.8	58	23.1	48	5.29	279.5	10.7	4.5	6.2	0.098	11.2
5	3	2	3180	1.09	44.3	48.3	23.1	48	5.25	232.4	8.8	6	2.8		
5	3	3	2620	1.03	39.1	40.3	23.1	48	4.96	193.8	7.8	4.5	3.3		
5	3	4	2090	0.53	45.6	24.1	23.1	48	2.55	116.3	6.1	3.5	2.6		
5	3	5	1540	0.27	27.2	7.4	23.1	48	1.30	35.3	3.8	3.5	0.3		
6	1	1	3850	0.9	41	36.9	21.6	59	3.29	135.1	12.1	7.9	4.2	0.043	20.9
6	1	2	3410	0.68	45.6	31	21.6	59	2.49	113.5	9.8	6.3	3.5		
6	1	3	2960	0.42	33	13.9	21.6	59	1.54	50.7	8.2	4.4	3.8		
6	1	4	2620	0.33	27.5	9.1	21.6	59	1.21	33.2	5.5	3.3	2.2		
6	1	5	2330	0.28	29.6	8.3	21.6	59	1.03	30.3	4.5	3.3	1.2		
6	1	6	1970	0.21	35.5	7.4	21.6	59	0.77	27.3	3.5	3.2	0.3		
6	2	1	5250	0.65	45.3	29.5	21.6	59	2.38	107.8	14.9	9.6	5.3	0.046	14.1
6	2	2	4950	1	31.9	31.9	21.6	59	3.66	116.8	13.4	7.9	5.5		
6	2	3	4460	0.73	26.7	19.5	21.6	59	2.67	71.4	10.5	6.1	4.4		
6	2	4	4140	0.54	28.9	16.2	21.6	59	1.98	57.1	8.2	4.7	3.5		
6	2	5	3630	0.51	35	17.7	21.6	59	1.87	65.3	6.3	4.5	1.8		
6	2	6	3080	0.35	16.5	5.8	21.6	59	1.28	21.1	5.8	3.9	1.9		
6	3	1	4870	0.77	28.1	21.5	21.6	59	2.82	79.2	14.6	10	4.6	0.036	21.4
6	3	2	4500	0.62	33.6	20.8	21.6	59	2.27	76.3	13.6	7.6	6		
6	3	3	4090	0.41	41.4	17	21.6	59	1.50	62.1	11.8	6.5	5.3		
6	3	4	3750	0.36	27.3	9.9	21.6	59	1.32	36.0	10.2	5.6	4.6		

animal 1 = black goat; 2 = brown goat; 3 = calf 100; 4 = calf 104;
5 = sheep 141; 6 = sheep 26.
trf = Turf number
Grz = Grazing
PM = Pasture Mass kgDM/ha
BW = Bite weight g
BR = Bite rate, prehending bites/minute
IR = Intake rate, g fresh material/minute
DM% = Dry matter percentage of the grazed horizon
LW = Liveweight kg's
BW_1 = Bite weight, mgDM/kgLW
IR_1 = Intake rate, mgDM/kgLW/min
SH = Surface height, cm
GD = Grazed depth, cm
BD = Bite depth, cm (SH - GD)
DEN = Density, kg fresh/cm^2 (weight per cm^2 above the GD)
BA = Bite area cm^2

Table 5.1 Intake and bite variables for sheep grazing ryegrass turfs indoors of three heights and three clipping treatments within height (trial one Chapter 5).

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
1	1	1	1	1	2	3	111	28	46.0	0.114	0.0205	1.56	0.0046	24.8	5.4	15.1	13.7	8	0.62	5.72	3	5	0	0	0	0	0	0	0
1	1	1	1	2	2	3	111	28	46.0	0.114	0.0205	1.56	0.0046	24.8	5.4	15.1	13.7	6	1.76	12.08	1	2	1	1	0	1	0	0	0
2	1	1	1	1	1	2	65.6	30	29.3	0.600	0.2585	21.15	0.0117	51.1	17.4	52.3	350.3	10	0.96	8.24	4	1	4	1	0	0	0	0	0
2	1	1	1	2	1	2	65.6	30	29.3	0.600	0.2585	21.15	0.0117	51.1	17.4	52.3	350.3	5	0.98	8.88	1	2	1	1	0	0	0	0	0
3	1	1	1	1	3	1	148.8	23	50.3	0.535	0.0816	5.12	0.0107	49.8	9.9	22.8	20.6	6	1.86	7.6	3	1	1	1	0	0	0	0	0
3	1	1	1	2	3	1	148.8	23	50.3	0.535	0.0816	5.12	0.0107	49.8	9.9	22.8	20.6	11	1.18	8.57	6	0	4	0	0	1	0	0	0
4	1	1	1	1	2	3	110.5	19	32.0	0.337	0.0523	2.71	0.0044	75.9	23.7	45.1	47.1	9	0.91	9.13	1	5	1	2	0	0	0	0	0
4	1	1	1	2	2	3	110.5	19	32.0	0.337	0.0523	2.71	0.0044	75.9	23.7	45.1	47.1	9	0.87	8.56	2	3	3	1	0	0	0	0	0
5	1	1	1	1	3	2	153.3	14	92.2	1.04	0.1679	6.41	0.0056	186.0	20.2	28.2	45.6	2	3.24	16.74	0	0	1	0	1	0	0	0	0
5	1	1	1	2	3	2	153.3	14	92.2	1.043	0.1679	6.41	0.0056	186.0	20.2	28.2	45.6	3	1.24	7.35	0	3	0	0	0	0	0	0	0
6	1	1	1	1	1	1	69.1	22	23.7	0.695	0.1194	7.16	0.0115	60.6	25.6	56.3	80.7	12	0.6	6.03	7	3	1	1	0	0	0	0	0
6	1	1	1	2	1	1	69.1	22	23.7	0.695	0.1194	7.16	0.0115	60.6	25.6	56.3	80.7	10	0.42	5.5	5	4	1	0	0	0	0	0	0
1	2	1	1	1	3	2	145.7	26	62.6	0.746	0.1445	10.25	0.0062	120.4	19.2	50.0	78.5	7	3.25	17.4	1	2	0	1	0	3	0	0	0
1	2	1	1	2	3	2	145.7	26	62.6	0.746	0.1445	10.25	0.0062	120.4	19.2	50.0	78.5	7	1.89	11.96	1	3	2	0	0	1	0	0	0
2	2	1	1	1	2	1	103.5	18	25.8	0.800	0.1057	5.19	0.0190	42.0	16.3	29.3	50.3	6	1.46	12.52	2	0	1	2	1	0	0	0	0
2	2	1	1	2	2	1	103.5	18	25.8	0.800	0.1057	5.19	0.0190	42.0	16.3	29.3	50.3	5	1.58	14.09	0	2	1	1	1	0	0	0	0
3	2	1	1	1	1	3	71.1	21	25.1	0.310	0.0424	2.43	0.0073	42.2	16.8	35.3	69.6	3	1.85	10.61	0	1	2	0	0	0	0	0	0
3	2	1	1	2	1	3	71.1	21	25.1	0.310	0.0424	2.43	0.0073	42.2	16.8	35.3	69.6	4	0.88	8.49	1	2	1	0	0	0	0	0	0
4	2	1	1	1	1	2	55.7	29	23.0	0.197	0.0321	2.54	0.0049	40.0	17.4	50.4	41.2	13	0.33	3.26	11	2	0	0	0	0	0	0	0
4	2	1	1	2	1	2	55.7	29	23.0	0.197	0.0321	2.54	0.0049	40.0	17.4	50.4	41.2	11	0.54	5.08	7	3	1	0	0	0	0	0	0
5	2	1	1	1	2	1	104.6	37	22.9	0.454	0.0746	7.53	0.0112	40.5	17.7	65.4	37.9	10	0.88	7.18	4	4	2	0	0	0	0	0	0
5	2	1	1	2	2	1	104.6	37	22.9	0.454	0.0746	7.53	0.0112	40.5	17.7	65.4	37.9	9	0.4	3.3	8	1	0	0	0	0	0	0	0
6	2	1	1	1	3	3	143.4	29	81.6	0.983	0.1886	14.92	0.0066	149.1	18.3	53.0	54.5	11	1.45	9.32	4	2	3	1	1	0	0	0	0
6	2	1	1	2	3	3	143.4	29	81.6	0.983	0.1886	14.92	0.0066	149.1	18.3	53.0	54.5	9	1.9	12.7	1	2	2	4	0	0	0	0	0
1	3	1	1	1	1	1	59.5	27	17.4	0.322	0.0512	3.77	0.0155	20.8	11.9	32.2	47.9	5	1.84	16.17	0	1	1	1	1	1	0	0	0
1	3	1	1	2	1	1	59.5	27	17.4	0.322	0.0512	3.77	0.0155	20.8	11.9	32.2	47.9	10	0.7	13.2	7	2	1	0	0	0	0	0	0
2	3	1	1	1	3	3	124.9	22	68.4	1.095	0.2091	12.55	0.0115	95.5	14.0	30.7	62.4	10	1.5	10.3	7	3	0	0	0	0	0	0	0
2	3	1	1	2	3	3	124.9	22	68.4	1.095	0.2091	12.55	0.0115	95.5	14.0	30.7	62.4	9	1.47	12.4	7	2	0	0	0	0	0	0	0
3	3	1	1	1	2	2	98.5	30	28.1	0.423	0.0684	5.60	0.0073	57.7	20.6	61.7	68.5	9	1.17	7.25	1	7	1	0	0	0	0	0	0
3	3	1	1	2	2	2	98.5	30	28.1	0.423	0.0684	5.60	0.0073	57.7	20.6	61.7	68.5	5	1.48	12.03	0	2	2	0	1	0	0	0	0
4	3	1	1	1	3	1	145.4	23	63.5	0.609	0.0991	6.22	0.0087	70.3	11.1	25.5	13.2	3	0.85	8.07	0	2	1	0	0	0	0	0	0
4	3	1	1	2	3	1	145.4	23	63.5	0.609	0.0991	6.22	0.0087	70.3	11.1	25.5	13.2	10	0.56	6.64	3	5	2	0	0	0	0	0	0

continued...

. . . Table 5.1 continued . . .

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
5	3	1	1	1	1	3	63.7	33	9.5	0.376	0.1043	9.39	0.0183	20.5	21.6	71.3	159.3	13	0.55	6.61	5	5	3	0	0	0	0	0	0
5	3	1	1	2	1	3	63.7	33	9.5	0.376	0.1043	9.39	0.0183	20.5	21.6	71.3	159.3	7	1.64	11.3	2	1	2	2	0	0	0	0	0
6	3	1	1	1	2	2	95.3	34	47.2	0.465	0.0882	8.17	0.0059	79.2	16.8	57.0	64.7	8	0.79	6.82	2	4	2	0	0	0	0	0	0
6	3	1	1	2	2	2	95.3	34	47.2	0.465	0.0882	8.17	0.0059	79.2	16.8	57.0	64.7	9	0.69	6.01	4	4	1	0	0	0	0	0	0
1	4	1	1	1	1	2	55.2	35	18.6	0.220	0.0449	4.29	0.0085	25.7	13.8	48.4	52.3	11	0.39	5.5	5	6	0	0	0	0	0	0	0
1	4	1	1	2	1	2	55.2	35	18.6	0.220	0.0449	4.29	0.0085	25.7	13.8	48.4	52.3	8	0.69	8.64	3	1	2	2	0	0	0	0	0
2	4	1	1	1	3	1	147.7	27	73.3	1.104	0.1781	13.11	0.0095	116.4	15.9	42.9	37.4	7	2.3	12.08	0	2	4	1	0	0	0	0	0
2	4	1	1	2	3	1	147.7	27	73.3	1.104	0.1781	13.11	0.0095	116.4	15.9	42.9	37.4	9	2.01	15.27	0	2	1	4	2	0	0	0	0
3	4	1	1	1	2	3	102.6	32	27.6	0.359	0.0566	4.94	0.0062	58.0	21.0	67.3	38.0	8	0.83	8.01	1	5	2	0	0	0	0	0	0
3	4	1	1	2	2	3	102.6	32	27.6	0.359	0.0566	4.94	0.0062	58.0	21.0	67.3	38.0	8	0.87	7.67	2	4	2	0	0	0	0	0	0
4	4	1	1	1	3	2	132.3	28	73.1	0.714	0.1247	9.52	0.0076	93.4	12.8	35.8	21.8	3	2.07	10.29	1	1	0	1	0	0	0	0	0
4	4	1	1	2	3	2	132.3	28	73.1	0.714	0.1247	9.52	0.0076	93.4	12.8	35.8	21.8	10	1.41	11.02	0	6	2	1	1	0	0	0	0
5	4	1	1	1	1	1	55.7	23	9.9	0.304	0.0654	4.10	0.0131	23.2	23.4	53.8	84.4	2	3.43	22.59	0	0	1	0	0	0	1	0	0
5	4	1	1	2	1	1	55.7	23	9.9	0.304	0.0654	4.10	0.0131	23.2	23.4	53.8	84.4	5	1.43	7.97	0	5	0	0	0	0	0	0	0
6	4	1	1	1	2	3	98.9	54	56.7	0.478	0.0838	12.35	0.0077	62.3	11.0	59.3	49.1	5	1.48	12.23	0	2	2	1	0	0	0	0	0
6	4	1	1	2	2	3	98.9	54	56.7	0.478	0.0838	12.35	0.0077	62.3	11.0	59.3	49.1	11	0.78	7.83	3	6	1	1	0	0	0	0	0
1	5	1	1	1	2	1	103.8	23	43.8	0.591	0.1174	7.36	0.0062	95.2	21.7	50.0	74.2	11	0.76	6.09	7	1	3	0	0	0	0	0	0
1	5	1	1	2	2	1	103.8	23	43.8	0.591	0.1174	7.36	0.0062	95.2	21.7	50.0	74.2	6	2.8	15.56	1	1	0	3	1	0	0	0	0
2	5	1	1	1	1	3	62.3	28	28.1	0.675	0.1289	9.84	0.0110	61.2	21.8	61.0	103.5	16	0.84	11.09	3	4	4	4	1	0	0	0	0
2	5	1	1	2	1	3	62.3	28	28.1	0.675	0.1289	9.84	0.0110	61.2	21.8	61.0	103.5	17	0.81	10.67	2	7	4	3	0	1	0	0	0
3	5	1	1	1	3	2	143.9	24	61.7	0.871	0.1779	11.64	0.0079	109.9	17.8	42.7	49.2	6	2.53	13.92	4	0	0	0	1	0	0	0	1
3	5	1	1	2	3	2	143.9	24	61.7	0.871	0.1779	11.64	0.0079	109.9	17.8	42.7	49.2	8	2.73	16.56	0	2	1	3	0	1	1	0	0
4	5	1	1	1	2	1	102.3	27	22.8	0.422	0.0876	6.45	0.0100	42.4	18.6	50.2	54.1	5	0.45	10.16	2	1	0	1	1	0	0	0	0
4	5	1	1	2	2	1	102.3	27	22.8	0.422	0.0876	6.45	0.0100	42.4	18.6	50.2	54.1	19	0.95	15.96	0	5	4	4	4	2	0	0	0
5	5	1	1	1	3	3	146.1	30	99.5	0.657	0.1371	11.22	0.0087	75.5	7.6	22.8	25.5	5	4.06	24.24	0	0	0	2	0	2	1	0	0
5	5	1	1	2	3	3	146.1	30	99.5	0.657	0.1371	11.22	0.0087	75.5	7.6	22.8	25.5	5	6.03	17.5	0	0	2	3	0	0	0	0	0
6	5	1	1	1	1	2	53	34	26.1	0.394	0.0786	7.29	0.0080	49.0	18.8	63.8	81.0	5	0.77	6.55	3	1	0	1	0	0	0	0	0
6	5	1	1	2	1	2	53	34	26.1	0.394	0.0786	7.29	0.0080	49.0	18.8	63.8	81.0	10	0.47	5.26	4	5	1	0	0	0	0	0	0
1	6	1	1	1	3	3	125.7	23	58.6	0.765	0.1901	11.92	0.0057	133.9	22.8	52.5	43.2	3	11.7	37.8	0	0	0	1	0	0	0	0	2
1	6	1	1	2	3	3	125.7	23	58.6	0.765	0.1901	11.92	0.0057	133.9	22.8	52.5	43.2	6	4.1	18.39	0	2	0	1	0	3	0	0	0
2	6	1	1	1	2	2	103.9	37	50.8	0.665	0.0916	9.24	0.0070	94.9	18.7	69.1	53.5	14	0.57	5.93	7	5	2	0	0	0	0	0	0
2	6	1	1	2	2	2	103.9	37	50.8	0.665	0.0916	9.24	0.0070	94.9	18.7	69.1	53.5	8	1.57	11.28	2	1	3	2	0	0	0	0	0

continued . . .

