EFFECT OF SWARD SURFACE HEIGHT ON HERBAGE INTAKE AND PERFORMANCE OF FINISHING BEEF CATTLE

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ABSTRACT

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This study examined the effects of sward surface height (SSH) on the herbage intake, ingestive behaviour and performance of steers finished on ryegrass (*Lolium perenne*) /white clover (*Trifolium repens*) pastures during summer. The influence of this initial treatment contrast on subsequent cattle performance under common grazing conditions during early-autumn was also studied. Twenty six month-old steers with an initial liveweight of 522 ± 7.6 kg, 14 Angus x (Hereford x Friesian) and 10 Angus x (Hereford x Jersey), were set stocked on swards maintained at SSHs of 5 and 10 cm (L vs. H) from 18 November 1996 to 4 March 1997, with 3 replicate groups of 4 animals per treatment balanced as far as possible for "breed". Six steers from each treatment balanced for "breed" were slaughtered on 4 March and carcass and meat quality characteristics compared. The remaining animals were grazed for another 5 weeks on common pastures until the final slaughter on 8 April.

Over the SSH control period, the 5 and 10 target swards averaged 4.8 ± 1.36 and 10.0 ± 3.24 cm. Herbage on the H swards contained more dead material, less crude protein, lower dry matter digestibility and live:dead tiller ratio than that on the L swards. Estimates of herbage dry matter intake were higher for steers grazing at 10 cm than for those grazing at 5 cm SSH (8.0 vs. 4.8 kg DM d^{-1} from 2 estimates and 2 alkane pairs, $P < 0.05$ for each comparison). Steers were unable to increase their grazing time in response to limiting sward conditions sufficiently to compensate for lower intake rates in short swards, resulting in reduced herbage intakes. Daily liveweight gain over the summer was higher on the 10 cm than on the 5 cm SSH (1.10 ± 0.23 vs. 0.32 ± 0.21 kg d^{-1}, $P < 0.01$) and carcass weight at first slaughter was significantly higher for steers on the H swards (332 ± 10.6 vs. 287 ± 7.5 kg, $P < 0.05$). SSH treatment did not affect other carcass or meat quality characteristics of steers. Liveweight and carcass weight gain per hectare were 71 % and 43 % greater (318 vs. 186 kg and 166 vs. 116 kg) for steers grazing at 10 cm despite the lower stocking rate (2.86 vs. 5.80 steers ha^{-1}) maintained by the tall swards.

Over the common grazing period previously restricted steers had higher intakes, greater grazing and ruminating times, lower resting time and grew faster compared to steers previously grazed at 10 cm SSH. However, none of these parameters were significantly different between the steer groups with the exception of resting time. Increased autumn growth rates by previously restricted steers did not compensate for the differences in liveweight established during summer, and significant differences in carcass weight were still evident at the end of the compensatory period between the steer groups (335 ± 9.4 vs. 297 ± 9.4 kg, $P < 0.05$). There were no significant differences in meat quality characteristics with the exception of meat brightness which was higher for previously restricted steers.

These results suggest that maintaining a sward height of 10 cm offers advantages in terms of individual animal output and output per hectare compared with grazing at 5 cm and that compensatory growth does not seem to be an important phenomenon in heavy (over 500 kg liveweight) finishing steers.

Keywords: sward height; herbage intake; grazing behaviour; n-alkanes; liveweight; carcass; meat quality; compensatory growth; beef cattle.

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CHAPTER 1

INTRODUCTION

Beef cattle production systems in New Zealand rely almost exclusively on grazed forage. An understanding of the relationships between sward conditions, herbage intake and animal performance is important for efficient operation of such grazing systems. Sward surface height is an important determinant of the performance of beef cattle at pasture (Jamieson and Hodgson 1979b, Lowman *et al.* 1988, Swift *et al.* 1989, Morris *et al.* 1993a) and has been used as a criterion for grazing management guidelines. However, less experimental effort has been made with cattle than sheep to establish responses to different sward conditions (Nicol and Nicoll 1987), and there is little comparative information relating sward surface height to the herbage intake and performance of heavy finishing steers under continuous grazing. Information is required for cattle of different ages and breeds, grazing pastures of different yields, composition, and maturity, at different times of the year (Marsh 1979). There is also limited information available, regarding the extent to which improved grazing conditions towards the end of the autumn finishing period affect the performance, carcass and meat quality characteristics of beef steers maintained under restrictive grazing management in spring and summer.

With a view to developing appropriate grazing management recommendations for farmers, the experiment reported here was conducted to quantify the relationships between SSH of ryegrass (*Lolium perenne*)/white clover (*Trifolium repens*) pastures, herbage intake, ingestive behaviour and performance of heavy (over 500 kg liveweight) finishing steers under continuous grazing during summer. It was also aimed to evaluate the effect of contrasting sward conditions during summer on subsequent cattle performance under common grazing conditions during early autumn.

CHAPTER 2

LITERATURE REVIEW

The primary objective of this review is to bring together some of the available information on the relationship between sward surface height (SSH), herbage intake and animal performance, with special reference to ryegrass/white clover pastures and finishing beef cattle under continuous grazing. Since limited information is available in the literature for finishing cattle, the influence of sward surface height on the performance of sheep, beef and dairy cows is also summarized. Nutritional effects on beef quality characteristics are briefly reviewed in a second section; and finally, an overview of the advantages and limitations of the use of n-alkanes to measure herbage intake and estimate diet composition of the grazing animal is presented.

2.1. Effect of sward surface height on herbage intake and animal performance.

2.1.1. Introduction

In any grazing system it is desirable to base management decisions on objective criteria established from a knowledge of the way in which grazing systems respond. This allows decisions to be taken in response to changing conditions and also makes the consequences of those decisions more predictable (Wright and Whyte 1989).
Hodgson (1981) argued that sward-based measurements should be used in managing grazing systems and suggested that the surface height of the undisturbed sward is probably the best simple variable for predicting both animal and sward responses, appearing to be the most useful indicator for management purposes. This is particularly the case for swards maintained in a relatively steady state under set-stocking conditions where between-sward differences in characteristics such as leaf area, leaf density and canopy structure, are closely related to height differences (Hodgson 1985).

Herbage mass could be used as the criterion on which to base decision making. However, grazing management guidelines based on sward height are likely to be more easily understood by farmers and animals respond more consistently to variations in sward height than in herbage mass. In addition, it is easily measured (Hodgson 1990).

Swift *et al.* (1989) related cattle growth to sward height and assessed management guidelines for achieving target heights; Wright *et al.* (1996) assessed the feasibility of controlling sward height as an operational management tool in spring and summer for beef cow systems; while Davies *et al.* (1989) investigated the use of sward height as a criterion for determining the time of stocking-rate changes in a sheep production experiment. The results of these studies confirmed the usefulness of sward height as a basis on which to make adjustments to stocking rates, providing further evidence for the value of sward height as an aid to efficient grazing management.

2.1.2. Effect of sward surface height on herbage intake and ingestive behaviour.

Levels of herbage production and animal performance are closely related to sward conditions (Hodgson 1990). SSH influences sward structure and herbage growth (Bircham and Hodgson 1983; Parsons and Johnson 1986), which in turn affect herbage intake and hence animal performance (Hodgson 1981, Baker *et al.* 1981b). It was established that on relatively simple temperate grass pastures the intake by the grazing animal and its performance, were positively related to, and determined by SSH (Wright *et al.* 1996).

Non-nutritional factors (pasture structure, pasture mass, pasture allowance) relating to the physical harvesting of forage are probably the most important factors limiting intake by grazing ruminants in New Zealand (Poppi *et al.* 1987). Hodgson (1985) noted that herbage mass and herbage height are good indicators of accessibility of herbage in temperate grasses. They determine bite weight, and finally exert a dominant positive influence upon daily herbage intake (Chacon and Stobbs 1976; Forbes 1988).

Herbage intake can be viewed as a consequence of three behavioural variates: intake per bite, biting rate and grazing time. All three variables, but specially intake per bite, are influenced by sward conditions, such as height, mass or density of the herbage. Rate of intake is the product of the rate of biting and the amount of herbage in each individual bite (Hodgson 1986; Hodgson 1990).

Intake per bite, is the variable most directly influenced by sward conditions, and usually decreases sharply as herbage mass or sward height declines. Biting rate generally tends to increase with decreasing intake per bite, but the rate of increase is rarely fast enough to prevent a concomitant decline in the rate of herbage intake (Hodgson 1981). Although biting rate has been seen as a compensatory response, it seems to be due primarily to a reduction in the number of manipulative jaw movement required on shorter swards, and should therefore be considered as a direct effect of variation in sward conditions (Hodgson 1985).

The most adaptive response is the increase in grazing time which usually occurs when the rate of intake declines. However, the degree of compensation is again limited. Thus, variation in the rate of herbage intake is likely to be a major determinant of daily herbage intake (Hodgson 1981). As canopy height increases in temperate pastures, intake per bite increases (Forbes 1988) and biting rate generally decreases (Black and Kenney 1984), but with an overall increase in rate of herbage intake (Jamieson and Hodgson 1979b).

2.1.3. The influence of sward surface height on sheep performance.

Sward height has been shown to be the major factor influencing both net herbage production and herbage intake by grazing sheep during pregnancy (Morris *et al.* 1993b) and lactation (Bircham and Hodgson 1983, Parsons *et al.* 1983, Maxwell and Treacher 1987, Morris *et al.* 1994) and to be positively correlated with levels of utilised metabolizable energy by ewes and lambs (Alcock *et al.* 1986) and with the performance of lambs after weaning (Chestnutt 1992). Bircham and Hodgson (1983) and Penning (1986) showed that herbage intakes of sheep are restricted below a sward height of 5-6 cm, with maximum intake rates achieved at heights of 6 cm and above.

Burnham *et al.* (1994) studied the effect of pasture height on herbage intake and ewe performance under continuous stocking management during autumn. Their results suggested that maximum herbage intake and ewe performance on ryegrass-white clover pastures can be obtained at a sward height of about 4 cm, and that pasture digestibility and dead matter content in the pastures are the major limiting factors at this time of the year which is in agreement with Hawkins *et al.* (1993). Prior studies by Korte (1982) and Rattray and Clark (1984) have indicated that maintaining the development of plant reproductive material during the late spring-early summer is a critical prerequisite to maintaining pasture digestibility. Morris *et al.* (1994) found for winter-lambing ewes in good condition that a SSH of 4 cm under continuous stocking should ensure near to maximum ewe and lamb performance.

Armstrong *et al.* (1995) evaluated the inter-relationships between sward conditions (constant 3.5 and 6.0 cm, 3.5 increasing to 6.0 cm and 6.0 decreasing to 3.5 cm) and the performance of weaned lambs grazing a pure ryegrass sward under continuous variable stocking. It was found that sward height and especially the direction of its change were potent influences on lamb growth rate which was a consequence of differences in herbage intake, strongly influenced by bite mass. These results are in agreement with Doney *et al.* (1987) who suggested that change in sward height influenced the performance of weaned lambs grazing perennial ryegrass swards more than did the maintenance of different constant sward heights.

The structure of short swards influences the ingestive behaviour of sheep (Hodgson 1986; Penning *et al.* 1989, 1991). Barthram and Grant (1984) showed that younger leaves were higher in the sward than were older leaves, and that the pseudostem layer appeared to restrict the depth of the grazed horizon on short swards. This may modify the relationship between ingestive behaviour and sward height, particularly in limiting bite mass and hence the amount of herbage eaten daily, which may affect the performance of grazing animals. Armstrong *et al.* (1995) reported that there was evidence that pseudostem acted as a barrier to defoliation on the short swards and also that the proportion of youngest leaf in the diet of lambs was positively related to sward height and to increases in sward height.

2.1.4. The influence of sward surface height on the performance of beef and dairy cows and their calves.

It has been shown on a number of occasions that under continuous grazing the height of the sward grazed by beef cows and their calves has a large effect on their intake and performance (Baker *et al.* 1981b; Russel *et al.* 1986; Wright and Russel 1987; Wright and Whyte 1989), and that restricting herbage allowance or sward height will lead to a reduction in cow and calf liveweight gain and cow milk yield. These studies have shown that spring-calving cows and their calves grazing perennial ryegrass dominated swards achieve maximum liveweight gain at a SSH of 8 to 10 cm.

Wright and Russel (1987) showed that herbage intake of beef cows grazing a sward of 5.3 cm surface height was 10.3 kg organic matter per day compared to 13.6 kg OM per day for cows on a 8.5 cm sward. Cows gained weight and condition and sustained high levels of milk production grazing on the 8 to 10 cm sward, while cows and calves liveweight gains were considerably reduced on the shorter sward, suggesting that swards should be maintained at a height of at least 8 cm.

Wright and Whyte (1989) demonstrated the marked effect of sward height on cow and calf performance over a range of sward heights (4.5, 6.0, 7.0, 9.1 and 11.0 cm) and suggested that pasture height should be maintained at no more than 8 cm in spring and early summer to avoid unacceptable levels of ungrazed material; but once the risk of flower stem development is past the sward height can be increased to 9 to 10 cm. Wright *et al.* (1990) assessed the herbage intake and performance of autumn-calving beef cows and their calves grazing continuously at two sward heights, and concluded that the sward heights recommended for spring-calving cows are equally appropriate for autumn-calving cows.

Wright *et al.* (1996) studied the effect of grazed sward height and stocking rate (2.0 or 2.5 cows ha^{-1}) on animal performance and output from beef cow systems. Cows grazed at 7-8 cm SSH gained significantly more liveweight than those grazed at 4-5 cm (0.841 vs. 0.496 kg day^{-1}) as did the calves (1.167 vs. 1.105), but the stocking rate treatment had no effect. The results showed that it was possible to control sward height in temperate beef cow systems by adjusting the area available for grazing.

Ferrer and Petit (1995) examined how female Charolais cattle (weaned calves, heifers and dry cows) respond in terms of grass intake and behavioural components to height (15 cm vs. 32 and 52 cm) of leafy cocksfoot swards. It was found that bite weight was lower, grazing time and biting rate greater, and organic matter intake of grass higher on shorter swards, the latter being related to a higher *in vitro* digestibility and nitrogen concentration. Although bite weights were largely depressed on animals grazing short swards, their intake was not limited, probably because herbage mass and height were not low enough in these swards.

Subsequent studies were carried out by Ferrer *et al.* (1995) to explore shorter cocksfoot swards (7.5, 10.2 and 21.1 cm) where behavioural adaptations could be compromised.

Calves tended to maintain intake, whereas cows and heifers reduced their intake as sward height decreased. Bite weight decreased linearly with sward height and biting rates increased as sward height decreased. Cows and heifers were unable to increase their grazing time sufficiently to compensate for lower intake rates in 7.5 and 10.2 cm swards, resulting in reduced herbage intakes. These results, along with Ferrer and Petit (1995), indicated that herbage intake in leafy cocksfoot swards is limited at mean sward heights below 8 cm for large cattle but not for calves, and by herbage digestibility in older leafy swards (above 25 cm) for all cattle.

Rook *et al.* (1994) analysed the effects of compressed sward height (4, 6 or 8 cm) and concentrate supplementation on the performance of spring calving dairy cows grazing perennial ryegrass-white clover swards. Their results suggested that maintaining a sward height of 6 cm offers advantages in terms of individual animal output and output per ha compared with grazing at greater or lower sward heights. Intakes were lower on the lower swards, suggesting that intake was being constrained by sward height. The similarity in individual animal milk yields at 6 and 8 cm indicate that a compressed sward height of 6 cm can be recommended in practice as output per ha will be greater due to the higher stocking rate.

2.1.5. Effect of sward surface height on the performance and compensatory growth of finishing beef cattle.

Although behavioural responses to a wide range of sward heights have been studied in sheep (e.g. Allden and Whittaker 1970; Penning *et al.* 1991) and in dairy cows (Rook *et al.* 1994), there is little comparative information on the behavioural response of beef cattle to variation in sward characteristics (Mursan *et al.* 1989). In particular, there is a need to quantify the rate of intake and liveweight gain of beef cattle differing in age and sex at different sward heights, and also the effect of SSH between seasons within a particular animal class (Hodgson 1986).

Two experiments were conducted at Massey University to define the relationship between SSH, herbage intake and liveweight gain in yearling Friesian bulls and Charolais x Angus steers during autumn and spring (Morris *et al.* 1993a). These experiments confirmed overseas research findings indicating that liveweight gain in continuously grazed finishing steers and bulls increases with sward surface height to a maximum of 8-10 cm on spring ryegrass/white clover pastures while, in autumn, swards of 12-15 cm height are required to achieve maximum performance.

Liveweight gains achieved by the cattle were linearly related to pasture height in the autumn but the relationship was curvilinear in the spring. The observed curvilinear relationship between organic matter intake and sward height has also been reported by Hodgson (1985). Baker *et al.* (1981a) found that with set-stocked beef cows and calves the relationship between intake and sward height was asymptotic due primarily to the fact that the herbage selected by the cattle declined in digestibility with increasing sward height. A curvilinear relationship between herbage allowance and growth of Friesian steers during six-month trials over summer/autumn was also reported by Marsh (1979), while Wright *et al.* (1986) using a range of sward surface heights between 4.0 and 7.5 cm found a linear response between SSH and intake for cattle grazing ryegrass swards.

Earlier work by Marsh (1975) suggested that cattle growth on autumn pasture was less than that on spring pasture at the same herbage allowance. These differences could be attributed to differences in digestibility (Clark and Brougham 1979) but Reid (1986) reported that seasonal differences in liveweight gain were not associated with differences in *vitro* digestibility or N concentration. Reid (1986) concluded that pasture allowances required for maintenance or for maximum growth rates of beef cattle are higher in autumn/winter than in spring and potential growth rates in spring approximately double those in autumn. Morris *et al.* (1993a) suggested that seasonal effects might be due to differences in daylength. During short daylength periods, e.g. autumn, grazing time may be reduced and so ability to increase grazing time to compensate for reduced bite size on low SSH may be limited.

Lowman *et al.* (1988) examined the effects of varying sward SSH on performance and carcass quality in cattle. These authors found that a pasture height of 10 cm increased liveweight gains over the summer by around 0.15 kg head^{-1} day^{-1} compared to cattle grazing swards of 7 cm. The results indicated that a low SSH will reduce carcass weight, carcass conformation and fatness at the same slaughter date. It was concluded that to achieve similar carcasses slaughter of cattle grazing at 7 cm will have to be delayed by at least five weeks, compared with cattle grazing at 10 cm SSH.

Swift *et al.* (1989) related animal growth to sward height, assessed management guidelines for achieving target heights and described the resultant sward height profiles, as part of a continuing study of winter and summer feeding strategies for finishing January and spring-born calves at grass. It was concluded that optimal sward height for highest gain of set stocked finishing cattle is 8-10 cm. The authors analysed curves of daily liveweight gains against SSH over a range of 5-12 cm. The model predicted highest gains in the range 8-10 cm, with a peak at 9.0 cm sward height, with a higher or lower daily liveweight gain when SSH was increasing or decreasing.

The height profiles provided further evidence for the value of sward height in grazing management and indicated that a sward maintained at 10 cm will have approximately 50 % of the area above this height and 20 % below 7 cm, giving rise to a mosaic of under- and over-grazed areas. This heterogeneity and "patchiness" in cattle-grazed swards is consistent with other observations. Gibb and Ridout (1986 and 1988) fitted double normal distributions to sward height measurements collected under cattle grazing, and postulated that the two parts of the distribution corresponded to "frequently grazed" and "infrequently grazed" components. These results are in agreement with the observations of Kitessa and Nicol (1996) who compared the frequency distribution of sward height on pastures grazed by cattle alone or co-grazed with sheep.

Wright and Whyte (1989) concluded that the infrequently grazed component can be kept below 20% for most of the grazing season if mean sward height is maintained below 8 to 9 cm. This suggestion is in agreement with the observation of Hodgson (1990) that patchy grazing and seed-head development are unlikely to be a problem in swards maintained below 8-10 cm in cattle systems.

Mursan *et al.* (1989) analysed the relationship between sward height, bite dimensions and bite weight for one-year-old Friesian steers and bulls. Both bite weight and bite depth increased with sward height whereas bite area was not influenced by either sward height or density as it remained unchanged as sward height increased from 5 to 15 cm and the bulk density of the grazed horizon decreased from 20.94 to 9.18 mg/cm^3. The significant changes in bite weight in this trial were due to increased bite depth which resulted in greater bite volume. These results suggested that sward height, which determines bite depth, appeared to be the major determinant of bite weight and consequently of daily intake.

Further work with heavier cattle grazing spring ryegrass white clover swards also found bite area unchanged as sward surface height increased from 5 to 15 cm (Elliot 1988 cited by Mursan *et al.* 1989). Contrary to these studies, Laca *et al.* (1992) showed that average bite area of cattle grazing homogeneous swards was not constant as often assumed, but decreased linearly with density and increased quadratically with height. Their results indicated that the area and depth of bite by cattle are significantly and predictably affected by sward height and bulk density.

Steen (1994) compared systems of bull beef production involving continuous housing or pasture grazing from 5 to 10 months of age and examined the effects of SSH (7, 9 and 11 cm) and concentrate supplementation on lifetime performance and carcass quality. Reducing SSH from 11.0 to 9.3 cm did not affect performance but further reductions to 7.9 and 6.7 cm reduced liveweight gain by 0.13 and 0.32 kg/day, respectively. The absence of any major depression in performance of calves when SSH was reduced from 11.0 to 9.3 cm is in line with findings of Wright and Whyte (1989) with suckled calves. The decrease in performance when further reductions in SSH to 7.9 and 6.7 cm occurred, is again in line with those recorded by Lowman *et al.* (1988) who recorded a proportional depression in cattle performance of 0.18 when SSH was reduced from 10 to 7 cm.

Differences in liveweight at 10 months of age due to feeding treatments imposed from 5 to 10 months of age were largely retained until slaughter at 17 months as there was little compensatory growth during the residual period. The treatments did not affect carcass composition when data were adjusted to a constant carcass weight, or meat quality characteristics. Drennan *et al.* (1982) in an extensive series of studies carried out over 4 years and Wilkinson and Prescott (1970) also found that animals of similar age and weight to those used by Steen (1994) did not exhibit compensatory growth following a depression in performance at pasture due to the imposition of high stocking rates. This was despite the fact that, during the residual period, Wilkinson and Prescott (1970) recorded a significantly higher food intake per unit liveweight for the animals which had the lower level of performance at pasture.

Steen (1994) observed no effect of growth rate from 5 to 10 months of age on carcass composition at 17 months which is in line with the results of previous studies with steers. These have generally shown that, following a period of realimentation, any effects of growth rate during early life on final carcass composition are mediated through their effect on liveweight or carcass weight at slaughter, and that when animals have been slaughtered at constant carcass weight any earlier effects on carcass composition have been eliminated (Drennan 1979; Berge 1991).

It has been suggested that cattle exhibit compensatory growth to a greater extent when previous changes in growth rate have reduced fat deposition rather than protein deposition (Moran and Holmes 1978) or altered body composition (Beever and Baker 1986). However, the effects of body composition at the end of the treatment period on the subsequent expression of compensatory growth are by no means clear, as compensatory growth has been expressed in some studies in the absence of a difference in body composition at the end of the treatment period (Baker *et al.* 1985; Gibb and Baker 1991).

Yarrow *et al.* (1996) examined the interactions between winter nutrition and the subsequent performance of Limousin x Friesian steers grazing grass/clover swards at differing compressed sward heights (5.5 and 7.5 cm). Their results shown that animals kept on a relatively low plane of nutrition during winter tended to grow faster in the subsequent grazing season than those kept on a high plane of winter nutrition. Increased rates of gain during summer grazing did not fully compensate for winter restriction and more animals reached slaughter weight during the grazing season from the high than the low winter treatments.

Animals grazed at a compressed SH of 5.5 cm tended to grow more slowly than those grazed at 7.5 cm and animal performance was related to herbage mass rather than compressed SH *per se*. It was found that above an herbage mass of about 3.5 t DM ha^{-1}, growth rate of the cattle was not affected by an increase in compressed SH. The target compressed sward heights of 5.5 and 7.5 cm approximated to SSHs of 7.5 and 9.2 cm (R.H. Johnson, unpublished).

Mean stocking rates over the 2 years were 5.2 vs. 4.3 head ha^{-1} on the 5.5 cm and the 7.5 cm treatments respectively and liveweight gain ha^{-1} also tended to be higher on the short than the tall swards (670 vs. 572 kg ha^{-1}). The higher stocking rates, associated with the 5.5-cm treatment, also enabled a greater proportion (20%) of the plot area to be cut for silage. The low winter treatment and the 5.5-compressed SH treatment both led to fewer animals reaching slaughter condition before the end of the summer grazing period in the second year and thus would incur extra winter feeding costs before they could be marketed.

It was concluded that small restrictions in growth rate in the winter feeding period can be compensated for during the summer grazing period, but at the expense of a decrease in summer stocking rate. However, the authors pointed out that in practice, there is unlikely to be a single optimum combination of winter and summer factors, with probably one of the most important being the optimization of slaughter date to maximize financial returns.

Wright *et al.* (1986) examined and quantified the effects of winter food level on compensatory growth of weaned, suckled calves continuously stocked on perennial ryegrass swards maintained at either 4 to 5 cm or 6 to 8 cm SSH. During summer sward height had a large positive effect on herbage intake and liveweight gain and it was concluded that for maximum intake on ryegrass swards continuously grazed by cattle, SSH should be at least 8 cm. However, the authors pointed out that there is a need to establish the exact shape of the response curves between herbage intake, animal performance and sward height as well as the implications for output per unit area.

During summer there was a significant effect of winter food level on animal performance when liveweight gains were accordingly greater for the low, medium and high levels of winter feeding. It was found that the level of winter feeding affected not only liveweight gain but also the body composition of the cattle at the end of the winter. The cattle showing compensatory growth had higher herbage intakes and it was postulated that this occurred because of a negative association between body fat and herbage intake. This negative association has often been demonstrated as, for example, in dairy cows by Bines *et al.* (1969) and in beef cows by Hodgson *et al.* (1980).

Despite the fact that compensatory growth was evident, the compensation was not complete. It was concluded that there is a clear need to investigate further the relative importance of both increased food intake and alteration of the composition of the tissue gained during compensatory growth in cattle. It was also concluded that the choice of winter food level for weaned, suckled calves is an economic one and that there is unlikely to be a single optimum choice, but rather a range of options depending on availability of winter foodstuffs, the length of the winter feeding period and summer grazing season, and the desired time of slaughter and type of carcass to be produced.

2.1.6. Conclusions

Levels of herbage production and animal performance are closely related to sward conditions which can be reasonably summarised into sward surface height, particularly under continuous stocking management. Control of sward height of a grazed pasture is now widely recognised as a useful aid to efficient grazing management. The indications are that sward height is a major determinant of individual animal performance and output per unit area and that performance can be controlled, despite variations in the seasonal pattern of herbage production, in a predictable manner by keeping sward surface height within defined limits.

Target sward heights have been suggested for all classes of livestock (Hodgson *et al.* 1986). The information available indicates that the optimal sward height for highest gain of set stocked finishing cattle is 8-10 cm. Within this range of sward height, individual animal performance and output per ha as well as pasture quality seem to be compatible. However, a reasonable compromise to ensure an adequate balance between requirements for high animal performance and for efficient herbage utilisation is needed (Hodgson 1990). Further increases in sward height are not associated with improved animal performance but can lead to a reduction in sward density and pasture quality. The results indicate that a low sward surface height will reduce liveweight gain, carcass weight, carcass conformation and fatness at the same slaughter date of finishing beef cattle.

Swift *et al.* (1989) proposed that target range for finishing beef cattle is 6-8 cm during spring rising to 7-9 cm in summer, but evidence is lacking to support these target heights particularly under New Zealand pastoral conditions. If sward height is to be used as a criterion on which to base decision-making in grazing systems, there is a need for quantitative information on the response of beef finishing cattle performance to a range of sward heights. In particular, there is a need to quantify the rate of intake and liveweight gain of beef cattle differing in age, breed and sex at different sward heights, and also the effect of sward surface height between seasons within a particular animal class (Hodgson 1986).

2.2. Nutritional effects on beef quality characteristics

Over the last five years there has been a major change in New Zealand's dependence on the traditional North American manufacturing beef market. The development of the North Asian market; Japan, South Korea and Taiwan in particular; has counteracted the declining North American demand (Forgie 1993). The Asian beef markets require continuity of supply and consistency of product specification. Thus, considering the greater participation of these markets in New Zealand's beef exports, the issue of meat quality becomes increasingly important for New Zealand.

Animal nutrition manipulation is known to have an important effect on meat quality characteristics, and major differences have been reported for carcasses of cattle finished on pasture relative to those of grain-fed animals. Numerous studies have indicated that as the energy content of the finishing diet fed to cattle is increased, there is an improvement in carcass quality grade and sometimes in meat quality characteristics (Larick *et al.* 1987).

2.2.1. Meat tenderness

Although eating satisfaction results from the interaction of tenderness, juiciness, and flavour; meat tenderness is the quality characteristic which is often most closely correlated with overall consumer acceptance. This is particularly important for beef meat where concern about toughness seems to be greatest (Purchas *et al.* 1989). Many aspects of meat quality; such as colour, odour and fat content; can to some extent be assessed before purchase, but tenderness remains the most variable and least obvious of meat quality characteristics.

Consequently, solving the problem of consumer dissatisfaction associated with unacceptable variation in meat tenderness is a top priority of the meat industry. This issue is one of great significance for New Zealand, with meat industry foreign exchange earnings contributing substantially to the country's economy. The ability to differentiate meat product on the basis of increased tenderness offers significant financial incentive.

2.2.1.1. Nutritional effects on meat tenderness

Tenderness has two components, a myofibrillar component and a connective tissue component. The myofibrillar component is influenced by the degree of contraction of muscles postmortem, ultimate pH and the extent to which the muscle has been aged before cooking, as well as by the degree of cooking. Thus nutritional or compositional effects must influence the myofibrillar component of toughness by affecting the extent of contraction of muscles postmortem, the ultimate pH, muscles susceptibility to ageing, or combinations of these (Shorthose and Harris 1991).

There is little clear evidence for specific nutritional effects on meat tenderness (Purchas 1989). Apparently the widely reported beneficial effects of finishing cattle on high-energy diets is mainly an effect of age and fatness, although the collagen in meat from animals that have been on a high level of nutrition has also been suggested to be more soluble (Miller *et al.* 1983).

Muscles from fatter, heavier carcasses have been shown to produce more tender meat cuts because they chill more slowly and, as a result, are less susceptible to cold-induced toughening (Shorthose and Harris 1991). Subcutaneous fat cover is thought to act as an insulator, retarding the rate of cooling and consequently decreasing the extent of cold-induced myofibrillar shortening and toughening. Several researchers investigated the effects of preslaughter nutritional regimen on beef carcass traits. In general intensive feeding of animals has shown to increase both weight and fatness of the carcasses they produce (Purchas and Davies 1974, Bowling *et al.* 1977, Schroeder *et al.* 1980, Bidner *et al.* 1981).

Bowling *et al.* (1977) reported that cattle finished on grain produced the heaviest, fattest, most massive carcasses and the most tender steaks. In addition grain-finished beef sustained less myofibrillar shortening during postmortem chilling (28.4% *vs* 17.2% sarcomere shortening for forage-finished and grain-finished beef, respectively).

Purchas and Davies (1974) found consistently higher mean Warner-Bratzler shear values for meat from animals fed on pasture than for grain-finished animals of the same carcass weight. It was also found that the response to cold-shortening was significantly greater for meat from the pasture group than from the grain-fed group, in terms both of the distance shortened and of the proportional change in tenderness.

Van Koevering *et al.* (1995) studied the effect of time on feed (105, 119, 133, or 147 days) on performance, carcass characteristics, and tenderness and composition of *Longissimus* muscles of feedlot British and Continental crossbred yearling steers (329 kg initially). It was found that tenderness of ribeye steaks tended to increase linearly with time on feed. Performance and carcass characteristics indicated an ideal feedlot finishing period of 119 to 133 days, since feeding for a longer time did not improve substantially quality grade and tenderness. Schnell *et al.* (1997) also found improved sensory tenderness by feeding high-energy concentrate diets to cull beef and dairy cows for periods up to 56 days. However, Warner-Bratzler shear force was not affected by feeding.

Factors which influence the connective tissue component of toughness have been much less well defined. Nutritional or compositional effects on the connective tissue component of toughness seems to act by influencing the amount or nature (degree of cross-linking or heat stability) of connective tissue (Shorthose and Harris 1991).

It has been suggested that intensive preslaughter feeding appears to counter the adverse effect of animal age on meat tenderness (Tatum 1981). Clayton *et al.* (1981) cited by Tatum (1981) studied the effect of preslaughter feeding regimen (fed *vs* non-fed) and carcass maturity (youthful *vs* mature) on beef palatability, and found a significant maturity by feeding regimen interaction. Similar beef tenderness was found from youthful and mature animals when cattle were finished on a high-energy diet. However, the detrimental effects of maturity on tenderness (Warner-Bratzler shear force) were evident when maturity comparisons were restricted to beef from non-fed cattle.

Miller *et al.* (1987) investigated the effect of preslaughter feeding regimen for 84 days on collagen characteristics and muscle quality of mature cows. Cows fed a high-energy diet were fatter, had more marbling, increased percentage of heat-labile collagen, less sensory panel detectable connective tissue and lower shear force values than cows fed a maintenance-energy diet.

However, it is important to consider that tenderness increases with time on feed up to a certain point after which animal age may have a greater influence leading to reduced tenderness. Epley *et al.* (1968) suggested 139 days, Zinn *et al.* (1970) 150 to 180 days and Van Koevering *et al.* (1995) 119 to 133 days.

2.2.1.2. Effect of marbling on meat tenderness

Intensively fed animals have been observed to have more extensively marbled lean than slaughtered animals fed on pasture. Early theories assumed logically that intensive feeding enhanced marbling and marbling, in turn, enhanced tenderness. However, these assumptions were based only on practical observations and were not supported with experimental evidence (Tatum 1981). To date, research has established only a low to moderate relationship between marbling and meat tenderness (Campion *et al.* 1975, Crouse *et al.* 1978, Tatum *et al.* 1980, Tatum 1981, Wood and Warriss 1992, Wood 1995, Jeremiah 1996).

Bowling *et al.* (1977) compared forage-finished and grain-finished beef carcasses which were selected to have the same marbling and maturity scores. In this study, grain-finished beef was superior in tenderness to forage-finished beef despite the lack of variation in marbling. These data demonstrate that improved tenderness associated with intensive preslaughter feeding has little dependence upon intramuscular fat deposition.

However, May *et al.* (1992) found a correlation of -0.61 between marbling score and shear force in steaks from Angus x Hereford steers fed for different amounts of time on a high-energy diet. Fatness and tenderness increased as the days of the finishing period with the high concentrate diet increased up to 112 days. Nevertheless, the authors believe that this relationship between marbling score and tenderness was increased by using a serial slaughter technique, uniform cattle type, and a breed cross known for its ability to marble.

Recently, attempts have been made to define threshold values for marbling fat below which eating quality is unacceptably low and above which no obvious improvement occurs, as a response of the clear desire of consumers for very lean meat, and the desire of meat traders to maintain the level of eating quality (Wood 1995). In the US, visual marbling score has been an important commercial indicator of beef quality, and some studies (Campion *et al.* 1975, Smith *et al.* 1984, Dikeman 1987) have concluded that the 'slight' level of marbling, equivalent to about 3% ether-extractable lipid, is the threshold value for beef steaks.