. . . Table 5.1 continued . . .

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
3	6	1	1	1	1	1	55.1	23	17.8	0.674	0.1485	9.31	0.0151	44.6	25.1	57.6	123.2	7	0.71	8.68	2	2	2	1	0	0	0	0	0
3	6	1	1	2	1	1	55.1	23	17.8	0.674	0.1485	9.31	0.0151	44.6	25.1	57.6	123.2	5	1.14	11.28	2	1	0	1	0	1	0	0	0
4	6	1	1	1	1	3	56.8	36	23.1	0.339	0.0705	6.92	0.0099	34.2	14.8	53.3	55.5	5	0.92	9.13	2	2	0	0	1	0	0	0	0
4	6	1	1	2	1	3	56.8	36	23.1	0.339	0.0705	6.92	0.0099	34.2	14.8	53.3	55.5	12	0.69	8.6	5	2	2	2	1	0	0	0	0
5	6	1	1	1	2	2	107.7	25	41.2	0.448	0.0740	5.05	0.0057	79.2	19.2	48.1	46.8	10	0.56	4.1	8	2	0	0	0	0	0	0	0
5	6	1	1	2	2	2	107.7	25	41.2	0.448	0.0740	5.05	0.0057	79.2	19.2	48.1	46.8	1	0.31	5.5	0	1	0	0	0	0	0	0	0
6	6	1	1	1	3	1	147.8	28	68.1	0.782	0.1666	12.72	0.0092	85.2	12.5	35.0	35.6	12	1.07	7.95	8	1	0	1	0	2	0	0	0
6	6	1	1	2	3	1	147.8	28	68.1	0.782	0.1666	12.72	0.0092	85.2	12.5	35.0	35.6	10	2.06	16.99	1	0	4	1	2	2	0	0	0
1	1	2	1	1	1	1	54.1	56	28.1	0.407	0.0784	11.97	0.0198	20.6	7.3	41.0	57.0	3	2.47	14.83	0	0	1	2	0	0	0	0	0
1	1	2	1	2	1	1	54.1	56	28.1	0.407	0.0784	11.97	0.0198	20.6	7.3	41.0	57.0	6	2.91	17.31	2	1	0	0	0	1	2	0	0
2	1	2	1	1	3	3	141.5	26	72.6	0.696	0.1633	11.58	0.0057	122.1	16.8	43.7	33.1	6	3.35	13.48	2	0	2	1	0	1	0	0	0
2	1	2	1	2	3	3	141.5	26	72.6	0.696	0.1633	11.58	0.0057	122.1	16.8	43.7	33.1	6	1.48	8.56	1	3	2	0	0	0	0	0	0
3	1	2	1	1	2	2	99.6	19	50.4	0.337	0.0722	3.74	0.0032	106.1	21.1	40.0	41.9	7	0.92	7.21	1	5	1	0	0	0	0	0	0
3	1	2	1	2	2	2	99.6	19	50.4	0.337	0.0722	3.74	0.0032	106.1	21.1	40.0	41.9	7	0.83	6.51	3	4	0	0	0	0	0	0	0
4	1	2	1	1	1	2	57.9	34	18.3	0.206	0.0468	4.34	0.0058	35.5	19.4	66.0	63.3	9	0.19	3.81	7	2	0	0	0	0	0	0	0
4	1	2	1	2	1	2	57.9	34	18.3	0.206	0.0468	4.34	0.0058	35.5	19.4	66.0	63.3	10	0.39	5.12	6	3	1	0	0	0	0	0	0
5	1	2	1	1	2	1	107.5	18	36.3	0.461	0.0791	3.88	0.0062	74.4	20.5	36.9	25.2	3	1.93	13.83	0	1	1	0	1	0	0	0	0
5	1	2	1	2	2	1	107.5	18	36.3	0.461	0.0791	3.88	0.0062	74.4	20.5	36.9	25.2	5	0.9	11.4	1	1	3	0	0	0	0	0	0
6	1	2	1	1	3	3	143.5	26	54.3	0.704	0.1506	10.68	0.0064	110.1	20.3	52.7	39.1	9	2.2	13.56	2	1	1	3	2	0	0	0	0
6	1	2	1	2	3	3	143.5	26	54.3	0.704	0.1506	10.68	0.0064	110.1	20.3	52.7	39.1	8	2.01	11.84	2	0	5	0	1	0	0	0	0
1	2	2	1	1	2	3	103.5	25	17.8	0.276	0.0544	3.71	0.0062	44.7	25.1	62.7	64.0	8	1.57	10.16	2	2	2	2	0	0	0	0	0
1	2	2	1	2	2	3	103.5	25	17.8	0.276	0.0544	3.71	0.0062	44.7	25.1	62.7	64.0	5	1.13	5.8	2	3	0	0	0	0	0	0	0
2	2	2	1	1	1	2	55.6	10	21.3	0.360	0.0820	2.24	0.0047	75.9	35.6	35.6	83.7	4	0.48	4.82	2	2	0	0	0	0	0	0	0
2	2	2	1	2	1	2	55.6	10	21.3	0.360	0.0820	2.24	0.0047	75.9	35.6	35.6	83.7	3	0.86	8.75	1	1	1	0	0	0	0	0	0
3	2	2	1	1	3	1	159.3	24	81.6	0.862	0.1433	9.38	0.0063	137.5	16.8	40.4	40.2	9	1.34	8.88	4	2	1	1	1	0	0	0	0
3	2	2	1	2	3	1	159.3	24	81.6	0.862	0.1433	9.38	0.0063	137.5	16.8	40.4	40.2	8	1.39	7.14	2	4	2	0	0	0	0	0	0
4	2	2	1	1	3	1	153.6	29	59.9	0.714	0.1415	11.19	0.0072	99.2	16.6	48.0	41.7	3	2.04	19.06	0	0	0	2	1	0	0	0	0
4	2	2	1	2	3	1	153.6	29	59.9	0.714	0.1415	11.19	0.0072	99.2	16.6	48.0	41.7	6	2.22	12.77	1	1	2	1	1	0	0	0	0
5	2	2	1	1	1	3	58.4	19	14.6	0.326	0.0667	3.46	0.0112	29.1	19.9	37.8	55.6	5	1.17	8.16	1	2	1	1	0	0	0	0	0
5	2	2	1	2	1	3	58.4	19	14.6	0.326	0.0667	3.46	0.0112	29.1	19.9	37.8	55.6	5	0.69	7.16	1	4	0	0	0	0	0	0	0
6	2	2	1	1	2	2	93.6	35	52.2	0.343	0.0727	6.94	0.0046	75.2	14.4	50.4	40.4	10	0.5	4.4	7	3	0	0	0	0	0	0	0
6	2	2	1	2	2	2	93.6	35	52.2	0.343	0.0727	6.94	0.0046	75.2	14.4	50.4	40.4	8	0.2	3.15	7	1	0	0	0	0	0	0	0

continued . . .

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
1	3	2	1	1	3	2	147.4	30	85.7	0.797	0.1888	15.44	0.0072	110.3	12.9	38.6	44.8	5	5.22	26.67	0	0	0	1	1	2	0	1	0
1	3	2	1	2	3	2	147.4	30	85.7	0.797	0.1888	15.44	0.0072	110.3	12.9	38.6	44.8	6	3.41	13.97	1	0	2	3	0	0	0	0	0
2	3	2	1	1	2	1	103.9	25	38.8	0.524	0.1146	7.81	0.0096	54.8	14.1	35.3	45.5	8	1.5	10.71	2	2	1	3	0	0	0	0	0
2	3	2	1	2	2	1	103.9	25	38.8	0.524	0.1146	7.81	0.0096	54.8	14.1	35.3	45.5	4	2.62	13.86	0	1	1	2	0	0	0	0	0
3	3	2	1	1	1	3	56	27	13.1	0.241	0.0518	3.82	0.0128	18.8	14.3	38.7	39.7	9	0.61	5.06	5	3	1	0	0	0	0	0	0
3	3	2	1	2	1	3	56	27	13.1	0.241	0.0518	3.82	0.0128	18.8	14.3	38.7	39.7	7	0.87	5.27	4	2	0	1	0	0	0	0	0
4	3	2	1	1	2	3	104	37	43.5	0.408	0.0939	9.47	0.0069	59.4	13.6	50.5	40.5	10	0.84	7.99	3	4	2	1	0	0	0	0	0
4	3	2	1	2	2	3	104	37	43.5	0.408	0.0939	9.47	0.0069	59.4	13.6	50.5	40.5	11	0.83	8.2	3	5	2	1	0	0	0	0	0
5	3	2	1	1	3	2	147.4	28	93.4	0.721	0.1615	12.34	0.0065	111.7	12.0	33.5	40.4	6	4.41	22.24	1	0	0	3	0	0	0	1	1
5	3	2	1	2	3	2	147.4	28	93.4	0.721	0.1615	12.34	0.0065	111.7	12.0	33.5	40.4	8	2.29	11.6	2	2	0	4	0	0	0	0	0
6	3	2	1	1	1	1	60.2	31	16.2	0.245	0.0834	7.05	0.0104	23.5	14.5	45.0	52.1	12	0.46	6.2	5	5	2	0	0	0	0	0	0
6	3	2	1	2	1	1	60.2	31	16.2	0.245	0.0834	7.05	0.0104	23.5	14.5	45.0	52.1	10	1.37	8.44	0	7	3	0	0	0	0	0	0
1	4	2	1	1	3	3	153	24	66.8	0.808	0.2423	15.86	0.0092	87.7	13.1	31.5	32.7	4	5.03	21.84	2	0	0	0	1	0	0	0	1
1	4	2	1	2	3	3	153	24	66.8	0.808	0.2423	15.86	0.0092	87.7	13.1	31.5	32.7	10	1.43	10.29	4	2	1	2	0	0	1	0	0
2	4	2	1	1	2	2	101.5	33	43.4	0.494	0.0827	7.44	0.0050	97.9	22.6	74.4	65.4	8	0.85	6.22	2	6	0	0	0	0	0	0	0
2	4	2	1	2	2	2	101.5	33	43.4	0.494	0.0827	7.44	0.0050	97.9	22.6	74.4	65.4	6	0.72	6.49	2	4	0	0	0	0	0	0	0
3	4	2	1	1	1	1	61.3	28	26.6	0.379	0.1062	8.11	0.0157	24.1	9.1	25.4	75.8	9	1.68	15.02	2	1	0	3	2	1	0	0	0
3	4	2	1	2	1	1	61.3	28	26.6	0.379	0.1062	8.11	0.0157	24.1	9.1	25.4	75.8	3	2.33	16.68	0	0	1	1	1	0	0	0	0
4	4	2	1	1	2	1	101.5	23	22.6	0.339	0.0651	4.08	0.0088	38.3	17.0	39.0	30.8	8	1.06	8.05	4	1	3	0	0	0	0	0	0
4	4	2	1	2	2	1	101.5	23	22.6	0.339	0.0651	4.08	0.0088	38.3	17.0	39.0	30.8	5	0.34	3.95	5	0	0	0	0	0	0	0	0
5	4	2	1	1	3	3	142.7	24	52.3	0.725	0.1777	11.63	0.0059	122.7	23.5	56.3	54.1	5	4.54	21.98	0	1	1	1	0	1	0	0	1
5	4	2	1	2	3	3	142.7	24	52.3	0.725	0.1777	11.63	0.0059	122.7	23.5	56.3	54.1	5	4.54	21.98	0	1	1	1	0	1	0	0	1
6	4	2	1	1	1	2	48.1	43	23.6	0.193	0.0393	4.61	0.0083	23.1	9.8	42.1	41.9	15	0.5	6.27	7	5	2	1	0	0	0	0	0
6	4	2	1	2	1	2	48.1	43	23.6	0.193	0.0393	4.61	0.0083	23.1	9.8	42.1	41.9	7	0.99	8.42	1	4	2	0	0	0	0	0	0
1	5	2	1	1	1	2	54.6	32	18.6	0.281	0.0582	5.08	0.0081	34.9	18.8	60.0	58.8	8	1.89	13.91	1	2	3	1	0	0	1	0	0
1	5	2	1	2	1	2	54.6	32	18.6	0.281	0.0582	5.08	0.0081	34.9	18.8	60.0	58.8	7	1.51	11.41	2	1	2	1	1	0	0	0	0
2	5	2	1	1	3	1	138.1	25	51.7	0.948	0.1880	12.82	0.0091	103.8	20.1	50.2	74.3	7	1.54	9.92	2	0	3	2	0	0	0	0	0
2	5	2	1	2	3	1	138.1	25	51.7	0.948	0.1880	12.82	0.0091	103.8	20.1	50.2	74.3	6	2.81	12.69	1	3	0	1	0	1	0	0	0
3	5	2	1	1	2	3	100.1	28	35.8	0.414	0.1077	8.23	0.0093	44.5	12.4	34.8	75.8	8	1.73	9.98	2	3	1	2	0	0	0	0	0
3	5	2	1	2	2	3	100.1	28	35.8	0.414	0.1077	8.23	0.0093	44.5	12.4	34.8	75.8	9	0.88	7.42	3	4	2	0	0	0	0	0	0
4	5	2	1	1	1	3	54.3	31	11.1	0.277	0.0556	4.70	0.0133	20.8	18.7	58.1	62.1	8	1.24	12.53	2	1	1	3	0	1	0	0	0
4	5	2	1	2	1	3	54.3	31	11.1	0.277	0.0556	4.70	0.0133	20.8	18.7	58.1	62.1	11	0.69	7.61	4	3	4	0	0	0	0	0	0

continued . . .

. . . Table 5.1 continued . . .

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
5	5	2	1	1	2	2	95.7	26	46.3	0.369	0.0608	4.31	0.0049	74.7	16.1	41.9	24.1	10	0.65	5.24	5	5	0	0	0	0	0	0	0
5	5	2	1	2	2	2	95.7	26	46.3	0.369	0.0608	4.31	0.0049	74.7	16.1	41.9	24.1	3	1.13	9.06	1	1	1	0	0	0	0	0	0
6	5	2	1	1	3	1	155	26	77.8	0.965	0.1547	10.97	0.0126	76.3	9.8	25.5	29.9	5	1.6	12.23	0	2	2	1	0	0	0	0	0
6	5	2	1	2	3	1	155	26	77.8	0.965	0.1547	10.97	0.0126	76.3	9.8	25.5	29.9	5	1.67	12.83	1	1	2	0	0	1	0	0	0
1	6	2	1	1	2	1	110.4	10	110.4	*	*	*	*	*	*	*	*	4	1.49	6.04	3	0	0	1	0	0	0	0	0
1	6	2	1	2	2	1	110.4	10	110.4	*	*	*	*	*	*	*	*	2	3.26	10.65	0	1	1	0	0	0	0	0	0
2	6	2	1	1	1	3	54.2	9	54.2	0.278	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
2	6	2	1	2	1	3	54.2	9	54.2	0.278	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
3	6	2	1	1	3	2	151	18	82.4	0.672	0.1240	6.09	0.0048	141.3	17.1	30.9	27.8	7	2.29	12.36	0	3	1	3	0	0	0	0	0
3	6	2	1	2	3	2	151	18	82.4	0.672	0.1240	6.09	0.0048	141.3	17.1	30.9	27.8	8	1.89	11.25	2	3	1	1	0	0	1	0	0
4	6	2	1	1	3	2	152	19	44.3	0.821	0.1912	9.91	0.0049	166.1	37.5	71.2	108.6	5	1.73	9.51	1	1	3	0	0	0	0	0	0
4	6	2	1	2	3	2	152	19	44.3	0.821	0.1912	9.91	0.0049	166.1	37.5	71.2	108.6	10	1.84	15.88	2	2	1	2	2	0	0	0	1
5	6	2	1	1	1	1	55.3	0	55.3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
5	6	2	1	2	1	1	55.3	0	55.3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
6	6	2	1	1	2	3	79.6	30	29.3	0.450	0.0896	7.33	0.0077	58.1	19.8	59.5	91.9	4	0.39	4.77	3	1	0	0	0	0	0	0	0
6	6	2	1	2	2	3	79.6	30	29.3	0.450	0.0896	7.33	0.0077	58.1	19.8	59.5	91.9	7	0.6	6.16	2	5	0	0	0	0	0	0	0
1	1	3	1	1	3	2	171.6	13	82.2	0.923	0.2119	7.51	0.0034	269.1	32.7	42.6	53.8	4	3.16	19.96	0	0	1	2	0	0	1	0	0
1	1	3	1	2	3	2	171.6	13	82.2	0.923	0.2119	7.51	0.0034	269.1	32.7	42.6	53.8	5	2.16	8.59	1	2	2	0	0	0	0	0	0
2	1	3	1	1	2	1	97.2	15	42.6	0.607	0.1005	4.11	0.0078	77.4	18.2	27.2	48.8	6	1.8	9.42	2	2	1	0	0	1	0	0	0
2	1	3	1	2	2	1	97.2	15	42.6	0.607	0.1005	4.11	0.0078	77.4	18.2	27.2	48.8	5	0.28	3.01	4	1	0	0	0	0	0	0	0
3	1	3	1	1	1	3	54.6	24	23.0	0.317	0.0714	4.68	0.0091	34.8	15.2	36.4	54.5	3	0.88	7.89	0	2	1	0	0	0	0	0	0
3	1	3	1	2	1	3	54.6	24	23.0	0.317	0.0714	4.68	0.0091	34.8	15.2	36.4	54.5	4	0.72	6.99	0	4	0	0	0	0	0	0	0
4	1	3	1	1	3	1	157.9	38	70.7	0.724	0.1481	15.35	0.0078	93.0	13.2	50.0	31.0	4	1.12	8.96	1	2	0	1	0	0	0	0	0
4	1	3	1	2	3	1	157.9	38	70.7	0.724	0.1481	15.35	0.0078	93.0	13.2	50.0	31.0	8	1.27	9.09	3	2	1	2	0	0	0	0	0
5	1	3	1	1	1	3	60.7	25	22.7	0.388	0.0950	6.47	0.0069	56.5	24.9	62.2	83.7	3	1.16	8.76	0	2	1	0	0	0	0	0	0
5	1	3	1	2	1	3	60.7	25	22.7	0.388	0.0950	6.47	0.0069	56.5	24.9	62.2	83.7	4	1.01	7.82	0	3	1	0	0	0	0	0	0
6	1	3	1	1	2	2	102.4	29	44.4	0.597	0.1297	10.25	0.0056	106.4	24.0	69.5	119.2	12	0.45	6.8	5	6	1	0	0	0	0	0	0
6	1	3	1	2	2	2	102.4	29	44.4	0.597	0.1297	10.25	0.0056	106.4	24.0	69.5	119.2	8	0.47	7.21	2	4	2	0	0	0	0	0	0
1	2	3	1	1	1	1	55	13	18.5	0.285	0.0569	2.02	0.0074	38.7	20.9	27.2	49.9	3	2.93	10.74	0	2	0	1	0	0	0	0	0
1	2	3	1	2	1	1	55	13	18.5	0.285	0.0569	2.02	0.0074	38.7	20.9	27.2	49.9	4	1.94	13.02	1	1	0	1	1	0	0	0	0
2	2	3	1	1	3	3	147.4	22	74.0	1.055	0.2201	13.21	0.0053	198.1	26.8	58.9	56.7	8	2.66	12.29	0	4	1	2	1	0	0	0	0
2	2	3	1	2	3	3	147.4	22	74.0	1.055	0.2201	13.21	0.0053	198.1	26.8	58.9	56.7	6	2.84	11.71	1	2	0	3	0	0	0	0	0

continued . . .

. . . Table 5.1 continued . . .

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
3	2	3	1	1	2	2	102.8	26	48.1	0.412	0.0665	4.72	0.0052	79.8	16.6	43.1	59.2	13	0.47	6.6	5	6	2	0	0	0	0	0	0
3	2	3	1	2	2	2	102.8	26	48.1	0.412	0.0665	4.72	0.0052	79.8	16.6	43.1	59.2	5	0.75	7.06	3	1	0	1	0	0	0	0	0
4	2	3	1	1	2	3	103.8	24	41.8	0.554	0.1123	7.35	0.0051	108.2	25.9	62.1	83.2	11	0.66	6.43	4	7	0	0	0	0	0	0	0
4	2	3	1	2	2	3	103.8	24	41.8	0.554	0.1123	7.35	0.0051	108.2	25.9	62.1	83.2	4	0.81	6.37	1	3	0	0	0	0	0	0	0
5	2	3	1	1	3	2	142.3	21	55.1	0.671	0.1295	7.42	0.0068	99.2	18.0	37.8	42.3	6	4.06	20.23	1	0	0	1	2	1	1	0	0
5	2	3	1	2	3	2	142.3	21	55.1	0.671	0.1295	7.42	0.0068	99.2	18.0	37.8	42.3	2	1.03	9.8	0	1	1	0	0	0	0	0	0
6	2	3	1	1	1	1	62.2	35	22.5	0.349	0.0580	5.54	0.0143	24.4	10.9	38.0	35.6	8	0.92	9.19	0	5	2	1	0	0	0	0	0
6	2	3	1	2	1	1	62.2	35	22.5	0.349	0.0580	5.54	0.0143	24.4	10.9	38.0	35.6	7	0.75	7.38	1	5	1	0	0	0	0	0	0
1	3	3	1	1	2	3	114.4	19	56.0	0.774	0.1440	7.46	0.0068	113.1	20.2	38.4	80.0	6	0.89	7.59	3	1	1	0	1	0	0	0	0
1	3	3	1	2	2	3	114.4	19	56.0	0.774	0.1440	7.46	0.0068	113.1	20.2	38.4	80.0	8	0.93	8.2	4	1	2	1	0	0	0	0	0
2	3	3	1	1	1	2	44	28	16.1	0.311	0.0552	4.22	0.0137	22.6	14.1	39.4	58.6	7	0.49	6.1	3	4	0	0	0	0	0	0	0
2	3	3	1	2	1	2	44	28	16.1	0.311	0.0552	4.22	0.0137	22.6	14.1	39.4	58.6	6	0.7	6.33	2	3	1	0	0	0	0	0	0
3	3	3	1	1	3	1	130	18	37.6	0.889	0.1637	8.04	0.0085	105.1	28.0	50.3	79.5	5	4.6	29.79	0	0	0	2	0	2	0	0	1
3	3	3	1	2	3	1	130	18	37.6	0.889	0.1637	8.04	0.0085	105.1	28.0	50.3	79.5	5	2.8	29.5	0	0	0	2	0	2	0	0	1
4	3	3	1	1	1	2	55.2	37	22.7	0.268	0.0654	6.60	0.0096	27.9	12.3	45.4	77.4	10	0.75	8.14	4	4	0	2	0	0	0	0	0
4	3	3	1	2	1	2	55.2	37	22.7	0.268	0.0654	6.60	0.0096	27.9	12.3	45.4	77.4	9	0.66	6.51	4	4	1	0	0	0	0	0	0
5	3	3	1	1	2	1	114.5	33	47.3	0.470	0.0962	8.66	0.0064	73.8	15.6	51.5	58.0	7	0.89	7.11	2	4	0	1	0	0	0	0	0
5	3	3	1	2	2	1	114.5	33	47.3	0.470	0.0962	8.66	0.0064	73.8	15.6	51.5	58.0	5	2.22	6.17	3	1	0	1	0	0	0	0	0
6	3	3	1	1	3	3	148.8	24	67.2	0.696	0.1707	11.18	0.0051	135.1	20.1	48.3	50.8	9	1.35	9.27	2	5	0	1	1	0	0	0	0
6	3	3	1	2	3	3	148.8	24	67.2	0.696	0.1707	11.18	0.0051	135.1	20.1	48.3	50.8	6	1.87	10.59	1	1	3	1	0	0	0	0	0
1	4	3	1	1	2	1	104.1	33	42.2	0.536	0.0694	6.25	0.0075	71.2	16.9	55.7	52.8	8	0.68	7	4	1	2	1	0	0	0	0	0
1	4	3	1	2	2	1	104.1	33	42.2	0.536	0.0694	6.25	0.0075	71.2	16.9	55.7	52.8	5	0.72	6.3	3	1	1	0	0	0	0	0	0
2	4	3	1	1	1	3	60.8	26	26.2	0.662	0.1538	10.91	0.0113	58.4	22.3	57.9	102.5	9	1.23	10.5	2	4	1	1	1	0	0	0	0
2	4	3	1	2	1	3	60.8	26	26.2	0.662	0.1538	10.91	0.0113	58.4	22.3	57.9	102.5	9	1.03	8.36	3	2	3	1	0	0	0	0	0
3	4	3	1	1	3	2	127.7	24	55.1	0.879	0.1750	11.45	0.0080	109.4	19.8	47.6	78.8	6	2.95	15.11	1	1	1	1	1	1	0	0	0
3	4	3	1	2	3	2	127.7	24	55.1	0.879	0.1750	11.45	0.0080	109.4	19.8	47.6	78.8	8	2.57	16.35	0	2	1	2	2	1	0	0	0
4	4	3	1	1	1	3	54	33	15.6	0.388	0.0695	6.26	0.0112	34.8	22.3	73.6	97.0	10	2.31	15.83	0	0	5	4	1	0	0	0	0
4	4	3	1	2	1	3	54	33	15.6	0.388	0.0695	6.26	0.0112	34.8	22.3	73.6	97.0	11	2.39	16.48	0	0	5	5	1	0	0	0	0
5	4	3	1	1	2	2	113.5	26	44.7	0.454	0.0840	5.96	0.0070	64.4	14.4	37.5	59.5	4	0.68	5.71	2	1	1	0	0	0	0	0	0
5	4	3	1	2	2	2	113.5	26	44.7	0.454	0.0840	5.96	0.0070	64.4	14.4	37.5	59.5	6	1.25	9.96	2	1	2	1	0	0	0	0	0
6	4	3	1	1	3	1	181.8	43	79.8	0.921	0.1892	22.18	0.0080	115.7	14.5	62.4	163.5	6	1.43	8.98	2	2	2	0	0	0	0	0	0
6	4	3	1	2	3	1	181.8	43	79.8	0.921	0.1892	22.18	0.0080	115.7	14.5	62.4	163.5	9	1.09	7.12	4	2	3	0	0	0	0	0	0

continued . . .

. . . Table 5.1 continued . . .