2.2.1.3. Effect of ultimate pH on beef tenderness

Ultimate pH is known to have a major influence on meat characteristics, with higher pH values (above about 5.8) being associated with decreasing tenderness (up to pH 6.0-6.1), darker colour, poorer keeping quality, a higher water-holding capacity, and generally a less acceptable flavour and, hence, its fundamental importance to product quality (Shorthose and Harris 1991, Purchas 1992, Guignot *et al.* 1994, Wright *et al.* 1994; Purchas and Keohane 1995; Ockerman and Sun 1996).

When carcasses of commercially slaughtered cattle are cooled quickly, the relationships between ultimate pH and tenderness and ultimate pH and shear force in muscles free to shorten such as *M. longissimus thoracis* are curvilinear (Shorthose and Harris 1991; Purchas and Aungsupakorn 1993; Devine 1994). Shorthose and Harris (1991) suggested that part of the effect of ultimate pH on tenderness, in muscles which can cold shorten, relates to the relationship between time of onset of rigor mortis and ultimate pH and hence to the extent of myofibrillar contraction.

New Zealand work found that beef with pH values around 6.1 had shorter sarcomeres than beef with pH values about 5.5, indicating that it was more contracted when rigor mortis occurred (Purchas 1992). However, Purchas (1992) suggested that a single mechanism explaining the lower tenderness at a pH of 6.1 relative to that at a pH of 5.5 should not be assumed. Other factors in addition to the degree of contraction may be involved. For example, there are indications that collagen can be affected by pH leading to changes in tenderness. Ultimate pH can also affect the rate of autolysis which is responsible for *post mortem* tenderization of meat. Koohmaraie (1992) reported that with decreasing pH, the rate of autolysis was significantly increased in bovine skeletal muscle.

2.2.2. Lean meat colour

Meat colour is an important determinant of the eye attraction of meat. Consumers appear to have different preferred colour optima for different cuts of meat. However, for most beef products and cuts consumers seem to prefer a bright red colour, and to dislike colours which are extremely pale or dark (Shorthose and Harris 1991). Dark coloured beef is not acceptable for some important export markets, particularly Japan which has set beef colour standards.

2.2.2.1. Nutritional effects on lean meat colour

Various factors influence lean meat colour. Muscle pigment concentration (myoglobin and haemoglobin) is an important factor. Myoglobin concentration increases with animal age and carcass weight (Lawrie 1974), but because age and weight are closely related it is difficult to determine which factor is most important. The final, or ultimate pH of muscle has a large effect on meat colour, as the ultimate pH gets higher meat gets darker (Purchas 1992, Guignot *et al.* 1994).

The rate of cooling of muscles also influences meat colour; slower cooling results in paler meat. Intramuscular fat concentration may also have an effect, as the concentration of marbling increases, measured meat colour tends to get lighter. Shorthose and Harris (1991) concluded that beef of the darkest colour is found in high ultimate pH, superficial muscles of carcasses of old cattle, that have not been electrically stimulated and have been cooled rapidly. Nutritional effects would influence one or more of these factors and thus influence meat colour. The influence of plane of nutrition *per se* on meat colour has not been the subject of much study.

Carcasses of cattle finished on pasture may differ from those of grain-fed animals in various meat characteristics including meat colour (Craig *et al.* 1959; Walker *et al.* 1990). Craig *et al.* (1959) and Murray (1989) reported that meat from lot-fed animals was brighter than that from pasture-fed cattle. However, Dinius and Cross (1978) and Reagan *et al.* (1977) reported no difference in meat colour between animals finished on pasture and grain fed animals.

Greater muscle myoglobin concentrations has been suggested in grazing animals compared to feedlot animals due to their greater physical activity. However, Craig *et al.* (1966) found similar myoglobin concentrations in the *longissimus thoracis* muscles of steers fed grain on pasture compared to steers fed cut forage and grain in drylot, indicating that such differences in physical activity did not significantly influence muscle myoglobin concentrations.

The final pH of beef has long been of considerable concern to the meat industry, but this has not been primarily in regard to concerns about tenderness. Rather it has been due to the fact that high ultimate pH values lead to darker meat colour and a shortened shelf life of beef (Purchas 1992). Darkness of meat colour may be increased if planes of nutrition increase the susceptibility of animals to preslaughter stress sufficiently to increase final pH values. Dark-cutting beef is a direct result of low muscle glycogen stores at the time of slaughter (Hall *et al.* 1944 cited by McVeigh and Tarrant 1982).

Shorthose (1988) reported a greater prevalence of dark-cutting beef in carcasses of grazing, rather than lot-fed, animals. Glycogen deficiency may result from undernourishment, stress and over exercise. If an animal is starved, driven too hard by dogs or separated from a group before slaughter, these events will combine to affect its meat quality increasing pH in the meat once those animals are slaughtered. (McVeigh and Tarrant 1982).

2.2.3. Beef fat colour

The colour of beef fat has assumed much greater importance during recent years because excessive fat colour is regarded as undesirable, and seriously affects certain overseas markets, such as Japan (Yang *et al.* 1993). For this reason, beef grading systems in many countries include the measurement of fat colour which may cause considerable economic loss, when carcasses show excessively yellow fat leading to downgrading or even rejection of these carcasses (Yang *et al.* 1992). This problem becomes increasingly important for New Zealand considering the greater participation of the Asian markets, and particularly Japan, in New Zealand's beef exports.

Cattle in New Zealand graze green pastures over most of the year. The fat on the carcasses derived from grazing cattle is usually a creamy-yellow colour which results from yellow pigments that occur naturally in the pastures, and yellow fat will not develop in cattle unless these pigments are present in the diet (Tume and Yang 1996). The aspect of yellow fat is therefore indicative of a pasture-fed product, which, in some consumers' minds, may be associated with an odour and flavour that are less attractive (Tume and Yang 1996).

2.2.3.1. Nutritional effects on fat colour

Carcasses of cattle finished on pasture may differ from those of grain-fed animals in fat and meat colour (Craig *et al.* 1959; Walker *et al.* 1990). Green, fresh pastures usually contain high quantities of carotenoids (up to 500 ppm of dry matter) whereas dry or cut hay (less than 50 ppm) and most grains (usually less than 5 ppm of dry matter) may have considerably less (Tume and Yang 1996). Cattle, fed grain or dry grass/hay, will therefore have a low carotenoid intake and, hence, a less yellow fat colour (Tume and Yang 1996).

Moreover, the fat colour of carcasses from grass-fed cattle is known to become whiter after animals are fed a high grain diet for an extended period (Craig *et al.* 1959, Dinius and Cross 1978, Forrest 1981, Hidiroglou *et al.* 1987, Strachan *et al.* 1993, Schnell *et al.* 1997). Forrest (1981) reported that yearling steers reared on grass for 169 days and not carrying an excessive amount of subcutaneous fat, can produce acceptable coloration after a concentrate feedlot finishing period of 56 days.

However, some researchers have found no effect on fat colour when grain was fed for periods of less than 60 days (Bidner *et al.* 1981, Yang *et al.* 1993). Knight *et al.* (1996) reported no change in beef fat colour after feeding a diet of 70% barley and 30% pasture-silage for 62 or 104 days on a feedlot, while Morris *et al.* (1997) assessing the effect of short-term grain feeding on carcass and meat quality, found that 30 days were insufficient to affect fat colour characteristics.

McGillivray (1960) and Morgan *et al.* (1969) reported marked fat colour variations between breeds, and also among individuals of the same breed. Morgan *et al.* (1969) showed that carcass fat of the Jersey is more yellow than that of the Friesian and Angus breeds, Jersey crosses with Friesian, Charolais and Hereford breeds being intermediate in fat colour. These authors concluded that genetic manipulation can effectively reduce the incidence and intensity of fat colour and, to a large extent, eliminate the marketing problem of yellow fat.

Tume and Yang (1996) concluded that apart from these breed effects, grain feeding is presently the only way of reducing fat colour of grass-fed cattle to an acceptable level. However, the time required to change fat colour to match the Japanese and other markets requirements is not known (Strachan *et al.* 1993), but recent studies suggest that more than 60 days may be needed.

2.2.4. Meat flavour

Meat flavour is influenced by compounds contributing to the sense of taste as well as those stimulating the olfactory organ (Purchas *et al.* 1989). Other sensations such as mouth feel and juiciness will also influence the overall flavour sensation (Mottram 1992). It is the volatile compounds formed during cooking that determine the odour attributes and contribute most to the characteristic flavours of meat. It seems that no single compound or group of compounds can define the complex aroma associated with cooked meat, and it would appear that meat flavour is due to the presence of a mixture of different compounds (Mottram 1992).

2.2.4.1. Effect of nutrition on meat flavour

Several studies have revealed that beef from cattle finished on high energy grain diets has a more desirable or a more intense flavour than that from cattle finished on low energy forage diets (Larick *et al.* 1987, Westerling and Hedrick 1979, Schroeder *et al.* 1980, Tatum *et al.* 1980, Melton 1990).

Purchas and Davies (1974) reported superior flavour of meat from animals finished on barley compared to animals finished on pasture. Bowling *et al.* (1977) also found that grain-finished beef was more tender, more desirable in flavour and more satisfactory in overall palatability than forage-finished beef. Berry *et al.* (1988) investigated the effects of different silage diets and a corn concentrate diet on beef flavour intensity. Beef produced on the corn diet had a higher beef flavour intensity (5.7) than beef produced on corn silage (5.3) on an 8-point scale (8=extremely intense, 1=extremely bland flavour).

On the other hand, several studies have shown that beef produced on pasture has similarly intense, or equally acceptable flavour as beef produced on grain. The underlying reasons for these results are unknown. According to Melton (1990) this could be due to differences in sensory panels or to the high quality of some pastures.

The less desirable flavour of forage-fed beef for some consumers has been attributed to an intense "grassy" flavour (Larick *et al.* 1987). This flavour decreases in intensity with time as steers are fed grain for an increased number of days after being removed from grass pasture (Melton, 1983; Larick *et al.* 1987). Westerling and Hedrick (1979) reported that meat from animals fed a concentrate diet for 112 days was more desirable in flavour than meat from animals fed a concentrate diet for 56 days.

According to Larick *et al.* (1987) and Melton (1983) the greatest sensory difference in beef from forage-fed and grain-fed steers appears to be in the flavour of the fat. Melton (1990) reported that beef produced on corn diets compared with beef produced on grass pastures has different concentrations of various flavour precursors. Westerling and Hedrick (1979) and Melton *et al.* (1982a,b) reported higher levels of saturated fatty acids in beef from animals fed on pasture compared with beef from animals fed on grain. Saturated fatty acids have been reported to be negatively associated with sensory panel scores (Westerling and Hedrick 1979).

2.2.5. Conclusions

There is clear evidence which suggests that preslaughter nutrition may have a pronounced effect on beef quality characteristics. Generally, however, more differences have been found between beef produced mainly on pasture and beef produced on grain than in beef produced on different pastures. It also seems that more studies have been reported in which differences were found between beef produced on grass and beef produced on grain than those studies in which none were found.

Although there is some indication that preslaughter nutrition directly influences various intrinsic properties of postmortem muscle, based on existing evidence, it can be concluded that at least a part of the variation in meat tenderness can be ascribed to intensive preslaughter feeding, which exerts an indirect influence on meat tenderness via its effects on carcass weight, fatness and postmortem chilling rate. However, considering currently changes in consumer desires toward the consumption of leaner beef products and increasing costs of production, it would be wrong to conclude that efforts should not continue to be made to reduce average fat levels in meat. Thus, it appears inevitable that shorter preslaughter finishing periods, leaner carcasses and reliance on technology, rather than intensive preslaughter feeding are preferable as approaches to ensure the production of tender cuts of meat (Tatum 1981).

Considering the available evidence in regard to the effects of ultimate pH muscle on meat quality characteristics, and its importance to the meat industry it is apparent that further research efforts should be done in order to elucidate the mechanisms involved in these pH effects. Purchas (1992) pointed out that these mechanisms may be complex, but an understanding of them may reveal practical ways of avoiding or preventing the problems.

Since concentrate diets are more expensive than pastures, it seems necessary to combine genetic and nutritional manipulation in order to avoid extended periods of grain feeding just to improve fat colour. Thus the time needed to change fat colour through more concentrate diets requires further investigation.

Although it is clear that feed can affect the flavour of meat, these effects have not been fully investigated. Research is needed to determine what feeds cause desirable and undesirable flavours, and also the precursors and volatile compounds responsible for these flavours need to be identified.

2.3. An overview of the advantages and limitations of the n-alkane technique.

2.3.1. Introduction

Feed efficiency, the amount of feed eaten to produce a desired product, is one of the most important determinants of profitability in the farm industry. Feed efficiency can be improved in different ways. The most immediate is through improvements in the quantity and balance of ingested nutrients. Although in the longer term feed efficiency can be increased through genetic improvements, Parker *et al.* (1990) pointed out that the inability to estimate intake accurately, in individual animals, can hinder attempts to select animals which are genetically superior in the utilisation of nutrients.

Estimates of individual animal performance can be readily obtained, however it is difficult to estimate the herbage intake of individual animals. It is even more difficult to partition the intake of the animal into its component plant species or plant parts. Therefore, predicting the response of animals, in quantitative terms, to a given change in the amount or botanical composition of pasture is still difficult. The key to understand animal production from grazed pastures relates to a proper estimation of voluntary intake, which in turn leads to a better understanding of plant-animal interactions. In this section, the use of n-alkanes to estimate herbage intake and diet composition is considered and some of the problems inherent in their use are highlighted.

2.3.2. Use of n-alkanes to estimate herbage intake

Herbage intake in grazing animals is usually estimated from faecal dry matter output, calculated from the dilution of orally-administered chromium sesquioxide (Cr_2O_3), and an *in vitro* estimate of herbage digestibility. This method may be prone to error arising principally from errors in the digestibility estimate, which is applied to all the experimental animals, and therefore it does not provide truly individual herbage intakes (Dove and Mayes 1991).

More recently, a combination of the faecal levels of n-hydrocarbons (alkanes) of plant cuticular waxes (predominantly odd-numbered carbon chain length) and those of orally-administered synthetic alkanes (even-numbered chain length) have been used to estimate herbage intake accurately (Mayes *et al.* 1986a). Neither type of alkane is wholly indigestible but, since alkanes of adjacent chain length have very similar faecal recoveries, the errors arising from incomplete recoveries cancel out in the calculation of intake. It is important to consider that even if there is a difference in faecal recovery of the alkanes, this will result in a smaller error in the estimated intake than an equivalent error in the *in vitro* estimate of digestibility.

Herbage intake from natural odd-chain and synthetic even-chain alkanes:

$$I = \frac{Fi}{Fj} Dj \Big/ \left[Hi - \frac{Fi}{Fj} Hj \right]$$

Values H_i and F_i are respective herbage and faecal concentrations of the odd-chain alkane, and H_j, F_j and D_j are the respective herbage and faecal concentrations, and the dose rate of the even-chain alkane (Mayes *et al.* 1986a).

Dove and Mayes (1991) identified three possible sources of error associated with digestibility estimated using *in vitro* procedures previously calibrated with *in vivo* measurements, and based on herbage samples collected with oesophageally-fistulated (OF) animals. The relationship between the *in vitro* and *in vivo* estimates of digestibility may not apply to the test animals; only a single digestibility value is obtained regardless of any differences in individual levels of intake, supplement intake or parasite burden; and individual test animals may select a diet which differs in digestibility from that selected by the OF animal. The use of n-alkanes to measure intake can overcome the problems associated with the first two sources of error, but may still be susceptible to the errors associated with the third.

A major advantage of the alkane method for estimating intake is that it is more truly 'individual' because it accommodates the level of digestibility occurring in individual animals (Dove and Mayes 1996). It is thus well suited to grazing situations where levels of intake may differ between treatments or where supplements are used in some treatments.

Herbage intake can also be determined when feed supplements are fed (see equation presented by Mayes *et al.* 1986a and Dove and Mayes 1991), as long as individual intakes of supplement are known or can be estimated by other techniques such as those discussed by Dove and Coombe (1992). Dove and Mayes (1996) suggested that supplements with negligible alkane contents can be ignored in the intake calculation. Alternatively, if the feed supplement has an alkane pattern very different from that of the basal diet, the authors suggested that the approach for measuring the botanical composition of the diet can be adopted (for details see review of Dove and Mayes 1991 and 1996, Dove and Moore 1995, Newman *et al.* 1995).

Although digestibility is not required to estimate intake using alkanes, it is often desirable to obtain an indication of the nutritive value of the grazed herbage. According to Dove and Mayes (1991) the ideal approach could be to monitor the herbage and faecal concentrations of an indigestible marker occurring naturally on or in the pasture which would provide and estimate of herbage diet digestibility in individual animals. However, from the many plant components that have been evaluated as internal markers (Kotb and Luckey 1972), none of them has been satisfactory due mainly to difficulties in their analysis. Thus, the reason that herbage intake studies have concentrated on the use of alkanes as markers is simply that they are widely spread in cuticular waxes and are easily analysed by gas-chromatographic methods (Dove and Mayes 1991).

Corrections for incomplete faecal recovery would be required if the natural alkanes were to be used on their own as markers to estimate digestibility (Dove and Mayes 1996). Assuming a single recovery value for any alkane will be associated with errors, particularly working with cattle, since estimates of alkane recovery have been more variable than in sheep (Dove and Mayes 1991). Using an assumed faecal recovery of 0.95, C_{35} alkane has been used to provide estimates of digestibility, in sheep, which were more accurate than either *in vitro* estimates (Dove *et al.* 1990) or those derived using lignin as a marker (Dove and Coombe 1992).