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
1	5	3	1	1	3	3	173.8	22	77.5	0.677	0.1380	8.28	0.0052	129.9	16.8	36.9	33.6	6	4.08	20.91	1	0	0	1	0	1	1	1	0
1	5	3	1	2	3	3	173.8	22	77.5	0.677	0.1380	8.28	0.0052	129.9	16.8	36.9	33.6	4	4.23	21.27	1	0	0	1	0	0	1	1	0
2	5	3	1	1	2	2	101.7	24	39.8	0.800	0.1401	9.17	0.0064	124.4	31.2	75.0	36.1	6	1.25	9.78	0	3	3	0	0	0	0	0	0
2	5	3	1	2	2	2	101.7	24	39.8	0.800	0.1401	9.17	0.0064	124.4	31.2	75.0	36.1	10	0.63	4.57	7	1	2	0	0	0	0	0	0
3	5	3	1	1	1	1	67.8	29	31.4	0.403	0.0707	5.59	0.0098	41.0	13.1	37.9	25.3	16	0.75	7.68	7	3	5	0	1	0	0	0	0
3	5	3	1	2	1	1	67.8	29	31.4	0.403	0.0707	5.59	0.0098	41.0	13.1	37.9	25.3	4	1.79	11.94	1	1	0	2	0	0	0	0	0
4	5	3	1	1	3	2	154.3	29	94.9	0.483	0.0836	6.61	0.0056	86.9	9.2	26.6	25.6	7	1.24	10.24	2	2	2	0	1	0	0	0	0
4	5	3	1	2	3	2	154.3	29	94.9	0.483	0.0836	6.61	0.0056	86.9	9.2	26.6	25.6	6	1.4	8.79	2	1	2	1	0	0	0	0	0
5	5	3	1	1	1	1	67.3	17	28.2	0.694	0.1472	6.83	0.0084	82.6	29.3	49.8	184.0	8	1.04	11.51	2	2	1	2	1	0	0	0	0
5	5	3	1	2	1	1	67.3	17	28.2	0.694	0.1472	6.83	0.0084	82.6	29.3	49.8	184.0	7	0.48	4.74	5	1	1	0	0	0	0	0	0
6	5	3	1	1	2	3	111.4	31	44.6	0.377	0.0782	6.61	0.0051	73.8	16.6	51.3	47.5	6	0.5	4.22	4	2	0	0	0	0	0	0	0
6	5	3	1	2	2	3	111.4	31	44.6	0.377	0.0782	6.61	0.0051	73.8	16.6	51.3	47.5	7	0.53	4.52	4	3	0	0	0	0	0	0	0
1	6	3	1	1	1	2	55.2	26	21.4	0.288	0.1025	7.27	0.0067	43.2	20.2	52.4	168.9	10	0.48	4.33	7	3	0	0	0	0	0	0	0
1	6	3	1	2	1	2	55.2	26	21.4	0.288	0.1025	7.27	0.0067	43.2	20.2	52.4	168.9	6	0.43	6.12	4	0	2	0	0	0	0	0	0
2	6	3	1	1	3	1	154.2	22	88.7	1.323	0.2748	16.49	0.0088	150.6	17.0	37.4	54.5	5	5.31	25.59	0	0	0	0	3	0	1	1	0
2	6	3	1	2	3	1	154.2	22	88.7	1.323	0.2748	16.49	0.0088	150.6	17.0	37.4	54.5	6	3.38	17.18	0	1	2	0	3	0	0	0	0
3	6	3	1	1	2	3	115.4	26	47.6	0.508	0.0679	4.82	0.0057	89.8	18.9	49.1	51.0	8	1.1	8.68	3	3	1	0	0	1	0	0	0
3	6	3	1	2	2	3	115.4	26	47.6	0.508	0.0679	4.82	0.0057	89.8	18.9	49.1	51.0	6	0.76	6.78	1	4	1	0	0	0	0	0	0
4	6	3	1	1	2	1	102.5	17	18.8	0.388	0.0985	4.56	0.0076	51.0	27.1	46.2	88.9	3	1.16	8.76	0	2	1	0	0	0	0	0	0
4	6	3	1	2	2	1	102.5	17	18.8	0.388	0.0985	4.56	0.0076	51.0	27.1	46.2	88.9	5	0.53	3.65	4	1	0	0	0	0	0	0	0
5	6	3	1	1	3	3	167.7	19	60.1	0.995	0.2227	11.54	0.0061	162.9	27.1	51.5	81.9	6	0.5	4.22	4	2	0	0	0	0	0	0	0
5	6	3	1	2	3	3	167.7	19	60.1	0.995	0.2227	11.54	0.0061	162.9	27.1	51.5	81.9	6	2.21	13.53	0	1	2	3	0	0	0	0	0
6	6	3	1	1	1	2	56.7	27	23.7	0.293	0.0532	3.92	0.0067	43.6	18.4	49.7	59.7	13	0.25	2.53	12	1	0	0	0	0	0	0	0
6	6	3	1	2	1	2	56.7	27	23.7	0.293	0.0532	3.92	0.0067	43.6	18.4	49.7	59.7	7	0.54	5.44	5	1	0	1	0	0	0	0	0
1	1	1	2	1	1	3	56.7	29	15.0	0.455	0.0879	6.95	0.0128	35.6	23.7	68.8	82.9	5	0.79	7.06	3	1	1	0	0	0	0	0	0
1	1	1	2	2	1	3	56.7	29	15.0	0.455	0.0879	6.95	0.0128	35.6	23.7	68.8	82.9	6	0.58	6.54	2	3	1	0	0	0	0	0	0
2	1	1	2	1	1	1	61.2	29	27.7	0.621	0.1202	9.51	0.0139	44.5	16.1	46.6	79.4	9	1.43	11.79	2	4	2	0	0	0	0	0	1
2	1	1	2	2	1	1	61.2	29	27.7	0.621	0.1202	9.51	0.0139	44.5	16.1	46.6	79.4	10	0.66	7.5	5	3	0	1	1	0	0	0	0
3	1	1	2	1	1	2	52.9	34	23.0	0.335	0.0812	7.53	0.0088	38.2	16.6	56.4	80.0	9	0.8	7.35	1	7	1	0	0	0	0	0	0
3	1	1	2	2	1	2	52.9	34	23.0	0.335	0.0812	7.53	0.0088	38.2	16.6	56.4	80.0	11	1.02	8.48	4	5	0	1	1	0	0	0	0
4	1	1	2	1	3	2	139	31	71.6	0.639	0.1353	11.44	0.0075	84.7	11.8	36.7	30.6	7	2.34	13.04	1	1	2	2	1	0	0	0	0
4	1	1	2	2	3	2	139	31	71.6	0.639	0.1353	11.44	0.0075	84.7	11.8	36.7	30.6	11	1.03	9.97	3	2	4	2	0	0	0	0	0

continued . . .

. . . *Table 5.1 continued* . . .

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
5	1	1	2	1	1	2	59.3	12	29.3	0.442	0.0754	2.47	0.0068	64.7	22.1	26.5	76.4	11	0.7	5.7	6	5	0	0	0	0	0	0	0
5	1	1	2	2	1	2	59.3	12	29.3	0.442	0.0754	2.47	0.0068	64.7	22.1	26.5	76.4	11	0.53	4.4	8	3	0	0	0	0	0	0	0
6	1	1	2	1	2	2	93.7	34	35.3	0.429	0.0754	6.99	0.0094	45.8	13.0	44.1	43.0	5	0.96	8.43	2	1	2	0	0	0	0	0	0
6	1	1	2	2	2	2	93.7	34	35.3	0.429	0.0754	6.99	0.0094	45.8	13.0	44.1	43.0	9	1.11	10.16	2	2	3	2	0	0	0	0	0
1	2	1	2	1	2	2	96	18	36.1	0.506	0.0693	3.40	0.0055	91.7	25.4	45.7	59.1	6	0.45	4.43	4	2	0	0	0	0	0	0	0
1	2	1	2	2	2	2	96	18	36.1	0.506	0.0693	3.40	0.0055	91.7	25.4	45.7	59.1	7	0.22	4.23	5	2	0	0	0	0	0	0	0
2	2	1	2	1	2	3	101.9	27	36.7	0.478	0.0821	6.05	0.0071	67.4	18.4	49.6	89.0	6	1.46	10.26	1	1	4	0	0	0	0	0	0
2	2	1	2	2	2	3	101.9	27	36.7	0.478	0.0821	6.05	0.0071	67.4	18.4	49.6	89.0	5	1.27	8.05	1	3	0	1	0	0	0	0	0
3	2	1	2	1	2	1	108.3	28	35.9	0.607	0.1424	10.88	0.0089	67.9	18.9	53.0	93.1	6	1.28	8.84	1	2	2	1	0	0	0	0	0
3	2	1	2	2	2	1	108.3	28	35.9	0.607	0.1424	10.88	0.0089	67.9	18.9	53.0	93.1	9	0.42	4.72	7	2	0	0	0	0	0	0	0
4	2	1	2	1	1	3	62.1	20	19.4	0.335	0.1001	5.46	0.0082	40.6	20.9	41.9	106.7	6	0.98	6.75	1	4	1	0	0	0	0	0	0
4	2	1	2	2	1	3	62.1	20	19.4	0.335	0.1001	5.46	0.0082	40.6	20.9	41.9	106.7	6	0.6	8.45	1	4	1	0	0	0	0	0	0
5	2	1	2	1	2	3	105.2	23	37.4	0.261	0.0491	3.08	0.0043	61.4	16.4	37.7	30.0	6	0.67	5.16	4	1	0	1	0	0	0	0	0
5	2	1	2	2	2	3	105.2	23	37.4	0.261	0.0491	3.08	0.0043	61.4	16.4	37.7	30.0	4	1.27	10.32	0	1	3	0	0	0	0	0	0
6	2	1	2	1	3	3	143.1	25	57.2	0.728	0.1813	12.36	0.0095	76.8	13.4	33.6	50.8	11	0.52	5.14	8	2	1	0	0	0	0	0	0
6	2	1	2	2	3	3	143.1	25	57.2	0.728	0.1813	12.36	0.0095	76.8	13.4	33.6	50.8	8	0.67	4.43	6	1	1	0	0	0	0	0	0
1	3	1	2	1	3	1	146.3	21	61.0	0.748	0.1807	10.35	0.0097	76.9	12.6	26.5	37.4	3	4.25	22.11	0	0	0	2	0	0	1	0	0
1	3	1	2	2	3	1	146.3	21	61.0	0.748	0.1807	10.35	0.0097	76.9	12.6	26.5	37.4	5	2.46	15.33	1	0	2	0	1	1	0	0	0
2	3	1	2	1	3	2	131.9	24	69.1	1.129	0.2229	14.59	0.0070	161.2	23.3	56.0	50.3	5	5.73	21.88	0	2	0	0	0	1	1	1	0
2	3	1	2	2	3	2	131.9	24	69.1	1.129	0.2229	14.59	0.0070	161.2	23.3	56.0	50.3	6	3.23	14.7	1	0	2	2	1	0	0	0	0
3	3	1	2	1	3	3	158.2	31	65.7	0.865	0.2182	18.45	0.0080	108.4	16.5	51.1	54.3	4	4.08	16.14	0	0	2	1	1	0	0	0	0
3	3	1	2	2	3	3	158.2	31	65.7	0.865	0.2182	18.45	0.0080	108.4	16.5	51.1	54.3	6	1.47	8.96	2	1	2	1	0	0	0	0	0
4	3	1	2	1	2	1	103.9	27	15.4	0.404	0.0632	4.65	0.0149	27.1	17.6	47.6	54.9	10	0.39	4.37	5	5	0	0	0	0	0	0	0
4	3	1	2	2	2	1	103.9	27	15.4	0.404	0.0632	4.65	0.0149	27.1	17.6	47.6	54.9	8	0.52	5.33	3	5	0	0	0	0	0	0	0
5	3	1	2	1	3	1	147.1	28	42.1	1.061	0.2038	15.56	0.0127	83.5	19.8	55.5	55.8	2	3.13	13.03	0	0	2	0	0	0	0	0	0
5	3	1	2	2	3	1	147.1	28	42.1	1.061	0.2038	15.56	0.0127	83.5	19.8	55.5	55.8	10	0.59	4.04	7	2	1	0	0	0	0	0	0
6	3	1	2	1	1	1	58.4	37	20.9	0.341	0.0915	9.23	0.0151	22.5	10.8	39.9	64.4	15	0.81	8.75	1	10	4	0	0	0	0	0	0
6	3	1	2	2	1	1	58.4	37	20.9	0.341	0.0915	9.23	0.0151	22.5	10.8	39.9	64.4	14	0.78	7.13	6	4	3	1	0	0	0	0	0
1	4	1	2	1	3	2	144.9	20	73.7	0.995	0.2267	12.37	0.0061	164.4	22.3	44.6	66.3	6	1.29	7.61	3	0	2	1	0	0	0	0	0
1	4	1	2	2	3	2	144.9	20	73.7	0.995	0.2267	12.37	0.0061	164.4	22.3	44.6	66.3	6	3.1	17.9	1	0	1	0	3	1	0	0	0
2	4	1	2	1	3	3	131.2	26	59.4	0.865	0.1536	10.89	0.0082	105.1	17.7	46.0	49.7	7	1.77	8.35	2	3	1	1	0	0	0	0	0
2	4	1	2	2	3	3	131.2	26	59.4	0.865	0.1536	10.89	0.0082	105.1	17.7	46.0	49.7	7	2.29	14.17	0	1	3	3	0	0	0	0	0

continued . . .

. . . Table 5.1 continued . . .

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
3	4	1	2	1	3	1	154.2	23	80.2	1.100	0.2584	16.21	0.0092	120.2	15.0	34.5	67.8	4	4.53	22.52	1	0	1	0	1	0	0	0	1
3	4	1	2	2	3	1	154.2	23	80.2	1.100	0.2584	16.21	0.0092	120.2	15.0	34.5	67.8	6	4.49	18.76	1	1	1	1	0	1	0	0	1
4	4	1	2	1	1	1	57.2	32	16.6	0.294	0.0726	6.33	0.0155	18.9	11.4	36.4	45.3	5	0.4	6.13	2	2	1	0	0	0	0	0	0
4	4	1	2	2	1	1	57.2	32	16.6	0.294	0.0726	6.33	0.0155	18.9	11.4	36.4	45.3	8	1.42	14.32	0	2	3	2	0	1	0	0	0
5	4	1	2	1	2	1	115.4	27	43.0	0.426	0.0747	5.50	0.0059	72.7	16.9	45.6	24.5	2	8.93	15.07	0	1	0	0	1	0	0	0	0
5	4	1	2	2	2	1	115.4	27	43.0	0.426	0.0747	5.50	0.0059	72.7	16.9	45.6	24.5	4	0.64	9.44	2	1	0	0	1	0	0	0	0
6	4	1	2	1	3	1	157.2	23	78.3	0.770	0.1749	10.97	0.0080	96.1	12.3	28.2	58.7	8	1.36	9.63	2	2	3	1	0	0	0	0	0
6	4	1	2	2	3	1	157.2	23	78.3	0.770	0.1749	10.97	0.0080	96.1	12.3	28.2	58.7	6	1.27	8.73	1	3	2	0	0	0	0	0	0
1	5	1	2	1	1	1	53	38	21.0	0.366	0.1045	10.84	0.0111	33.0	15.7	59.7	86.5	5	1	6.93	4	0	0	0	1	0	0	0	0
1	5	1	2	2	1	1	53	38	21.0	0.366	0.1045	10.84	0.0111	33.0	15.7	59.7	86.5	6	1.38	10.15	0	4	0	2	0	0	0	0	0
2	5	1	2	1	1	2	52	20	22.3	0.300	0.0713	3.89	0.0060	49.9	22.4	44.8	66.9	6	0.64	5.62	2	3	1	0	0	0	0	0	0
2	5	1	2	2	1	2	52	20	22.3	0.300	0.0713	3.89	0.0060	49.9	22.4	44.8	66.9	11	0.72	6.5	5	4	2	0	0	0	0	0	0
3	5	1	2	1	1	3	60.2	26	15.0	0.523	0.1111	7.88	0.0144	36.3	24.2	63.0	105.4	7	0.36	4.73	3	4	0	0	0	0	0	0	0
3	5	1	2	2	1	3	60.2	26	15.0	0.523	0.1111	7.88	0.0144	36.3	24.2	63.0	105.4	5	0.33	4.71	3	2	0	0	0	0	0	0	0
4	5	1	2	1	2	2	84.1	32	12.6	0.319	0.0568	4.96	0.0116	27.5	21.8	69.9	73.0	10	1.12	11.14	5	1	1	2	0	0	0	1	0
4	5	1	2	2	2	2	84.1	32	12.6	0.319	0.0568	4.96	0.0116	27.5	21.8	69.9	73.0	7	0.9	7.31	2	3	2	0	0	0	0	0	0
5	5	1	2	1	3	2	145.5	18	77.1	1.039	0.2138	10.50	0.0065	160.2	20.8	37.4	63.9	1	4.1	36.87	0	0	0	0	0	0	0	1	0
5	5	1	2	2	3	2	145.5	18	77.1	1.039	0.2138	10.50	0.0065	160.2	20.8	37.4	63.9	5	2.41	11.91	2	0	1	0	2	0	0	0	0
6	5	1	2	1	1	2	49.4	27	15.5	0.233	0.0479	3.53	0.0078	29.9	19.3	52.1	71.1	6	0.48	5.43	4	1	1	0	0	0	0	0	0
6	5	1	2	2	1	2	49.4	27	15.5	0.233	0.0479	3.53	0.0078	29.9	19.3	52.1	71.1	5	0.23	3.76	4	1	0	0	0	0	0	0	0
1	6	1	2	1	2	3	92.3	22	32.6	0.509	0.4641	27.85	0.0061	83.4	25.6	56.3	436.6	5	1.08	7.16	2	2	1	0	0	0	0	0	0
1	6	1	2	2	2	3	92.3	22	32.6	0.509	0.4641	27.85	0.0061	83.4	25.6	56.3	436.6	6	3.15	14.07	2	0	1	2	0	0	1	0	0
2	6	1	2	1	2	1	97.6	25	39.1	0.756	0.1137	7.75	0.0077	98.5	25.2	63.0	86.6	7	1.24	8.24	2	3	0	2	0	0	0	0	0
2	6	1	2	2	2	1	97.6	25	39.1	0.756	0.1137	7.75	0.0077	98.5	25.2	63.0	86.6	8	1.38	6.91	3	3	1	1	0	0	0	0	0
3	6	1	2	1	2	2	109.9	29	49.6	0.448	0.0752	5.94	0.0050	89.7	18.1	52.4	50.0	10	1.04	8.46	2	6	1	1	0	0	0	0	0
3	6	1	2	2	2	2	109.9	29	49.6	0.448	0.0752	5.94	0.0050	89.7	18.1	52.4	50.0	13	0.39	5.09	8	3	1	1	0	0	0	0	0
4	6	1	2	1	3	3	160.7	20	50.3	1.040	0.2462	13.43	0.0082	127.0	25.2	50.5	112.9	2	2.66	16.02	0	0	1	1	0	0	0	0	0
4	6	1	2	2	3	3	160.7	20	50.3	1.040	0.2462	13.43	0.0082	127.0	25.2	50.5	112.9	7	0.9	7.26	3	2	1	1	0	0	0	0	0
5	6	1	2	1	1	3	52.6	30	17.6	0.283	0.0798	6.53	0.0108	26.2	14.9	44.7	109.2	3	0.7	7.06	1	1	1	0	0	0	0	0	0
5	6	1	2	2	1	3	52.6	30	17.6	0.283	0.0798	6.53	0.0108	26.2	14.9	44.7	109.2	3	0.48	4.81	2	1	0	0	0	0	0	0	0
6	6	1	2	1	2	3	103.6	29	41.2	0.314	0.0703	5.56	0.0042	74.3	18.0	52.3	49.2	10	0.52	3.51	7	3	0	0	0	0	0	0	0
6	6	1	2	2	2	3	103.6	29	41.2	0.314	0.0703	5.56	0.0042	74.3	18.0	52.3	49.2	9	0.26	3.84	7	2	0	0	0	0	0	0	0

continued . . .