Unfortunately, the low levels of C_{35} occurring in many dietary plant species could result in the reliability of the digestibility estimate being limited by the accuracy and precision of the analytical procedure for this alkane. The greater uncertainty about faecal recoveries of shorter alkanes limits their use as internal markers, although they can be used if an independent assessment of recovery is considered (Dove and Mayes 1991). Problems associated with low alkane concentrations in some species has also been reported by Laredo *et al.* (1991). They indicated that forage species contain variable quantities of alkanes and the concentrations of C_{33} may be too low in some tropical forages for use as the internal marker. This can require the use of a shorter chain length with a lower percent recovery in the faeces and possibly result in errors in calculation of intake. However, Dove (1991) pointed out that the variation from species to species in alkane composition can be used to advantage by solving a set of simultaneous equations and estimating the species composition of the diet.

If faecal output is estimated using an indigestible marker (such as chromium oxide) at the same time as intake is estimated using n-alkanes, diet digestibility can be determined. C_{36} could be used to determine faecal output, since it has a relatively high faecal recovery of approximately 0.95 (Mayes *et al.* 1986b); if C_{36} is dosed together with C_{32} alkane both intake and faecal output, and hence diet digestibility, can be estimated with only one faecal analysis. Mayes *et al.* (1986c) suggested that further evaluation of C_{36} as a marker is necessary since the mean estimate of DMD using C_{36} to determine faecal output and estimated intake (0.752±0.0091) was slightly less than the DMD measured from actual intake and faecal excretion (0.775±0.0078) in grazing cattle.

Mayes *et al.* (1995) pointed out that recently there have been a number of detailed studies on factors which may contribute to errors in the estimation of intake using the alkane marker technique. As a consequence strategies could be developed to minimise experimental errors. Vulich *et al.* (1991) suggested that replicate analyses for alkanes in herbage and faeces was unnecessary. Diurnal variations in faecal chromium concentrations have been reported and extensively reviewed (Langlands 1975). In the same way, consideration has also been given to diurnal variation in faecal alkane ratios. Within-day variation in the faecal concentration of dosed alkane is small for sheep dosed once daily with alkane-impregnated paper or twice daily with alkane on powdered cellulose, but may be greater with cattle (Dove and Mayes 1991). Although not found in housed sheep (Mayes *et al.* 1986a), diurnal variation has been reported in housed dairy cattle (Dillon and Stakelum 1995 cited by Mayes *et al.* 1995); the dosed alkane being responsible for this variation when twice and once daily dosing were compared.

The impact of diurnal variation effects on intake estimates in free-ranging animals is not really known, since the existence of diurnal variation in such situations has not, as yet, been established. However, since no difference in alkane ratios between total collections or rectal grab samples of faeces from grazing sheep were observed (Dove and Mayes 1991), it may be expected, according to Mayes *et al.* (1995), that the effect of any diurnal variation on intake estimations under such conditions would be slight.

The influence of the method of dosing (e.g. pellet containing the even-chain alkanes incorporated into shredded paper, powdered cellulose in gelatine capsules) with even-chain alkane upon the accuracy and precision of intake estimates has also been investigated. Dove and Mayes (1991) pointed out that the form in which the external marker is dosed has no significant effect on the resultant faecal alkane levels.

Controlled release devices (CRD), similar in design to those used for administering Cr_2O_3, have been developed to deliver even-chain alkanes into the rumen, allowing intake measurement without the need for repeated dosing of animals. Tests with sheep have shown that they can give accurate estimates of intake (Mayes *et al.* 1991, Dove *et al.* 1991, Champion *et al.* 1995). Some results using Cr_2O_3 have been promising (Parker *et al.* 1989; Inwood *et al.* 1992; Khadem *et al.* 1993; Morris *et al.* 1993a,b,c; Morris *et al.* 1994; Montossi *et al.* 1997) with the use of the CRD and its performance has been reviewed by Parker *et al.* (1990). However, the CRD was not tested in a wide enough range of environments with a broad enough range of forage species (Brandyberry *et al.* 1991).

Also some problems have been observed using CRD when dosing chromium oxide which include large deviations between observed and manufacturer-specified released rates (Brandyberry *et al.* 1991), variation in release rates (Buntix *et al.* 1992), and feed and animal by CRD interaction (Parker *et al.* 1989). Thus, release rate may be dependent on the particular animal and forage being tested. However, the devices may be useful in the future if the current problems can be solved (Burns *et al.* 1994).

Alkane-based estimates of intake have shown to agree well with known intakes in validation studies with lambs (Mayes *et al.* 1986a and 1986b, Vulich *et al.* 1991), sheep (Mayes *et al.* 1991, Dove *et al.* 1991), beef cattle (Mayes *et al.* 1986c) and dairy cattle (Dillon and Stakelum 1989, Stakelum and Dillon 1990, Dillon 1993 cited by Dove and Mayes 1996).

More recently, Fisher *et al.* (1995 and 1996) working with dairy cows, dosed twice daily with pellets containing synthetic C_{32} alkane, grazing perennial ryegrass swards obtained reliable estimates of herbage intake. Hepp *et al.* (1996) also found reliable estimates of herbage intake working with ewes and lambs, dosed once daily with paper pellets impregnated with C_{32} alkane, grazing perennial ryegrass-dominant swards.

Robaina *et al.* (1997) analysed responses to grain feeding by grazing dairy cows and estimated herbage intake for individual cows dosed twice daily with gelatine capsules using the alkane-based technique. The authors concluded that the alkane method appeared to provide plausible estimates of pasture intake, but an underestimate of diet digestibility which may be improved by reassessing the figure used for recovery rate in calculations. Mackle *et al.* (1996) also obtained reliable pasture intakes working with primiparous Friesian and Jersey cows dosed twice daily with gelatine capsules containing C_{32} alkane.

Malossini *et al.* (1996) compared n-alkanes and chromium oxide methods for estimating herbage intake by grazing dairy cows. The authors concluded that the smaller variability of the n-alkane excretion in the faeces gives them an advantage, as the number of sample required daily can be reduced and there is the possibility of administering the markers only once daily. Considering the mode of executing the two methods, they found that the n-alkane technique was easier to perform and less laborious.

Reeves *et al.* (1996) compared three techniques (rising plate meter, standard energy requirements in reverse and plant wax alkanes as internal markers) to determine the herbage intake of diary cows grazing kikuyu (*Pennisetum clandestinum*) pasture. It was concluded that the rising plate meter and the energy requirements techniques did not provide precise intake data on individual animals, and that the alkane technique provided a direct and precise estimate of pasture intake, and overcame some of the problems associated with the use of the other two techniques to determine the intake of kikuyu grass pastures.

Finally, the accuracy of the estimates of intake obtained using herbage and faecal alkane concentrations depends upon a range of factors such as obtaining a representative sample of consumed herbage, accurate administration of synthetic alkanes to grazing animals, dosing procedures and obtaining a representative sample of faeces, validity of the assumption of similar recoveries for an adjacent pair of alkanes and accuracy of sample preparation and extraction for alkane analysis (Dove and Mayes 1991).

Dove and Mayes (1996) pointed out that factors which may possibly influence the reliability of the technique when used with grazing or browsing animals, such as within- and between-day variations in feeding pattern have not been extensively studied, although the work of Dillon (1993) cited by Dove and Mayes (1996) with dairy cows suggests that resultant errors from such effects are likely to be small. The authors emphasised that the main precaution required in the use of the method is to ensure that the diet sample, in terms of its alkane concentrations, is representative of that consumed by the experimental animals.

For uniform, sown pastures, this is relatively easy to achieve by hand-plucking or by collecting extrusa samples from OF animals (Vulich *et al.* 1993). Under conditions in which animals can feed on complex vegetation communities, it may be extremely difficult or impossible to obtain feed samples having alkane concentrations which are representative of those in the diets of individual animals. In such situations, the characterization of the botanical composition of the diet would enable intake to be assessed using the alkane technique; the alkane concentrations of individual dietary components would have to be determined. Approaches which could be adopted to assess botanical composition of the diet are discussed in detail by Dove and Mayes 1991 and 1996, Dove and Moore 1995, Newman *et al.* 1995.

2.3.3. Use of n-alkanes to estimate diet composition

The consideration of the potential for using alkanes for estimating diet selection starts with a consideration of the disadvantages of previous methods which can be described as tedious, difficult or unable to estimate species composition (Dove 1993). For example, the botanical composition of oesophageal samples has been estimated by microscopic examination (Hamilton and Hall 1975), but such techniques are difficult and tedious. Most chemical methods suffer from the disadvantages that they cannot identify individual plant species in the diet, and are not applicable to faecal samples (Dove 1993).

Different plant species exhibit different patterns of individual alkanes which allow the quantification of the intake of individual plant species by individual animals. In the same way the differences in alkane levels between plant parts within species can be used to estimate the dietary proportions of those parts, for example, leaf vs. stem (Dove and Mayes 1996). For greater sensitivity, the total alkane contents of the component species should be similar, but their patterns markedly different (Dove and Mayes 1991). Such estimates can be made using simultaneous equations (Dove 1991) or least squares algorithms (Dove and Moore 1995, Newman *et al.* 1995).

When faecal alkane concentrations are used to estimate diet composition, corrections for incomplete faecal recovery of alkanes may be necessary. To validate diet composition estimates obtained using alkanes as markers, comparison with known dietary mixtures is desirable (Dove and Mayes 1996). Validation of the technique for estimating botanical composition of plant mixtures is relatively straightforward and has been carried out by Dove (1992), but effective assessment of the method for diet composition in grazing animals is more difficult. Validation studies with housed animals showed that alkanes can be used as markers to obtain an accurate estimate of the species composition of the consumed diet (Mayes *et al.* 1995 cited by Dove and Mayes 1996). However, limited studies have been done with free-grazing animals attempting this approach.

The problem of determining diet composition in complex environments, where more plant species are available to the animals than there are available alkane markers, may be addressed by combining the microscopic and alkane approaches as indicated by Salt *et al.* (1994). Alkanes were used to estimate total herbage intake and the proportion of this coming from each vegetation type. Microscopic examination of extrusa samples collected from each vegetation type was then used to further subdivide the intake, within each vegetation type, into individual species. Dove and Mayes (1996) suggested that, in the long term, the use of other markers in addition to n-alkanes could be used to extend the capacity of alkanes to distinguish the dietary components.

2.3.4. Conclusions

Recent results indicate that estimates of herbage intake obtained with alkanes appear to be more accurate and more truly individual than those obtained with previous methods. Since they accommodate the level of digestibility occurring in individual animals, they can thus be used in genetic studies of the differences between individuals in intake, digestibility and food conversion efficiency.

Dosed C_{36} alkane has been suggested to determine faecal output with the advantage, if dosed together with C_{32} alkane, of estimating both intake and faecal output, and hence diet digestibility, with only one faecal analysis. Nevertheless further evaluation of C_{36} as a marker is needed. C_{35} natural alkane has been used to provide estimates of digestibility, but these estimates may be limited by the low concentrations of this alkane occurring in many dietary plant species. Errors in digestibility may be greater in cattle in which the faecal recovery of alkanes appears to be lower and more erratic than in sheep (Dove and Mayes 1991). Thus, further assessment of faecal recoveries will be necessary.

Difficulties in dosing with external markers may be largely avoided by the use of CRD's. However, limited work has been done using alkane CRD's, particularly with grazing beef cattle. Consequently, further testing is essential on different types of herbage, levels of herbage intake, and management systems before they can be routinely applied to studies of voluntary herbage intake.

Dove and Mayes (1996) emphasised that the main precaution required in the use of the method is to ensure that the diet sample, in terms of its alkane concentrations, is representative of that consumed by the experimental animals. This seems relatively easy to achieve for uniform, sown pastures; however, for complex vegetation communities, it may be extremely difficult or impossible to achieve. In such situations, the characterization of the botanical composition of the diet would enable intake to be assessed using the alkane technique. Research investigating the use of n-alkanes to identify individual plant species in a mixture or to estimate the botanical composition of the herbage consumed by the free-grazing animal is suggested, as there has been limited research effort on this approach.

CHAPTER 3

MATERIALS AND METHODS

3.1. Site preparation and management

The experiment was conducted on perennial ryegrass/white clover pastures at the Sheep and Beef Cattle Research Unit, Haurongo Block, at Massey University (41° 10' S) Palmerston North, New Zealand from November 1996 to April 1997 (20 weeks).

The soils are classified as Tokomaru Silt Loam (heavy clay), and the soil test results were P=18 µg/ml, K=0.45 meq/100g, S=12.5 µg/g and pH=5.7. Potassic and phosphate fertiliser was applied to the experimental area in March 1996 (200kg of 20 % potassic super phosphate ha^{-1}; N 0, P 7, K 10, S 8), and nitrogen fertiliser (50 kg of Urea ha^{-1}) was applied in October 1996. The experimental area was sprayed for thistle control in August 1996 with MCPB (31 litres ha^{-1} in 500 litres of water).

Six hectares of ryegrass/white clover dominated permanent pastures were divided into three replicates of 2 hectares prepared to two sward surface heights (SSH), low (L) 5 cm and high (H) 10 cm, over a six-week period. Paddocks were divided using electric fences, grazed by sheep and then left to accumulate herbage to achieve the desired pasture heights. Two paddocks had been managed under rotational grazing with heifers in the previous winter, and the other paddock had been rotationally grazed by sheep and cattle.

3.2. Experimental design

The experiment was divided into two main periods: from 18 November 1996 (day 0) to 4 March 1997 (day 105) to evaluate the effect of contrasting sward heights on cattle performance; and from 4 March to 8 April 1997 (day 140) to assess the residual effect of previous treatment on animal performance under common grazing conditions.

During the first experimental period twenty six month-old steers, 14 Angus x (Hereford x Friesian) and 10 Angus x (Hereford x Jersey), were set-stocked on plots prepared to two SSH (5 vs. 10 cm, Plates 3.1 and 3.2) on each replicate paddock (block). Two replicate swards from each treatment were grazed by 2 A x (H x F) and 2 A x (H x J)

Plate 3.1. View of the experimental area during Period 1, 5 cm SSH treatment.

Plate 3.2. View of the experimental area during Period 1, 10 cm SSH treatment.

steers, and the third replicate sward from each treatment was grazed by 3 A x (H X F) and 1 A (H x J) steers (Figure 3.1.a). Animals were treated for internal and external parasites (Ivermectin MSD AGVET) and faecal samples were collected for egg count analysis on day 20 of the trial.

Six animals from each treatment balanced for "breed" were slaughtered at the end of Period 1 on 4 March. During Period 2 electric fences controlling SSH in each replicate paddock were removed and the remaining 4 steers (2 from each SSH treatment) had access to both swards until the second slaughter on 8 April (Figure 3.1.b).

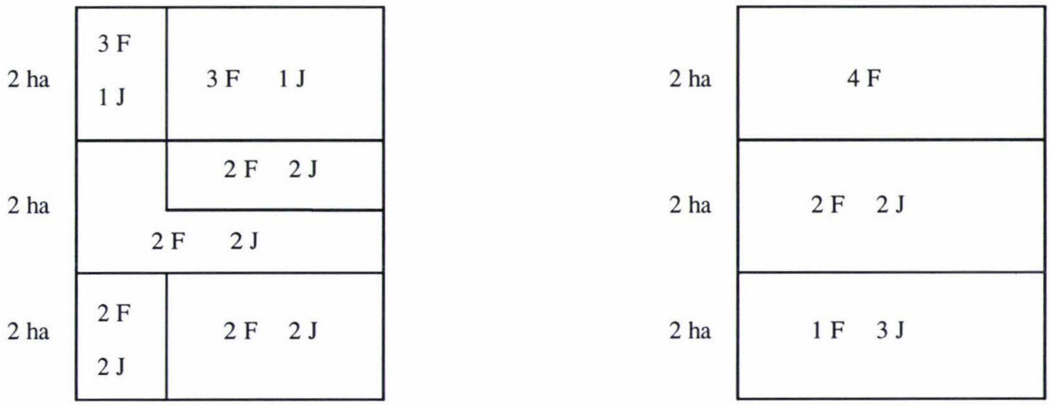


Figure 3.1.a **Figure 3.1.b**

Figure 3. 1. Plot layout during Period 1 (3.1.a) and Period 2 (3.1.b).

3.3. Sward measurements

Sward surface height (SSH) was measured weekly using the Hill Farming Research Organisation (HFRO) sward stick (Bircham 1981; Barthram 1986). Fifty readings were recorded randomly for each treatment replicate. Adjustments of stocking rate to maintain target SSHs at 5 and 10 cm on a put-and-take system, with additional non-experimental steers, were made when necessary following measurements of SSH.

Herbage mass was measured by cutting six $0.1m^2$ quadrats to ground level with an electric shearing handpiece in each plot monthly. The samples were washed and then dried in a forced-draught oven for 72 hours at a temperature of 70-80°C. A sample of herbage was cut adjacent to each quadrat, bulked within each replicate, and subsequently subsampled and separated into species (ryegrass, other grasses, white clover, dead matter and weeds) to determine botanical composition of the swards, then dried and weighed as above.

The vertical distribution of plant tissue within the sward canopy was measured monthly using an inclined point quadrat (Warren Wilson 1963) set at 32.5° to the horizontal. Two hundred contacts were recorded in each plot for species (ryegrass, other grasses, white clover, weeds), morphology (leaf, stem, petiole, stolom, flower), and state (live and dead).

Tiller population was estimated from 30 tiller cores (22 cm^2 each) removed at random from each plot on three occasions (November, January, March). The core samples were hand separated into species (ryegrass, other grasses, white clover, dead matter and weeds), and the number of live tillers of ryegrass and other grasses and dead tillers were recorded and a mean obtained for each sward. The species components were oven dried for 48 hours and subsequently weighed.

3.4. Animal measurements

3.4.1. Liveweight

Unfasted liveweights were recorded fortnightly and fasted liveweights (18 h off pasture) were taken on 19 November, 14 January, 27 February, 11 March and 4 April.

3.4.2. Dry matter intake

Dry matter intake was measured using the alkane technique (Mayes *et al.* 1986a) on three occasions (November, January and March). Seven days before each intake measurement period, animals were orally administered with controlled release alkane capsules containing synthetic C_{32} and C_{36} with a release rate for both alkanes of 355 mg/day. This 7-day equilibration period was to ensure faecal concentration of dosed alkanes reached equilibrium before any faecal sampling (Mayes *et al.* 1986a).

After the equilibration period individual faecal samples were obtained daily at 0600 hours for two consecutive periods of four days (days 7 to 10 and days 13 to 16). Daily faecal samples were dried immediately in an oven at 60°C to a constant weight for approximately 7 days. Two grams DM from each daily sample were finely ground and bulked together within 4-day periods for each steer, for subsequent alkane analysis.

Hand-plucked herbage samples were obtained from the areas and at the same height that the animals were observed to be eating to represent the herbage selected by the grazing animals. The samples were obtained daily to coincide with faecal collection during the 4-day periods. Herbage samples were bulked together and two sub-samples were obtained from each sampling period. One sub-sample was retained intact whereas the other sub-sample was separated into three components: ryegrass, other grasses and white clover.

Herbage samples were freeze-dried, and finely ground before alkane analysis of the intact sample and the three components. The intact samples were also analysed for nitrogen content, dry matter digestibility, and neutral detergent fibre.

Intake was calculated as follows using the alkane pairs C_{31}-C_{32} and $C_{32}C_{33}$ (Mayes *et al.* 1986a):

$$I \text{ (kg DM/animal/day)} = ((F_i / F_j)*D_j)/(H_i - (F_i / F_j)*H_j)$$

where:

H_i and F_i are the herbage and faecal concentrations of the odd-chain alkane.

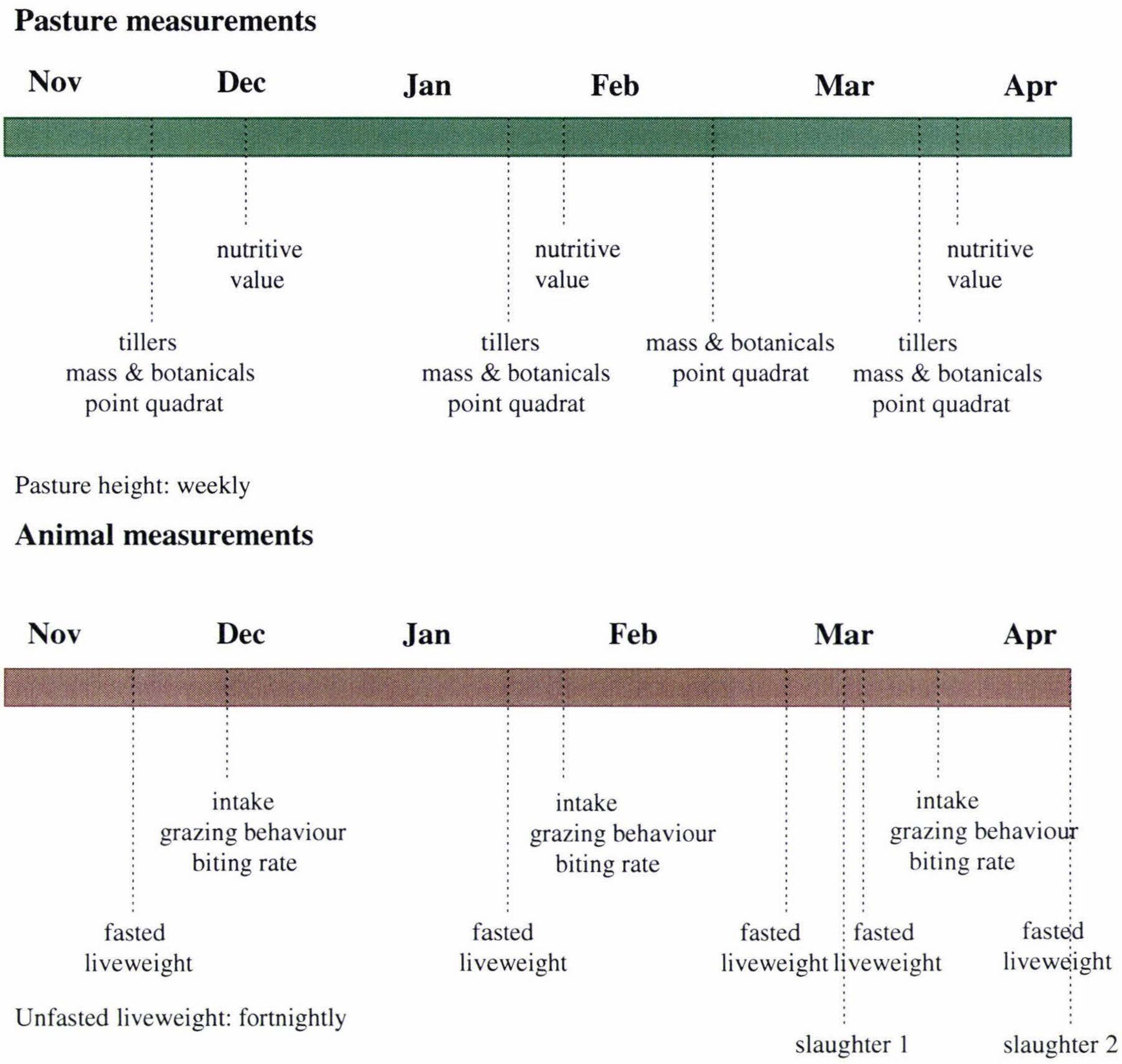
H_j and F_j are the herbage and faecal concentrations of the even-chain alkane.

D_j is the daily dose of even-chain alkane.

3.4.3. Grazing behaviour

Two 24 hour grazing behaviour observations were carried out during each faecal sampling period. The activity of each animal in grazing, ruminating and idling was recorded at intervals of 10 minutes.

Rate of biting (bites/minute) was recorded for each animal using a 20-bites technique (Jamieson and Hodgson 1979a) recorded by stop-watch during grazing periods at morning and evening.



Pasture height: weekly

Unfasted liveweight: fortnightly

Figure 3. 1. Pasture and animal measurements schedule.

3.4.4. Slaughter procedure and carcass measurements

At each of the March and April slaughter times, steers were weighed off pasture at c. 0830h, transported about 20 km to a meat plant (Manawatu Beef Packers, Feilding) and slaughtered 26 hours after removal from pasture.

Steers were slaughtered and dressed under normal commercial conditions and carcasses were electrically stimulated immediately following exsanguination. Kidney and pelvic fat from both sides of each carcass were combined and weighed. Carcass length for each carcass side was measured from the distal end of the tarsal bones to the midpoint of the cranial edge of the first rib.

Carcass sides were subjectively assessed for muscling by plant personnel according to the muscling classes 1, 2 and 3 with + and - values to give a nine-point scale with +1 being the highest muscling and -3 the lowest. For analysis purposes the given scores were converted to values on a 1 to 9 scale (1 = -3 and 9 = +1).

The colour of the subcutaneous fat was assessed prior to weighing the carcass, on the fat overlying the proximal part of the *gracillus* muscle using a series of eight painted plastic paddles as colour standards. The yellowness of the eight paddles in terms of b* values from a Minolta Chroma Meter 200 were 11, 19, 33, 42, 55, 64, 71 and 74, for scores 1 to 8, respectively.

A sample of *Longissimus thoracis* (LT) muscle (c. 800-1200 g) from the 10th to 13th rib region of the right side of each carcass was taken within 90 min post-mortem and held at ambient temperature (17-20°C) for 24 h. These samples were then held at 0-2°C for 6 days before being frozen at -15 to -20°C for up to 6 weeks.

Following quartering between ribs 12 and 13 on the day after slaughter, fat depths were measured at a point over the LT muscle three-fourths the distance from its medial to its lateral edges. LT transverse sections were traced and subsequently assessed for area using a Tamaya Planix-7 digital planimeter. The weights of the three major hind-quarter cuts: knuckle, inside round and outside round were recorded in the boning room (Purchas and Aungsupakorn 1993).

3.4.5. Meat quality measurements

Quality evaluations were made on the LT muscle after thawing the frozen samples for about 1 h at ambient temperature and 20-22 h at 3-5°C. A thin slice (2-10 mm) was removed from the cranial end to square it up. A 10-15 mm thick slice was taken to be used for sarcomere length assessment and colour tests. The middle portion of this slice was used for colour, and a sliver was taken from the medial portion and stored in a test tube at 3-5 °C for sarcomere length measurement.

A 25 mm thick slice was cut and placed in a plastic bag and cooked in a water bath at 70°C for 90 minutes. The weight before cooking and after chilling for more than 8 hours at 1-3°C was recorded in order to determine cooking loss percent. The sample was then assessed for tenderness using the Warner-Bratzler (WB) shear force device fitted with a square blade as described by Purchas and Aungsupakorn (1993). A 40-50 mm thick slice (depending on the size of the sample remaining) was cut for assessment of ultimate pH and water holding capacity.

3.4.5.1. Sarcomere length

Sarcomere length was determined by using a laser diffraction method as described by Cross *et al.* (1981). A small bundle of fibres was removed from the medial region of the selected muscle and then small groups of fibres were teased out on a microscope slide with 2-3 drops of buffered sucrose solution, covered with a coverslip, and flattened.

The slide was placed under a helium-neon laser beam to display an array of diffraction bands on the screen which was 100 mm below the sample. These bands were perpendicular to the long axis of the fibres. Twelve measurements were taken of the distance between the first order bands of each sample, and average values were used to calculate sarcomere length according to the equation given by Bouton *et al.* (1973).

3.4.5.2. Meat colour

Meat colour was assessed using a Minolta Chroma Meter (Warner 1989) as in fat colour assessment. L*, a* and b* values obtained indicated the brightness, redness and yellowness, respectively, of meat or fat colour being measured.

3.4.5.3. Warner-Bratzler Shear Force values

The Warner-Bratzler device was used to determine meat tenderness (Purchas and Aungsupakorn 1993). The 25 mm thick slices inside plastic bags were suspended after weighing in a 70°C water bath and cooked for 90 minutes. After cooking, liquids were drained off the cooked samples which were stored in a chiller at 1-2°C for more than eight hours. Samples were weighed after drying with paper towels to remove excess surface moisture to determine cooking loss.

Six cores 13 x 13 mm in cross section were cut parallel to the orientation of the muscle fibres for each meat cooked sample. The Warner-Bratzler device was connected to a computer which produced values for peak force (PF), initial yield (IY) and work index after each shear (Purchas and Aungsupakorn 1993). Each core was sheared twice. These values were used to calculate PF-IY.

3.4.5.4. Ultimate pH

A 2.0-2.5 g of meat sample was taken from the middle region of the muscle and placed in 10 ml of cold 5mM sodium iodoacetate and 150mM KCl (Bendall 1973) and homogenised to a fine slurry. A pH meter (Jenway 3020 pH meter with an Automatic Temperature Compensation Probe) was used to measure the ultimate pH of the slurry.

3.4.5.5. Water holding capacity

Water-holding capacity was assessed in terms of expressible water using a filter paper press method (Whatman N º 1 filter paper) with a meat sample weighing 500 ± 20 mg and a 10 kg weight applied to the sample between plexiglass plates for 5 minutes (Matyniak and Ziolecki 1983). Results were expressed as the total wetted area on the filter paper relative to the sample weight (cm^2 g^{-1}).

3.5. Statistical analyses

Pasture data were analysed using a Completely Randomised Block Design based on plot means using 3 blocks. Animal data were analysed using a Split-Plot Design with swards (H: 10 cm SSH and L: 5 cm SSH) as the main plot and "breed" (A x (H x F) vs. A x (H x J)) as the split-plot factor. The analysis was also based on plot means. A point quadrat package (Butler 1991) was used in the analysis of inclined point quadrat data and a computer program developed and described by Dove and Moore (1995) was used to estimate diet composition of individual animals. Steer liveweight, herbage intake and ingestive behaviour were analysed using repeated measures analysis (Gill and Hafs 1971) to test the effects of SSH treatment. The model used and the repeated measures analysis made it infeasible to use initial liveweight as a covariate for sequential liveweights and liveweight gains.

Dressing-out percentage (DO%) was calculated as the ratio of carcass weight to final liveweight (x 100) recorded at the meat plant. Carcass weight was used as a covariate when appropriate for carcass characteristics data. For the second slaughter carcass weight was adjusted to a constant fasted liveweight at the beginning of Period 2 by covariance analysis. All statistical analyses were performed using the General Linear Model procedure of the Statistical Analysis System computer package (SAS 1990) and the results are presented as means with their standard errors (SEM).

CHAPTER 4

RESULTS

Long-run temperatures on the experimental site range from 8.0 °C (July) to 17.3 °C (January) and the average annual precipitation is 995 mm. The monthly rainfall for November and December 1996 and January, February and March 1997 was 100.5 mm, 91.1 mm, 68 mm, 58 mm and 68.1 mm, respectively, compared with respective long-run averages of 78 mm, 94 mm, 79 mm, 67 mm and 69 mm. Temperatures for November and December 1996 and January, February and March 1997 were similar to long-run averages (13.2, 15.9, 16.4, 18.2 and 16.2 °C vs. 14.2, 16.1, 17.3, 17.6 and 16.4 °C, respectively).

4.1. Sward measurements

4.1.1. Sward surface height and herbage mass

Sward surface height (SSH) during the first experimental period was generally achieved in each treatment, as shown by Figure 4.1. Rapid grass growth resulted in heights on the H swards rising above the target at the beginning of January and non-experimental animals (1 per plot) were used for three weeks to reduce sward height to the target of 10 cm. It was also necessary to remove experimental animals (2 from one plot and 1 from another plot) from the L swards on two occasions during February, to avoid significant decreases in sward height below target for periods no longer than two weeks. Removed animals were grazed in swards prepared to the corresponding target sward height.

During the second experimental period when electric fences were removed and both pastures were available to the remaining animals, original L swards increased surface height faster than H swards. However, at the end of the trial a significant difference in height was still evident between the two swards.

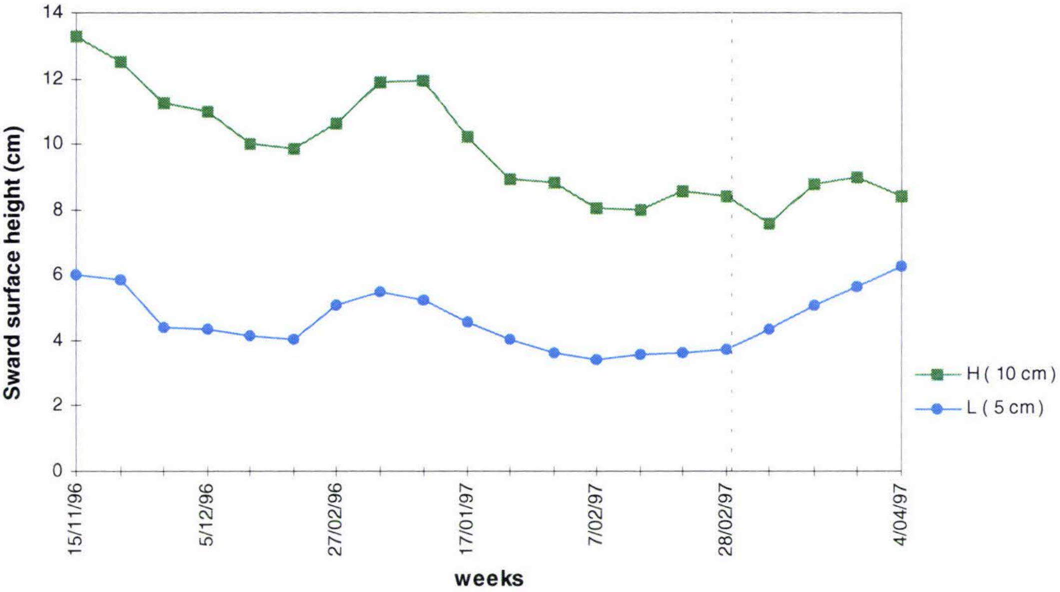
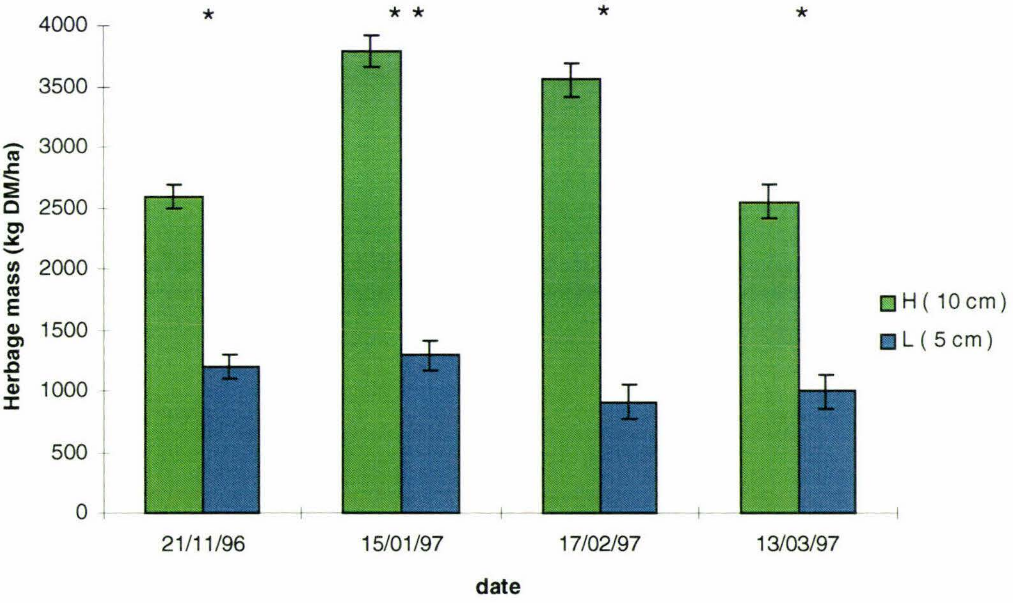


Figure 4. 1. Mean sward surface heights (cm) during the experiment for high (10 cm) and low (5 cm) treatments. Vertical dotted line indicates start of Period 2.