. . . Table 5.1 continued . . .

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
1	1	2	2	1	2	1	106.8	31	52.2	0.426	0.0733	6.20	0.0078	54.5	10.4	32.4	37.8	8	1.6	9.2	0	5	3	0	0	0	0	0	0
1	1	2	2	2	2	1	106.8	31	52.2	0.426	0.0733	6.20	0.0078	54.5	10.4	32.4	37.8	9	0.39	4.47	6	2	1	0	0	0	0	0	0
2	1	2	2	1	2	2	99.3	33	33.6	0.479	0.1210	10.89	0.0068	70.6	21.0	69.3	76.1	7	1.37	10.16	1	3	1	1	1	0	0	0	0
2	1	2	2	2	2	2	99.3	33	33.6	0.479	0.1210	10.89	0.0068	70.6	21.0	69.3	76.1	9	0.58	6.33	4	4	1	0	0	0	0	0	0
3	1	2	2	1	2	3	94.6	28	36.8	0.529	0.0915	6.99	0.0070	76.0	20.6	57.8	59.0	12	0.48	4.22	7	5	0	0	0	0	0	0	0
3	1	2	2	2	2	3	94.6	28	36.8	0.529	0.0915	6.99	0.0070	76.0	20.6	57.8	59.0	6	0.59	6.2	3	2	0	1	0	0	0	0	0
4	1	2	2	1	2	3	96.9	36	33.1	0.294	0.0632	6.20	0.0069	42.4	12.8	46.1	52.7	16	1.11	12.19	0	11	0	2	0	3	0	0	0
4	1	2	2	2	2	3	96.9	36	33.1	0.294	0.0632	6.20	0.0069	42.4	12.8	46.1	52.7	6	1.23	12.85	0	1	4	1	0	0	0	0	0
5	1	2	2	1	3	3	159.8	29	92.7	0.893	0.1723	13.62	0.0126	70.7	7.6	22.1	33.8	5	2.43	10.62	0	2	3	0	0	0	0	0	0
5	1	2	2	2	3	3	159.8	29	92.7	0.893	0.1723	13.62	0.0126	70.7	7.6	22.1	33.8	4	2.46	28.56	0	0	0	1	0	2	0	0	1
6	1	2	2	1	1	3	56.3	27	12.2	0.304	0.0569	4.19	0.0134	22.7	18.6	50.3	45.8	15	0.15	2.8	15	0	0	0	0	0	0	0	0
6	1	2	2	2	1	3	56.3	27	12.2	0.304	0.0569	4.19	0.0134	22.7	18.6	50.3	45.8	10	0.76	7.07	3	5	2	0	0	0	0	0	0
1	2	2	2	1	3	3	143.3	22	68.8	1.459	0.2654	15.93	0.0138	105.8	15.4	33.8	52.5	8	1.64	11.08	4	0	2	0	1	0	1	0	0
1	2	2	2	2	3	3	143.3	22	68.8	1.459	0.2654	15.93	0.0138	105.8	15.4	33.8	52.5	5	6.88	30.8	0	1	0	0	1	0	1	1	1
2	2	2	2	1	3	1	138.5	34	63.4	0.841	0.2093	19.41	0.0087	96.3	15.2	51.6	63.6	5	1.09	5.03	3	2	0	0	0	0	0	0	0
2	2	2	2	2	3	1	138.5	34	63.4	0.841	0.2093	19.41	0.0087	96.3	15.2	51.6	63.6	6	1.09	5.6	2	3	1	0	0	0	0	0	0
3	2	2	2	1	3	2	148.2	28	62.2	0.911	0.1639	12.51	0.0075	121.6	19.5	54.7	62.6	7	1.3	8.2	1	3	3	0	0	0	0	0	0
3	2	2	2	2	3	2	148.2	28	62.2	0.911	0.1639	12.51	0.0075	121.6	19.5	54.7	62.6	7	2.36	12.34	0	4	2	0	0	1	0	0	0
4	2	2	2	1	3	1	152.9	29	46.4	0.859	0.2056	16.26	0.0101	84.8	18.3	53.0	33.4	7	2.06	12.99	1	4	1	0	0	0	0	1	0
4	2	2	2	2	3	1	152.9	29	46.4	0.859	0.2056	16.26	0.0101	84.8	18.3	53.0	33.4	7	2.06	12.99	1	4	1	0	0	0	0	1	0
5	2	2	2	1	1	1	55.8	29	17.1	0.331	0.0949	7.51	0.0161	20.5	12.0	34.8	62.9	10	0.9	8.8	2	3	4	1	0	0	0	0	0
5	2	2	2	2	1	1	55.8	29	17.1	0.331	0.0949	7.51	0.0161	20.5	12.0	34.8	62.9	8	1.39	11.47	0	3	3	1	1	0	0	0	0
6	2	2	2	1	2	1	104.6	23	16.2	0.430	0.0741	4.65	0.0120	35.8	22.1	50.8	89.5	5	1.7	11.53	0	2	1	2	0	0	0	0	0
6	2	2	2	2	2	1	104.6	23	16.2	0.430	0.0741	4.65	0.0120	35.8	22.1	50.8	89.5	6	0.65	6.37	4	1	0	1	0	0	0	0	0
1	3	2	2	1	1	2	56.6	32	27.6	0.434	0.0635	5.54	0.0099	44.1	16.0	51.1	72.4	8	0.82	6.17	3	3	2	0	0	0	0	0	0
1	3	2	2	2	1	2	56.6	32	27.6	0.434	0.0635	5.54	0.0099	44.1	16.0	51.1	72.4	8	0.29	3.88	6	2	0	0	0	0	0	0	0
2	3	2	2	1	1	3	56.2	25	16.5	0.368	0.0767	5.23	0.0104	35.3	21.4	53.5	77.0	5	0.61	6.11	3	0	2	0	0	0	0	0	0
2	3	2	2	2	1	3	56.2	25	16.5	0.368	0.0767	5.23	0.0104	35.3	21.4	53.5	77.0	3	1.42	8.58	1	1	1	0	0	0	0	0	0
3	3	2	2	1	1	1	55.4	34	17.6	0.409	0.1060	9.83	0.0175	23.4	13.3	45.1	49.3	6	1.84	14.82	2	0	0	3	0	0	0	1	0
3	3	2	2	2	1	1	55.4	34	17.6	0.409	0.1060	9.83	0.0175	23.4	13.3	45.1	49.3	7	2.67	19.84	0	1	1	3	0	1	1	0	0
4	3	2	2	1	1	2	47	22	18.4	0.255	0.0474	2.85	0.0061	41.8	22.7	50.0	72.5	8	0.23	3.71	7	1	0	0	0	0	0	0	0
4	3	2	2	2	1	2	47	22	18.4	0.255	0.0474	2.85	0.0061	41.8	22.7	50.0	72.5	13	0.76	8.24	0	12	1	0	0	0	0	0	0

continued . . .

. . . Table 5.1 continued . . .

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
5	3	2	2	1	2	2	100.9	24	37.5	0.371	0.0815	5.33	0.0058	64.4	17.2	41.2	66.4	7	0.62	4.12	5	2	0	0	0	0	0	0	0
5	3	2	2	2	2	2	100.9	24	37.5	0.371	0.0815	5.33	0.0058	64.4	17.2	41.2	66.4	7	0.8	5.24	4	3	0	0	0	0	0	0	0
6	3	2	2	1	3	2	146.3	42	79.7	0.783	0.2426	27.79	0.0087	90.5	11.4	47.7	44.6	7	2.56	15.23	1	2	1	1	0	2	0	0	0
6	3	2	2	2	3	2	146.3	42	79.7	0.783	0.2426	27.79	0.0087	90.5	11.4	47.7	44.6	9	2.56	14.77	2	2	1	1	2	0	1	0	0
1	4	2	2	1	1	3	60.3	33	20.6	0.342	0.0586	5.27	0.0088	39.0	18.9	62.4	65.2	6	0.29	2.94	6	0	0	0	0	0	0	0	0
1	4	2	2	2	1	3	60.3	33	20.6	0.342	0.0586	5.27	0.0088	39.0	18.9	62.4	65.2	2	0.63	2.95	2	0	0	0	0	0	0	0	0
2	4	2	2	1	1	1	59.9	27	22.5	0.533	0.1768	13.02	0.0162	33.0	14.7	39.6	81.0	9	1.46	10.05	3	2	1	2	1	0	0	0	0
2	4	2	2	2	1	1	59.9	27	22.5	0.533	0.1768	13.02	0.0162	33.0	14.7	39.6	81.0	11	0.69	6.91	5	2	3	1	0	0	0	0	0
3	4	2	2	1	1	2	55.4	26	11.6	0.742	0.1262	8.95	0.0241	30.8	26.5	68.9	162.8	10	0.81	5.86	6	2	1	1	0	0	0	0	0
3	4	2	2	2	1	2	55.4	26	11.6	0.742	0.1262	8.95	0.0241	30.8	26.5	68.9	162.8	6	0.68	7.66	2	2	1	1	0	0	0	0	0
4	4	2	2	1	3	2	135.4	55	69.1	0.595	0.1411	21.16	0.0070	84.9	12.3	67.6	90.0	7	1.94	13.3	0	1	4	2	0	0	0	0	0
4	4	2	2	2	3	2	135.4	55	69.1	0.595	0.1411	21.16	0.0070	84.9	12.3	67.6	90.0	9	1.57	10.63	1	5	1	0	1	1	0	0	0
5	4	2	2	1	1	2	50.4	25	19.0	0.332	0.0723	4.93	0.0070	47.4	25.0	62.4	111.7	9	0.51	6.37	3	4	2	0	0	0	0	0	0
5	4	2	2	2	1	2	50.4	25	19.0	0.332	0.0723	4.93	0.0070	47.4	25.0	62.4	111.7	11	0.38	4.79	7	3	1	0	0	0	0	0	0
6	4	2	2	1	2	2	96.5	38	35.3	0.466	0.0945	9.80	0.0083	56.3	16.0	60.6	55.6	10	0.3	4.06	7	3	0	0	0	0	0	0	0
6	4	2	2	2	2	2	96.5	38	35.3	0.466	0.0945	9.80	0.0083	56.3	16.0	60.6	55.6	12	0.64	5.43	8	3	1	0	0	0	0	0	0
1	5	2	2	1	2	2	97.1	32	36.7	0.338	0.0676	5.90	0.0049	68.8	18.8	60.0	54.0	8	1.13	7.01	3	3	2	0	0	0	0	0	0
1	5	2	2	2	2	2	97.1	32	36.7	0.338	0.0676	5.90	0.0049	68.8	18.8	60.0	54.0	5	0.67	5.85	3	2	0	0	0	0	0	0	0
2	5	2	2	1	2	3	100	34	41.0	0.600	0.1147	10.64	0.0074	81.5	19.9	67.5	55.8	9	1.32	9.15	3	1	3	2	0	0	0	0	0
2	5	2	2	2	2	3	100	34	41.0	0.600	0.1147	10.64	0.0074	81.5	19.9	67.5	55.8	6	1.02	9.61	2	1	2	1	0	0	0	0	0
3	5	2	2	1	2	1	100.1	25	49.5	0.956	0.1856	12.65	0.0091	104.7	21.2	52.9	98.7	9	0.89	5.78	5	3	1	0	0	0	0	0	0
3	5	2	2	2	2	1	100.1	25	49.5	0.956	0.1856	12.65	0.0091	104.7	21.2	52.9	98.7	4	1.77	12.34	0	1	3	0	0	0	0	0	0
4	5	2	2	1	1	3	54.5	27	11.3	0.444	0.1724	12.70	0.0147	30.3	26.8	72.3	223.9	12	0.48	4.83	8	4	0	0	0	0	0	0	0
4	5	2	2	2	1	3	54.5	27	11.3	0.444	0.1724	12.70	0.0147	30.3	26.8	72.3	223.9	9	0.87	6.21	4	4	1	0	0	0	0	0	0
5	5	2	2	1	2	3	90.4	37	32.4	0.341	0.0845	8.52	0.0072	47.4	14.6	54.1	38.4	6	0.45	5.82	2	3	1	0	0	0	0	0	0
5	5	2	2	2	2	3	90.4	37	32.4	0.341	0.0845	8.52	0.0072	47.4	14.6	54.1	38.4	6	0.43	3.77	5	0	1	0	0	0	0	0	0
6	5	2	2	1	3	3	133.9	28	56.2	0.907	0.1850	14.13	0.0084	107.6	19.1	53.6	46.4	4	1.55	10.87	1	1	1	0	1	0	0	0	0
6	5	2	2	2	3	3	133.9	28	56.2	0.907	0.1850	14.13	0.0084	107.6	19.1	53.6	46.4	10	1.2	8.16	5	1	3	0	1	0	0	0	0
1	6	2	2	1	3	1	145.5	30	81.0	0.877	0.1792	14.67	0.0089	98.5	12.2	36.5	34.4	6	3.23	20.77	1	0	2	0	1	0	1	1	0
1	6	2	2	2	3	1	145.5	30	81.0	0.877	0.1792	14.67	0.0089	98.5	12.2	36.5	34.4	7	3.81	24.9	0	0	0	3	1	2	0	1	0
2	6	2	2	1	3	2	143.2	21	84.8	1.448	0.2628	15.05	0.0073	197.7	23.3	49.0	26.3	4	10.1	30.41	0	2	0	0	0	0	0	0	2
2	6	2	2	2	3	2	143.2	21	84.8	1.448	0.2628	15.05	0.0073	197.7	23.3	49.0	26.3	6	4.2	16.78	0	2	1	1	0	1	1	0	0

continued . . .