Estimates of herbage mass are presented in Figure 4.2. Mean herbage mass to ground level was more variable and significantly higher in the tall than the short swards throughout the experiment.



* $P < 0.05$, ** $P < 0.01$

Figure 4. 2. Herbage mass (kg DM ha^{-1}) for high and low sward surface heights. Vertical bars represent standard errors of the means.

4.1.2. Tiller population density

Estimates of live tillers of ryegrass and other grasses, dead tiller numbers and comparison of live:dead tiller ratios for each treatment and each period are shown in Table 4.1. L swards in both periods had higher densities of live tillers and lower densities of dead tillers than H swards. However, only dead tiller densities were significantly different as the season progressed. Total live tiller density increased substantially in short swards and only slightly in tall swards during Period 1, but the difference was not significant due to the high variability in the number of tillers m^{-2}. In Period 2, when electric fences were removed and sward heights were not controlled, tiller density decreased for the sward previously maintained at 5 cm and increased for the sward previously maintained at 10 cm SSH. The results showed that L swards had higher ratio of live:dead tillers compared with H swards, but this difference was significant only in Period 1 and was highest during mid-season.

Table 4. 1. Mean tiller densities of ryegrass and other grasses tillers, dead tillers (number m^{-2}), and mean ratios of live:dead tillers.

		Treatment			
Date		H (10 cm)	L (5 cm)	SEM	Signif.
21 Nov	Density of live tillers:	(number m^{-2})			
(Period 1)	ryegrass	4080	5270	707	NS
	other grasses	3750	4780	355	NS
	Density of dead tillers	330	180	37	NS
	live:dead tiller ratio	25.6	48.5	1.06	*
14 Jan	Density of live tillers:				
(Period 1)	ryegrass	2870	10050	2182	NS
	other grasses	5890	12500	1510	+
	Density of dead tillers	6500	380	757	*
	live:dead tiller ratio	1.4	62.8	6.47	*
	Density of live tillers:				
7 April	ryegrass	4270	8370	1610	NS
(Period 2)	other grasses	7670	10110	2123	NS
	Density of dead tillers	3930	950	463	*
	live:dead tiller ratio	3.4	42.0	18.19	NS

* $P<0.05$, + $P<0.10$

4.1.3. Sward structure

The number of contacts with ryegrass (stem, leaf and flower), other grasses (stem, leaf and flower), white clover (petiole and leaf), weeds and dead material within each 2 cm horizon are presented for both periods in Figure 4.3. Greater heights and lower numbers of contacts per horizon are obvious in the H swards reflecting the greater mean height of these pastures compared with L swards. The majority of the contacts are concentrated below 4 and 8 cm for L and H swards, respectively.

In the 10 cm treatment, grass (ryegrass and other grasses) and white clover leaf contacts were the major components over 6 cm, whereas in the 5 cm treatment most contacts were below this height but also concentrated in the upper horizons of the sward. Grass stem and white clover petiole contacts were confined below 8 and 6 cm respectively for H swards and below 6 and 4 cm for L swards. Therefore, the vertical distribution of contacts for both pastures showed a progressive increase of live leaf lamina contacts from the bottom to the top of the canopy, and of stem contacts in the opposite direction.

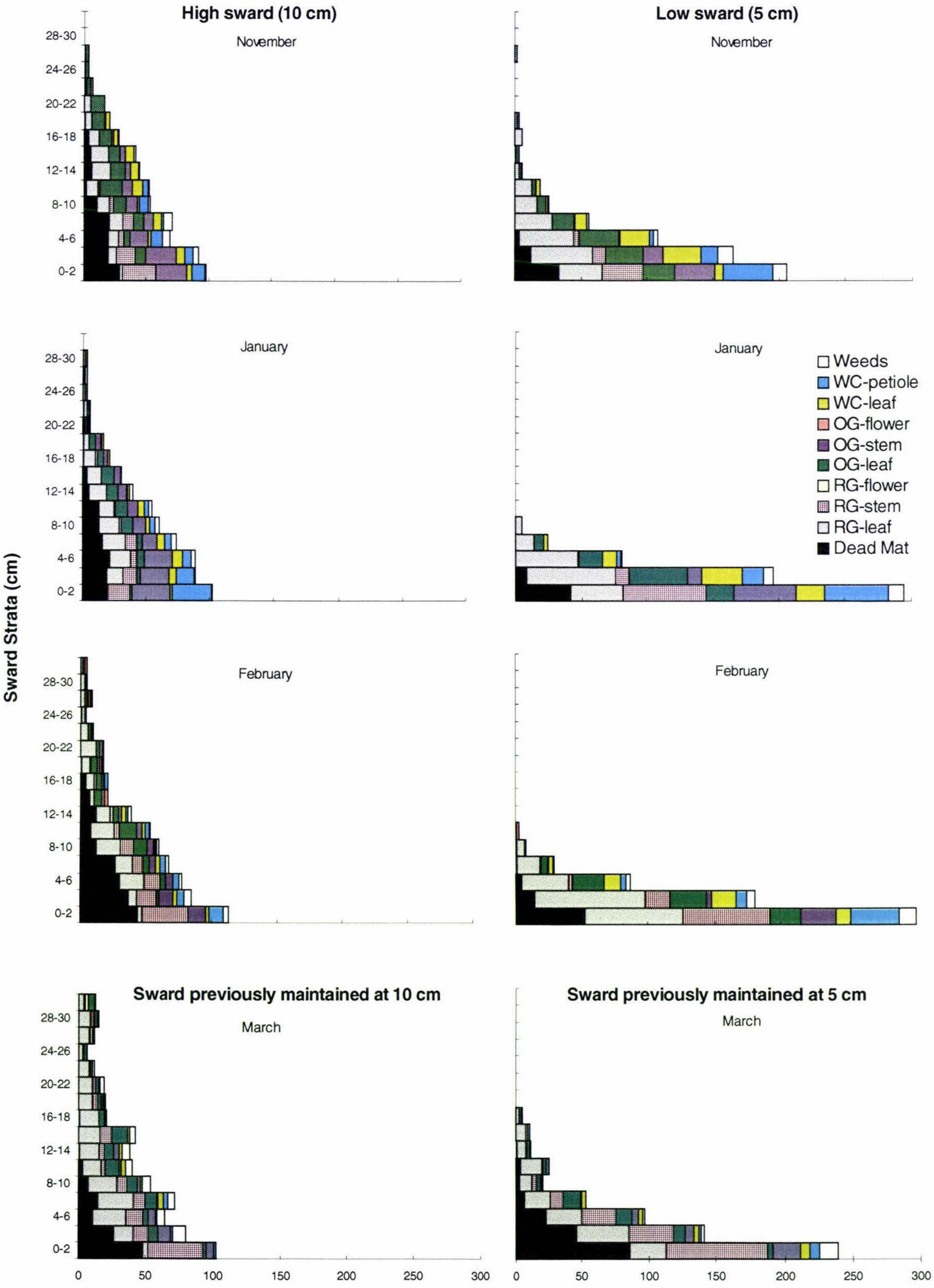
Dead material was more evenly distributed in the canopy of H treatment than in L treatment, but it was mainly concentrated in the lower horizons of both sward canopies (below 6 and 2 cm for H and L swards, respectively). There was an increase in the heights and numbers of dead material contacts as the season progressed for both swards, with the exception of H swards in Period 2. In this period, the heights of contacts increased for both swards reflecting the increase in mean heights of the pastures, particularly the 5 cm treatment.

4.1.4. Botanical and chemical composition

The botanical composition of the 5 and 10 cm swards determined from hand separation is shown in Figure 4.4 for Periods 1 and 2. Ryegrass and other grasses were the main contributors to both pastures. There was a tendency for the tall swards to have lower proportions of perennial ryegrass (22% and 33% on average for H and L treatments, respectively, $P < 0.10$ in February) and higher content of other grasses (37% vs. 30% for H and L swards, respectively).

White clover accounted for less than 10 % and 20 % of total DM components in H and L swards, respectively. Weeds were normally a minor component of the H sward, rarely exceeding a proportion of 2 %. The lower sward height treatment generally showed higher amounts of weeds (about 7% of total components), especially in Period 2 when the differences were significant ($P < 0.05$).

Figure 4.3. Proportional distribution of plant species and morphology for high (10 cm) and low (5 cm) sward surface height treatments during November, January, February and March determined from inclined point quadrat contacts.



The 10 cm sward height treatment generally showed significantly higher amounts of dead material than the 5 cm sward ($P < 0.01$, end of Period 1 and $P < 0.05$ in Period 2). Dead material content increased over Period 1 and decreased slightly in Period 2. Since similar proportions of sward components to those obtained from hand separation were found from assessment of tiller cores and point quadrat data, those results are not presented here.

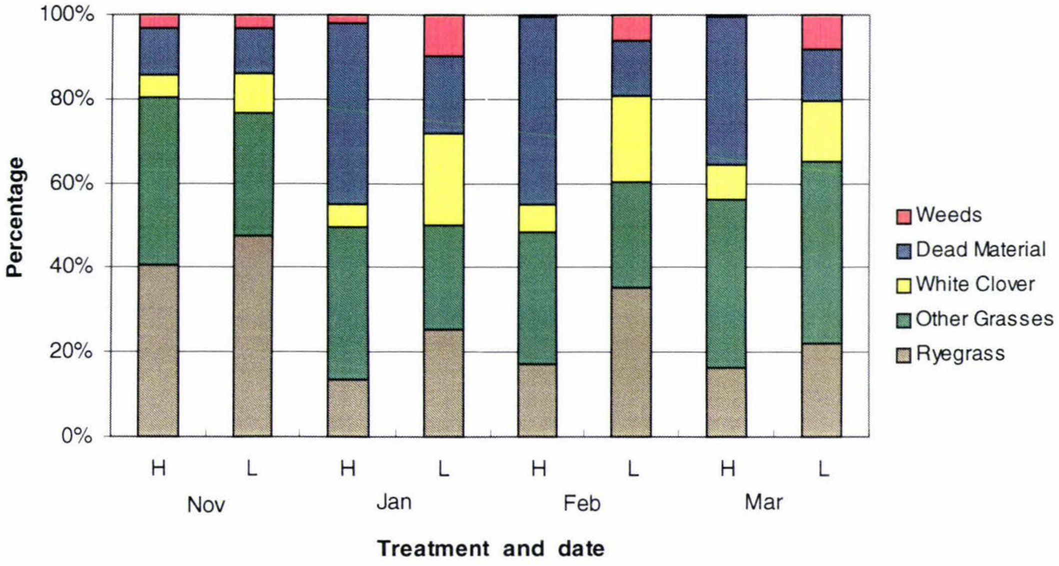


Figure 4. 4. Proportions (% DM) of components of H and L swards during Periods 1 (November-February) and 2 (March).

The chemical composition determined from hand-plucked samples of the swards is summarized in Table 4.2. In all comparisons crude protein and dry matter digestibility were higher in L than in H swards (this effect was only significant at $P < 0.10$ at the beginning of the grazing season, but at $P < 0.05$ as the season progressed). All digestibility values for H swards declined slightly with time from their highest level in November, whereas these values for the L treatment increased slightly over time. Table 4.2 also shows consistently higher fibre values for the 10 cm than for the 5 cm sward.

Table 4. 2.Chemical composition (% DM) of the swards (hand-plucked samples) for Periods 1 and 2.

Date		Treatment		SEM	Sign.
		H (10 cm)	L (5 cm)		
26 Nov-5 Dec	CP (%)	18.1	23.5	0.90	+
(Period 1)	DMD (%)	67.6	69.3	1.69	+
	NDF (%)	49.4	44.5	1.86	+
21 - 30 Jan	CP (%)	17.1	24.3	0.60	*
(Period 1)	DMD (%)	66.2	71.9	0.61	*
	NDF (%)	46.8	40.5	0.51	**
18 - 27 March	CP (%)	20.8	28.1	0.18	**
(Period 2)	DMD (%)	65.0	74.7	0.40	**
	NDF (%)	49.4	40.8	0.25	*

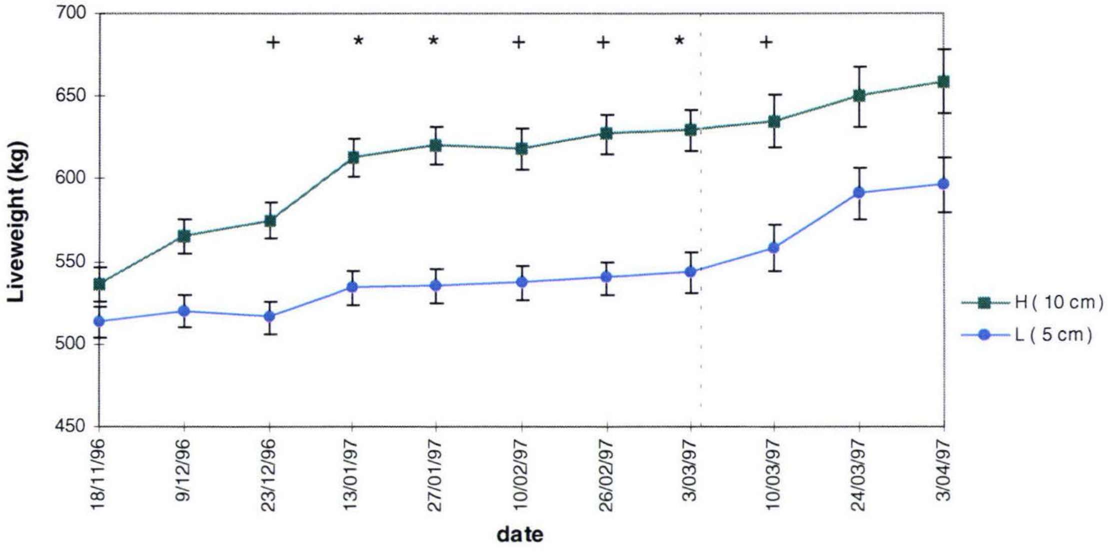
+ $P< 0.10$ * $P< 0.05$ ** $P<0.01$

4.2. Animal measurements

“Breed” (A x (H x F) vs. A x (H x J)) and its interaction with treatment were fitted in the statistical model, but “breed” means and tests of differences are not presented as they were not significant for any of the variables tested and they were not the subject of an *a priori* hypothesis.

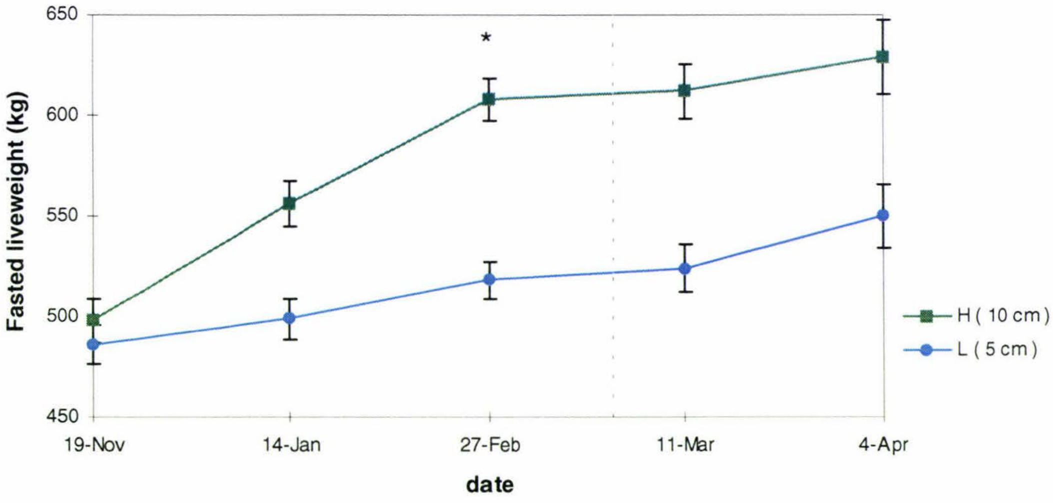
4.2.1. Liveweight and liveweight change

The pattern of mean liveweight change over Periods 1 and 2 is shown in Figures 4.5 and 4.6. Initial cattle liveweights were not significantly different between the SSH treatments. However, the steers on the H treatment were on average 12 kg heavier (498 ± 10.9 kg) than the steers on the L treatment (486 ± 9.7 kg) at this time. In Period 1 liveweight was generally maintained or increased slightly by steers on the 5 cm sward while those on the 10 cm sward increased liveweight substantially. Treatment differences at each measurement time reached significance ($P < 0.05$) from 13 January until the end of Period 1. Overall liveweight differences were significant ($P < 0.05$) for this period. During Period 2 liveweight differences between steers were not significant ($P > 0.10$). However, steers previously restricted showed greater increase in liveweight than those previously grazed on the 10 cm sward.



+ P< 0.10 * P< 0.05

Figure 4. 5. Mean fortnightly liveweights of steers for Periods 1 and 2. Vertical dotted line indicates start of Period 2 and vertical bars represent standard errors of the means.



* P< 0.05

Figure 4. 6. Mean fasted liveweights of steers for Periods 1 and 2. Vertical dotted line indicates start of Period 2 and the vertical bars represent standard errors of the means.

The effect of SSH on steer liveweights and daily liveweight gains is summarized in Table 4.3 for Periods 1 and 2. Mean fasted liveweight gain over Period 1 was significantly higher ($P < 0.01$) at 10 cm SSH than at 5 cm (1.1 vs. 0.3 kg day^{-1}, respectively). In Period 2, animals previously grazed at 5 cm SSH showed higher liveweight gains than those grazed at 10 cm (1.1 vs. 0.7 kg day^{-1}, respectively), but this difference was not significant. Although mean liveweight gains were lower for Period 1 and higher for Period 2 than fasted values, differences between treatments in liveweight gains were similar.

Table 4. 3. Effect of SSH treatment on liveweight (LW) and liveweight gain (LWG) of steers grazing ryegrass/white clover pastures (mean ± SEM) during Periods 1 and 2.

	Treatment			Treatment		
	H (10 cm) Unfasted LW	L (5 cm) Unfasted LW	Sign.	H (10 cm) Fasted LW ‡	L (5 cm) Fasted LW ‡	Sign.
Period 1 (Nov-Feb)						
Number of animals	12	12		12	12	
Initial LW (kg)	533 ± 10.1	513 ± 9.3	NS	498 ± 10.9	486 ± 9.7	NS
Final LW (kg) †	632 ± 11.1	538 ± 9.9	*	609 ± 10.8	518 ± 9.6	*
Daily LWG (kg/day) §	0.7 ± 0.13	0.1 ± 0.12	*	1.1 ± 0.23	0.3 ± 0.21	**
Period 2 (March)						
Number of animals	6	6		6	6	
Day 112 (kg)	635 ± 16.1	558 ± 14.0	+	612 ± 13.5	524 ± 11.7	+
Day 136 (kg)	659 ± 19.4	596 ± 16.8	NS	629 ± 18.1	550 ± 15.7	NS
Daily LWG (kg/day) §	1.0 ± 0.26	1.4 ± 0.23	NS	0.7 ± 0.34	1.1 ± 0.31	NS

§ using repeated measures analysis

† day 105 for unfasted LW, day 100 for fasted LW; ‡ fasted liveweight (18 h off pasture)

NS not significant, + P<0.10, * P<0.05, ** P<0.01

4.2.2. Herbage intake and grazing behaviour

Estimations of herbage DM intake (DMI) from calculations of n-alkane concentrations using pairs C_{31}-C_{32} and C_{32}-C_{33} are presented in Table 4.4. Herbage intake estimates were variable and some extreme values (outside the range mean ± 2 sd) were omitted from the calculations representing 9, 8 and 5 % of intake data for the 2 intake measurements in Period 1 and one measurement in Period 2, respectively. The short sward significantly reduced herbage intakes to about 40 % that of the cattle grazing the tall sward in Period 1 ($P < 0.05$). Results were similar for the two pairs of alkanes suggesting approximate intakes of 4.8 kg DM head^{-1} for steers grazed at 5 cm SSH and 8 kg DM head^{-1} for those grazed at 10 cm. January intakes were slightly higher than those estimated in November-December.

There was a marked increase in DMI values during Period 2 compared with Period 1 by steers previously maintained on L treatment. The results indicated that mean herbage intake was greater for steers coming from the L than from the H treatment when comparisons were made using the alkane pair C_{31}-C_{32}, while pair C_{32}-C_{33} showed higher intakes for the group of steers previously grazed on H swards. When intake values were adjusted by the corresponding steer fasted liveweights by covariance analysis, both pairs of alkanes showed higher intakes for previously restricted animals, but none of these differences were significant ($P > 0.10$).

The botanical composition of the herbage consumed by steers was also estimated using the n-alkane technique. However, results were inconsistent and are not presented here.

Table 4. 4. Estimated dry matter intake of grazed swards calculated from n-alkane technique (mean ± SEM).

Date	Alkane pair	Treatment		Sign.
		H (10 cm)	L (5 cm)	
26 Nov-5 Dec	31-32	7.5 ± 0.21	5.0 ± 0.18	*
(Period 1)†	32-33	7.9 ± 0.20	4.1 ± 0.18	*
21 - 30 Jan	31-32	7.8 ± 0.38	5.0 ± 0.33	*
(Period 1) †	32-33	8.8 ± 0.74	4.9 ± 0.65	*
18 - 27 March	31-32	8.6 ± 0.35	9.2 ± 0.32	NS
(Period 2) ‡	31-32 §	8.0 ± 0.51	9.9 ± 0.49	NS
	32-33	9.4 ± 0.54	7.4 ± 0.49	NS
	32-33 §	8.3 ± 0.75	8.6 ± 0.72	NS

† 3 replicate groups of 4 animals per treatment
‡ 3 replicate groups of 2 animals per treatment
§ covariate: fasted LW; NS not significant, * $P<0.05$

The effect of sward height on ingestive behaviour is shown in Table 4.5. Steers on the H sward generally spent significantly less time grazing and more time ruminating than steers on the L sward, while estimated resting times were similar for both treatments. During Period 2 previously restricted animals spent more time grazing and ruminating and less time resting, but these differences were not significant with the exception of resting time which was 18 % lower for previously restricted steers ($P < 0.01$). All steers had similar bite rates.

Table 4. 5. Mean values for bite rate, grazing and ruminating behaviour of steers during Periods 1 and 2 (mean ± SEM).

Date	Total time (hr/day) spent:	Treatment H (10 cm)	Treatment L (5 cm)	Sign.
26 Nov-5 Dec (Period 1) †	Grazing	7.9 ± 0.23	10.8 ± 0.22	**
	Ruminating	8.4 ± 0.16	6.8 ± 0.15	NS
	Resting	7.7 ± 0.21	6.4 ± 0.20	NS
	Bite rate (per min)	54.2 ± 1.54	65.8 ± 1.50	*
21 - 30 Jan (Period 1) †	Grazing	8.9 ± 0.16	11.1 ± 0.15	*
	Ruminating	8.1 ± 0.18	5.0 ± 0.17	*
	Resting	7.0 ± 0.22	7.8 ± 0.21	NS
	Bite rate (per min)	57.2 ± 1.29	73.6 ± 1.19	*
18 - 27 March (Period 2) ‡	Grazing	9.6 ± 0.24	10.3 ± 0.23	NS
	Ruminating	7.4 ± 0.18	8.0 ± 0.17	NS
	Resting	7.1 ± 0.29	5.8 ± 0.27	**
	Bite rate (per min)	70.3 ± 1.03	70.1 ± 1.03	NS

† 3 replicate groups of 4 animals per treatment
‡ 3 replicate groups of 2 animals per treatment
* $P<0.05$, ** $P<0.01$

4.2.3. Carcass and Meat Quality Characteristics

Carcass characteristics of steers for the first and second slaughter are shown in Tables 4.6 and 4.7, respectively. Although carcass characteristics were adjusted to a constant carcass weight by covariance analysis, only the raw values are presented in Tables 4.6 and 4.7 since the carcass weight covariate was significant only for topside cut in the first slaughter and for the hindquarter cuts and kidney and pelvic fat in the second slaughter. There were also poor associations between carcass weight and some carcass characteristics such as fat depth, probably due to the narrow range of carcass weights obtained in this experiment.

Results in Tables 4.6 and 4.7 show that mean carcass weight was significantly higher for steers in the H group than for those in the L treatment for both slaughters. However, at the second slaughter date when carcass weight was adjusted to a constant fasted liveweight at the beginning of Period 2 to test whether differences in carcass weight in the second slaughter were due to carry over effects of differential treatments during Period 1, differences in final carcass weight were not significant.

In the first slaughter group the weights of knuckle and outside cuts were higher and the muscularity score was lower (greater muscularity) for steers in the H group than those in the L group, while there were no significant treatment differences for the other carcass characteristics. When adjusted to a constant carcass weight, only the weight of outside cut was significantly different ($P < 0.05$) among treatments. In the second slaughter group significant differences between previously restricted steers and those previously maintained at 10 cm SSH were found for the weight of outside cut, kidney and pelvic fat and fat depth. When these parameters were adjusted to a constant carcass weight, outside cut weight was not significantly different while there was a slight difference ($P < 0.10$) in fat depth and a significant difference ($P < 0.05$) in kidney and pelvic fat.

Table 4. 6. Effects of sward surface height on carcass characteristics of steers slaughtered at the end of Period 1 (4 March, mean ± SEM).

	Treatment		Sign.
	H (10 cm)	L (5 cm)	
Number of animals	6	6	
Carcass weight (kg)	332 ± 10.6	287 ± 7.5	*
Dressing-out (%)	57.8 ± 0.47	58.5 ± 0.33	NS
Carcass length (mm)	2200 ± 43	2153 ± 30	NS
Kidney + pelvic fat (kg)	11.3 ± 0.85	8.4 ± 0.60	NS
Fat depth (mm)	9.3 ± 1.89	7.4 ± 1.33	NS
Muscularity (1>9) †	3.2 ± 0.18	4.3 ± 0.13	*
Eye muscle area (cm^2)	83.7 ± 2.02	69.5 ± 1.42	NS
Hindquarter cuts:			
Knuckle (kg)	5.6 ± 0.20	5.0 ± 0.14	*
Outside (kg)	9.0 ± 0.24	7.9 ± 0.17	*
Topside (kg)	9.2 ± 0.07	8.2 ± 0.05	NS

NS not significant, * $P<0.05$

† 1 most muscular, 9 least muscular

Table 4. 7. Effects of changes in sward conditions on carcass characteristics of steers slaughtered at the end of Period 2 (8 April, mean ± SEM).

	Treatment		SEM	Sign.
	H (10 cm)	L (5 cm)		
Number of animals	6	6		
Carcass weight (kg)	335	297	9.4	*
Carcass weight (kg) §	318	319	7.1	NS
Dressing-out (%)	56.0	56.3	0.46	NS
Carcass length (mm)	2168	2137	18	NS
Kidney + pelvic fat (kg)	8.0	4.1	0.53	**
Fat depth (mm)	10.0	7.2	0.71	*
Muscularity (1>9)	3.0	3.7	0.52	NS
Eye muscle area (cm^2)	72.2	70.1	2.77	NS
Hindquarter cuts:				
Knuckle (kg)	5.3	5.0	0.15	NS
Outside (kg)	8.7	7.9	0.28	+
Topside (kg)	9.0	8.4	0.31	NS

§ covariate: fasted LW at the beginning of Period 2
NS not significant, + $P<0.10$, * $P<0.05$, ** $P<0.01$
† 1 most muscular, 9 least muscular

Meat quality characteristics for *M. longissimus* samples of steers for the first and second slaughter are summarised in Tables 4.8 and 4.9, respectively. SSH treatments had no effect on any of the meat quality characteristics measured with the exception of meat brightness ($P < 0.05$) for steers previously grazed at 10 cm SSH in the second slaughter. In the first slaughter cooking loss and expressed juice were slightly higher ($P < 0.10$) for the steers grazed at 5 cm SSH during Period 1 than for steers grazed at 10 cm.

Table 4. 8. Effects of sward surface height on meat quality characteristics of *M. Longissimus* of steers slaughtered at the end of Period 1 (4 March, mean ± SEM).

	Treatment		Sign.
	H (10 cm)	L (5 cm)	
Number of animals	6	6	
Meat quality characteristics			
Ultimate pH	5.9 ± 0.55	5.8 ± 0.38	NS
Sarcomere length (µm)	1.6 ± 0.13	1.7 ± 0.09	NS
Cooking loss (%)	23.7 ± 3.05	27.5 ± 2.14	+
Expressed juice ($cm^2.gr^{-1}$)	33.2 ± 5.60	34.9 ± 3.93	+
Meat colour:			
L* (brightness)	31.1 ± 5.20	32.4 ± 3.65	NS
a* (redness)	21.0 ± 7.04	21.3 ± 4.95	NS
b* (yellowness)	8.9 ± 4.45	9.9 ± 3.13	NS
Fat colour (1<8)	3.5 ± 1.05	3.2 ± 1.2	NS
WB shear force parameters:			
WB initial yield (IY, kg)	8.1 ± 1.20	8.6 ± 0.84	NS
WB peak force (PF, kg)	9.3 ± 1.82	10.3 ± 1.28	NS
WB (PF-IY) (kg)	1.2 ± 0.68	1.7 ± 0.48	NS

NS not significant, + P<0.10

Table 4. 9. Effects of changes in sward conditions on meat quality characteristics of *M. Longissimus* of steers slaughtered at the end of Period 2 (8 April, mean ± SEM).

	Treatment		SEM	Sign.
	H (10 cm)	L (5 cm)		
Number of animals	6	6		
Meat quality characteristics				
Ultimate pH	5.7	5.9	0.19	NS
Sarcomere length (µm)	1.7	1.6	0.07	NS
Cooking loss (%)	24.9	24.7	1.10	NS
Expressed juice ($cm^2.gr^{-1}$)	38.1	35.7	1.44	NS
Meat colour:				
L* (brightness)	34.4	30.5	1.05	*
a* (redness)	20.5	18.8	2.03	NS
b* (yellowness)	9.6	8.1	1.05	NS
Fat colour (1<8)	4.3	4.5	0.37	NS
WB shear force parameters:				
WB initial yield (IY, kg)	6.8	8.0	0.79	NS
WB peak force (PF, kg)	8.1	9.4	0.86	NS
WB (PF-IY) (kg)	1.3	1.5	0.17	NS

NS not significant, * P<0.05

CHAPTER 5

DISCUSSION AND CONCLUSIONS

5.1. Discussion

An understanding of the relationships between sward surface height, herbage intake and ingestive behaviour is important for prediction of animal performance. With a view to developing appropriate grazing management recommendations for farmers, the experiment reported here aimed to quantify these relationships for heavy (over 500 kg liveweight) finishing steers under two contrasting sward heights continuously grazed during summer. It was also aimed to evaluate the effect of summer treatment contrast on cattle performance under common grazing conditions during early autumn. The discussion will focus separately on the two main phases of the trial attempting to evaluate appropriate grazing management strategies for finishing steers. A preliminary section deals with assessment of the effectiveness of experimental procedures.

5.1.1. Evaluation of the effectiveness of experimental procedures.

During the sward height control period from the beginning of the experiment to the time of first slaughter, reasonable success was achieved in maintaining sward height close to the targets of 5 cm and 10 cm (Figure 4.1). Small stocking rate adjustments by adding or removing individual animals were necessary for periods no longer than three weeks on some plots during January and February to avoid important deviations from target heights.

As the growth rate of herbage varies within and between seasons and is influenced by variations in weather and fertiliser application, stocking rates within season must change to maintain a target SSH. In practice this may be more easily achieved by adjusting the grazing area rather than animal numbers (Swift *et al.* 1989). Guidelines have been produced by Hodgson *et al.* (1986) which give a set of stocking rate adjustments providing a basis for management decisions. Swift *et al.* (1989) pointed out that the decisions must be few and simple to operate to be acceptable to the farmer.

Steers were all treated for internal and external parasites and no serious health problems were encountered. Temporary throat damage caused by capsule dosing limited the use of one steer for intake measurements.

Dove and Mayes (1996) emphasised that the main precaution in the use of n-alkanes to estimate individual herbage intakes is to ensure that the diet sample, in terms of its alkane concentrations, is representative of that consumed by the experimental animals. This seems relatively easy to achieve for uniform, sown pastures; however, for complex vegetation communities, it may be difficult or impossible to achieve. In such situations, characterization of the botanical composition of the diet would enable intake to be assessed and the alkane concentrations of individual dietary components would have to be determined.

In the present study the botanical composition of the herbage consumed by steers was estimated using the n-alkane technique. However, the proportions of dietary components predicted in this experiment were too inconsistent to be used in the calculation of diet composition or herbage intake. Therefore, hand-plucked samples were used for the estimation of dietary alkane concentrations. Although there is always some doubt as to the extent to which hand plucking herbage simulates grazing, care was taken to collect herbage samples that were as representative as possible of that selected by the cattle.

Herbage intake estimates were variable and some extreme values (outside the range mean ± 2 sd) were omitted from the calculations. In general the experimental design and the model used were appropriate to assess treatment contrast and "breed" effects, but the low number of replicates per treatment may have limited the level of significance of some measurements.

5.1.2. Effect of SSH on herbage intake and steer performance.

There was a clear effect of sward height treatment on herbage intake and steer liveweight gain. Mean herbage intakes were significantly reduced on the 5 cm sward to about 40 % that of the cattle grazing the 10 cm sward. Both alkane pairs (C_{31}-C_{32} and C_{32}-C_{33}) showed similar results, suggesting approximate intakes of 4.8 and 8 kg DM head^{-1} for steers grazing the short and tall swards, respectively (Table 4.4). There is limited information in the literature comparing intakes of heavy steers (over 500 kg LW) on contrasting sward heights under New Zealand conditions. The levels of herbage intake measured in this experiment are somewhat lower than the values calculated from feeding tables (7 and 10-11 kg DM head^{-1} for L and H treatments, respectively, AFRC 1993). However, the differences in DMI between the H and L treatments were similar to differences suggested by feeding tables.

Previous studies at Massey University using intraruminal chromium controlled release capsules by Morris *et al.* (1993a) found that DMIs, were approximately 2.60 and 2.87 kg 100 kg LW^{-1} for Charolais x Angus steers (325 kg LW) grazing at 5 and 10 cm SSH during spring, and growing at 0.67 and 1.47 kg day^{-1}, respectively. Comparative values for this trial were approximately 1.03 and 1.61 kg 100 kg LW^{-1} for steers grazing at 5 and 10 cm during summer, and growing at 0.32 and 1.10 kg day^{-1}. Aranda-Osorio *et al.* (1996) showed that 14-month-old Angus x (Hereford x Friesian) and Friesian steers (300 kg LW) growing at 0.71 kg day^{-1} consumed 2.31 kg 100 kg LW^{-1} during spring.

Differences in average herbage DMI between the treatments are supported by differences in components of ingestive behaviour. Intake per bite is the variable most directly influenced by sward conditions, and usually decreases sharply as sward height declines. Biting rate generally tends to increase with decreasing intake per bite, but the rate of increase is rarely fast enough to prevent a concomitant decline in the rate of herbage intake (Hodgson 1981). In the present study intake per bite was not estimated, but it was calculated on a treatment mean basis from daily herbage intake divided by the total number of bites per day multiplied by grazing time (DMI / RB x GT, Table 5.1). Although these values need to be interpreted carefully as they include any errors inherent in the estimates of herbage intake, grazing time and biting rate, the effect of SSH on intake per bite is clear.

Mean rate of biting was significantly increased by 25 % for steers grazing at 5 cm SSH relative to those grazing at 10 cm (Table 4.5). The lower rate of biting of the steers grazing the tall swards may be related to a greater time spent on selective grazing as herbage availability increased (Langlands and Sanson 1976), as well as the greater masticatory requirements of the large bites (Spalinger and Hobbs 1992) harvested on taller swards. Suggestions of variation in biting rate reflecting variations in the relative proportions of prehension, biting and chewing have also been made by Laca *et al.*

(1993) who demonstrated that larger bites require more chewing and thus, more time per bite.