. . . Table 5.1 continued . . .

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
3	6	2	2	1	3	3	149.1	28	80.8	0.750	0.1721	13.14	0.0064	117.9	14.6	40.9	45.8	8	2.31	13.2	2	2	1	0	2	1	0	0	0
3	6	2	2	2	3	3	149.1	28	80.8	0.750	0.1721	13.14	0.0064	117.9	14.6	40.9	45.8	9	1.64	12.19	2	1	3	2	1	0	0	0	0
4	6	2	2	1	2	1	103.7	31	48.2	0.471	0.1396	11.80	0.0078	60.1	12.5	38.6	66.8	12	0.62	7.45	6	1	3	2	0	0	0	0	0
4	6	2	2	2	2	1	103.7	31	48.2	0.471	0.1396	11.80	0.0078	60.1	12.5	38.6	66.8	6	1.4	10.84	1	1	4	0	0	0	0	0	0
5	6	2	2	1	3	1	143.4	28	77.4	0.979	0.2079	15.88	0.0100	97.5	12.6	35.3	38.4	7	2.88	15.99	2	0	2	1	0	0	2	0	0
5	6	2	2	2	3	1	143.4	28	77.4	0.979	0.2079	15.88	0.0100	97.5	12.6	35.3	38.4	9	1.2	8.15	5	0	3	0	1	0	0	0	0
6	6	2	2	1	1	1	51.3	36	9.5	0.314	0.0897	8.80	0.0292	10.8	11.3	40.8	68.2	8	0.78	7.51	2	5	1	0	0	0	0	0	0
6	6	2	2	2	1	1	51.3	36	9.5	0.314	0.0897	8.80	0.0292	10.8	11.3	40.8	68.2	9	1.26	8	3	3	2	1	0	0	0	0	0
1	1	3	2	1	3	2	131.9	31	*	0.548	*	*	*	*	*	*	*	8	2.04	11.25	3	2	2	0	0	0	1	0	0
1	1	3	2	2	3	2	131.9	31	*	0.548	*	*	*	*	*	*	*	5	3.59	24.01	0	0	2	1	0	0	0	1	1
2	1	3	2	1	3	3	135.1	22	*	1.586	*	*	*	*	*	*	*	6	3.22	9.86	3	1	1	0	0	1	0	0	0
2	1	3	2	2	3	3	135.1	22	*	1.586	*	*	*	*	*	*	*	4	5.54	16.21	0	0	2	1	1	0	0	0	0
3	1	3	2	1	3	1	145.8	40	*	0.933	*	*	*	*	*	*	*	6	3.17	15.67	0	3	0	1	1	0	1	0	0
3	1	3	2	2	3	1	145.8	40	*	0.933	*	*	*	*	*	*	*	5	2.86	21.05	0	1	0	2	1	0	1	0	0
4	1	3	2	1	1	1	53.1	36	*	0.622	*	*	*	*	*	*	*	12	1.39	9.9	3	7	1	0	0	0	0	0	1
4	1	3	2	2	1	1	53.1	36	*	0.622	*	*	*	*	*	*	*	11	2.01	17.01	2	0	3	3	1	0	2	0	0
5	1	3	2	1	2	1	101.3	29	*	0.641	*	*	*	*	*	*	*	7	0.16	2.3	7	0	0	0	0	0	0	0	0
5	1	3	2	2	2	1	101.3	29	*	0.641	*	*	*	*	*	*	*	7	0.19	2.99	6	1	0	0	0	0	0	0	0
6	1	3	2	1	3	1	121	49	*	0.620	*	*	*	*	*	*	*	13	0.49	4.8	8	5	0	0	0	0	0	0	0
6	1	3	2	2	3	1	121	49	*	0.620	*	*	*	*	*	*	*	10	0.53	5.8	6	4	0	0	0	0	0	0	0
1	2	3	2	1	1	1	48.9	38	*	0.445	*	*	*	*	*	*	*	11	3.11	19.05	2	1	2	4	0	0	0	0	2
1	2	3	2	2	1	1	48.9	38	*	0.445	*	*	*	*	*	*	*	8	1.27	10.28	0	4	2	2	0	0	0	0	0
2	2	3	2	1	1	2	54.9	36	*	0.325	*	*	*	*	*	*	*	7	1.61	9.39	0	4	3	0	0	0	0	0	0
2	2	3	2	2	1	2	54.9	36	*	0.325	*	*	*	*	*	*	*	8	0.76	7.32	4	2	0	2	0	0	0	0	0
3	2	3	2	1	1	3	55.1	26	*	0.450	*	*	*	*	*	*	*	12	0.6	6.46	7	2	2	1	0	0	0	0	0
3	2	3	2	2	1	3	55.1	26	*	0.450	*	*	*	*	*	*	*	9	0.5	6.03	3	5	1	0	0	0	0	0	0
4	2	3	2	1	2	2	93.5	25	*	0.476	*	*	*	*	*	*	*	13	0.93	10.02	5	3	2	2	1	0	0	0	0
4	2	3	2	2	2	2	93.5	25	*	0.476	*	*	*	*	*	*	*	7	0.3	4.44	6	1	0	0	0	0	0	0	0
5	2	3	2	1	3	2	134.8	21	*	0.576	*	*	*	*	*	*	*	3	1.08	8.98	0	2	1	0	0	0	0	0	0
5	2	3	2	2	3	2	134.8	21	*	0.576	*	*	*	*	*	*	*	8	0.95	8.47	4	2	1	0	0	1	0	0	0
6	2	3	2	1	1	2	50.8	34	*	0.247	*	*	*	*	*	*	*	11	0.63	4.91	6	5	0	0	0	0	0	0	0
6	2	3	2	2	1	2	50.8	34	*	0.247	*	*	*	*	*	*	*	5	2.62	9.16	0	4	1	0	0	0	0	0	0

continued . . .

. . . Table 5.1 continued . . .

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
1	3	3	2	1	2	3	103.6	35	*	0.503	*	*	*	*	*	*	*	6	1.2	7.09	1	4	0	1	0	0	0	0	0
1	3	3	2	2	2	3	103.6	35	*	0.503	*	*	*	*	*	*	*	7	1.21	7.82	3	1	3	0	0	0	0	0	0
2	3	3	2	1	2	1	121.8	24	*	0.717	*	*	*	*	*	*	*	4	1.3	7.44	1	2	1	0	0	0	0	0	0
2	3	3	2	2	2	1	121.8	24	*	0.717	*	*	*	*	*	*	*	4	0.83	6.57	1	3	0	0	0	0	0	0	0
3	3	3	2	1	2	2	85.8	31	*	0.648	*	*	*	*	*	*	*	8	0.45	7.06	4	2	1	1	0	0	0	0	0
3	3	3	2	2	2	2	85.8	31	*	0.648	*	*	*	*	*	*	*	6	0.55	5.5	3	3	0	0	0	0	0	0	0
4	3	3	2	1	3	3	145.4	46	*	0.541	*	*	*	*	*	*	*	8	1.69	10.63	1	4	2	0	0	1	0	0	0
4	3	3	2	2	3	3	145.4	46	*	0.541	*	*	*	*	*	*	*	10	1.43	10	2	2	6	0	0	0	0	0	0
5	3	3	2	1	1	3	71.1	27	*	0.481	*	*	*	*	*	*	*	5	1.57	5.22	4	0	0	1	0	0	0	0	0
5	3	3	2	2	1	3	71.1	27	*	0.481	*	*	*	*	*	*	*	11	0.34	4.14	9	2	0	0	0	0	0	0	0
6	3	3	2	1	2	3	75.2	33	*	0.330	*	*	*	*	*	*	*	12	0.6	5.73	4	8	0	0	0	0	0	0	0
6	3	3	2	2	2	3	75.2	33	*	0.330	*	*	*	*	*	*	*	7	0.79	7.07	4	1	1	1	0	0	0	0	0
1	4	3	2	1	2	1	112.2	24	*	0.779	*	*	*	*	*	*	*	4	1.61	11.66	1	0	2	0	1	0	0	0	0
1	4	3	2	2	2	1	112.2	24	*	0.779	*	*	*	*	*	*	*	12	0.44	4.83	8	3	0	1	0	0	0	0	0
2	4	3	2	1	2	2	104.6	26	*	0.754	*	*	*	*	*	*	*	7	0.94	6.88	1	5	1	0	0	0	0	0	0
2	4	3	2	2	2	2	104.6	26	*	0.754	*	*	*	*	*	*	*	7	1.44	11.88	1	2	3	0	1	0	0	0	0
3	4	3	2	1	2	3	100.2	29	*	0.500	*	*	*	*	*	*	*	8	1.58	10.43	2	1	4	1	0	0	0	0	0
3	4	3	2	2	2	3	100.2	29	*	0.500	*	*	*	*	*	*	*	10	1.09	10.9	2	3	3	1	1	0	0	0	0
4	4	3	2	1	2	3	96.7	32	*	0.322	*	*	*	*	*	*	*	7	0.66	6.41	2	5	0	0	0	0	0	0	0
4	4	3	2	2	2	3	96.7	32	*	0.322	*	*	*	*	*	*	*	10	0.98	8.25	4	2	3	0	1	0	0	0	0
5	4	3	2	1	3	3	164.9	19	*	1.153	*	*	*	*	*	*	*	1	2.92	24.53	0	0	0	0	1	0	0	0	0
5	4	3	2	2	3	3	164.9	19	*	1.153	*	*	*	*	*	*	*	3	3.28	23.78	0	0	0	1	1	1	0	0	0
6	4	3	2	1	1	3	58.6	31	*	0.429	*	*	*	*	*	*	*	12	0.79	6.42	1	10	1	0	0	0	0	0	0
6	4	3	2	2	1	3	58.6	31	*	0.429	*	*	*	*	*	*	*	5	0.68	6.8	1	4	0	0	0	0	0	0	0
1	5	3	2	1	3	3	145	23	*	1.065	*	*	*	*	*	*	*	7	4.27	21.19	0	2	2	0	0	2	0	0	1
1	5	3	2	2	3	3	145	23	*	1.065	*	*	*	*	*	*	*	10	1.54	11.69	3	1	2	3	1	0	0	0	0
2	5	3	2	1	3	1	143.3	31	*	0.861	*	*	*	*	*	*	*	8	2.25	14.16	2	0	3	1	1	1	0	0	0
2	5	3	2	2	3	1	143.3	31	*	0.861	*	*	*	*	*	*	*	7	4.22	22.88	0	1	1	2	1	0	0	0	2
3	5	3	2	1	3	2	141.4	31	*	0.432	*	*	*	*	*	*	*	9	2.06	15.36	0	3	3	1	1	0	0	1	0
3	5	3	2	2	3	2	141.4	31	*	0.432	*	*	*	*	*	*	*	5	0.82	6.75	2	2	1	0	0	0	0	0	0
4	5	3	2	1	3	1	137.7	38	*	0.584	*	*	*	*	*	*	*	10	1.97	16.49	1	1	2	2	3	1	0	0	0
4	5	3	2	2	3	1	137.7	38	*	0.584	*	*	*	*	*	*	*	10	1.95	15.08	1	1	2	4	1	0	1	0	0

continued . . .

. . . *Table 5.1 continued* . . .

a	b	c	d	e	f	g	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGZ	PLB	FBN	IMP	MFRC	F1	F2	T	U	V	W	X	Y	Z
5	5	3	2	1	1	1	44.8	26	*	0.219	*	*	*	*	*	*	*	7	0.93	10.3	2	1	3	0	1	0	0	0	0
5	5	3	2	2	1	1	44.8	26	*	0.219	*	*	*	*	*	*	*	3	0.87	6.64	2	0	1	0	0	0	0	0	0
6	5	3	2	1	2	1	139.9	39	*	0.431	*	*	*	*	*	*	*	9	0.97	5.92	2	7	0	0	0	0	0	0	0
6	5	3	2	2	2	1	139.9	39	*	0.431	*	*	*	*	*	*	*	9	0.49	6.91	3	5	0	1	0	0	0	0	0
1	6	3	2	1	1	2	46.4	79	*	0.322	*	*	*	*	*	*	*	8	0.86	7.05	3	2	3	0	0	0	0	0	0
1	6	3	2	2	1	2	46.4	79	*	0.322	*	*	*	*	*	*	*	6	0.93	8.9	1	4	1	0	0	0	0	0	0
2	6	3	2	1	1	3	54.7	15	*	1.000	*	*	*	*	*	*	*	5	1.47	9.86	1	2	1	1	0	0	0	0	0
2	6	3	2	2	1	3	54.7	15	*	1.000	*	*	*	*	*	*	*	15	0	0.24	15	0	0	0	0	0	0	0	0
3	6	3	2	1	1	1	50	28	*	0.529	*	*	*	*	*	*	*	9	1.3	16.74	2	2	0	0	2	3	0	0	0
3	6	3	2	2	1	1	50	28	*	0.529	*	*	*	*	*	*	*	7	1.16	7.12	3	2	2	0	0	0	0	0	0
4	6	3	2	1	1	2	54.1	26	*	0.519	*	*	*	*	*	*	*	5	1	11.44	0	2	2	1	0	0	0	0	0
4	6	3	2	2	1	2	54.1	26	*	0.519	*	*	*	*	*	*	*	6	0.39	6.05	3	1	2	0	0	0	0	0	0
5	6	3	2	1	2	2	96.6	49	*	0.488	*	*	*	*	*	*	*	10	0.79	6.46	5	3	1	1	0	0	0	0	0
5	6	3	2	2	2	2	96.6	49	*	0.488	*	*	*	*	*	*	*	5	0.88	8.89	0	4	0	1	0	0	0	0	0
6	6	3	2	1	3	2	143.7	31	*	1.023	*	*	*	*	*	*	*	9	1.9	13.82	2	1	2	1	3	0	0	0	0
6	6	3	2	2	3	2	143.7	31	*	1.023	*	*	*	*	*	*	*	6	2.92	13.73	1	1	1	2	1	0	0	0	0

continued . . .

... Table 5.1 continued ...

Key for table 5

a	sheep
b	period
c	day
d	week
e	run
f	treatment height where 1=50, 2=100, 3=150mm.
g	clipping treatments 1 = trimmed 5cm prior to grazing, 2 = grown 5cm to the desired grazing height, 3 = maintained by trimming at desired height.
HT1	Height (mm) pre grazing.
BN	Bite number in 25s.
BD	Bite depth (mm).
FBW	Fresh bite weight (g).
DBW	Dry bite weight (g) calculated from DM% of grazed stratum.
GSBD	Grazed stratum bulk density (g fresh/cm^3).
BV	Apparent volume of pasture encompassed in a bite (cm^3).
BA	Apparent area of pasture at the mean grazed depth encompassed in a bite (cm^2).
PGD	Proportion of the turf surface area grazed (%).
PLB	Average number of grass components per bite.
FBN	Bites recorded on force plate.
IMP	Impulse (Ns)
MFRC	Mean of the peak bite forces for FBN (N).
F1	No of bites whose peak force was below 5N.
F2	FBN between 5 and 10N.
T	FBN between 10 and 15N.
U	FBN between 15 and 20N.
V	FBN between 20 and 25N.
W	FBN between 25 and 30N.
X	FBN between 30 and 35N.
Y	FBN between 35 and 40N.
Z	FBN forces above 40N.