Grazing time was also increased as an adaptive response to the decline in the rate of intake by restricted steers. However, the degree of compensation was again limited resulting in reduced herbage intakes for steers grazing the L swards. Although grazing times of up to 12 hours have been recorded for adult cattle in tropical climates (Smith 1959, Stobbs 1970), steers grazing the L sward appeared to have achieved maximum compensation in grazing time at about 11.1 hours (Table 4.5).

Table 5. 1. Mean values for herbage intake, grazing time, biting rate and intake per bite for steers during Period 1.

	Treatment	
	H (10 cm SSH)	L (5 cm SSH)
Herbage intake (kg DM head^{-1} day^{-1})	8.0	4.8
Grazing time (minutes day^{-1})	504	657
Biting rate (bites minute^{-1})	55.7	69.7
Intake per bite (g DM bite^{-1})	0.29	0.11

Wright and Whyte (1989) demonstrated that SSH also influences the way in which the swards are utilized. They reported that a surface height of 11 cm has a high proportion of the sward infrequently grazed. This mosaic of short, frequently grazed areas and tall, infrequently grazed areas is a characteristic of swards continuously stocked with cattle (Gibb *et al.* 1989, Gibb 1991) and is consistent with other observations. Gibb and Ridout (1986 and 1988) described this mosaic of frequently and infrequently grazed areas by fitting double-normal distributions to measurements of sward height frequency. These results are in agreement with the observations of Kitessa and Nicol (1996) who compared the frequency distribution of sward height on pastures grazed by cattle alone or co-grazed with sheep.

In this experiment, the infrequently grazed areas in the L swards were limited to rejected patches associated with urine and faecal deposits. In the H sward where grazing pressure was lower (3 vs. 6 steers ha^{-1} for H and L swards, respectively) and opportunities for selective grazing higher, the initially infrequently grazed areas of the sward matured and were subsequently rejected by the animals in preference for younger regrowth material in the frequently grazed areas. However, the similar coefficient of variation in surface height of both swards (H 32 vs. L 28 %) over the sward height control period suggested that heterogeneity and 'patchiness' in the H swards were reasonably controlled by steer grazing. Wright and Whyte (1989) concluded that the infrequently grazed component can be kept below 20% for most of the grazing season if mean sward height is maintained below 8 to 9 cm. This suggestion is in agreement with the observation of Hodgson (1990) that patchy grazing and seed-head development are unlikely to be a problem in swards maintained below 8-10 cm in cattle systems.

The results of the inclined point quadrat study demonstrated the large differences in the vertical distribution of plant material between the H and L swards (Figure 4.3). There was an obvious increase in the heights of contacts and a decrease in the number of contacts per horizon in the H swards, reflecting the greater mean height and lower density of these pastures. The majority of the contacts were concentrated below 4 cm for the L treatment and below 8 cm for the H treatment. Grass (ryegrass and other grasses) and white clover leaf contacts were concentrated over 6 cm and 4cm for H and L swards, respectively, while grass stem and white clover petiol contacts were confined below these heights.

Clearly the depth of the leaf layer was higher and more accessible for steers in the H than in the L sward. Hodgson (1985) noted that sward height is a good indicator of accessibility of herbage in temperate pastures determining bite weight, and consequently exerting dominant influence upon daily herbage intake. Mursan *et al.* (1989) reported that bite depth was the major determinant of cattle intake and that SSH was the best predictor of bite depth. These results are in agreement with Laca *et al.* (1993) who reported that bite depth is affected by height and the degree of vertical heterogeneity in stiffness and suggested that leaf length, not total sward height, becomes the relevant limit to bite area since stem acts as the pivotal point for captured leaves.

In this study, the pseudostem layer appeared to have acted as a barrier to defoliation on the short swards restricting the depth of the grazed horizon and limiting bite size and rate of intake and hence the amount of herbage eaten daily. Increased allowance in this situation would not be expected to increase intake, except that this might improve sward conditions (Jamieson and Hodgson 1979b).

Imposing low SSHs in summer resulted in increased tiller density and live:dead tiller ratio compared with high SSHs (Table 4.1), but only dead tiller densities and the ratio of live:dead tillers were significantly different between the swards. Illius *et al.* (1986) reported that compared to a short sward, a 10 cm sward would be expected to have a lower tiller density. The botanical composition of the swards was not significantly different between treatments, with the exception of the proportion of dead material particularly during mid- and late season (Figure 4.4).

Results from analysis of inclined point quadrat data showed that dead material was more evenly distributed in the canopy of H treatment than in L treatment, but it was mainly concentrated in the lower horizons of both sward canopies (Figure 4.3). As a consequence of the higher proportion of dead material in the tall pastures, the nutritive value of the swards was significantly different with lower crude protein content and DMD in the H than the L swards (Table 4.2). This effect was only significant at $P < 0.10$ at the beginning of the grazing season as a consequence of the herbage accumulated during the pre-experimental period to prepare the 5 and 10 cm swards, but at $P < 0.05$ as the season progressed and the proportion of dead material increased in the H swards.

Ryegrass and white clover pastures, where the greenest leaf is produced near the surface of the sward, allow the animals to select for leaf rather than stem or senescent material (Inwood *et al.* 1992). The greater amount of young leaf in the grazed horizon and the greater accessibility and availability of the H swards, together with lower bite rates, suggest that steers grazing at 10 cm SSH spent longer searching for food items. Despite grazing selectivity the diet achieved by steers on the tall swards (estimated from hand-plucked samples) was of lower quality than that of steers grazing the short swards. This is consistent with the observation of Illius *et al.* (1986) who reported that a 10 cm sward would be expected to be lower in quality in terms of live leaf compared to a short sward. Forbes (1986) proposed a target digestibility value of 67 % to limit intake in cattle. In this study, the DMD values of the tall swards (68 % ± 1.69 and 66 % ± 0.61) during the sward height control period appear unlikely to have limited steer intake, and most authors agree that the asymptote of maximal intake for cattle is reached at about 8 to 10 cm sward height (Baker *et al.* 1981b, Phillips and Leaver 1986, Wright *et al.* 1986).

Herbage intake and grazing behaviour differences between treatments were reflected in steer rate of liveweight gain. Liveweight was generally maintained or increased slightly by steers on the L swards which suggests that, at a SSH of 5 cm, steers are only just able to consume sufficient quantities of herbage to satisfy their maintenance requirements. Steers on the 10 cm sward increased liveweight substantially throughout the 105 days of the sward height control period, and treatment differences reached significance ($P<0.05$) from day 56 onwards (Figure 4.5).

Fasted liveweight values showed an advantage in average daily gain of 0.8 kg day^{-1} ($P < 0.01$) for steers on the H swards (1.1 kg day^{-1}) compared to those on the L swards (0.32 kg day^{-1}). When unfasted liveweights were analysed as repeated measures, daily liveweight gains were 0.7 and 0.1 kg for H and L treatments, respectively (Table 4.3). Since liveweights were recorded fortnightly and subsequent unfasted liveweights of some animals were not always consistent, repeated measures analysis may have given distorted liveweight gain values. When the analysis was carried out considering only the difference between initial (day 0) and final liveweights (day 105), mean daily liveweight gains of 0.94 ± 0.05 for H treatment and 0.24 kg day^{-1} ± 0.04 for L treatment were obtained. These values are close to the fasted liveweight gains, suggesting similar advantage in average daily gain of 0.7 kg day^{-1} ($P < 0.05$) for steers on the H swards compared to those on the L swards.

Two experiments conducted at Massey University indicated that liveweight gain in continuously grazed yearling steers and bulls increases with SSH to a maximum of 8-10 cm on spring ryegrass/white clover pastures while, in autumn, swards of 12-15 cm height are required to achieve maximum performance (Morris *et al.* 1993a). Swift *et al.* (1989) proposed that optimal sward height for highest gain of set stocked finishing cattle on perennial ryegrass-dominant swards is 6-8 cm during spring rising to 7-9 cm in summer. Lowman *et al.* (1988) found that a pasture height of 10 cm increased liveweight gains over the summer by around 0.15 kg head^{-1} day^{-1} compared to cattle grazing swards of 7 cm.

For beef cows and calves it has been suggested that sward height should be maintained at no more than 8 cm in spring and early summer to avoid unacceptable levels of ungrazed material, but once the risk of flower stem development is past the sward height can be increased slightly to 9 to 10 cm (Wright and Whyte 1989). Baker *et al.* (1981b), Russel *et al.* (1986) and Wright and Russel (1987) also suggested that swards should be maintained at a SSH of 8 to 10 cm under continuous grazing by beef cows and their calves to achieve maximum intakes and performance.

Superior liveweight gain of the cattle grazing on the high SSH was reflected in a significant advantage in carcass weight which was about 16 % higher for the steers grazing the tall compared with the short swards (high 332 ± 10.6 vs. low 287 ± 7.5 kg, $P < 0.05$, Table 4.6). There were no treatment effects on the weight of three major hindquarter cuts, with the exception of outside cut which was about 14 % ($P < 0.05$) heavier for the steers of the H group. No significant differences were evident for other carcass characteristics. The results showed that while SSH had no significant effect on any of the meat quality characteristics measured, L treatment tended to increase cooking loss and expressed juice values of the meat ($P < 0.10$, Table 4.8).

Output per hectare in terms of steer liveweight and carcass weight gain is presented in Table 5.2. The mean stocking rates over the sward height control period, considering the temporary adjustments in steer numbers to avoid deviations from target sward heights, were 5.80 vs. 2.86 steers ha^{-1} on the 5cm and 10 cm treatments, respectively. Calculations of liveweight and carcass weight gains ha^{-1} were made using treatment mean values, and no statistical analysis was attempted. Liveweight gain ha^{-1} was 71-95 % greater for steers grazed at 10 cm compared with those grazed at 5 cm SSH. Consequently, output per ha^{-1} in terms of carcass weight gain was 43-64 % higher for the H than the L treatment.

Although the stocking rate was double for the L treatment, individual performance of steers grazing on the short swards was low enough to yield a lower carcass output per hectare than that of steers grazing on the tall swards. The results of this experiment suggest that, for steers continuously stocked on a ryegrass/clover sward during summer, maintaining a SSH of 10 cm offers advantages in terms of individual animal output and output per hectare compared with grazing at 5 cm SSH. Wright and Whyte (1989) suggested that a sward height for beef cows and calves in the range of 8 to 10 cm will allow high levels of animal performance, efficient utilization of grass and high output per hectare.

Table 5. 2. Treatment effects on output per hectare (kg carcass and LW gain ha^{-1}) for Period 1 (105 days).

	Unfasted LW		Fasted LW	
	H (10 cm SSH)	L (5 cm SSH)	H (10 cm SSH)	L (5 cm SSH)
Liveweight gain head^{-1} (kg)	99	25	111	32
Carcass gain head^{-1} (kg) *	50	15	58	20
Stocking rate (steers ha^{-1})	2.86	5.80	2.86	5.80
Output (kg LW gain ha^{-1})	283	145	318	186
Output (kg carcass gain ha^{-1})	143	87	166	116

* assuming dressing-out = 53 % and 55 % for inital unfasted and fasted LW, respectively

5.1.3. The influence of contrasting sward heights during summer on subsequent cattle performance under common grazing conditions.

During the first experimental period the three replicates from each SSH were grazed by 4 steers. After the first slaughter (4 March, day 105) electric fences controlling SSH in each replicate paddock were removed and the remaining 4 steers (2 from each SSH treatment) had access to both swards. Stocking rate was maintained at 2 steers ha^{-1} to ensure high herbage availability during the compensatory period. Swards previously maintained at 5 cm increased surface height faster than those maintained at 10 cm SSH. However, at the end of the experiment a significant difference in height was still evident between the two swards.

There was a marked increase in DMI values in Period 2 compared with Period 1 by previously restricted steers. These greater intakes associated with changes in grazing behaviour were reflected in higher liveweight gains during the compensatory period by steers previously grazed at 5 cm SSH (Table 4.3). The lower performance of steers from the H treatment during Period 2 compared with Period 1 (Table 4.3) may be explained by an increase in energy requirements associated with an increase in animal size (Nicol and Nicoll 1987) and also due to lower growth potential towards the end of the grazing season.

The phenomenon of animals showing enhanced performance after periods of nutritional restriction has been known for many years and has been comprehensively reviewed (Wilson and Osbourn 1960, Allden 1970, O'Donovan 1984, Hogg 1991, Nicol and Kitessa 1995). However, Hogg (1991) noted that many authors discuss compensatory growth while few of them have observed true compensatory growth and made reference to the review of Moran and Holmes (1978) who found that compensatory growth occurred in only 30 % of the 27 trials they reviewed.

Owens *et al.* (1993) support the view that restricted animals exhibit compensatory growth when the rate of weight gain during realimentation is greater than for counterparts that never were restricted. Hogg (1991) reported that true compensatory growth probably occurs for only a very limited period following realimentation, usually about four weeks, and its occurrence can be highly unpredictable, given the many factors that can influence animal growth.

In the present experiment, animals from the L treatment subsequently tended to increase herbage intake (when adjusted for fasted LW at the end of Period 1, Table 4.4), show slightly greater grazing and ruminating times and lower resting time (Table 4.5) and grow faster compared to steers from the H treatment (Table 4.3). However, none of these parameters were significantly different between the groups with the exception of resting time.

Increased autumn growth rates by previously restricted steers did not compensate for the differences in liveweight established during the summer, and significant differences in carcass weight were still evident at the end of the compensatory period between the steer groups. When carcass weight was adjusted to a constant fasted liveweight at the beginning of Period 2 to test whether differences in carcass weight in the second slaughter were due to carry over effects of differential treatments during Period 1, differences in final carcass weight were not significant (Table 4.7). These results emphasise the absence of compensatory growth in carcass weight by previously restricted animals.

It should be noted, however, that differences in unfasted and fasted liveweights were not significant between animal groups at the end of Period 2 (Table 4.3), which may suggest that there was evidence of compensatory growth by previously restricted animals. However, Owens *et al.* (1993) suggested that liveweight is an inaccurate predictor of lean body mass. Tolley *et al.* (1988) concluded that differences in digesta alone could account fully for the compensatory growth phenomenon. A large contribution to the change in liveweight and composition of the animal during the recovery period is made by the increase in size and activity of the internal organs (particularly liver, gut and intestines), which are very sensitive to changes in nutrition, possibly because they are metabolically very active (Hogg 1991). Weight of the empty digestive tract plus liver can change within a few weeks (Williams et al. 1992).

Nicol and Kitessa (1995) argued that high levels of liveweight gain during recovery will only be achieved when an intense restriction has been imposed on older cattle and the recovery period has been long and at a high rate of liveweight gain. This may suggest that the compensatory period of 35 days in this experiment may have not been long enough for steers previously restricted to exhibit compensation.

It has been suggested that cattle exhibit compensatory growth to a greater extent when previous changes in growth rate have reduced fat deposition rather than protein deposition (Moran and Holmes 1978), or altered body composition (Beever and Baker 1986). However, the effects of body composition at the end of the treatment period on the subsequent expression of compensatory growth are by no means clear, as compensatory growth has been expressed in some studies in the absence of a difference in body composition at the end of the treatment period (Baker *et al.* 1985; Gibb and Baker 1991). In this experiment, although the steers on tall swards showed slightly higher fat depths at first slaughter than those on short swards (Table 4.6), there were no significant differences between treatments suggesting important changes in carcass composition during Period 1.

As in the first slaughter, there were no significant differences in meat quality characteristics measured with the exception of meat brightness ($P < 0.05$), which was higher for steers previously grazed on the tall swards than those previously restricted. These results are consistent with the lower ultimate pH value of beef from the H treatment, as this is usually associated with lighter-coloured meat.

5.2. Conclusions

The results of this experiment demonstrate clearly the large effect of sward height on the herbage intake, ingestive behaviour and performance of finishing steers. For heavy (over 500 kg liveweight) steers continuously stocked on a ryegrass/white clover sward during summer a SSH of 10 cm compared with 5 cm, increased liveweight gains by 0.8 kg head^{-1} day^{-1} (high 1.1 vs. low 0.3 kg d^{-1}) and increased carcass weight at the same slaughter date by 13 %. Despite a decreased stocking rate from 5.8 to 2.9 steers ha^{-1}, it would appear that maintaining a SSH of 10 cm offers advantages in terms of individual animal output and output per hectare (166 vs. 116 kg carcass gain ha^{-1} for 105 days) compared with grazing at 5 cm. SSH was shown to have no effect on cattle carcass characteristics, or meat quality which was satisfactory for both treatments.

The better performance of the steers on the tall sward may be explained by their greater herbage intake associated with greater herbage accessibility. Limitations in the herbage intake of steers continuously stocked on short swards reflect severe reductions in bite size and rate of herbage intake which are not compensated for despite substantial increases in biting rate and grazing time. Results from previous experiments (Lowman *et al.* 1988, Swift *et al.* 1989, Morris *et al.* 1993a), along with this one, indicate that herbage intake in ryegrass/white clover swards is limited at mean sward heights of 5 cm and that to achieve maximal daily liveweight gain of heavy finishing cattle, set stocked throughout the summer, SSH should be maintained in the range of 8-10 cm, but further work is necessary to define the optimum sward height. Increases in SSH over 10 cm appear to be not associated with improved animal performance but can lead to a reduction in sward density and pasture quality (Hodgson 1985).

Increased early-autumn growth rates by previously restricted steers did not compensate for the differences in liveweight established during the summer, and significant differences in carcass weight were still evident at the end of the compensatory period between the steer groups. This suggests that it is unrealistic to expect compensatory growth in heavy finishing steers on late summer pastures for a month recovery period, and that farm management practices assuming such compensation will yield poor benefits in terms of carcass gain.

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