Table 5.2 Intake and bite variables of sheep grazing immature white clover, fescue and prairie grass indoors (trial 2, experiment 3, chapter 5)

A	B	C	D	E	HT1	BN	FBW	DM%	DBW	IR	BD	GSBD	BV	BA	PGD	PBT	FB	IMP	MFR	F1	F	T	U	V	W	X	Y	Z
1	3	1	1	1	124	18	0.900	0.204	0.184	9.03	62.1	0.0046	196.1	31.6	56.8	135.5	5	0.6	8.3	1	3	1	0	0	0	0	0	0
1	3	1	1	2	124	18	0.900	0.204	0.184	9.03	62.1	0.0046	196.1	31.6	56.8	135.5	4	0.8	7.5	2	1	1	0	0	0	0	0	0
2	1	1	1	1	113	27	1.137	0.169	0.192	9.43	60.9	0.0062	184.7	30.3	81.9	58.9	2	0.0	2.0	2	0	0	0	0	0	0	0	0
2	1	1	1	2	113	27	1.137	0.169	0.192	9.43	60.9	0.0062	184.7	30.3	81.9	58.9	7	0.7	5.3	3	3	1	0	0	0	0	0	0
3	2	1	1	1	135	22	0.914	0.143	0.134	6.58	61.2	0.0048	188.9	30.9	67.9	47.2	4	1.2	9.7	2	1	0	0	0	1	0	0	0
3	2	1	1	2	135	22	0.914	0.143	0.134	6.58	61.2	0.0048	188.9	30.9	67.9	47.2	8	1.4	9.3	2	4	0	1	1	0	0	0	0
4	3	1	1	1	142	28	0.514	0.273	0.140	6.88	78	0.0027	191.0	24.5	68.6	59.3	6	0.8	8.8	1	2	3	0	0	0	0	0	0
4	3	1	1	2	142	28	0.514	0.273	0.140	6.88	78	0.0027	191.0	24.5	68.6	59.3	8	0.6	8.4	2	4	1	0	1	0	0	0	0
1	2	2	1	1	137	20	0.785	0.100	0.079	3.87	78.4	0.0040	198.5	25.3	50.6	39.7	5	0.3	3.3	4	1	0	0	0	0	0	0	0
1	2	2	1	2	137	20	0.78	0.100	0.079	3.87	78.4	0.0040	198.5	25.3	50.6	39.7	7	0.2	2.7	6	1	0	0	0	0	0	0	0
2	3	2	1	1	141	22	0.891	0.205	0.183	8.97	76.4	0.0039	230.7	30.2	66.4	109.7	4	1.3	11.3	0	1	3	0	0	0	0	0	0
2	3	2	1	2	141	22	0.891	0.205	0.183	8.97	76.4	0.0039	230.7	30.2	66.4	109.7	13	0.9	7.5	6	3	2	1	1	0	0	0	0
3	1	2	1	1	97	33	0.809	0.164	0.133	6.51	48.7	0.0082	98.8	20.3	66.9	42.3	15	0.6	6.6	7	5	1	2	0	0	0	0	0
3	1	2	1	2	97	33	0.809	0.164	0.133	6.51	48.7	0.0082	98.8	20.3	66.9	42.3	11	0.7	7.7	3	4	3	1	0	0	0	0	0
4	2	2	1	1	157	24	0.858	0.145	0.124	6.10	76.3	0.0047	183.4	24.0	57.7	39.6	4	1.7	11.7	1	1	0	2	0	0	0	0	0
4	2	2	1	2	157	24	0.858	0.145	0.124	6.10	76.3	0.0047	183.4	24.0	57.7	39.6	11	0.7	6.8	5	3	2	1	0	0	0	0	0
1	1	3	1	1	121	25	1.300	0.119	0.155	7.59	67.3	0.0076	170.2	25.3	63.2	68.9	8	0.6	6.1	2	4	2	0	0	0	0	0	0
1	1	3	1	2	121	25	1.300	0.119	0.155	7.59	67.3	0.0076	170.2	25.3	63.2	68.9	10	0.7	6.7	5	2	2	1	0	0	0	0	0
2	2	3	1	1	152	25	0.920	0.133	0.122	6.00	93.3	0.0032	286.1	30.7	76.7	50.5	8	0.8	8.7	2	3	1	2	0	0	0	0	0
2	2	3	1	2	152	25	0.920	0.133	0.122	6.00	93.3	0.0032	286.1	30.7	76.7	50.5	4	0.7	6.8	1	3	0	0	0	0	0	0	0
3	3	3	1	1	143	26	0.769	0.159	0.122	6.00	92.1	0.0036	214.7	23.3	60.6	46.2	7	1.6	11.5	1	2	3	0	1	0	0	0	0
3	3	3	1	2	143	26	0.769	0.159	0.122	6.00	92.1	0.0036	214.7	23.3	60.6	46.2	4	0.6	5.9	2	2	0	0	0	0	0	0	0
4	1	3	1	1	121	32	1.031	0.169	0.174	8.56	54.1	0.0081	126.8	23.4	75.0	113.4	10	1.0	11.2	3	2	1	3	0	1	0	0	0
4	1	3	1	2	121	32	1.031	0.169	0.174	8.56	54.1	0.0081	126.8	23.4	75.0	113.4	12	0.9	9.1	3	4	4	1	0	0	0	0	0
1	1	1	2	1	98	27	0.852	0.164	0.140	6.86	42.2	0.0081	105.7	25.1	67.6	87.3	8	1.7	11.8	1	2	3	2	0	0	0	0	0
1	1	1	2	2	98	27	0.852	0.164	0.140	6.86	42.2	0.0081	105.7	25.1	67.6	87.3	8	0.2	3.8	6	2	0	0	0	0	0	0	0
2	2	1	2	1	148	26	1.077	0.126	0.135	6.65	76.4	0.0046	235.1	30.8	80.0	39.1	5	1.4	7.7	2	1	1	1	0	0	0	0	0
2	2	1	2	2	148	26	1.077	0.126	0.135	6.65	76.4	0.0046	235.1	30.8	80.0	39.1	4	1.0	7.1	1	2	1	0	0	0	0	0	0
3	3	1	2	1	145	31	0.710	0.180	0.128	6.26	89.3	0.0035	204.4	22.9	71.0	40.5	11	0.6	5.8	4	6	1	0	0	0	0	0	0
3	3	1	2	2	145	31	0.710	0.180	0.128	6.26	89.3	0.0035	204.4	22.9	71.0	40.5	9	0.9	7.1	3	5	1	0	0	0	0	0	0
4	1	1	2	1	69	41	0.761	0.276	0.210	10.3	31.4	0.0134	56.9	18.1	83.3	107.8	7	1.0	9.5	3	1	2	0	1	0	0	0	0
4	1	1	2	2	69	46	0.761	0.276	0.210	10.3	31.4	0.0134	56.9	18.1	83.3	107.8	9	0.6	6.0	4	3	2	0	0	0	0	0	0
1	3	2	2	1	150	26	0.577	0.158	0.091	4.48	84.3	0.0028	202.6	24.0	62.5	38.3	10	0.8	5.6	7	0	2	1	0	0	0	0	0
1	3	2	2	2	150	26	0.577	0.158	0.091	4.48	84.3	0.0028	202.6	24.0	62.5	38.3	12	0.8	5.2	8	2	1	1	0	0	0	0	0
2	1	2	2	1	78	16	0.500	0.294	0.147	7.22	34.5	0.0067	75.0	21.7	34.8	49.5	6	1.1	6.7	3	1	2	0	0	0	0	0	0
2	1	2	2	2	78	16	0.500	0.294	0.147	7.22	34.5	0.0067	75.0	21.7	34.8	49.5	7	1.3	8.3	3	1	3	0	0	0	0	0	0
3	2	2	2	1	155	28	0.786	0.112	0.088	4.30	74.6	0.0043	183.2	24.6	68.8	26.0	9	0.6	5.2	5	4	0	0	0	0	0	0	0
3	2	2	2	2	155	28	0.786	0.112	0.088	4.30	74.6	0.0043	183.2	24.6	68.8	26.0	7	0.6	4.9	2	5	0	0	0	0	0	0	0
4	3	2	2	1	137	25	0.640	0.163	0.104	5.12	79.4	0.0030	211.7	26.7	66.7	55.5	6	1.2	9.2	1	2	3	0	0	0	0	0	0
4	3	2	2	2	137	24	0.640	0.163	0.104	5.12	79.4	0.0030	211.7	26.7	66.7	55.5	6	0.5	6.6	1	5	0	0	0	0	0	0	0
1	2	3	2	1	141	17	1.176	0.137	0.162	7.94	73.9	0.0047	248.4	33.6	57.1	45.8	8	0.6	5.8	4	3	1	0	0	0	0	0	0

Table 5.2 continued.....

A	B	C	D	E	HT1	BN	FBW	DM%	DBW	IR	BD	GSBD	BV	BA	PGD	PBT	FB	IMP	MFR	F1	F	T	U	V	W	X	Y	Z
1	2	3	2	2	141	17	1.176	0.137	0.162	7.94	73.9	0.0047	248.4	33.6	57.1	45.8	6	0.8	8.4	2	2	1	1	0	0	0	0	0
2	3	3	2	1	144	20	0.850	0.164	0.139	6.84	92	0.0035	244.4	26.6	53.1	65.9	20	0.0	0.6	20	0	0	0	0	0	0	0	0
2	3	3	2	2	144	20	0.850	0.164	0.139	6.84	92	0.0035	244.4	26.6	53.1	65.9	4	0.2	5.1	2	2	0	0	0	0	0	0	0
3	1	3	2	1	121	34	1.353	0.211	0.285	14.0	70.5	0.0087	156.4	22.2	75.4	103.2	8	0.4	4.3	5	2	1	0	0	0	0	0	0
3	1	3	2	2	121	34	1.353	0.211	0.285	14.0	70.5	0.0087	156.4	22.2	75.4	103.2	10	0.9	6.4	5	3	1	1	0	0	0	0	0
4	2	3	2	1	143	21	0.762	0.104	0.080	3.90	70.4	0.0036	214.6	30.5	64.0	34.3	3	0.7	7.0	1	1	1	0	0	0	0	0	0
4	2	3	2	2	143	21	0.762	0.104	0.080	3.90	70.4	0.0036	214.6	30.5	64.0	34.3	8	0.9	9.0	3	1	3	1	0	0	0	0	0
1	2	1	3	1	151	22	0.727	0.142	0.103	5.08	79.2	0.0037	198.6	25.1	55.2	30.8	7	1.1	7.2	3	2	2	0	0	0	0	0	0
1	2	1	3	2	151	22	0.727	0.142	0.103	5.08	79.2	0.0037	198.6	25.1	55.2	30.8	7	0.5	6.1	4	2	1	0	0	0	0	0	0
2	3	1	3	1	153	21	0.429	0.182	0.078	3.83	75	0.0021	200.9	26.8	56.3	46.7	5	0.5	4.7	3	2	0	0	0	0	0	0	0
2	3	1	3	2	153	21	0.429	0.182	0.078	3.83	75	0.0021	200.9	26.8	56.3	46.7	9	0.5	4.5	6	2	1	0	0	0	0	0	0
3	1	1	3	1	85	29	0.690	0.214	0.148	7.25	36.9	0.0084	82.1	22.2	64.5	48.0	8	3.3	18.3	2	1	1	1	2	0	0	0	1
3	1	1	3	2	85	29	0.690	0.214	0.148	7.25	36.9	0.0084	82.1	22.2	64.5	48.0	9	1.2	9.4	2	3	3	1	0	0	0	0	0
4	2	1	3	1	148	20	0.650	0.118	0.076	3.76	72.5	0.0028	235.6	32.5	65.0	26.9	5	0.6	5.2	2	3	0	0	0	0	0	0	0
4	2	1	3	2	148	20	0.650	0.118	0.076	3.76	72.5	0.0028	235.6	32.5	65.0	26.9	13	0.6	5.3	8	3	2	0	0	0	0	0	0
1	1	2	3	1	91	25	0.600	0.213	0.128	6.27	37.2	0.0091	65.6	17.6	44.1	61.9	8	1.2	9.4	2	2	4	0	0	0	0	0	0
1	1	2	3	2	91	25	0.600	0.213	0.128	6.27	37.2	0.0091	65.6	17.6	44.1	61.9	11	0.8	7.0	5	3	3	0	0	0	0	0	0
2	2	2	3	1	149	28	0.786	0.122	0.096	4.72	87.9	0.0039	203.1	23.1	64.7	36.7	10	0.8	6.1	5	3	2	0	0	0	0	0	0
2	2	2	3	2	149	28	0.786	0.122	0.096	4.72	87.9	0.0039	203.1	23.1	64.7	36.7	12	0.4	4.0	7	5	0	0	0	0	0	0	0
3	3	2	3	1	142	24	0.458	0.165	0.076	3.72	86.9	0.0029	159.3	18.3	44.0	28.9	7	0.9	7.2	3	2	2	0	0	0	0	0	0
3	3	2	3	2	142	24	0.458	0.165	0.076	3.72	86.9	0.0029	159.3	18.3	44.0	28.9	8	0.8	8.5	2	4	1	1	0	0	0	0	0
4	1	2	3	1	37	31	0.581	0.277	0.161	7.90	25.1	0.0092	63.4	25.2	78.3	97.8	11	0.8	8.4	4	3	2	1	1	0	0	0	0
4	1	2	3	2	37	31	0.581	0.277	0.161	7.90	25.1	0.0092	63.4	25.2	78.3	97.8	10	1.0	9.5	2	3	4	1	0	0	0	0	0
1	3	3	3	1	150	21	0.571	0.164	0.094	4.60	82.2	0.0023	247.2	30.1	63.2	40.4	7	0.8	8.3	3	1	1	2	0	0	0	0	0
1	3	3	3	2	150	21	0.571	0.164	0.094	4.60	82.2	0.0023	247.2	30.1	63.2	40.4	5	1.2	10.5	1	2	1	1	0	0	0	0	0
2	1	3	3	1	77	13	0.462	0.245	0.113	5.55	12.8	0.0086	53.7	42.0	54.5	34.6	9	0.4	5.5	4	4	1	0	0	0	0	0	0
2	1	3	3	2	77	13	0.462	0.245	0.115	5.55	12.8	0.0086	53.7	42.0	54.5	34.6	7	0.5	6.2	2	3	2	0	0	0	0	0	0
3	2	3	3	1	146	20	0.600	0.113	0.068	3.32	64.3	0.0030	203.1	31.6	63.2	26.2	6	1.1	6.7	3	2	1	0	0	0	0	0	0
3	2	3	3	2	146	20	0.600	0.113	0.068	3.32	64.3	0.0030	203.1	31.6	63.2	26.2	9	0.7	4.6	4	5	0	0	0	0	0	0	0
4	3	3	3	1	132	27	0.556	0.151	0.084	4.11	64.1	0.0037	148.4	23.1	62.5	37.8	6	0.9	10.4	1	1	2	2	0	0	0	0	0
4	3	3	3	2	132	27	0.556	0.151	0.084	4.11	64.1	0.0037	148.4	23.1	62.5	37.8	10	0.7	7.8	2	5	3	0	0	0	0	0	0
1	3	1	4	1	141	23	0.609	0.134	0.082	4.01	71.9	0.0035	175.1	24.3	56.0	59.3	5	0.9	7.1	3	1	0	0	1	0	0	0	0
1	3	1	4	2	141	23	0.609	0.134	0.082	4.01	71.9	0.0035	175.1	24.3	56.0	59.3	4	1.4	9.1	1	1	1	1	0	0	0	0	0
2	2	1	4	1	142	25	0.960	0.131	0.126	6.18	76	0.0049	197.2	25.9	64.9	93.6	4	1.2	9.7	2	2	1	0	0	0	0	0	0
2	2	1	4	2	142	25	0.960	0.131	0.126	6.18	76	0.0049	197.2	25.9	64.9	93.6	8	1.4	9.3	2	2	4	0	0	0	0	0	0
3	1	1	4	1	0	27	0.000	0.114	0.000	0.00	0	0.0000	0.0	0.0	0.0	0.0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	1	4	2	0	27	0.000	0.114	0.000	0.00	0	0.0000	0.0	0.0	0.0	0.0	0	0	0	0	0	0	0	0	0	0	0	0
4	3	1	4	1	138	27	0.704	0.199	0.140	6.86	68.2	0.0038	184.6	27.1	73.1	74.2	9	2.0	13.2	1	2	3	2	0	1	0	0	0
4	3	1	4	2	138	27	0.704	0.199	0.140	6.86	68.2	0.0038	184.6	27.1	73.1	74.2	9	1.3	8.9	3	3	2	1	0	0	0	0	0
1	2	2	4	1	146	22	0.636	0.125	0.080	3.91	67.6	0.0033	195.5	28.9	63.6	22.2	6	0.6	5.5	2	3	1	0	0	0	0	0	0
1	2	2	4	2	146	22	0.636	0.125	0.080	3.91	67.6	0.0033	195.5	28.9	63.6	22.2	9	0.8	6.4	5	1	2	1	0	0	0	0	0

. . . Table 5.2 continued . . .

A	B	C	D	E	HT1	BN	FBW	DM%	DBW	IR	BD	GSBD	BV	BA	PGD	PBT	FB	IMP	MFR	F1	F	T	U	V	W	X	Y	Z
2	3	2	4	1	120	24	0.625	0.124	0.078	3.81	65.2	0.0044	140.5	21.6	51.7	58.1	4	0.3	3.9	3	1	0	0	0	0	0	0	0
2	3	2	4	2	120	24	0.625	0.124	0.078	3.81	65.2	0.0044	140.5	21.6	51.7	58.1	11	1.2	10.1	3	2	3	2	1	0	0	0	0
3	1	2	4	1	125	25	0.960	0.202	0.194	9.52	74.6	0.0052	183.6	24.6	61.5	82.2	12	0.9	7.3	6	1	4	1	0	0	0	0	0
3	1	2	4	2	125	25	0.960	0.202	0.194	9.52	74.6	0.0052	183.6	24.6	61.5	82.2	11	0.6	5.3	7	2	1	1	0	0	0	0	0
4	2	2	4	1	147	18	0.833	0.099	0.083	4.07	67.5	0.0043	194.0	28.7	51.7	33.1	3	1.4	9.9	1	0	1	1	0	0	0	0	0
4	2	2	4	2	147	18	0.833	0.099	0.083	4.07	67.5	0.0043	194.0	28.7	51.7	33.1	9	0.7	7.2	3	3	1	2	0	0	0	0	0
1	1	3	4	1	99	18	0.444	0.228	0.101	4.97	35.8	0.0067	66.3	18.5	33.3	10.3	3	0.5	4.9	1	2	0	0	0	0	0	0	0
1	1	3	4	2	99	18	0.444	0.228	0.101	4.97	35.8	0.0067	66.3	18.5	33.3	10.3	6	1.0	6.0	3	2	1	0	0	0	0	0	0
2	2	3	4	1	144	21	0.952	0.141	0.135	6.61	71.6	0.0046	206.6	28.9	60.6	44.2	6	0.6	5.9	2	3	1	0	0	0	0	0	0
2	2	3	4	2	144	21	0.952	0.141	0.135	6.61	71.6	0.0046	206.6	28.9	60.6	44.2	9	0.8	9	3	3	1	1	1	0	0	0	0
3	3	3	4	1	105	21	0.556	0.130	0.072	3.55	55.6	0.0041	134.3	24.2	43.5	52.9	6	2.4	11.6	1	1	1	3	0	0	0	0	0
3	3	3	4	2	105	18	0.556	0.130	0.072	3.55	55.6	0.0041	134.3	24.2	43.5	52.9	11	0.6	7	6	3	1	0	0	1	0	0	0
4	1	3	4	1	96	30	0.667	0.148	0.099	4.84	34.1	0.0085	78.4	23.0	69.0	47.9	8	1.1	9.1	2	2	2	2	0	0	0	0	0
4	1	3	4	2	96	30	0.667	0.148	0.099	4.84	34.1	0.0085	78.4	23.0	69.0	47.9	9	0.7	8.0	3	3	2	1	0	0	0	0	0

Key for table 5.2

a	sheep
b	pasture species where 1 = white clover, 2 = prairie grass and 3 = tall fescue.
c	day
d	run
HT1	Height (mm) pre grazing.
BN	Bite number in 25s.
FBW	Fresh bite weight (g).
DM%	Dry matter percentage in the grazed stratum.
DBW	Dry bite weight (g) calculated from DM% of grazed stratum.
IR	Intake rate (gDM/min).
BD	Bite depth (mm).
GSBD	Bulk density of the grazed stratum (gfresh/cm$^{3)}$
BV	Apparent volume of pasture encompassed in a bite (cm^2).
BA	Apparent area of pasture at the mean grazed depth encompassed in a bite (cm^2).
PGD	Proportion of the turf surface area grazed (%).
PLB	Average number of grass components per bite.
FBN	Bites recorded on force plate.
IMP	Impulse (Ns)
MFRC	Mean of the peak bite forces for FBN (N).
F1	No of bites whose peak bite force was below 5N.
F	FBN between 5 and 10N.
T	FBN between 10 and 15N.
U	FBN between 15 and 20N.
V	FBN between 20 and 25N.
W	FBN between 25 and 30N.
X	FBN between 30 and 35N.
Y	FBN between 35 and 40N.
Z	FBN forces above 40N.

Table 5.3 Intake and bite variables of sheep grazing paired ryegrass turfs with and without a grid restricting bite depth (experiment 3 Chapter 5).

a	b	c	HT1	GHT	HT2	SE	FBW	DBW	IR	GSBD	BV	BA	PGD	PBT	FBN	IMP	MFC	F1	F	T	U	V	W	X	Y
1	1	1	155.9				0.548	0.116	9.81	0.0045	121.5	13.2	40.8	41.2	11	1.95	11.4	3	4	2	1	0	0	0	1
1	1	2	65.5				0.389	0.088	4.56	0.0177	22.0	10.7	20.4	34.9	9	1.10	10.1	0	0	2	0	1	0	1	0
1	2	1	154.5	95.3	98.3	1.8	0.280	0.060	5.43	0.0033	83.7	14.9	74.5	34.0	12	1.56	9.73	3	3	4	2	0	0	0	0
1	2	2	95.2	73.5	73.3	2.6	0.250	0.057	5.01	0.0075	33.2	15.2	48.5	22.0	16	0.61	5.89	9	4	3	0	0	0	0	0
2	1	1	136.8				0.540	0.123	8.39	0.0041	132.4	21.3	53.1	71.3	12	0.64	5.28	5	7	0	0	0	0	0	0
2	1	2	76.1				0.279	0.055	4.93	0.0143	19.5	7.6	25.0	34.1	18	0.87	7.79	8	4	3	3	0	0	0	0
2	2	1	148.2	117.3	115.9	2.3	0.792	0.251	10.97	0.0071	111.7	34.6	83.0	67.6	8	0.61	5.43	3	4	1	0	0	0	0	0
2	2	2	119.6	81.2	80.9	1.6	0.220	0.041	2.55	0.0037	59.8	15.5	71.1	29.6	7	0.37	4.21	5	2	0	0	0	0	0	0
3	1	1	155.2				0.549	0.115	11.58	0.0053	103.7	14.0	51.9	31.4	18	1.49	11.7	4	5	3	4	1	1	0	0
3	1	2	80.8				0.388	0.104	7.08	0.0168	23.1	8.9	44.7	39.2	10	2.75	14.5	0	2	5	0	2	1	0	0
3	2	1	152.8	128.1	120.7	3.1	0.288	0.044	3.02	0.0029	44.9	24.3	60.6	19.0	18	0.85	7.01	7	7	3	1	0	0	0	0
3	2	2	118.5	60.7	72.5	1.3	0.348	0.060	5.44	0.0058	60.3	13.1	43.2	24.7	13	0.46	5.54	5	8	0	0	0	0	0	0
4	1	1	140.9				0.500	0.085	6.03	0.0038	130.2	18.7	48.5	35.7	17	0.96	7.98	7	7	1	1	0	1	0	0
4	1	2	72.4				0.368	0.069	5.23	0.0148	24.9	7.8	21.8	24.0	17	0.80	7.58	5	8	3	1	0	0	0	0
4	2	1	144.4	76.7	83.8	2.1	0.330	0.069	5.67	0.0028	117.6	19.4	58.2	15.4	10	1.13	8.79	2	5	2	0	1	0	0	0
4	2	2	81.0	46.2	54.2	1.7	0.283	0.051	3.80	0.0106	26.7	9.9	40.6	25.4	15	1.01	8.64	4	7	3	0	1	0	0	0

Key for table 5.3

a	sheep.
b	period.
c	grazing where 1= first grazing period on turf and 2 = second grazing period the same turf.
HT1	Height (mm) pre grazing .
GHT	Height of grid (mm) when used (ie period 2).
HT2	Height (mm) post grazing.
SE	Standard error of HT2.
FBW	Fresh bite weight (g).
DBW	Dry bite weight (g) calculated from DM% of grazed stratum.
IR	Intake rate (gDM/min).
BD	Bite depth (mm).
GSBD	Bulk density of the grazed stratum (gfresh/cm^{3})
BV	Apparent volume of pasture encompassed in a bite (cm^3).
BA	Apparent area of pasture at the mean grazed depth encompassed in a bite (cm^2).
PGD	Proportion of the turf surface area grazed (%).
PLB	Average number of grass components per bite (%).
FBN	Bites recorded on force plate.
IMP	Impulse (Ns)
MFRC	Mean of the peak bite forces for FBN (N).
F1	No of bites whose peak bite force was below 5N.
F	FBN between 5 and 10N.
T	FBN between 10 and 15N.
U	FBN between 15 and 20N.
V	FBN between 20 and 25N.
W	FBN between 25 and 30N.
X	FBN between 30 and 35N.
Y	FBN between 35 and 40N.

Table 5.4 Intake and bite variables of goats and sheep grazing 15cm turfs indoors (trial 4, experiment 3 chapter 5).

A	B	C	HT1	BN	BD	FBW	DBW	IR	GSBD	BV	BA	PGD	PBT	FBN	IMP	MFC	F1	F	T	U	V	W	X	Y	
1	1	1	151.9	40	50.2	0.215	0.034	3.73	0.36	0.0032	67.9	13.5	54.1	17.0	6	0.16	2.46	6	0	0	0	0	0	0	0
1	1	2	138.5	22	53.1	0.423	0.060	3.60	0.34	0.0029	147.7	27.8	61.2	24.4	10	0.18	3.04	9	1	0	0	0	0	0	0
2	1	1	150.8	28	60.7	0.218	0.035	2.70	0.25	0.0029	75.6	12.4	34.9	23.3	3	0.06	1.76	3	0	0	0	0	0	0	0
2	1	2	143.1	37	59.8	0.181	0.029	2.90	0.27	0.0026	68.5	11.5	42.4	15.3	8	0.16	4.75	5	3	0	0	0	0	0	0
3	1	1	138.7	36	63.8	0.317	0.070	6.92	0.61	0.0029	107.5	16.8	60.6	43.7	4	0.29	4.84	3	1	0	0	0	0	0	0
3	1	2	170.8	34	63.4	0.197	0.045	2.81	0.25	0.0028	71.0	11.2	38.1	18.6	15	0.29	4.50	13	2	0	0	0	0	0	0
4	1	1	134.6	71	61.5	0.169	0.027	5.30	0.52	0.0032	53.0	8.6	61.2	9.3	5	0.05	2.04	5	0	0	0	0	0	0	0
4	1	2	140.5	75	60.6	0.121	0.024	3.27	0.32	0.0027	45.4	7.5	56.2	13.5	6	0.19	2.50	6	0	0	0	0	0	0	0
1	2	1	145.7	26	62.6	0.746	0.145	10.25	0.46	0.0062	120.4	19.2	50.0	78.5	14	1.68	14.68	2	5	2	1	0	4	0	0
1	2	2	125.7	23	58.6	0.765	0.190	11.92	0.54	0.0057	133.9	22.8	52.5	43.2	9	6.65	24.86	0	2	0	2	0	3	0	0
2	2	1	148.8	23	50.3	0.535	0.082	5.12	0.21	0.0107	49.8	9.9	22.8	20.6	17	1.42	8.23	9	1	5	1	0	1	0	0
2	2	2	143.9	24	61.7	0.871	0.178	11.64	0.48	0.0079	109.9	17.8	42.7	49.2	14	2.64	15.43	4	0	2	1	4	0	1	0
3	2	1	153.3	14	92.2	1.043	0.168	6.41	0.28	0.0056	186.0	20.2	28.2	45.6	5	2.0	11.11	0	3	1	0	1	0	0	0
3	2	2	146.1	30	99.5	0.657	0.137	11.22	0.49	0.0087	75.5	7.6	22.8	25.5	10	5.05	20.87	0	0	2	5	0	2	1	0
4	2	1	143.4	29	81.6	0.983	0.189	14.92	0.65	0.0066	149.1	18.3	53.0	54.5	20	1.65	10.84	4	3	7	3	2	1	0	0
4	2	2	147.8	28	68.1	0.782	0.166	12.72	0.55	0.0092	85.2	12.5	35.0	35.6	22	1.52	12.06	9	1	4	2	2	4	0	0

Key for table 5.4

A	Animal number.
B	Animal species: 1 = goats and 2 = sheep.
C	replicate.
HT1	Height (mm) pre grazing.
BN	Bite number in 25s.
BD	Bite depth (mm).
FBW	Fresh bite weight (g).
DBW	Dry bite weight (g) calculated from DM% of grazed stratum.
IR	Intake rate (gDM/min).
IRMLW	Intake rate per kg metabolic weight.
GSBD	Bulk density of the grazed stratum (gfresh/cm^{3})
BV	Apparent volume of pasture encompassed in a bite (cm^{3}).
BA	Apparent area of pasture at the mean grazed depth encompassed in a bite (cm^{2}).
PGD	Proportion of the turf surface area grazed (%).
PLB	Average number of grass components per bite.
FBN	Bites recorded on force plate.
IMP	Impulse (Ns)
MFRC	Mean of the peak bite forces for FBN (N).
F1	No of bites whose peak bite force was below 5N.
F	FBN between 5 and 10N.
T	FBN between 10 and 15N.
U	FBN between 15 and 20N.
V	FBN between 20 and 25N.
W	FBN between 25 and 30N.
X	FBN between 30 and 35N.
Y	FBN between 35 and 40N.